

Qualitative Assessment and Typology of the Water Resource Used for the Production of Drinking Water in Duékoué, Western Côte d'Ivoire

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How to cite this paper: Benoit, K. K., Séraphin, K. K., Severin, A. K., Félix, K. K., Charles, B. K., & Martin, K. K. (2019). Qualitative Assessment and Typology of the Water Resource Used for the Production of Drinking Water in Duékoué, Western Côte d'Ivoire. *Journal of Geoscience and Environment Protection*, 7, 212-231. <https://doi.org/10.4236/gep.2019.75017>

Received: March 26, 2019

Accepted: May 27, 2019

Published: May 30, 2019

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Abstract

The objective of this study was to evaluate the typology of water through physicochemical and bacteriological characterization with the aim of highlighting its vulnerability as a drinking water resource. The methodology adopted was to evaluate the level of pollution by monitoring the spatiotemporal variation of the water pollution indicator levels of Lake Dohou. The sampling frequency is monthly for one year, from November 2017 to October 2018, in order to obtain a fairly representative image of water quality and its seasonal evolution in eight (8) well-defined stations. The parameters were determined using the standard methods defined by the French Association for Standardization (AFNOR). This study shows that the waters are acidic, with an average pH of 5.81 and a low electrical conductivity of between 42.67 ± 4.30 and $59.62 \pm 21.84 \mu\text{S}\cdot\text{cm}^{-1}$. At all stations, seasonal mean water transparencies are low (<1 m). It is also noted that 99.7% of the water samples collected had total nitrogen (TN) levels above the limit of $4 \text{ mg}\cdot\text{L}^{-1}$. All of the lake's waters have non-compliant BOD₅ ($<3 \text{ mgO}_2\cdot\text{L}^{-1}$) for raw water intended for the production of drinking water. Sites D6 and D7 have COD/BOD₅ ratio greater than 3, which indicates the presence of non-biodegradable organic matter in these areas. Total coliforms, *Escherichia coli* and Enterococci were present in 100% (28/28) water samples at concentrations ranging from 2300 to 173,000 CFU/100 mL, from 100 to 1650 CFU/100 mL and from 20 to 1140 CFU/100 mL respectively. For Salmonella pathogens, they were detected in 50% of the dry season samples and in 100% of the rainy season samples. This almost permanent presence of this pathogenic germ denotes a poor quality of water with reference to this parameter. The presence of total coliform and other micro-

bial contaminants suggests that supplied water is highly contaminated with pathogens and great reservoirs for them. Principal component analysis (PCA) of the physicochemical data set allowed defining three different classes of water on the Dohou Lake. Outside the upstream zone (D6 and D8), water could continue to be used for the production of drinking water.

Keywords

Dohou Lake, Water Quality, Coliform, Fecal Coliform, Physico-Chemical Parameters, Typology and Variation

1. Introduction

The use of water in many areas of human activity, the ever-increasing population and climatic variations are all factors that affect the water resource, in terms of quantity and quality, and constitute a major global concern in recent years. In Côte d'Ivoire, the crystalline and crystallophyllian environments (about 97% of the Ivorian territory's surface area) make it difficult to access groundwater, because most of the water is found in fractures (Goné, 2001). This has resulted in the use of surface water as the main source of water supply for urban populations (Goné, 2001). However, the pollution of peri-urban watercourses around the world and in particular in Côte d'Ivoire is a constant concern. It manifests itself through the phenomena of eutrophication, waterborne diseases and the loss of biodiversity (Yéo, 2015; Traoré, 2016). Also, the old thought was that rainwater, one of the components of urban waste, diluted the waste allowing their discharge into the river without harmful impacts, which also justified the use of weirs storms is still relevant in the study area. Although, studies in the field of liquid waste management eventually revealed that urban discharges contained a wide variety of pollutants with multiple origins. In Duékoué, a city located in the west of Côte d'Ivoire, the production of drinking water is in a special situation because of the vulnerability of the resource used (distributed water is produced from superficial resources). This situation is linked to agricultural pressures, climatic hazards, urbanization, geological and topographical factors that favor the leaching of pollutants (nitrogen, phosphorus, organic matter and pesticides) to these resources. This region is known for heavy rainfall during the rainy season and high heat during the dry season (Kouassi et al., 2011). However, heavy precipitation can also mobilize and leach soluble and particulate substances into surface water through runoff. Increases in turbidity and organic matter (OM) are generally observed after precipitation (Ritson et al., 2014; Yéo, 2015). The increase in OM also promotes the transport of micropollutants. Heavy rains can lead to sewer overflows and heavy urban runoff leading to a surge of contamination in surface water. These changes in the quality of the raw water can pose several problems for water treatment, such as fouling and blockage of membranes, an increase in the dosage of the chemical and a decrease in

the duration of the execution of filter (Ritson et al., 2014). All of these problems require treatment adjustments that can lead to significant increases in operational costs (Cousin, 2012). Finally, following an increase in OM content in water, an increase in disinfection by-products (SPDs) such as trihalomethanes (THMs) and haloacetic acids in distributed water could be observed (Delpla & Rodriguez, 2014, Delpla & Rodriguez 2017). Droughts can reduce the dilution capacity of surface water and lead to an accumulation of pollutants from point sources, including urban wastewater (Mosley, 2015). Recent studies show that drought can have a pronounced effect on drinking water quality, including episodes of taste and odor, increased color, increased turbidity, pathogens and control difficulties of SPD (Mosley, 2015). Higher temperatures and heatwaves could create more favorable conditions for algae growth in nutrient-rich water bodies; in addition, a warmer climate could favor the dominance of cyanobacteria on phytoplankton in the water column and increase the number of cyanobacterial blooms (Ritson et al., 2014). These blooms generate some problems for drinking water production, such as taste and odor, increased potential for SPD formation and toxin production. It is against these issues that WHO is advocating a new type of preventive risk management approach with the water safety plan (wsp). This approach introduces the concept of risk assessment and risk management throughout the production cycle of drinking water. It is proposed to characterize risks and to prioritize them by distinguishing two types: primary (medium and long-term) risk that is essentially microbiological and therefore infectious and a generally chemical secondary (Bartram et al., 2010; WHO, 2011). In addition, Bessonneau et al. (2011) proposes relative gradation of health risk according to the type of water resources and underlines the greater vulnerability of surface water, linked to anthropic and climatic pressures. The adverse effects of water pollution on environmental and human health have been reported for many decades by numerous studies conducted in different parts of Côte d'Ivoire. Indeed, Amon et al. (2017) evaluated the physicochemical quality of the Aghien lagoon with regard to its drinking water consumption and showed that the stations near the zones of disturbance caused by the arrivals of tributary rivers were very polluted. Also, Eblin et al. (2014) also showed that the water resources studied in the Tahou area were strongly influenced by anthropogenic activities, with the presence of faecal coliforms such as *Escherichia coli* and faecal streptococci, which are the result of pollution of recent human origin. Ahoussi et al. (2013) evaluated the physicochemical and microbiological quality of the spring waters of Mangouin Yrongouin village in the Biankouman locality (Cote d'Ivoire). They indicated that microbiologically, spring waters contained high levels of *Escherichia coli* and *Clostridium perfringens*, and mineralization was controlled by phenomena such as rain-leaching of soils, acid hydrolysis of rocks, and related to human activities. They point out that the consumption of these waters outside of any treatment presented health risks for the populations. Goné et al. (2008) rather hung over the effect of the organic matter in the process of

coagulation of a lake used for the production drinking water. Yapo (2002) reported that the eutrophication of Buyo Lake was a sign of the degradation of the quality of its waters. They insist that this poor quality revealed by the proliferation of a large biomass of algae. However, few studies have been conducted on the impoundments used for water production in the region. This study aims to contribute to knowledge about the impact of spatial factors (land use) and temporal factors on the quality of a resource used for the production of drinking water in an agricultural and peri-urban environment. The aim will be to evaluate the typology of water through physico-chemical and bacteriological characterization with the aim of highlighting its vulnerability as a drinking water resource.

