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Physico-Chemical Quality and Metallic Contamination of the Waters of Lake Bra Kanon (Daloa, West-Central Côte d'Ivoire)

Elogne Guessan Zoro[1*], Yao Joseph Adjoumani[2], Amadou Kouyaté[3], Sindou Touré[3], Ali Sanou[1,2], Mougo André Tigori[3], Namory Méité[4], Brou Dibi[3]

[1]Laboratoire des Sciences Physiques Fondamentales et Appliquées (LSPFA), Ecole Normale Supérieure (ENS), Abidjan, Côte d'Ivoire
[2]Laboratoire des Procédés Industriels de Synthèses, de l'Environnement et des Energies Nouvelles (LAPISEN), Institut National Polytechnique Félix Houphouët-Boigny (INP-HB), Yamoussoukro, Côte d'Ivoire
[3]Laboratoire des Sciences et Technologies de l'Environnement (LSTE), Université Jean Lorougnon Guédé, UFR Environnement, Daloa, Côte d'Ivoire
[4]Laboratoire de Constitution et Réaction de la Matière (LCRM), Université Félix Houphouët-Boigny (UFHB), UFR SSMT, Abidjan, Côte d'Ivoire
Email: *elognezoro@gmail.com

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Abstract

The objective of this study is to determine the physicochemical quality and the level of metal contamination of the waters of Lake Bra Kanon located in Daloa in the center-west of Côte d'Ivoire. Two (02) sampling campaigns were carried out in August 2020 (long dry season) and in December 2020 (short dry season), followed by laboratory analyses. A total of fifteen (15) parameters were analyzed including six (06) physicochemical parameters (Temperature, Hydrogen potential, Electrical conductivity, Dissolved oxygen, Dissolved oxygen saturation rate, Oxidation-reduction potential), four (4) nutrient salts (Nitrate, Nitrite, Phosphate, Ammonium) and five (5) heavy metals (Cadmium, Zinc, Lead, Iron and Manganese). The values obtained from the water samples analyzed were compared to the recommended standards for drinking water in order to assess the potential for using this water resource as a source of drinking water. The comparative analysis showed that most water quality parameters had values consistent with those intended for human consumption. Indeed, twelve (12) parameters (80%) fall within the WHO drinking water standards. However, three (03) parameters, *i.e.*, 20%, including two (02) physicochemical parameters (Temperature and Dissolved Oxygen) on all sites and one (01) metal, namely cadmium, at site S1 only, were deemed inappropriate for water intended for human consumption. These non-compliant values of temperature, dissolved oxygen, and cadmium are a sign of the vulnerability of the lake waters.

Keywords

Lake Bra Kanon, Physicochemical Parameters, Nutrient Salts, Heavy Metals, Contamination

1. Introduction

Water is an essential resource for life, development, and the environment [1]. Thus, it can be used as drinking water, dishwashing water, laundry water, and personal hygiene water essential for human well-being [2]. However, access to drinking water and sanitation is a daily challenge for hundreds of thousands of people who live mainly in developing countries [3] [4]. Indeed, growing and uncontrolled urbanization, particularly in poor and developing countries, has a negative impact on the quantity and quality of water resources [5]. According to the World Health Organization, 1.5 billion people in the world do not have access to drinking water, while around 30,000 people die every day due to dehydration or drinking dangerous water. Furthermore, millions of people around the world suffer from a lack of water [6].

Having good quality water, therefore, becomes a permanent quest with the aim of preventing these scourges and water-borne diseases linked to water quality [7]. This is why the United Nations (UN) recommends access for all to water and sanitation and sustainable management of said resource [8].

Faced with galloping demographics associated with socio-economic development, there is a strong need for water while state structures are overwhelmed by this strong demand [9]. To meet their water needs, the population often uses groundwater (spring water, borehole water, and traditional well water) and surface water (river water, ponds, and lakes).

Daloa, a town in west-central Ivory Coast, is no exception to this reality. Thus, the waters of Lake Bra Kanon are used for multiple uses by households, such as laundry, dishwashing, agriculture, livestock, and often for consumption as drinking water. However, surface waters, such as Lake Bra Kanon, are facing a permanent degradation of their quality in the face of anthropogenic activities [10]. Indeed, recent studies carried out in Côte d'Ivoire have reported the vulnerability of surface waters [10]-[13].

Given the interest in the water retention of Lake Bra Kanon, it is therefore important and necessary to carry out studies on the quality of the water of the lake in order to prevent the health risks linked to its direct use, without prior treatment, for domestic uses and as drinking water. The objective of this study is therefore to evaluate the physicochemical quality and the level of metal contamination of the waters of Lake Bra Kanon.

2. Materials and Methods

2.1. Location of the Study Area

The study area is located in Daloa in the west-central part of Côte d'Ivoire. Daloa is the capital of the Haut Sassandra region. It is approximately 383 km from Abidjan, the economic capital [14]. This city is located between latitudes 6˚30 and 8˚ North and longitudes 5˚ and 8˚ West, and Lake Bra Kanon (**Figure 1**), a water reservoir created by the first Mayor of the city of Daloa, with an area of 84,551 m^2, which constitutes the study area, is located in the Eveche district [15] [16].

The climate is subequatorial (hot and humid), characterized by four seasons, including the long rainy season from April to mid-July, the short dry season from mid-July to mid-September, the short rainy season from mid-September to November, and the long dry season from December to March [17].

Figure 1. Overview of Bra Kanon Lake [18].