2. Material and Method

2.1. Study Area

Dohou Lake (Figure 1) is located on the outskirts in the town of Duékoué chief town of the region of Guémon between two plutonic domes and precisely between 6.752 and 6.762 latitude North and between -7.364 and -7.35 west longitude. It is reservoir of water made on river that bears his name. The climatic regime prevailing at the Duekoué zone is a mountainous sub-equatorial climate, with a unimodal regime characterized by two seasons. It is characterized by annual rainfall averaging between 1600 mm and 2000 mm (Kouamé, 2011). The average temperature hovers around 25°C per year. Vegetation consists of dense, moist forest marked by grassland areas (Brou, 2005). The relief is part of the mountain range of the west of the country; it is quite rugged, with an average altitude of 300 m. There are vast high plateaus, plains, very extensive bottomlands

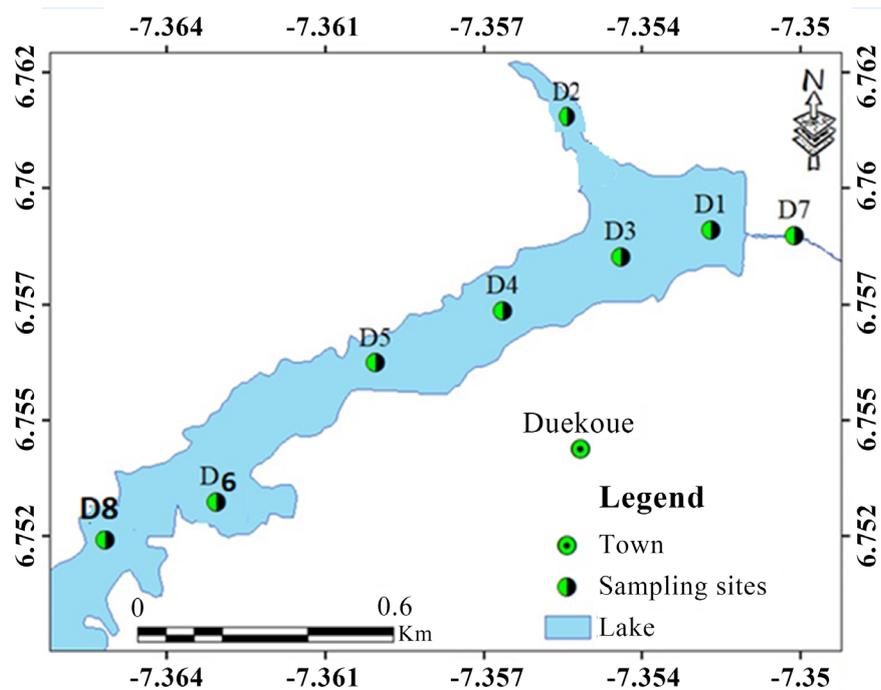


Figure 1. Sampling sites locations on Dohou Lake.

and mountain ranges. The soils are of ferritic type with medium chemical fertility and constitute a broad area for the development of agriculture (Kouassi et al., 2011). There are also soils developed on basic rocks potentially rich in mineral salts and hydromorphic soils (shallows). The soils of this zone of the country result directly from the natural process of feralization and ferrugination (Goné, 2001). These processes are supplemented by three types of handling, namely: leaching, depletion and induration, which are the result of the alteration of the rock formations that have been put in place. These soils, given the nuances they present, constitute the assets for agricultural production. The hydrographic coverage of the Duékoué region is ensured by the Sassandra River and its tributaries. The vegetation, like western Côte d'Ivoire, is located in the forest zone. This agriculture-friendly area is home to extensive rubber plantations, cocoa, coffee and food crops throughout the river's watershed. Fertilizers injected into these plantations, as well as discards from livestock and poultry production units and inhabitants, are found in the lake and are likely to promote eutrophication. Also, on the banks of this reservoir of water, there is a stiff competition between buildings and vegetable crops.

2.2. Sampling

For this study, 8 sampling and monitoring sites were carefully selected, 6 located on the lake, one upstream (D8) and the eighth downstream (D7). The choice of sampling stations was made based on the hydrographic network and the potential sources of pollution. The sampling frequency is monthly for one year, from November 2017 to October 2018, in order to obtain a fairly representative image of water quality and its seasonal and annual evolution. The samples were taken using a sampler integrated from the surface to a depth of 1m below and collected in plastic bottles and amber glasses to avoid photo-degradation of the parameter BOD5 sensitive to solar rays. Regarding the sampling of samples for microbiological analysis, they were made according to the seasons of the study area. Samples were taken in the sterile vials taking care not to contaminate or modify the samples. All samples are stored in a cooler at $\pm 4^{\circ}\text{C}$ and transported to the laboratory. A total of 21 parameters were analyzed for the control and assessment of water quality in this study. Temperature, pH, dissolved oxygen (DO), conductivity, redox potential and total dissolved solids were measured in situ using a multi parameter HANNA HI 9828PH/ORP/CE/DO. Transparency was also determined in situ with the Secchi disk. A portable turbidimeter was used to determine the turbidity of the water. Nitrate, nitrite, ammonium, ortho-phosphate and total phosphorus were estimated according to the standard (AFNOR standard ISO 7890-3, ISO 6777, T 90015, T900-23 respectively) after filtration of the samples on Whatman filter paper of 0.45 μm porosity. The spectrophotometer (SHIMADZU UV/visible-1700 pharma) was used for these analyzes. The SO_4^{2-} anion is obtained by the nephelometry method. Kjeldahl nitrogen is determined by the Kjeldahl method after selenium mineralization prescribed by the AFNOR T 90-110 standard. The COD analysis protocol is based on the hot potassium

dichromate mineralization and the determination of the excess dichromate by a solution of iron and ammonium sulfate II in the presence of ferroin used as an indicator (AFNOR NF T 90-101). BOD₅ was measured using the WARBURG respirometer principle method, in which biomass respiration is directly measured by Oxytop. The microbiological parameters were determined by seeding the microbes in culture media specific to each type of bacteria. Thus, the following media were used for microbial search and enumeration: Hecktoen agar is the selective isolation medium used for salmonella. On Hektoen agar, Salmonella gives green colonies with black centers, which become completely black at the end of incubation. BEA agar (Bile Esculin Azide) for faecal Streptococci (Enterococci). For enumeration of total coliforms and *Escherichia coli*, Rapid[®] *E. coli* Agar was used in this analysis. This culture medium is a chromogenic medium that differentiates *E. coli* from other coliforms. On this medium, *E. coli* appear pink to purple while other coliforms are blue. Then, after incubation, pink and purple colonies only are counted for *E. coli* and all blue, pink and purple colonies are counted for total coliforms.

2.3. Data Analysis

Significant differences in spatial and seasonal data were evaluated with the Kruskal-Wallis tests with the Paleontological Statistics software version 3.14 (PAST) and the principal component analysis was performed using STATISTICA.13.3.

3. Results

3.1. Physico-Chemical Parameters

Seasonal values of the physico-chemical parameters (Temperature, Dissolved Oxygen, Conductivity, Redox Potential, pH, Turbidity, Total Dissolved Solids and Transparency) measured from November 2017 to October 18 in the waters of Dohou Lake are shown in **Table 1**. Temperature varies seasonally from $26.5^{\circ}\text{C} \pm 1.13^{\circ}\text{C}$ to $28.21^{\circ}\text{C} \pm 1.48^{\circ}\text{C}$, with an average of $26.93^{\circ}\text{C} \pm 0.33^{\circ}\text{C}$. Maximum temperatures were recorded during the dry season and low during the rainy season. The pH values range from 5.38 ± 0.40 to 6.21 ± 0.48 , with an average of 5.8 ± 0.23 pH units. The mean concentrations per station of dissolved oxygen over the entire stream range from $3.59 \pm 1.78 \text{ mg}\cdot\text{L}^{-1}$ at $6.78 \pm 1.85 \text{ mg}\cdot\text{L}^{-1}$, with an average of $5.59 \pm 0.45 \text{ mg}\cdot\text{L}^{-1}$. The average electrical conductivity per water station varies between 42.67 ± 4.30 and $59.62 \pm 21.84 \text{ }\mu\text{S}\cdot\text{cm}^{-1}$, with an average of $48.43 \pm 2.67 \text{ }\mu\text{S}\cdot\text{cm}^{-1}$. The mean values per station of turbidity and TDS vary between 27.80 ± 7.37 and 69.75 ± 14.5 NTU respectively and between 21.00 ± 2.44 and $35.25 \pm 16.87 \text{ mg}\cdot\text{L}^{-1}$ for the study period. They have respective annual mean values of 36.69 ± 6.84 NTU and $24.33 \pm 1.81 \text{ mg}\cdot\text{L}^{-1}$. The values of the transparency per station are between 0.20 ± 0.14 and 0.70 ± 0.21 m, with an average of 0.51 ± 0.13 m. Seasonal levels of nutrients, in terms of chemical oxygen demand and biochemical demand in water ($\text{mg}\cdot\text{L}^{-1}$) of Dohou Lake are shown in **Table 2**.

Table 1. Seasonal variation in the physico-chemical parameters values of the waters of Dohou Lake from November 2017 to October 2018.

	Seasons	TEMP	DO	EC	PH	Eh	TDS	TURB	TRANS
D1	DS	27.32 ± 1.65	6.78 ± 1.85	49.31 ± 7.82	6.16 ± 1.03	45.64 ± 19.22	25.00 ± 4.57	34.06 ± 7.14	0.55 ± 0.86
	RS	26.53 ± 1.70	6.03 ± 1.29	43.80 ± 4.75	6.21 ± 0.48	24.65 ± 10.17	21.67 ± 2.70	31.10 ± 6.55	0.65 ± 0.17
D2	DS	27.70 ± 1.42	6.4 ± 1.35	49.67 ± 8.05	6.03 ± 0.95	53.72 ± 13.02	24.75 ± 3.77	38.25 ± 4.17	0.53 ± 0.11
	RS	27.00 ± 1.62	5.85 ± 0.88	42.67 ± 4.30	5.98 ± 0.66	25.36 ± 9.46	21.00 ± 2.44	27.80 ± 7.37	0.70 ± 0.21
D3	DS	27.77 ± 1.48	6.23 ± 1.22	53.27 ± 10.05	6.16 ± 0.94	52.22 ± 12.57	22.25 ± 5.67	35.06 ± 9.49	0.56 ± 0.12
	RS	27.13 ± 1.76	5.50 ± 1.26	43.73 ± 4.42	5.87 ± 0.63	26.70 ± 10.65	21.68 ± 2.59	31.46 ± 7.92	0.63 ± 0.14
D4	DS	27.8 ± 1.57	5.82 ± 0.97	51.68 ± 11.03	6.06 ± 0.91	51.71 ± 12.20	26.25 ± 6.16	37.68 ± 8.08	0.52 ± 0.13
	RS	27.17 ± 1.47	5.91 ± 0.74	43.90 ± 4.15	5.67 ± 0.52	24.55 ± 10.80	21.60 ± 2.58	31.11 ± 6.76	0.61 ± 0.10
D5	DS	28.11 ± 1.59	5.54 ± 1.22	50.07 ± 6.74	5.94 ± 0.92	50.00 ± 11.70	24.62 ± 4.02	46.00 ± 2.97	0.39 ± 0.03
	RS	27.02 ± 1.89	5.65 ± 1.21	46.32 ± 7.19	5.58 ± 0.59	25.12 ± 9.30	23.12 ± 4.00	33.17 ± 7.68	0.57 ± 0.11
D6	DS	28.21 ± 1.48	5.39 ± 0.99	58.67 ± 19.54	6.03 ± 1.02	56.37 ± 17.77	29.05 ± 9.67	39.90 ± 13.70	0.52 ± 0.21
	RS	26.76 ± 1.71	5.35 ± 1.31 ^b	46.28 ± 7.73	5.49 ± 0.59	26.86 ± 9.30	23.75 ± 4.89	32.50 ± 11.95	0.50 ± 0.14
D7	DS	27.46 ± 1.55	3.59 ± 1.78 ^a	56.60 ± 1.92	5.67 ± 0.74	52.65 ± 10.44	28.25 ± 1.70	42.82 ± 11.13	0.23 ± 0.06
	RS	26.43 ± 1.45	5.64 ± 0.42	50.38 ± 11.48	5.64 ± 0.56	24.80 ± 10.05	25.00 ± 5.53	40.25 ± 19.85	0.44 ± 0.13
D8	DS	26.94 ± 1.95	4.96 ± 0.68	59.62 ± 21.84	5.76 ± 0.84	51.27 ± 10.18	35.25 ± 16.87	69.75 ± 14.5	0.20 ± 0.14
	RS	26.5 ± 1.13	5.40 ± 1.30	47.37 ± 14.30	5.38 ± 0.40	25.35 ± 7.35	23.50 ± 7.19	34.87 ± 12.11	0.32 ± 0.18

DO: Dissolved Oxygen, TEMP: Temperature, EC Electrical Conductivity, Eh: Redox Potential, TURB: Turbidity, TDS: Total Dissolved Solids, TRANS: Transparency.

Table 2. Seasonal variation in Nutrient Salts, total phosphorus (TP), total nitrogen (TN), COD and BOD in Dohou Lake from November 2017 to October 2018.

	Seasons	NO ₃ ⁻	NO ₂ ⁻	PO ₄ ³⁻	SO ₄ ²⁻	NH ₄ ⁺	TP	TN	COD	BOD	COD/BOD
D1	DS	2.96 ± 2.10	0.012 ± 0.002	0.21 ± 0.10	12.58 ± 6.72	0.24 ± 0.10	2.01 ± 1.53	7.83 ± 5.78	6.56 ± 1.68	3.55 ± 0.53	1.85
	RS	4.17 ± 2.83	0.028 ± 0.010	0.32 ± 0.19	10.00 ± 5.66	0.19 ± 0.04	7.07 ± 5.80	14.62 ± 7.76	16.24 ± 3.99	7.62 ± 5.29	2.13
D2	DS	1.85 ± 1.43	0.010 ± 0.005	0.26 ± 0.16	12.31 ± 3.76	0.24 ± 0.14	1.25 ± 0.98	14.00 ± 6.89	5.95 ± 2.91	2.83 ± 0.87	2.10
	RS	4.37 ± 2.59	0.031 ± 0.019	0.33 ± 0.23	13.32 ± 3.74	0.17 ± 0.05	8.06 ± 5.02	16.12 ± 11.81	16.90 ± 7.85	11.70 ± 4.65	1.44
D3	DS	2.55 ± 1.11	0.010 ± 0.003	0.27 ± 0.08	12.13 ± 5.13	0.21 ± 0.08	1.30 ± 0.97	10.25 ± 6.23	5.53 ± 1.33	2.89 ± 0.41	1.91
	RS	4.50 ± 3.22	0.026 ± 0.011	0.28 ± 0.22	9.76 ± 4.39	0.17 ± 0.04	6.67 ± 4.10	13.43 ± 8.57	16.51 ± 4.22	11.62 ± 4.22	1.42
D4	DS	3.46 ± 2.25	0.012 ± 0.002	0.25 ± 0.18	10.03 ± 4.11	0.27 ± 0.09	1.43 ± 1.31	13.58 ± 12.21	8.11 ± 4.15	3.95 ± 1.34	2.05
	RS	4.00 ± 2.90	0.024 ± 0.010	0.33 ± 0.19	11.31 ± 6.43	0.16 ± 0.06	6.83 ± 2.75	12.83 ± 8.53	24.87 ± 7.26	11.02 ± 4.23	2.25
D5	DS	2.77 ± 2.08	0.014 ± 0.005	0.24 ± 0.16	12.90 ± 4.12	0.21 ± 0.08	1.80 ± 0.98	11.62 ± 9.51	13.01 ± 8.43	7.15 ± 4.11	1.82
	RS	4.84 ± 2.53	0.035 ± 0.027	0.34 ± 0.18	13.03 ± 7.37	0.15 ± 0.05	6.88 ± 4.63	13.81 ± 7.35	27.45 ± 8.85	10.44 ± 4.78	2.63
D6	DS	5.10 ± 3.16	0.012 ± 0.008	0.21 ± 0.21	5.62 ± 4.20	0.36 ± 0.16	1.97 ± 0.95	14.75 ± 11.70	18.45 ± 11.70	4.29 ± 1.68	4.3
	RS	6.22 ± 4.48	0.040 ± 0.027	0.52 ± 0.43	14.18 ± 7.77	0.22 ± 0.02	8.65 ± 7.04	15.87 ± 7.51	37.12 ± 17.17	8.69 ± 4.61	4.27
D7	DS	7.46 ± 5.49	0.028 ± 0.002	0.21 ± 0.17	32.48 ± 23.78	0.38 ± 0.14	1.82 ± 0.76	16.00 ± 8.36	65.67 ± 38.31	16.22 ± 5.01	4.04
	RS	7.11 ± 4.73	0.028 ± 0.013	0.47 ± 0.24	34.81 ± 26.36	0.34 ± 0.08	3.39 ± 1.19	16.50 ± 6.61	37.97 ± 27.45	5.52 ± 2.35	6.87
D8	DS	9.9 ± 3.43	0.061 ± 0.014	0.62 ± 0.40	55.23 ± 40.36	0.62 ± 0.140	2.15 ± 1.45	15.25 ± 7.27	9.07 ± 5.07	6.04 ± 3.68	1.50
	RS	7.65 ± 3.91	0.033 ± 0.013	0.33 ± 0.15	12.12 ± 10.43	0.18 ± 0.15	5.51 ± 2.80	12.75 ± 7.40	24.23 ± 12.19	8.22 ± 2.69	2.94

DS: Dry season et RS: Rain season.