2.2. Sampling and Measured Parameters

Two (02) sampling campaigns were carried out in August 2020 (long dry season) and in December 2020 (short dry season). Three stations were chosen to take water samples from the lake. A downstream station (S1), a middle station (S2), and an upstream station (S3) of the lake (**Figure 2**). The coordinates of the different stations are recorded in **Table 1**.

Table 1. Geographic coordinates of sampling stations.

Stations	Geographical Positions		Depths (m)
	X	Y	
S1	785,353	761,636	0.5
S2	785,479	761,673	0.5
S3	785,454	761,916	0.5

The water samples were taken using 1.5 L and 0.5 L plastic bottles previously rinsed with water from the site to be sampled. These samples were then stored in a cooler containing ice for nutrient and heavy metal analysis in the laboratory. However, a drop of concentrated hydrochloric acid was added to the samples intended for heavy metal analysis.

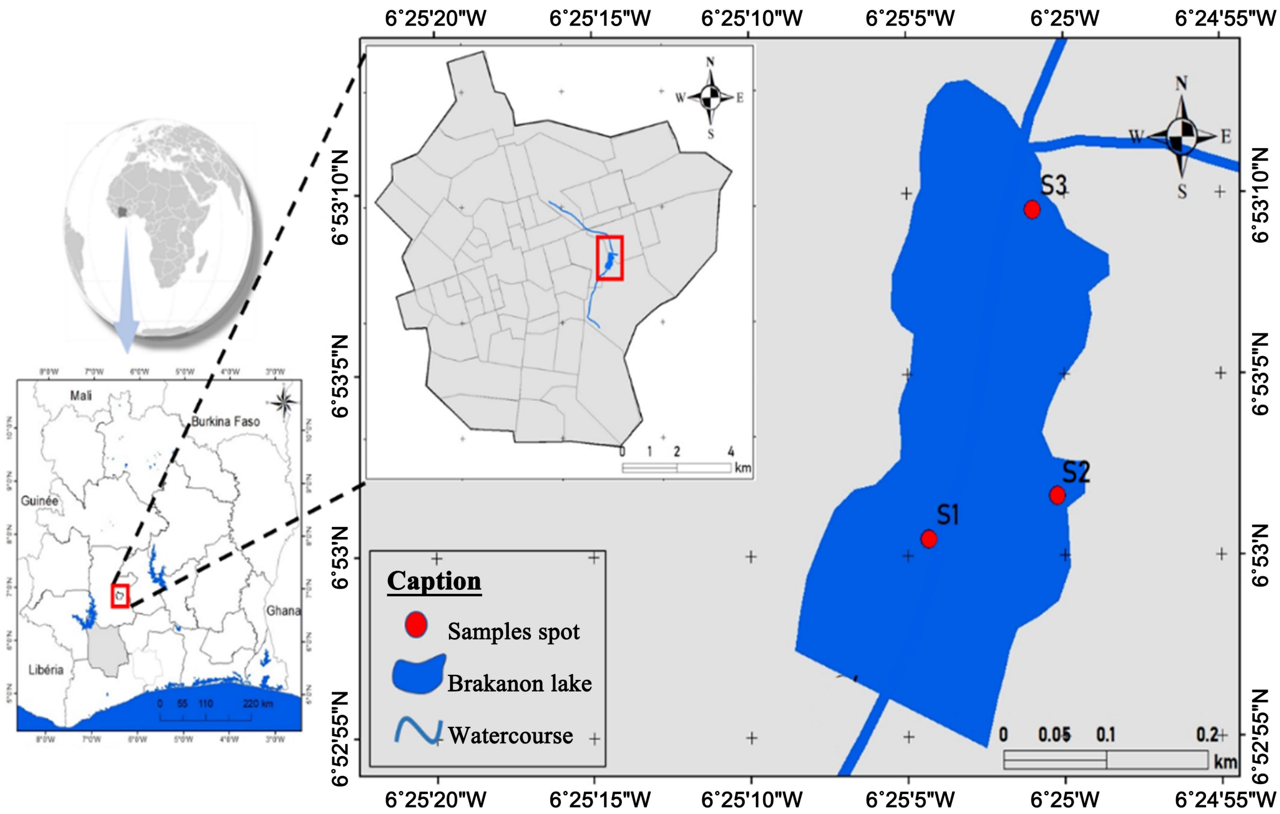

Figure 2. Presentation of the sampling points in the lake.

The analysis of physicochemical parameters and nutrient salts was carried out according to the techniques of Rodier *et al.* [19] and AFNOR [20]. Dissolved oxygen, saturation rate, temperature, pH, electrical conductivity, and redox potential were measured *in situ* using a HANNA HI 9828 portable multi-parameter.

Laboratory analyses focused on nutrient salts (NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}) and heavy metals (Cd, Cr, Fe, Pb, Zn, Mn). The ammonium ion content (NH_4^+) was determined according to the NF T 90-015 standard, following the Nessler spectrophotometric method using a spectrophotometer at a wavelength of 420 nm. Nitrates (NO_3^-) and nitrites (NO_2^-) were also measured spectrophotometrically according to AFNOR standardized methods: NF T 90-013/90-012 at wavelengths of 415 nm and 543 nm, respectively. Orthophosphate ions (PO_4^{3-}) are also measured by spectrophotometry, according to the method defined by standard NF T 90-923 at 530 nm. The spectrophotometer (DR 6000) was used for the determination of nitrate, nitrite, ammonium, and phosphate ions.