Seasonal mean values per station of nitrites range from 0.010 ± 0.003 to 0.061 ± 0.014 $\text{mg}\cdot\text{L}^{-1}$ and those of nitrate fluctuate between 1.85 ± 1.43 and 9.9 ± 3.43 $\text{mg}\cdot\text{L}^{-1}$, with respective annual averages of 0.027 ± 0.007 $\text{mg}\cdot\text{L}^{-1}$ and 5.13 ± 1.82 $\text{mg}\cdot\text{L}^{-1}$. The seasonal mean concentration per ammonium station varies from 0.15 ± 0.05 to 0.62 ± 0.140 $\text{mg}\cdot\text{L}^{-1}$, with an average of 0.23 ± 0.06 $\text{mg}\cdot\text{L}^{-1}$. Seasonal mean concentrations per station in total nitrogen range from 7.83 ± 5.78 to 16.12 ± 11.81 $\text{mg}\cdot\text{L}^{-1}$, with an average of 14.09 ± 1.42 $\text{mg}\cdot\text{L}^{-1}$. For the phosphorus forms (orthophosphate and total phosphorus) evaluated in lake waters, the seasonal mean values per station oscillate respectively by 0.21 ± 0.21 -0.62 ± 0.40 , and between 1.25 ± 0.98 -8.65 ± 7.04 $\text{mg}\cdot\text{L}^{-1}$. They have respective annual mean values of 0.34 ± 0.06 $\text{mg}\cdot\text{L}^{-1}$ and 4.96 ± 1.52 $\text{mg}\cdot\text{L}^{-1}$. The seasonal mean levels of SO_4^{2-} per station ranged from 9.76 ± 4.39 to 55.23 ± 40.36 $\text{mg}\cdot\text{L}^{-1}$, with a mean of 16.41 ± 8.82 $\text{mg}\cdot\text{L}^{-1}$. The mean seasonal concentrations of COD obtained during the sampling period ranged from 5.53 ± 1.33 to 65.67 ± 38.31 $\text{mgO}_2\cdot\text{L}^{-1}$, with an average value of 23.94 ± 12.67 . As for BOD5, it oscillates between 2.83 ± 0.87 and 16.22 ± 5.01 $\text{mgO}_2\cdot\text{L}^{-1}$, with an average of 8.50 ± 2.72 $\text{mgO}_2\cdot\text{L}^{-1}$. In order to evaluate the biodegradability of the organic matter as well as the nature of the effluent pollution, the COD/BOD5 ratios were calculated. These ratios oscillate between 1.42 and 2.62 at stations 1, 2, 3, 4, 5 and 8. The other two stations have ratios greater than 3. The Pearson correlation matrix (**Table 3**) shows that DO is

Table 3. Correlation matrix between variables.

	TEMP	DO	EC	pH	TDS	Eh	TURB	TRANS	NO_3^-	NO_2^-	PO_4^{3-}	SO_4^{2-}	NH_4^+	TP	TN	COD	BOD
TEMP	1																
DO	0.281	1															
EC	-0.422	-0.955	1														
pH	-0.075	0.878	-0.754	1													
TDS	-0.534	-0.911	0.950	-0.755	1												
Eh	0.320	-0.349	0.295	-0.423	0.287	1											
TURB	-0.557	-0.827	0.773	-0.751	0.881	0.025	1										
TRANS	0.601	0.875	-0.846	0.742	-0.928	-0.071	-0.987	1									
NO_3^-	-0.577	-0.926	0.951	-0.729	0.988	0.277	0.888	-0.944	1								
NO_2^-	-0.513	-0.740	0.718	-0.674	0.866	0.297	0.890	-0.874	0.850	1							
PO_4^{3-}	-0.445	-0.803	0.834	-0.686	0.913	0.581	0.741	-0.793	0.904	0.847	1						
SO_4^{2-}	-0.610	-0.812	0.765	-0.550	0.742	0.026	0.811	-0.861	0.825	0.626	0.633	1					
NH_4^+	-0.699	-0.788	0.848	-0.524	0.892	0.286	0.768	-0.849	0.929	0.725	0.895	0.835	1				
TP	0.571	0.546	-0.566	0.232	-0.451	0.353	-0.511	0.579	-0.538	-0.186	-0.248	-0.840	-0.602	1			
TN	0.007	-0.489	0.446	-0.328	0.332	0.762	0.123	-0.214	0.402	0.229	0.562	0.467	0.521	-0.244	1		
COD	-0.070	-0.737	0.763	-0.632	0.613	0.393	0.417	-0.487	0.613	0.351	0.625	0.564	0.604	-0.514	0.641	1	
BOD	0.061	-0.483	0.440	-0.566	0.339	-0.094	0.415	-0.389	0.311	0.223	0.229	0.382	0.216	-0.454	0.107	0.748	1

DO: Dissolved Oxygen, TEMP: Temperature, EC: Electrical Conductivity, Eh: Redox Potential, TURB: Turbidity, TDS: Total Dissolved Solids, TRANS: Transparency, TP: Total phosphorus and TN: Total nitrogen.

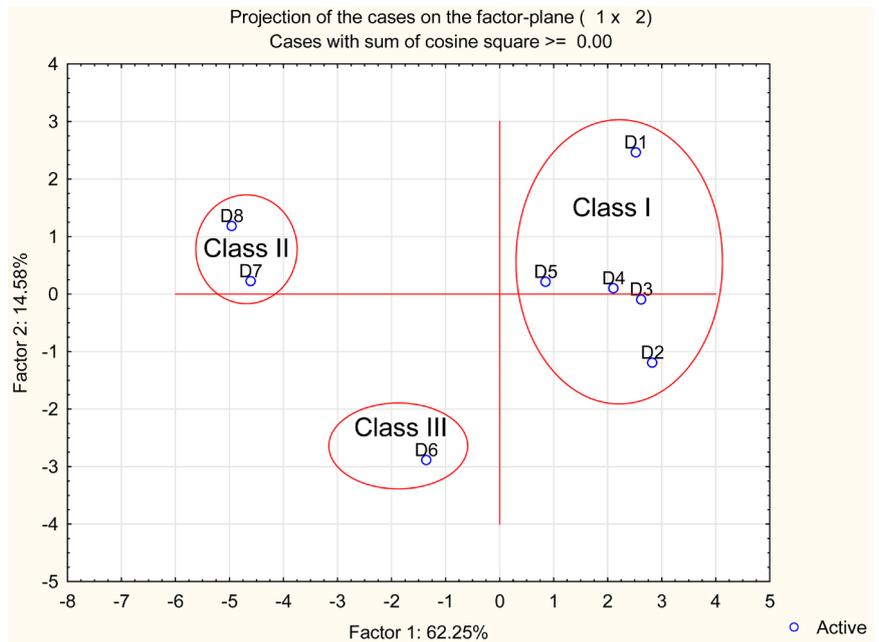
negatively correlated with nutrient salts (NO_3^- ($r = -0.92$), NO_3^- ($r = -0.7$), PO_4^{3-} ($r = -0.8$), SO_4^{2-} ($r = -0, 8$) and NH_4^+ ($r = -0.69$)). There is also a good correlation between TDS and EC ($r = 0.95$), between pH and DO ($r = 0.87$), between NH_4^+ and NO_2^- ($r = 0.72$) and between COD and BOD5 ($r = 0.75$). Turbidity, dissolved salts and EC are well correlated with nutrients.

3.2. Typology of a Water Resource

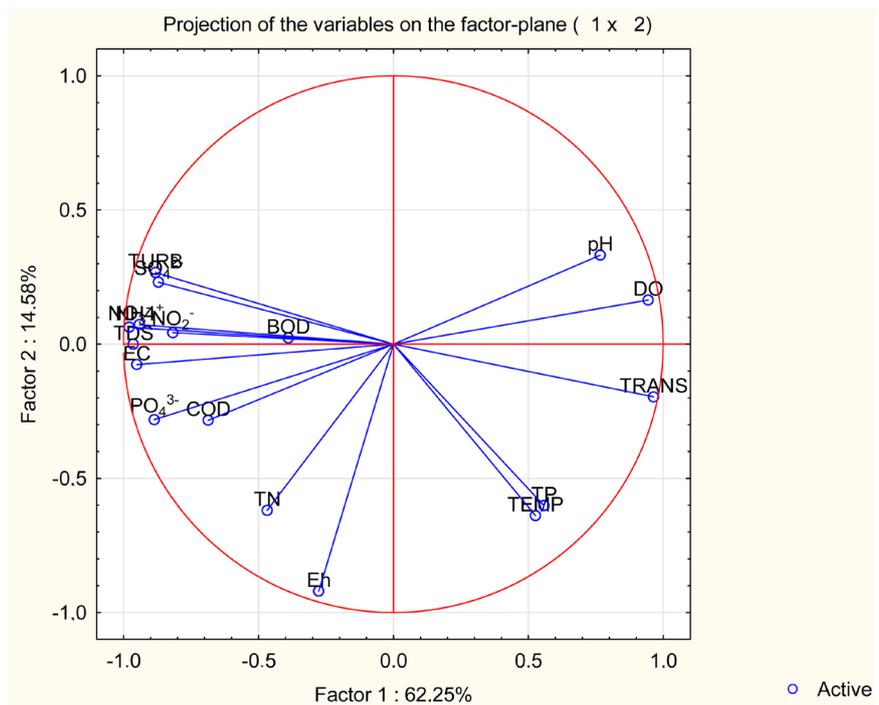
Dohou Lake typology was established using principal component analysis (Figure 2). The components (factor 1 and factor 2) account for 77.32% of the variation in the data set. The first axis expresses 63.14% of the total variance, against 14.18% for the second axis (Figure 2). The correlation circle (Figure 2(b)) shows that the variables positively correlated with axis 1 are transparency, dissolved oxygen, total phosphorus and pH, whereas ammonium, nitrates, nitrites, orthophosphates, turbidity, TDS, conductivity and COD are negatively correlated to this axis. The second axis is significantly correlated with total nitrogen, temperature and the redox potential in its positive part. The factor map of the stations associated with the correlation circle of the variables defines three classes of water on Dohou Lake (Figure 2(a)). Class I found at stations D1, D2, D3, D4 and D5 is characterized by aerated waters, with high transparency, pH and total phosphorus. This class is weakly mineralized and low in nutrients and organic matter. The second class (II) found in D7 and D8 is characterized by strongly mineralized waters and loaded with organic matter. Nutrient concentrations are high (NH_4^+ , NO_3^- , NO_2^- , PO_4^{3-} , SO_4^{2-}) and strongly affected by human activities. This area is very turbid. The third class (III) found at station D6 is characterized by high values of total nitrogen and COD. Figure 3 describes the state of the pollution level of the lake

3.3. Bacterial Contamination

The statistical results of the bacteriological parameters of the waters of Dohou Lake are reported in Table 4. Total coliforms were present in 100% (28/28) of the water samples taken during the study period at concentrations ranging from 2300 to 173,000 CFU/100 mL, with an average value of $43,546.4 \pm 27,627.6$ CFU/100 mL. The highest concentration of total coliforms was observed at station D2. On the other hand, the weakest was observed at the site D8. Site D3 samples had consistently high total coliform concentrations during the dry season and the rainy season (Figure 4(a)). We also note that 92.85% (26/28) of the water samples analyzed exceed the JORF standard for surface water used for the production of drinking water, which is 5000 CFU/100 mL for total coliforms. The mean total coliform content (45385 CFU/100 mL) in the dry season is not significantly different from that in the rainy season (41707 CFU/mL) ($p > 0.005$). Enterococci were also present in all water samples collected. Enterococci levels fluctuate between 20 and 1140 CFU/100 mL, with an average of 408.2 ± 202.9 CFU/100 mL. The highest concentration was observed at station D1 and the lowest at station D7. Samples taken from D1 showed high levels of enterococci in the dry (990



(a)



(b)

Figure 2. Projection of variables and sites on F1 and F2 axes (a= circle of the correlation of the variables, b = the factorial map of the sites).

CFU/100 mL) and rainy (589 CFU/100 mL) seasons, with the highest geometric mean of 743 CFU/100 mL at all stations during the study period (**Table 4**). 96.42% of the analyzed samples exceed the French standard for fresh water intended for the production of drinking water which is 20CFU/100 mL No significant difference was observed between the dry season (485 CFU/100 mL) and the

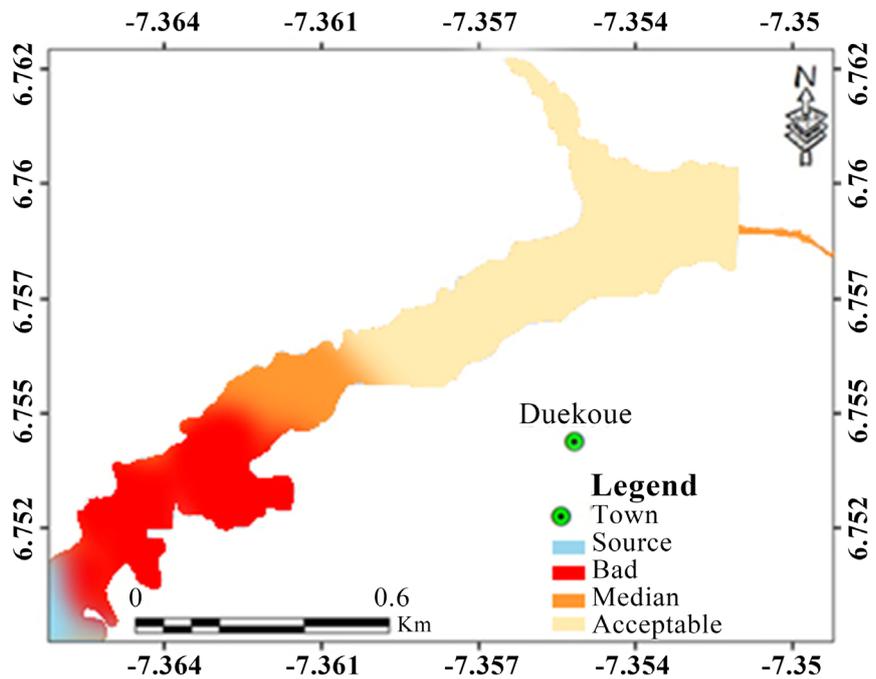


Figure 3. Pollution levels of Lake.

Table 4. Geometric mean (GM) of Total coliforms, Enterococci and *E. coli* at each site (unit: CFU/100 ml) and salmonella results in dry season and rain season water samples.

sites		D1	D2	D3	D4	D6	D7	D8
Total coli-forms	Mean	44,500	93,575	65,875	35,700	25,325	27,000	25,750
	min	21,000	18,000	18,500	18,200	12,300	2500	2300
	max	98,000	173,000	86,000	84,600	38,000	27,000	45,000
	GM	36,579.8	55,374.9	56,284.7	2801.8	23,368.3	9563	16,738.2
<i>E. coli</i>	Mean	1032	596	142	282	410	132	1332
	min	350	210	120	200	200	100	1180
	max	1530	1000	160	370	550	170	1650
	GM	902.41	487.13	141.36	274.57	384.06	129.98	1320.14
Enterococcus	Mean	790	502	322	175	247	460	360
	Mim	420	250	100	70	150	20	240
	Max	1140	970	550	320	460	980	530
	GM	743.55	431.38	269.56	147.27	220.88	185.79	343.30
Salmonella	Total/Présence	3/4	3/4	3/4	3/4	3/4	3/4	3/4

Min: Minimum; Max: Maximum.

rainy season (330 CFU/100 mL) samples ($p > 0.05$). *Escherichia coli* were present at all sites that were analyzed and their concentration ranged from 100 to 1650 CFU/mL, with an average of 559.6 ± 192.1 CFU/100 mL. Samples taken from D1 and D8 had *E. coli* counts consistently high in the dry season and in the rainy season (Figure 4(c)). All samples analyzed during the study period exceeded the

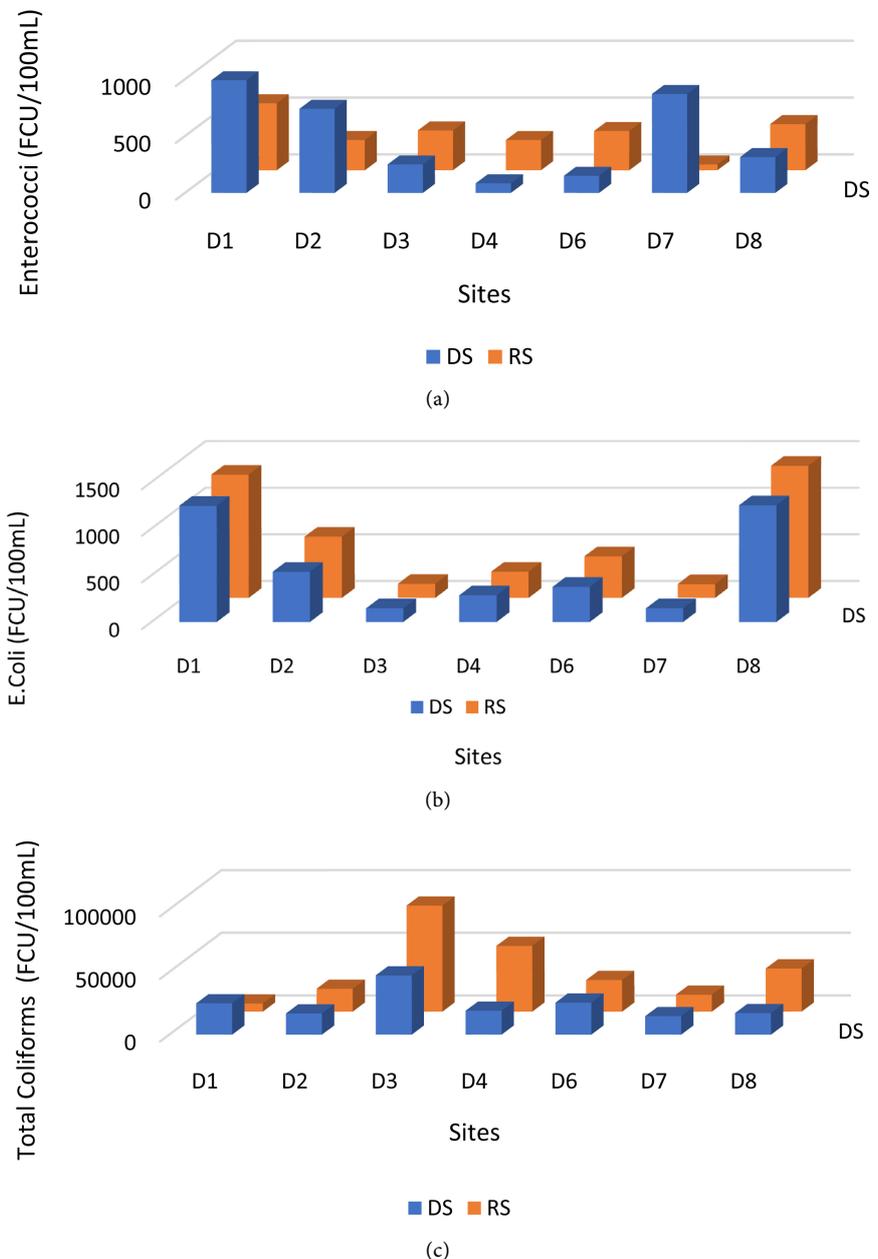


Figure 4. Concentrations of total coliforms (a), Enterococci (b) and *E. coli* (c) at each sampling sites during Dry season (DS) and rain season (RS).