Heavy metals were analyzed by spectrometry using an argon plasma ionizing source mass spectrometer (ICP-MS), according to EPA methods (200.8, 3050, 6020) [21] and Standard Method for the Evaluation of Water and Wastewater [22].

Before any analysis, the water samples were vacuum filtered on a filter membrane in order to retain all particles larger than 0.5 µm.

2.3. Statistical Processing

The Bravais-Pearson correlation test was used to establish possible relationships between physicochemical parameters, nutrient salts, and heavy metals. The Bravais-Pearson linear correlation coefficient r, varying from −1 to +1, indicates a perfect negative correlation for r = −1, a perfect positive correlation for r = +1, and an absence of correlation between the parameters when r = 0 [10] [16] [23].

3. Results and Discussion

3.1. Results

3.1.1. Physico-Chemical Parameters

Temperature

The temperature values vary from 25.9˚C (Site S3) to 29.2˚C (Site S1). The lowest values (25.9˚C - 27.7˚C) are observed in August, while the highest (28.2˚C - 29.2˚C) are recorded in December (**Figure 3(a)**). These values remain high at all sites and exceed the limit of 25˚C set by the WHO for water for human consumption.

Potential hydrogen

Figure 3(b) represents the variation of pH in the waters. Analysis of this graph shows that the pH values varied from 6.49 to 7.22. During this study, the pH remained neutral during the December period and acidic during August for site S1; acidic for S2 and S3 in the December period and slightly basic in August for S2 and S3. However, the recorded values comply with the accepted limits between 6.5 and 8.5 [24].

Electrical conductivity

The electrical conductivity values obtained oscillate on the one hand between 164 µS/cm at site S1 and 165.7 µS/cm at site S3 in the short dry season and on the other hand between 160.2 µS/cm at sites S1 and S3 and 160.3 µS/cm at site S2 in the long dry season (**Figure 3(c)**). It should be noted that all waters have values between 80 µS/cm and 300 µS/cm. Furthermore, the values recorded during the present study are all lower than the maximum limit recommended by the WHO, which is 1200 µS/cm.

Dissolved oxygen and oxygen saturation rate

Dissolved oxygen concentrations vary from 2.85 to 5.76 mg/L during the short dry season and from 3.6 to 9.02 mg/L during the long dry season (**Figure 3(d)**). The lowest value is observed at station S3 (2.85 mg/L) in December, while the maximum value is noted at the same site S3 (9.02 mg/L) in August. During the month of December, only site S1 is suitable for the WHO guidelines for drinking water (5 - 8 mg/L), while in August, it is site S2 with a content of 8.17 mg/L. The values recorded for site S3 (2.85 - 9.02 mg/L) during the two campaigns remain non-compliant with the interval set by the WHO for water for human consumption.

The percentage of dissolved oxygen saturation in the waters is shown in Figure 3(e) and varies from 28.2% at site S2 in the long dry season to 119.8% at site 3 in the short dry season. These saturation rate values of these waters are in agreement with the dissolved oxygen content.

Oxidation-reduction potential

The redox potential of water samples oscillates between 72.8 mV and 190.9 mV in the long dry season and between 167.7 mV and 184 mV in the short dry season (Figure 3(f)). The redox potential values are positive for both seasons and are generally higher during the long dry season (S1 and S2).

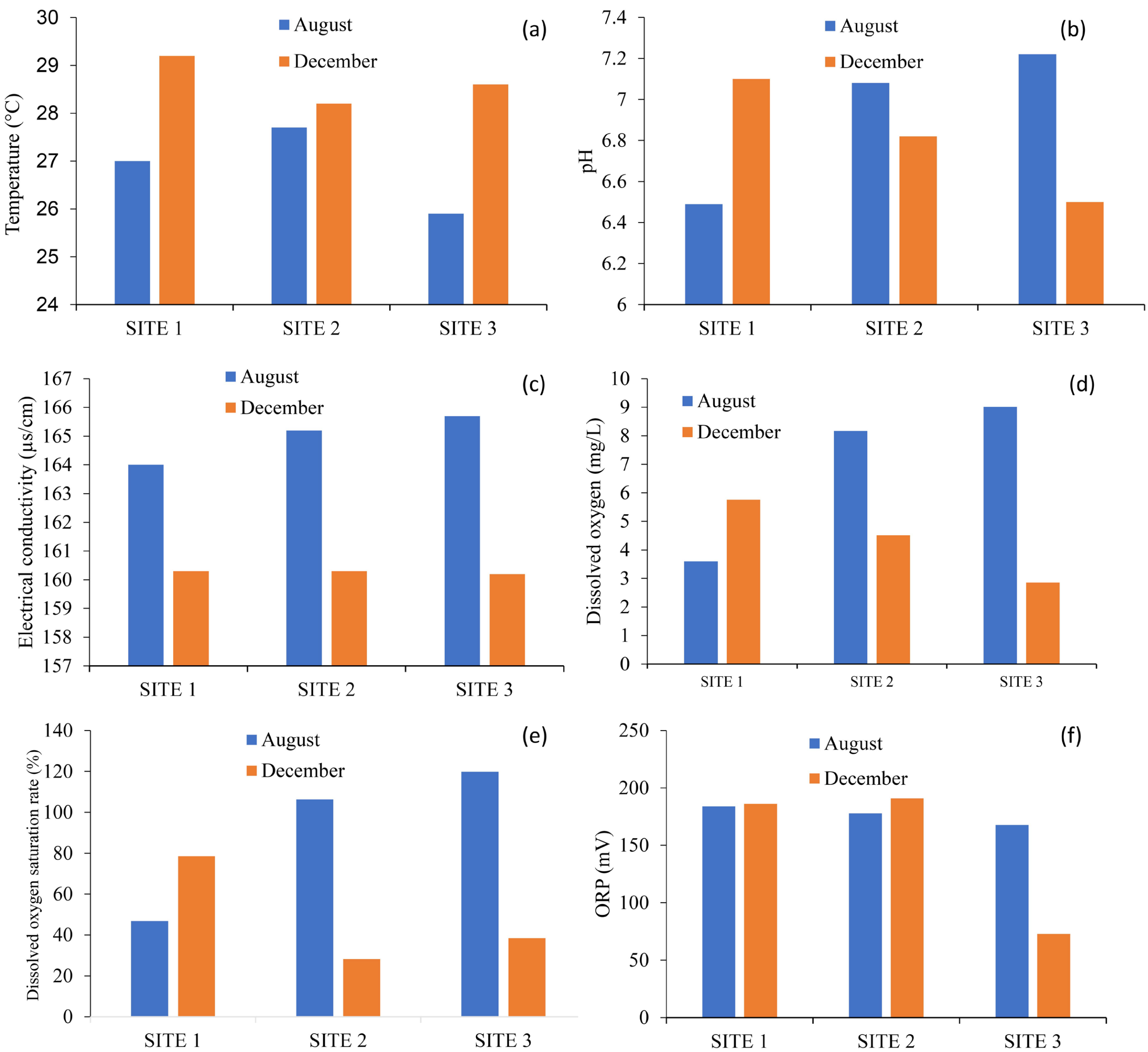

Figure 3. Monthly variation of physicochemical parameters of the waters of Lake Bra Kanon from August to December 2020.

3.1.2. Nutrient Salts

The monthly nutrient values of Lake Bra Kanon are shown in Figures 4(a)-(d).

Ammonium concentrations vary between 0.029 mg/L (site S2) and 0.047 mg/L (site S3) in the long dry season, while in the short dry season, the values oscillate between 0.02 mg/L (station S2) and 0.12 mg/L (station S3). Overall, there is a clear decrease in ammonium levels during the long dry season. Ammonium levels are below the WHO guidelines (0.5 mg/L) for drinking water. The variation of ammonium in the waters for the three stations during the two seasons is presented in Figure 4(a).