standard of 20 CFU/100 mL. Samples taken from the D8 station had the highest geometric mean (1320 CFU/100 mL) in the dry season. The geometric mean of *E. coli* at Station D7 was the lowest, with a geometric mean of 129 CFU/100 mL during the sampling period. The average concentration of *E. coli* in Dry-season (568 CFU/100 mL) is not significantly different from that of the rainy season (630 CFU/100 mL) ($p > 0.05$). Salmonella pathogens were detected in 50% of the dry season samples and in 100% of the rainy season samples. The overall concentrations of *E. coli* and Enterococci at each sampling station followed a similar pattern, with D1, D2 and D8 having consistently high concentrations (Figure

4(b) and Figure 4(c)).

4. Discussion

4.1. Physico-Chemical Characterization of Water

Maximum temperatures were recorded during the dry season and low during the rainy season. The increase in temperature in the dry season is also due to the prolonged absence of water flow. The results of work done by Baxter and Glende (1980) in 23 dams across Canada have identified this fact. The temperature remained high throughout the sampling period. These high values could affect the quality of the water. High temperatures and heat waves could create favorable conditions for algae growth in nutrient-rich water bodies. In addition, this high temperature could favor the proliferation of cyanobacteria (Ritson et al., 2014). These blooms generate certain problems for the production of drinking water, such as taste, smell, the potential for increased by-product production and the production of toxins. The dose of chemicals used for water treatment also depends on the temperature. Chlorinated disinfectant loss is usually accelerated when temperatures are warmer; chlorine decomposition rates in water generally double for each 5°C increase (Fisher et al., 2012). An inadequate dosage of chlorine causes the resistance of pathogenic bacteria and parasites. When the chlorine is absorbed by the body, it becomes estrogen, which can cause cancer and many other health problems, such as hair loss, tiredness, lack of libido, hypothyroidism, hypoglycemia, insomnia. Chlorine also hurts weight gain (Shami-muzzaman et al., 2019). A positive reaction at higher temperatures is a reduction in the survival of certain enteric pathogens in water (e.g., *Campylobacter*, *E. coli*, Enterovirus, when temperatures are between 20°C and 37°C), with the exception of *Vibrio cholera* (Hunter, 2003). According to Moumouni (2005), the rise in temperature promotes self-purification and increases the rate of sedimentation of suspended solids, which is favorable for the production of drinking water. The waters of Dohou Lake are acidic at all sites and those throughout the study period. The maximum pH value is lower than the guideline value of 6.5. The waters of Dohou Lake are therefore corrosive. Nevertheless, the pH of the water is in line with the recommended standard for raw water for the production of drinking water. The pH decreases slightly from the dry season to the rainy season. The decrease in pH results from the bacterial activity of decomposition of organic matter (El Addouli et al., 2010). The acidity of the waters could be explained by the hydration of CO₂, which produces carbonic acid whose ionization releases hydronium ions. The low conductivity of the water is beneficial for the production of drinking water. In fact, the increased salinization of water resources has consequences for drinking water infrastructures because it stimulates the corrosion of pipelines and can create water quality problems at the consumer's tap (Zakowski et al., 2014). In rainy periods, the low values of pH and water conductivity would be due to the effect of dilutions related to river inflow and precipitation. At all sites, seasonal mean water transparencies are low

(<1 m). The high values of turbidity and TDS in rainy seasons denote the contribution of rain-leaching. Moreover, this state of affairs will result in a greater number of suspended solids due to the transport of organic and mineral particles in the lake's waters. These suspended particles significantly reduce transparency and increase the turbidity of the water. At all sites, the mean turbidity values remain above the 5NTU guideline value. The strong correlation between TDS and turbidity ($r = 0.88$) indicates that the physical pollution of the water is probably due to erosion. The high turbidity of surface water has always been associated with the presence of microorganisms, colloidal particles and organic matter [Taiwo and Awomeso \(2017\)](#). Lake waters have mean DO concentrations above the standard of 5 mg/L (70%) for surface water intended to produce drinking water. According to [Amon et al. \(2017\)](#), the strong variation of dissolved oxygen would probably be related to the enrichment phenomenon (photosynthesis and exchange with the atmosphere) and consumption (oxidation of organic matter and respiration). [Rodier \(2009\)](#) notes that turbidity is all the higher as the density of the particles in the water is high. The low levels of dissolved oxygen can therefore be explained by the high turbidity of the water which does not allow photosynthesis to compensate for the oxygen losses. This parallel evolution of these two parameters is justified by the strong negative correlation ($r = -0.82$). To this cause, it is necessary to add the presence of aquatic plants to the stations (2, 5, 6 and 7) which constitute a screen with the penetration of the light thus limiting the production of the autotrophic phytoplankton organisms ([Wu et al., 2018](#)). For all forms of nitrogen in Dohou Lake, nitrite has the lowest concentrations. Also, 99.7% of the water samples collected had TN levels above the limit of 4 mg·L⁻¹ ([JORF, 2017](#)). At all sites, the waters of the rainy season are loaded with nutrients except the NH₄⁺ which has a development contrary to those mentioned above. This result is corroborated by the strong correlation between turbidity and these different parameters (NO₃⁻, NO₂⁻ and PO₄³⁻). Domestic sewage, storm spillways and garbage piles near this watercourse could undoubtedly justify the high rainfall content. Indeed, the use of sodium tripolyphosphates as additives in laundry detergents and dishwasher products is another source of water contamination by phosphates ([Traore et al., 2012](#)). These elevated orthophosphate values may interfere with coagulation efficiency and water softening ([Yéo, 2015](#)). The ammoniacal nitrogen (NH₄⁺) comes from nitrogen fertilizers used in plantations, vegetable crops, manure (cattle and poultry) farms that are the banks of this river and the decomposition of organic matter. Ammoniacal nitrogen (NH₄⁺) comes from nitrogen fertilizers used in plantations, vegetable crops, manure (cattle and poultry) farms that are the banks of this river and the decomposition of organic matter. In fact, a portion of animal droppings from livestock farms is used as fertilizer in market gardening crops. These contributions are not without dangers on the quality of the waters and the good functioning of this hydrosystem. According to [Kim et al. \(2017\)](#), high levels of nutrients can lead to 0.03 mg·L⁻¹ of NO₃⁻ and 0.01 mg·L⁻¹ of phosphorus, the in-

creased proliferation of algae. A state of affairs that leads to the appearance of eutrophication and development of cyanobacteria producing toxins very dangerous for the nervous system of aquatic species and harmful to the production of drinking water (Ritson et al., 2014). Ammonium showed a strong positive correlation ($r = 0.77$) with nitrite and nitrate ($r = 0.88$), which could be due to the fact that the oxidation of ammonia leads to the synthesis of nitrate via nitrite. The high concentration of dissolved nutrients may be related to non-high recycling rates, medium oxygenated water column, and low uptake by the phytoplankton and bacterial communities, resulting in particular in high concentrations of nitrogen and phosphorus compounds soluble in the lake. Nutrients are negatively correlated with physicochemical parameters (temperature, pH, DO) measured *in situ*, which means that these nutrients are usually brought to the water during rain events. The values of the ratio COD/BOD5 < 3 indicate the absence of industrial waste water in this part of the lake. The other two stations have ratios greater than 3. Indeed, the station 6 located near the activities of auto mechanics receives used oils engines. Station 7, on the other hand, is the wastewater outlet of the water treatment plant. The Pearson correlation coefficients (Table 3) show a positive correlation of turbidity with COD and BOD5. In contrast, they are negatively related to dissolved oxygen. The contents are relatively high in the rainy season. As a result, most of the organic matter in the water would be due to stormwater runoff. Indeed, runoff from slash-and-burn areas results in a significant influx of organic matter into the lake's waters, as well as high levels of nitrogen and phosphorus (Emelko et al., 2011). A high rate of COD and BOD5 could be due to the discharge of sewage directly into the lake by the riparian populations. Also, the average aeration of the lake would inhibit the biodegradation of the accumulating organic matter leading to an increase in BOD5. All lake water has a non-compliant BOD5 ($< 3 \text{ mg}_{\text{O}_2}\text{L}^{-1}$) for raw water. However, our results are weak compared to those of Goné (2010) in the water reservoir of Agboville in southern Côte d'Ivoire. The plutonic domes almost flanking the river could justify this fact. The Principal Component Analysis results show that Class II and III water are subject to both natural mineralization and organic mineralization. Organic mineralization is related to the decomposition of organic matter that is influenced by low values of environmental parameters such as pH, temperature, redox potential, and dissolved oxygen (Yéo, 2015). The growth rates of nitrating bacteria are influenced by the pH of the medium. According to Boursier (2003), if temperature values are below 30°C and the pH is below 7, the degradation rate of the organic matter decreases. The third class (III) found at site D6 is characterized by high values of total nitrogen and COD. This high COD value is probably due to its location near automotive mechanics activities.