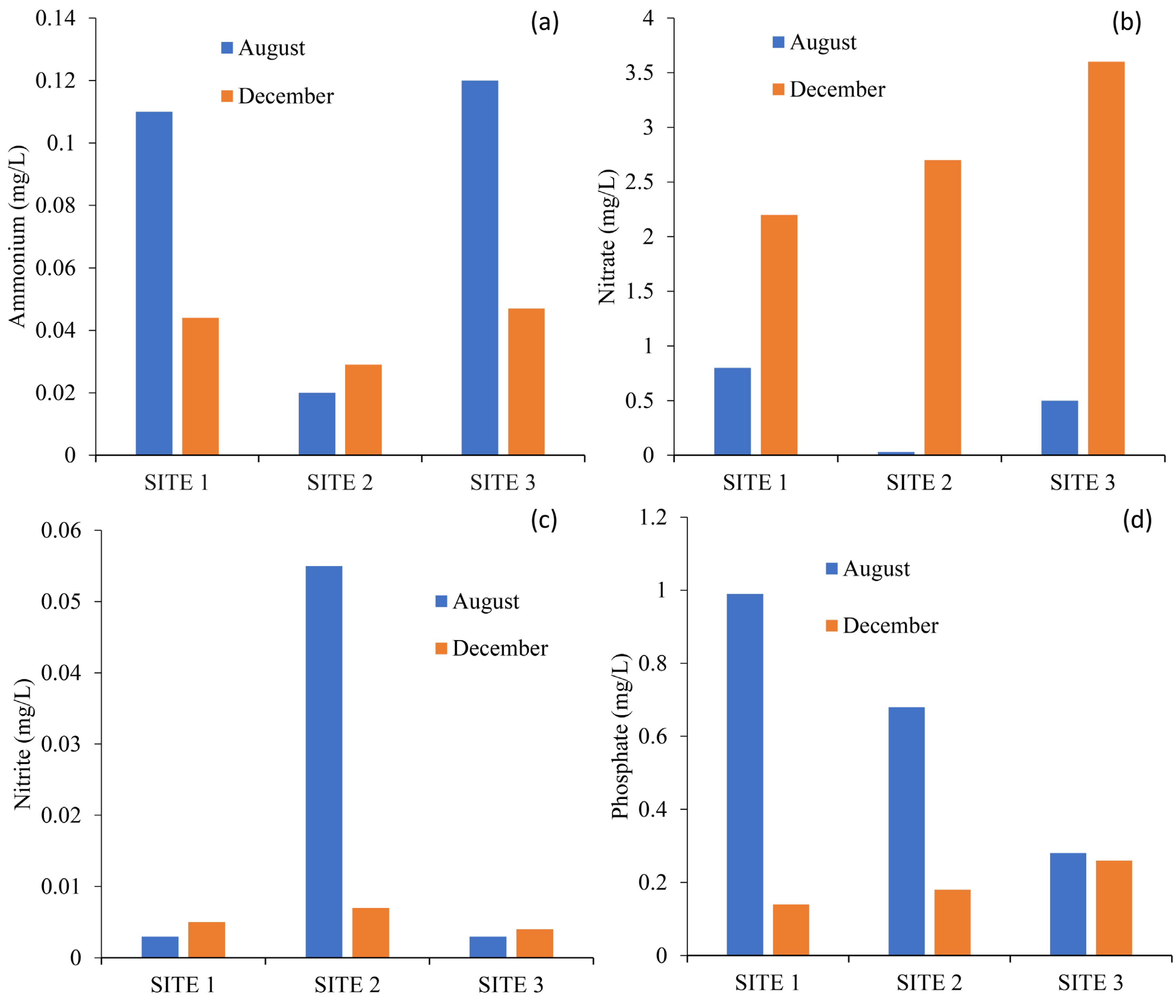

Figure 4. Monthly variation of nutrient salts in the waters of Lake Bra Kanon from August to December 2020.

During the short dry season, nitrite ion contents oscillate between 0.003 mg/L (sites S1 and S3) and 0.055 mg/L (site S2). During the long dry season, this parameter varies between 0.004 mg/L at site S3 and 0.007 mg/L at site S2. The highest rate is found in the short dry season at site S2, which records high values in both seasons (Figure 4(b)). However, the concentrations over both seasons are lower than the WHO guideline (0.1 mg/L) recommended for water for human consumption.

The nitrate values recorded vary between 0.03 mg/L at site S2 and 0.8 mg/L at site S1 in the short dry season. In the long dry season, the values obtained vary between 2.2 at site S1 and 3.6 mg/L at site S3 (**Figure 4(c)**). These values are higher in the long dry season than in the short dry season. However, these nitrate levels are much lower than the WHO guideline value (50 mg/L) relating to the potability of drinking water.

The phosphate ion contents vary between 0.14 and 0.99 mg/L during this study (**Figure 4(d)**). The long dry season has lower values than the short dry season. The phosphate values recorded for the three stations during the two seasons are lower than the value admissible by the WHO standard, which is 1.41 mg/L for water for human consumption.

3.1.3. Heavy Metals

The heavy metals measured in the waters of Lake Bra Kanon are cadmium, iron, manganese, lead, and zinc. The concentrations of these metals are shown in **Figure 5**. The variations of cadmium for the three sites range from 2.04 µg/L to 3.95 µg/L (**Figure 5**). The highest concentration (3.95 µg/L) is recorded at site S1, while the lowest concentration (2.04 µg/L) is observed at site S2. The concentrations at sites S2 and S3 are below the WHO guidelines (0.003 mg/L or 3 µg/L), while that at site S1 is above the WHO standard.

The iron concentrations in the waters for the three sites vary between 98.8 µg/L at site S2 and 123 µg/L at site S3. The results of the present study are below the WHO guidelines for drinking water for human consumption (0.3 mg/L or 300 µg/L) for all sites.

Manganese variations for the three sites range from 133.8 µg/L to 325.6 µg/L. The highest concentration (325.6 µg/L) is recorded at site S1, while the lowest (133.8 µg/L) is observed at site S2 (**Figure 5**). Concentrations at all three sites are below the WHO-recommended standard (0.4 mg/L or 400 µg/L) for human consumption.

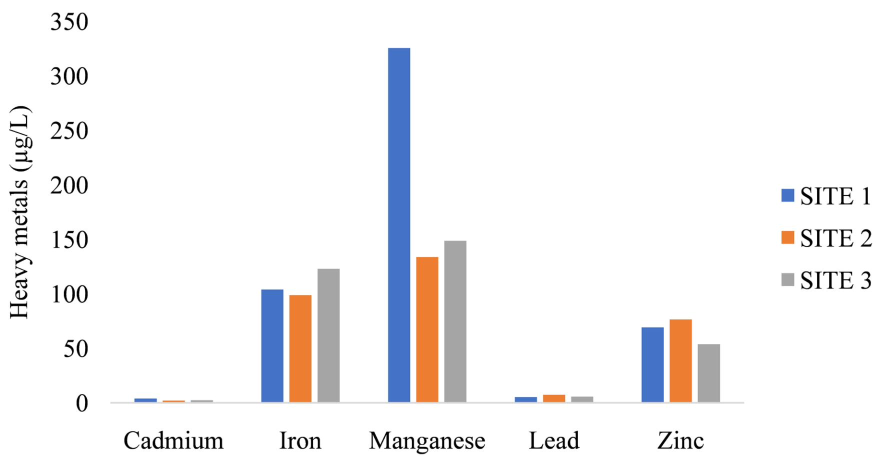

Figure 5. Variation of heavy metals in the waters of Lake Bra Kanon.

Figure 5 shows the variation of lead in the water for the three sites during sampling. Lead concentrations are between 5.3 µg/L and 7.3 µg/L. The highest lead content is recorded at site S2, and the lowest value at site S1. The results recorded during this study are lower than the maximum lead concentration authorized by the WHO relating to the potability of drinking water (0.01 mg/L or 10 µg/L) for all sites.

Zinc has concentrations that range between 53.9 µg/L at site S3 and 76.5 µg/L at site S2. These recorded values are much lower than the WHO guidelines recommended for the potability of water for human consumption (3 mg/L or 3000 µg/L) for all sites.