4.2. Microbiological Characterization of Waters

The almost permanent presence of faecal pollution indicators denotes poor lake

water quality. The similar evolution of *E. coli* and Enterococci in each sampling site shows that the presence of one condition that of the other. Site 8 is located on the Dohou River which is the largest tributary of the lake. Therefore, it is reasonable to assume that this river is the main source of faecal pollution because of its drainage area. The concentration of *E. coli* is globally high compared with enterococci. This difference in the results of these two indicator organisms was probably due to the relatively faster rate of decomposition of Enterococci in freshwater compared to that of *E. coli* (Jin et al., 2004). The concentration of *E. coli* decreased during the dry season for several reasons. At that time, the lake did not receive most of the runoff from the urban area. Secondly, solar radiation has a detrimental effect on the persistence of bacteria. During the dry period, the water samples received stronger solar radiation compared to samples taken during the rainy seasons. Sunlight is considered a major stressor for bacteria Downes and Blunt (1877). A recent study has shown that the rate of *E. coli* degradation increases significantly with light intensity (Chan et al., 2015). In the rainy season, however, rainwater drainage canals receive a variety of upstream inputs including sewer overflows, non-human street fecal matter, and residential and commercial water run-off high density (Cheng et al., 2013). The concentration of Enterococci decreased during the rainy season due to dilution. The results of *E. coli*, Salmonella, and Total Coliforms indicate that surface runoff after heavy precipitation is likely to provide a significant amount of faecal bacteria to the lake. Also, when a water sample contains coliforms or fecal coliforms, this indicates the presence of other pathogenic organisms. Not all *E. coli* bacteria are pathogenic, but some strains such as O157: H7 are responsible for bloody diarrhea and severe abdominal cramps (Shamimuzzaman et al., 2019). The presence of fecal coliforms in the water is an omen of pathogens responsible for dysentery, such as Salmonella. Salmonella is also responsible for salmonellosis and typhoid fever (CDC, 1993).

4.3. Current Treatment Method and Recommendation

The treatment steps applied are those of a conventional water treatment process. It takes into account pumping, pre-treatment, clarification, refining and disinfection. Chlorination is currently the disinfection process used because of the cost price of chlorine and for its simplicity of implementation. However, the combination of chlorine and organic matter, when incompletely removed in the previous steps, leads to the formation of potentially carcinogenic sapid compounds and organochlorine products. Chlorine dioxide, in liquid form will prevent the formation of these organochlorine compounds but remains more expensive and requires advanced technology for its implementation. In addition, it generates in the disinfected waters chlorite ions (and sometimes chlorates). Ozone could be recommended, for its great disinfecting power, especially with respect to viruses and bacterial spores, and its other properties in refining treatment. However, manufactured on the site, ozone is expensive and its implemen-

tation is relatively complex (EPA, 2011). Also, this process has no residual action and therefore requires an injection of chlorine disinfectant downstream to avoid contamination by the distribution network. Filtration is carried out on fine sand. However, filtration sand bed although efficient, simple and inexpensive, because of the huge volumes of water to be filtered requires periodic cleaning to remove the materials retained between the grains that slow the passage of water. In view of the foregoing and given the quality of the raw water to be treated it will be more judicious to use membrane filtration (including microfiltration) although expensive. Also, we recommend the establishment of a minimum protection zone of 10 m surrounding the terrestrial portion of the water intake by means of a fence of a minimum height of 1.8 m to prevent access to the view shore, pumping station or other works located on the shore or the construction of ditches to divert runoff water downstream of the intake. We also suggest posting posters at strategic locations indicating that it is a source of drinking water

5. Conclusion

The results of this study show that it is necessary to adopt measures to control and reduce nutrients and organic loads in the water in order to contain the eutrophication process of this reservoir. In this context, it is essential to monitor the physical, chemical and bacteriological parameters in order to evaluate the impact of human action on this water resource. The average values of physico-chemical parameters and nutrient salts during the two seasons (wet and dry) are generally lower than the French guideline values recommended for fresh water intended for the production of drinking water. However, some areas deserve to be monitored. The enumeration of the indicator bacteria of the faecal contamination and the spatio-temporal distribution of these microorganisms reflected a relatively intense faecal pollution. The abundance of faecal germs varies little from one season to another and the values recorded far exceed the standards of water intended for the production of drinking water. The search for certain pathogens, like salmonella, has led to disturbing results. The result is a need for urgent intervention to rehabilitate the site. Principal component analysis (PCA) of the set of physicochemical data indicated outside the upstream zone (D6 and D8), Dohou lake can continue to be used for the production of drinking water. However, with adequate technology, it is desirable to avoid some diseases to the people.

Acknowledgements

We would like to thank all the anonymous individuals who helped us during our research work and special thanks to Dr. DIBY, Associate Professor in the Laboratory of Science and Water Technology.

Conflicts of Interest

The authors declare they have no competing interest.

References

- Ahoussi, K. E., Koffi, Y. B., Kouassi, A. M., Soro, G., & Biemi, J. (2013). Étude hydrochimique et microbiologique des eaux de source de l'ouest montagneux de la Côte d'Ivoire: Cas du village de Mangouin-Yrongouin (Sous-préfecture de Biankouman). *Journal of Applied Biosciences*, *63*, 4703-4719. <https://doi.org/10.4314/jab.v63i1.87245>
- Amon, N. L., Konan, K. L., Coulibaly, S., Yapo, Y., Oyetola, S., & Dosso, M. (2017). Characterization and Typology of Aghien Lagoon Waters (South East of Cote d'Ivoire): Potential Resources for Drinking Water Production. *Journal of Applied Chemistry*, *10*, 2278-5736. <https://doi.org/10.9790/5736-1001020107>
- Bartram, J., Corrales, L., Davison, A., Drury, D., Gordon, B., & Stevens, M. (2010). *Water Safety Plan Manuel; Step-by-Step Risk Management for Drinking Water Supplier's* (108 p.). Geneva: World Health Organization.
- Baxter, R. M., & Glande (1980). *Les effets des barrages et des retenues d'eau sur l'environnement au Canada. Ministère des pêches et des océans* (32 p.).
- Bessonneau, H., Chaumet F., Roig, B., Thomas, O., & Baurés, E. (2011). *Evolution Issues of Water Quality Monitoring of Small Medium Water Supply Systems*. Cahier de l'association scientifique Européenne pour l'eau et la santé.
- Boursier, H. (2003). *Etude et modélisation des processus biologiques au cours du traitement aérobie du lisier de porcs en vue d'une optimisation du procédé* (190 p.). Thèse de Doctorat, Toulouse: Institut National des Sciences Appliquées de Toulouse.
- Brou, Y. T. (2005). *Climat, mutations socioéconomiques et paysages en Côte d'Ivoire. Mémoire de synthèse des activités scientifiques présenté en vue de l'obtention de l'Habilitation à Diriger des Recherches, Université des sciences et technologies de Lille, France* (226 p.).
- CDC (Centers for Disease Control and Prevention) (1993). *Preventing Foodborne Illness: Escherichia coli O157:H7*.
- Chan, Y. M., Thoe, W., & Lee, J. H. W. (2015). Field and Laboratory Studies of *Escherichia coli* Decay Rate in Subtropical Coastal Water. *Journal of Hydro-Environment Research*, *9*, 1-14. <https://doi.org/10.1016/j.jher.2014.08.002>
- Cheng, J., Niu, S., & Kim, Y. (2013). Relationship between Water Quality Parameters and the Survival of Indicator Microorganisms—*Escherichia coli*—in a Stormwater Wetland. *Water Science & Technology*, *68*, 1650-1656. <https://doi.org/10.2166/wst.2013.386>
- Cousin, A. (2012). Techniques et coût d'élimination des pesticides dans les filières de production d'eau potable à partir des eaux de surface. Protection des eaux de surface contre les transferts diffus de produits phytosanitaires (Paris, AFPP-SWAP-Life). *Environmental Contamination and Toxicology*, *88*, 78-83.
- Delpla, I., & Rodriguez, M. J. (2014). Effects of Future Climate and Land Use Scenarios on Riverine Source Water Quality. *Science of the Total Environment*, *493*, 1014-1024. <https://doi.org/10.1016/j.scitotenv.2014.06.087>
- Delpla, I., & Rodriguez, M. J. (2017). Variability of Disinfection By-Products at a Full-Scale Treatment Plant Following Rainfall Events. *Chemosphere*, *166*, 453-462. <https://doi.org/10.1016/j.chemosphere.2016.09.096>
- Downes, A., & Blunt, T. P. (1877). Researches on the Effect of Light upon Bacteria and Other Organisms. *Proceedings of the Royal Society of London*, *26*, 488-500. <https://doi.org/10.1098/rspl.1877.0068>
- Eblin, G., Sombo, P., Soro, G., Aka, N., Kambiré, O., & Soro, N. (2014). Hydrochimie des eaux de surface de la région d'Adiaké. *Journal of Applied Biosciences*, *75*, 6259-6271.

<https://doi.org/10.4314/jab.v75i1.10>

- EL Addouli, J., Chahlaoui, A., Berrahou, A., Chafi, A., & Ennabil, A. (2010). *Approche de la qualité biologique de l'ouedouislane, au voisinage des effluents bruts de la région de Meknes*. *Larhyss Journal* (pp. 21-33).
- Emelko, M. B., Silins, U., Bladon, K. D., & Stone, M. (2011). Implications of Land Disturbance on Drinking Water Treatability in a Changing Climate: Demonstrating the Need for "Source Water Supply and Protection" Strategies. *Water Research*, *45*, 461-472. <https://doi.org/10.1016/j.watres.2010.08.051>
- EPA (2011). *Water Treatment Manual on Disinfection*.
- Fisher, I., Kastl, G., & Sathasivan, A. (2012). A Suitable Model of Combined Effects of Temperature and Initial Condition on Chlorine Bulk Decay in Water Distribution Systems. *Water Research*, *46*, 3293-3303. <https://doi.org/10.1016/j.watres.2012.03.017>
- Goné, D. L. (2010). *Matières organiques naturelles dans les eaux de surface du bassin versant de l'Agnéby: Caractérisation et élimination par coagulation-floculation au cours de la production d'eau potable* (257 p.). Thèse d'État en Sciences et Gestion de l'Environnement, Abidjan: Université d'Abobo-Adjamé (Côte d'Ivoire).
- Goné, D. L., Kamagaté, B., Ligban, R., Seidel, J.-L., Batiot, C., & Biémi, J. (2008). Coagulation-Flocculation of a Tropical Surface Water with Alum for Dissolved Organic Matter (DOM) Removal: Influence of Alum Dose and pH Adjustment. *Journal of International Environmental Application and Science*, *3*, 247-257.
- Goné, D. L. (2001). *Contribution des paramètres physico-chimiques des eaux souterraines à l'étude fonctionnement des systèmes hydrauliques en milieu fissuré de la région semi-montagneuse de Man (Ouest de la Côte d'Ivoire)* (214 p.). Thèse de doctorat 3^e cycle en sciences et gestion de l'environnement, Abidjan: Université d'Abobo-Adjamé.
- Hunter, P. R. (2003). Climate Change and Waterborne and Vector-Borne Disease. *Journal of Applied Microbiology*, *94*, 37S-46S. <https://doi.org/10.1046/j.1365-2672.94.s1.5.x>
- Jin, G., Englande, A. J., Bradford, H., & Jeng, H. (2004). Comparison of *E. coli*, Enterococci, and Fecal Coliform as Indicators for Brackish Water Quality Assessment. *Water Environment Research*, *76*, 245-255. <https://doi.org/10.2175/106143004X141807>
- JORF (Journal Officiel de la République Française) (2017). *Limites et références de qualité des eaux douces superficielles utilisées pour la production d'eau destinée à la consommation humaine, à l'exclusion des eaux de sources conditionnées. Fixées pour l'application des dispositions prévues aux articles R.1321-38 à R.1321-41 Ministère de la Santé et des Solidarités. Arrêté du 04/08/2017 modifiant plusieurs arrêtés relatifs aux eaux et références de qualité des eaux brutes et des eaux destinées à la consommation*.
- Kim, H., Jo, B. Y., & Kim, H. S. (2017). Effect of Different Concentrations and Ratios of Ammonium, Nitrate, and Phosphate on Growth of the Blue-Green Alga (Cyanobacterium) *Microcystis aeruginosa* Isolated from the Nakdong River, Korea. *Algae*, *32*, 275-284. <https://doi.org/10.4490/algae.2017.32.10.23>
- Kouamé, K. F. (2011). *Gestion intégrée des ressources en eau en Afrique tropicale humide. Cas du bassin versant du N'zo à l'Ouest de la Côte d'Ivoire. Contribution de la télédétection, des systèmes d'informations géographiques et de la modélisation hydrologique* (250 p.). Thèse de Doctorat d'État, Abidjan: Université de Cocody Abidjan, Côte d'Ivoire.
- Kouassi, A. M., Yao, K. A., Ake, A. Y., & Biémi, J. (2011). Application des méthodes d'analyses statistiques multivariées à l'étude de la minéralisation des eaux des aquifères fissurés de la zone Guiglo-Duekoué (Ouest de la Côte d'Ivoire). *International Journal of Biological and Chemical Sciences*, *5*, 2155-2169. <https://doi.org/10.4314/ijbcs.v5i5.35>

- Mosley, L. M. (2015). Drought Impacts on the Water Quality of Freshwater Systems; Review and Integration. *Earth-Science Reviews*, 140, 203-214. <https://doi.org/10.1016/j.earscirev.2014.11.010>
- Moumouni, D. M. H. (2005). *Caractéristiques physico-chimiques, bactériologiques et impact sur les eaux de surface et les eaux souterraines* (135 p.). Thèse de doctorat, Bamako: université de Bamako.
- Ritson, J. P., Graham, N. J. D., Templeton, M. R., Clark, J. M., Gough, R., & Freeman, C. (2014). The Impact of Climate Changes the Treatability of Dissolved Organic Matter (DOM) in Upland Water Supplies: A UK Perspective. *Science of the Total Environment*, 473, 714-730. <https://doi.org/10.1016/j.scitotenv.2013.12.095>
- Rodier, J. (2009). *L'analyse de l'eau: Eaux naturelles, eaux résiduaires, eudémère* (9th ed., 1579 p.). Paris: Dunod.
- Shamimuzzaman, M., Nayeem, R. H., Ara, N., Rahman, M. M., Jahid, M. I. K., & Hasan, M. N. (2019). Physico-Chemical and Microbiological Quality Assessment of Supply Water around Dhaka City, Bangladesh. *Journal of Water Resource and Protection*, 11, 280-295. <https://doi.org/10.4236/jwarp.2019.113016>
- Taiwo, A. M., & Awomeso, J. A. (2017). Assessment of Trace Metal Concentration and Health Risk of Artisanal Gold Mining Activities in Ijeshaland, Osun State Nigeria—Part 1. *Journal of Geochemical Exploration*, 177, 1-10. <https://doi.org/10.1016/j.gexplo.2017.01.009>
- Traoré, A. (2016). *Impacts des changements climatiques et du changement de l'occupation et de l'utilisation du sol sur les ressources en eau de l'environnement lagunaire d'Aghien et de potou (sud-est de la côte d'ivoire)* (249 p.). Thèse unique doctorat en Sciences de la Terre et des Ressources Minières de l'Université Félix Houphouët-Boigny de Cocody.
- Traore, A., Soro, G., Kouadio, K. E., Bamba, S. B., Oga, S. M., Soro, N., & Biemi, J. (2012). Evaluation des paramètres physiques, chimiques et bactériologiques des eaux d'une lagune tropicale en période d'étiage: La lagune Aghien (Côte d'Ivoire). *International Journal of Biological and Chemical Sciences*, 6, 7048-7058. <https://doi.org/10.4314/ijbcs.v6i6.40>
- WHO (2011). *Guidelines to Drinking-Water Quality* (4th ed., 564 p.).
- Yapo, O. B. (2002). *Contribution à l'évaluation de l'état de trophie du barrage de Buyo (Sud-ouest de la Côte d'Ivoire): Etude Analytique et statistique des paramètres physico-chimiques et biologiques* (210 p.). Thèse de Doctorat 3^{ème} cycle, Abidjan: Université d'Abobo-Adjamé.
- Yéo, K. M. (2015). *Dynamique spatiale et temporelle des caractéristiques chimiques des eaux et des sédiments, et statut trophique du système lagunaire périurbain Adjin-Potou (Côte d'Ivoire)* (190 p.). Thèse unique, Abidjan: En Sciences et Gestion de l'Environnement de l'Université Nangui Abrogoua.
- Zakowski, K., Szocinski, M., & Darowicki, K. (2014). Influence of Water Salinity on Corrosion Risk—The Case of the Southern Baltic Sea Coast. *Environmental Monitoring and Assessment*, 186, 4871-4879. <https://doi.org/10.1007/s10661-014-3744-3>
- Wu, Z., Wang, X. L., Chen, Y. W., Cai, Y. J., & Deng, J. C. (2018). Assessing River Water Quality Using Water Quality Index in Lake Taihu Basin, China. *Science of the Total Environment*, 612, 914-922. <https://doi.org/10.1016/j.scitotenv.2017.08.293>