3.1.4. Correlation between Physicochemical Parameters, Nutrients, and Heavy Metals

The Bravais-Pearson correlation matrix was carried out to elucidate the relationships between the water quality parameters measured in Lake Bra Kanon. The correlation coefficients are presented in Table 2. Generally speaking, there are highly significant correlations between the physicochemical parameters, nutrients, and heavy metals on the one hand and between nutrients and heavy metals on the other hand. Additionally, there are correlations between the concentrations of certain heavy metals. Furthermore, each parameter analyzed is strongly and significantly correlated with at least one other parameter. Examination of the matrix indicates the existence of positive and significant correlations with coefficients ranging from r = 0.5 to r = 1. On the other hand, significantly negative correlations oscillate between r = −0.50 and r = −0.99.

Table 2. Correlation coefficients between chemical parameters, nutrient salts, and heavy metals.

	T	pH	CE	OD	TOD	NO_2^-	NO_3^-	NH_4^+	PO_4^{3-}	ORP	Cd	Fe	Mn	Pb	Zn
T	1														
pH	−0.07	1													
CE	**−0.80**	**0.65**	1												
OD	−0.44	**0.93**	**0.89**	1											
TOD	**−0.99**	0.18	**0.86**	**0.53**	1										
NO_2^-	0.35	**0.91**	0.28	**0.69**	−0.25	1									
NO_3^-	**−0.94**	−0.28	**0.55**	0.10	**0.90**	**−0.65**	1								
NH_4^+	−0.44	**−0.86**	−0.18	**−0.61**	0.34	**−0.99**	**0.73**	1							
PO_4^{3-}	**0.95**	−0.37	**−0.95**	**−0.69**	**−0.98**	0.05	**−0.79**	−0.15	1						
ORP	**0.98**	0.08	**−0.70**	−0.30	**−0.96**	0.49	**−0.98**	**−0.58**	**0.89**	1					
Cd	0.46	**−0.92**	**−0.90**	**−0.99**	**−0.55**	**−0.70**	−0.13	**0.59**	**0.71**	0.32	1				
Fe	**−0.93**	−0.29	**0.53**	0.08	**0.89**	**−0.67**	**0.99**	**0.74**	**−0.78**	**−0.98**	0.11	1			
Mn	**0.58**	**−0.85**	**−0.95**	**−0.99**	**−0.6***	**−0.56**	−0.26	0.47	**0.80**	0.45	**−0.99**	−0.25	1		
Pb	0.17	**0.97**	0.45	**0.81**	−0.06	**0.98**	**−0.50**	**−0.96**	−0.14	0.32	**−0.80**	**−0.51**	**−0.71**	1	
Zn	**0.88**	0.40	−0.43	0.04	**−0.83**	**0.75**	**−0.99**	**−0.81**	**0.70**	**0.95**	−0.01	**−0.99**	0.13	**0.61**	1

Values in bold are significant at $P < 0.05$.

3.2. Discussion

All sites presented a temperature above the acceptable limit, which is 25˚C recommended by the WHO [24]. These temperatures vary between 27˚C and 29.2˚C. These high values could be explained by the influence of ambient temperature on the water [12] [25] due to the direct contact of the sun's rays with the water surface [4] [26]. These high temperatures could lead to a reduction in the survival of certain enteric pathogens in water, promote self-purification, and increase the sedimentation rate of suspended matter, all of which is favorable to the production of drinking water [13]. The higher temperature in December is believed to be due to seasonal variation. Indeed, this month is included in the long dry season, where it is probably warmer, and the sunlight is more intense compared to the short dry season. The results of this study are of the same order as those obtained by Amon *et al.* [11] and Kouamé *et al.* [13], which oscillate between 26.32˚C ± 3.92˚C and 29.97˚C ± 3.56˚C, respectively, and between 26.43˚C ± 1.45˚C and 28.11˚C ± 1.59˚C.

Hydrogen potential is an important parameter in the assessment of water quality because it characterizes a large number of physicochemical balances and depends on several factors, including the origin of the water [10]. The pH values of the waters studied are between 6.49 and 7.22. The sites in our study area have water that generally complies with the standard set by the WHO for water for human consumption, with values between 6.5 and 8.5 [24]. The waters of Lake Bra Kanon have an acidic tendency with average values of 6.80, 6.90, and 6.86 at sites S1, S2, and S3, respectively. These values indicate that these waters have an aggressive (corrosive) tendency [13]. Consumption of these acidic waters could cause gastric disorders in consumers [27]. However, slightly acidic water is not harmful to the health of consumers [28]. These results are very close to those obtained by Kouyaté *et al.* [10] during the evaluation of the chemical quality of the Lobo River used for the production of drinking water for the populations of the city of Daloa (Ivory Coast). These authors, in fact, recorded values which varied from 6.51 to 7.52.

The electrical conductivity of water is an index of the total ionic content of water, which depends on the concentration of ions and the temperature of the water [29]. This parameter is also an indicator of the taste or salinity of water because high values of electrical conductivity are linked to a bad taste and a high percentage of total dissolved solids [30] [31]. The electrical conductivity of water from the sampled sites varies between 160.2 and 160.3 µS/cm in the long dry season and between 164 and 165.7 µS/cm in the short dry season. All waters have a conductivity between 100 and 200 µS/cm. They are therefore included between weakly mineralized waters ($0 < EC < 80$) and relatively well mineralized waters ($300 < EC < 500$) [14]. In addition, these waters have an electrical conductivity lower than 1200 µS/cm, the WHO upper limit, over both seasons. These values could reflect the good water quality of Lake Bra Kanon. Indeed, according to Dinesh *et al.* [32], high conductivity values are an indication of water pollution. Furthermore, according to the classification made by

Rodier *et al.*, waters with an electrical conductivity greater than 1000 µS/cm are highly mineralized and are unfit for human consumption [19]. These values are higher than those obtained by Kouamé *et al.* [13], who obtained results ranging from 42.67 µS/cm ± 4.30 µS/cm to 59.62 µS/cm ± 21.84 µS/cm.

Dissolved oxygen is an essential parameter, because it provides information on the state of the water and promotes the growth of microorganisms, which degrade organic matter [12] [33]. The values of this study are between 3.6 and 9.02 in the short dry season and between 2.85 and 5.76 in the long dry season. The strong variation in dissolved oxygen would probably be linked to the phenomenon of enrichment (photosynthesis and exchange with the atmosphere) and consumption (oxidation of organic matter and respiration) [11]. The values obtained for dissolved oxygen in the waters of Lake Bra Kanon are low and below the WHO standard (5 - 8 mg/L) for site S1 in August and for the two sites S2 and S3 in December. These low values of dissolved oxygen could favor the development of pathogenic germs [33]. The waters of the lake have dissolved oxygen contents lower than the standard of 5 mg/L recommended for surface water intended for the production of drinking water [13].

As for the redox potential, the values oscillate between 72.8 and 190.9 mV in the long dry season and between 167.7 and 184 mV in the short dry season. The lowest value was recorded during the second campaign at site S3. However, at sites 2 and 3, low values are recorded during the first sampling campaign. These values are in agreement with those of the dissolved oxygen and the saturation percentage in the waters of sites 1 and 3. Indeed, in well-oxygenated water, oxidation conditions dominate. In addition, when dissolved oxygen concentrations decrease, the environment becomes more reducing, leading to a reduction in the redox potential [34]. The ORP values recorded in our study are higher than those obtained by Kouamé *et al.* [13] on Lake Dohou (24.55 mV ± 10.80 mV to 56.37 mV ± 17.77 mV).

The ammonium ion is the main reducing agent in water and could constitute a significant pollutant in the long term because it contributes to the eutrophication of the aquatic environment [35]. Ammonium ion (NH_4^+) contents vary from 0.02 to 0.12 mg/L in the short dry season and from 0.029 to 0.047 mg/L in the long dry season. Levels are generally higher in the short dry season for this nutrient. However, ammonium levels in both seasons are lower than the standard (0.5 mg/L) set by the WHO for drinking water. These values are lower than those obtained by Kouyaté *et al.* [10], whose values vary from 0 mg/L to 3.44 mg/L. This increase in concentration can be explained by the use of fertilizers, herbicides, and other toxic chemicals for agricultural activities near water bodies [13]. It should be noted that these contributions are not without danger for water quality, the proper functioning of this hydrosystem, and human health. Indeed, depending on the dose ingested and the duration of exposure, ammonium can cause human health problems such as dysfunction of the nervous and renal systems, pulmonary edema, and an increase in blood pressure [36] [37].

In the present study, nitrate ions represented the most abundant nutrient in all sampled waters. The values obtained range between 0.03 mg/L and 3.6 mg/L. These values remain much lower than the value recommended by the WHO, which is 50 mg/L [24]. Concentrations are higher in the long dry season than in the short dry season. These high nitrate concentrations during the long dry season are due to the drop in water levels, which concentrates the salts [12]. This suggests possible evaporation or infiltration of the lake (source) water during this period [38]. Furthermore, these high concentrations could be due to point pollution [25]. Consumption of water polluted by nitrates can cause methemoglobinemia in infants under three months of age, pregnant women, and people genetically deficient in enzymes [39].

As for nitrite ions, the values oscillate in the short dry season between 0.003 and 0.055 mg/L. In the long dry season, these values oscillate between 0.004 and 0.007 mg/L. They are all lower than the standard set by the WHO, which is 3 mg/L [24]. The waters are not subject to a risk of pollution by this nutrient. These values are low compared to those reported by Amon *et al.* [11]. Indeed, these authors noted concentrations varying from 0.01 mg/L ± 0.00 mg/L to 0.15 mg/L ± 0.05 mg/L during the characterization and typology of the waters of the Aghien lagoon (southeast of the Ivory Coast) as potential resources for the production of drinking water. The low nitrite concentrations recorded in the present study are an advantage because nitrites have known adverse effects on human health. Indeed, an excess of nitrites in drinking water can cause methemoglobinemia, which can lead to asphyxia in bottle-fed newborns [10] [31]. In addition, there is a link between exposure to nitrites and cancer in humans [30] [31].

Phosphate ions have values between 0.28 and 0.99 mg/L in the short dry season and from 0.14 to 0.26 mg/L in the long dry season. The sites (S1 and S2) have a content that exceeds the required standard of 0.5 mg/L for this nutrient in the short dry season. These values are comparable to those obtained by Eblin *et al.* [40] in Adiaké (south-eastern Ivory Coast), varying from 0.03 mg/L to 1.88 mg/L, during the hydrochemical study of surface waters in the Adiaké region. The high contents observed at sites S1 and S2 could have various origins. According to Rodier *et al.*, in fact, water contamination by orthophosphates is linked to industrial and domestic discharges or to the leaching of cultivated land containing phosphate fertilizers or treated with certain pesticides. In the study area, there is no industrial establishment [19]. Water contamination is probably due to the leaching of neighboring agricultural land rich in phosphate fertilizers and pesticides, and to domestic waste rich in soap and detergents. High nutrient levels in waters can lead to increased algae blooms [41]. Regular consumption of water polluted by phosphate could cause digestive problems in consumers [42].

Aquatic environments constitute one of the largest reservoirs of environmental pollutants, including heavy metals [43]. Indeed, aquatic systems are often the seat of these metals, which represent a real danger for humans, animals, and the environment [44]-[46]. Chronic ingestion of heavy metals, beyond the tolerable limit in humans, has harmful effects and can cause neurological damage, headaches, and liver diseases [47]. It is therefore necessary to determine the level of metal contamination in aquatic systems in order to prevent damage to aquatic life and humans [48].

The values of heavy metal concentrations obtained in the waters of Lake Bra Kanon revealed that heavy metals varied between 2.04 and 3.95 µg/L for Cd, 98.8 to 123 µg/L for Fe, 133.8 and 325.6 µg/L for Mn, 5.3 to 7.3 µg/L for Pb, and 53.9 to 76.5 µg/L for Zn. Concentrations of heavy metals in water follow the following order: Mn > Fe > Zn > Pb > Cd. Manganese (Mn), lead (Pb), iron (Fe), and zinc (Zn) are the metals detected in water with levels below the standards recommended by the WHO, which are, respectively, 0.4 mg/L, 0.01 mg/L, 0.3 mg/L, and 3 mg/L [24] for water for human consumption. However, the concentrations of cadmium (Cd) determined in the sample studied at the site (S3) are higher than the standard set by the WHO (0.003 mg/L) [24] for the protection of consumer health, thus suggesting prior treatment before its use. The presence of cadmium in contaminated water can disrupt the body's physiological mechanisms and cause short or long-term problems [49]. Indeed, this metal does not appear to play any role in higher biological systems or in human nutrition [50]. In humans, exposure to cadmium can lead to kidney and liver damage, pulmonary and cardiovascular diseases, bone disorders, and neurotoxic effects [51] [52]. Furthermore, due to their persistence and their tendency to bioaccumulate in the food chain, metals, even in low quantities, present a potential risk for humans and ecosystems [53].

The Bravais-Pearson correlation matrix was carried out to elucidate the relationships between physicochemical parameters, nutrients, and heavy metals measured in the lake waters. The said matrix revealed significant correlations between the different variables analyzed. The significant correlations observed between physicochemical parameters, nutrients, and metals indicate the influence of these environmental parameters on nutrients and heavy metals [54] [55]. Generally, the correlation matrix indicates a positive and significant correlation between all nutrients, thus reflecting a common origin of nutrient salts [35] [56]. According to Abdel-Satar *et al.*, in fact, agricultural, domestic, and industrial waste could constitute a significant source of nitrogen and phosphorus inputs into the water body [57]. Cadmium is positively and significantly correlated with manganese (r = 0.99), while lead is positively and significantly correlated with zinc (r = 0.61). These correlations indicate a mutual dependence of these metals. Indeed, a high correlation coefficient between variables means that they have a common source, mutual dependence, and identical behavior during transport [23] [36] [56] [58]. The probable sources of contamination would be agricultural activities near the lake, with the use of agrochemicals such as herbicides and pesticides [43]. There are also other likely sources of pollution, including septic tanks, latrines, and illegal dumping. The significant and negative correlations observed between heavy metals: Cd-Pb (r = −0.80), Fe-Pb (r = −0.51), Fe-Zn (r = −0.99) and Mn-Pb (r = −0.71) show an inverse dependence between these metals, thus indicating that the content of one increases with the decrease of the other [16] [59] [60]. Furthermore, the low correlations or negative correlations observed between some variables could suggest that these variables have different sources of pollution [56] [58] [61].

4. Conclusions

This study consisted of evaluating the physicochemical quality and the level of metal contamination of the waters of Lake Bra Kanon in Daloa in the center-west of the Ivory Coast by studying the variation of certain parameters. A total of fifteen (15) parameters, including six (6) physicochemical parameters, four (4) nutrients, and five (5) heavy metals, were analyzed.

At the end of this study, it appears that the quality of water from the sites studied is acceptable for human consumption, both on a physico-chemical and metallic level. Indeed, twelve (12) of the parameters evaluated present levels consistent with the World Health Organization (WHO) guideline for drinking water at all study sites. However, three parameters (temperature, dissolved oxygen, and cadmium) have levels higher than the limit values prescribed by the WHO for water intended for drinking on at least one of the study sites. These values, which do not comply with the standard for drinking water, are mainly due to anthropogenic activities (agricultural practices such as the use of fertilizers and pesticides, artisanal fishing, watering of animals) around the lake and to the input of wastewater from surrounding households. The temperature, dissolved oxygen, and cadmium values obtained for the lake water could make it unsuitable for human consumption as drinking water under the WHO guidelines. Indeed, the consumption of polluted water as drinking water can have an impact on the health of populations who depend on this water for their daily drinking water needs and other domestic activities.

5. Recommendations for Future Research

To complete this study on the water quality of the Bra Kanon, it would be interesting to consider other studies to allow an analytical approach likely to increase the understanding of water-borne diseases and the water consumed, in particular:

- ✓ Take into account a greater number of parameters: physicochemical, microbiological, heavy metals, and major cations;
- ✓ Carry out the study over several seasons in order to see the effect of seasonal variation on the environmental quality of water;
- ✓ Use quality indices (water quality indices, metal contamination indices, and organic pollution index) to understand overall organic and metal pollution both on water quality and on consumer health.

Conflicts of Interest

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

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