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Seasonal variation, quality and typology of waters' abiotic parameters of a tropical lagoon: The hydrosystem Lake Togo-Lagoon of Aného (South-East of Togo)

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ABSTRACT: The objective of this study is to assess the abiotic parameters quality and seasonal variation of the hydrosystem Lake Togo-lagoon of Aného waters. For this purpose, 30 water samples were collected per season (dry and rainy season) from 30 sites. The physicochemical parameters were determined using French Association of Standardization (AFNOR) methods described by Rodier *et al*. The average pH in dry and rainy season are around neutrality (7.01 and 6.97). The concentration of dissolved salts is high. Indeed, the average values of conductivity, salinity, TDS, sulphates, chloride and bicarbonates reach respectively 27.42 mS/cm, 14.84, 235.75 g/l, 681.43, 8208.98 and 233.86 mg/l in the dry season. For turbidity, TSS and dissolved oxygen, they are respectively 37.36 NTU, 77.73 and 8.01 mg/l in the rainy season. The average nutrient salt contents are higher in the dry season for orthophosphate (1 mg/l) and total phosphorus (0.33 mg/l) and in the rainy season for ammonium (0.30 mg/l) and nitrate (2.26 mg/l). The average contents of Ca, K, Mg and Na are higher in the dry season and are respectively 175.97, 297.42; 766.86 and 2368.06 mg/l. The t-test reveals a very significant difference between seasonal mean values with the exception of pH. Principal Component Analysis has shown that the main origin of major ions is oceanic, whereas nitrogen compounds and TSS are essentially continental. Concerning phosphorus compounds, they are both continental and oceanic. This ecosystem is threatened by the phenomenon of eutrophication and needs special attention for its sustainable management.

KEYWORDS: Physicochemical quality, water, nutrients, Season, LakeTogo, Lagoon, Aného.

1 INTRODUCTION

All ecosystems are now affected in one way or another by the development of human societies as well as agricultural, urban, mining and industrial discharges that can lead to increased ecological pressure and high levels of pollution [1], [2]. Thus, coastal aquatic ecosystems are subject to strong anthropogenic pressures which contribute to the release of various organic and inorganic pollutants leading to the degradation of their quality [3], [4], [5]. The brackish coastal lagoons of tropical areas are environments of high biological productivity [6], [7] and strong opportunities for halieutic production. These are habitats and nurseries for many larval and juvenile stages of fish, crustacean and mollusc species [8], [9]. However, these coastal aquatic ecosystems suffer the greatest variations in abiotic factors [10]. Among other components, ammonium (NH_4^+) and ammonia (NH_3) are considered to be toxic substances for certain aquatic living beings such as fish especially in alkaline environment [11]. Also, the massive nutrient inputs related to human activities have very often caused the eutrophication of water bodies, characterized by the proliferation of aquatic plants [12] and pathogenic microorganisms harmful to the environment [13] such as Cyanobacteria which produce very dangerous toxins to the nervous system of aquatic organisms [14], [5].

In Togo, the hydrosystem Lake Togo-lagoon of Aného is located in the phosphorite mining area characterized by the rejection of various forms of waste without any prior treatment. It is exposed to mining effluents dumped into the sea at Kpémé through its mouth in Aného. Also, urban wastes, the leaching of mining and agricultural soils throughout the watershed where agrochemicals are irrationally used can be added. These inputs via the main tributaries (Haho and Zio rivers) are not free from danger on waters quality and good functioning of this ecosystem. Jiang et Sheng [15] showed that a continuous increase in the amount of phosphorus could be a major factor in the eutrophication of a lake. It is, therefore, essential to carry out regular monitoring of the physicochemical quality of this biotope on which the productivity of aquatic species and the socio-economic well-being of local populations depend. This study aims to assess the abiotic parameters quality of the hydrosystem Lake Togo-lagoon of Aného waters and its seasonal variation in order to identify the possible risks for aquatic species on the one hand and for human health on the other.

2 MATERIALS ET METHODS

2.1 STUDY AREA

The hydrosystem Lake Togo-lagoon of Aného is a part of a lagoon system in south-east of Togo. This system is located between latitudes 6° 17' 37''and 6° 14' 38'' North and longitudes 1° 23' 33''and 1° 37' 38'' East. It extends from the villages of Dékpo and Sévatonou in the north-west to the city of Aného in the South-East. With a total area of 64 km^2, it includes Lake Togo (46 km^2), lagoon of Togoville which is a channel of 13 km length, parallel to the coast and whose width varies between 150 and 900 m, Lake Zowla (6.55 km^2), and lagoon of Aného in the South-East, which is a network of narrow channels and deeper [16]. The entire lagoon system communicates with the sea at Aného and with the Mono river, via a channel called Gbaga towards the East. The main tributary rivers of the lagoon system are Zio (176 km; 9.9 m^3/s) and Haho (140 km; 5.8 m^3/s) [17]. The Lake Togo watershed enjoys a subequatorial or Guinean climate with two rainy seasons alternating with two dry seasons. The main economic activities around the lagoon system are agriculture, breeding and fishing with the abusive practice of ''Acadja'' which consists of the use of branches as a trap for fish.

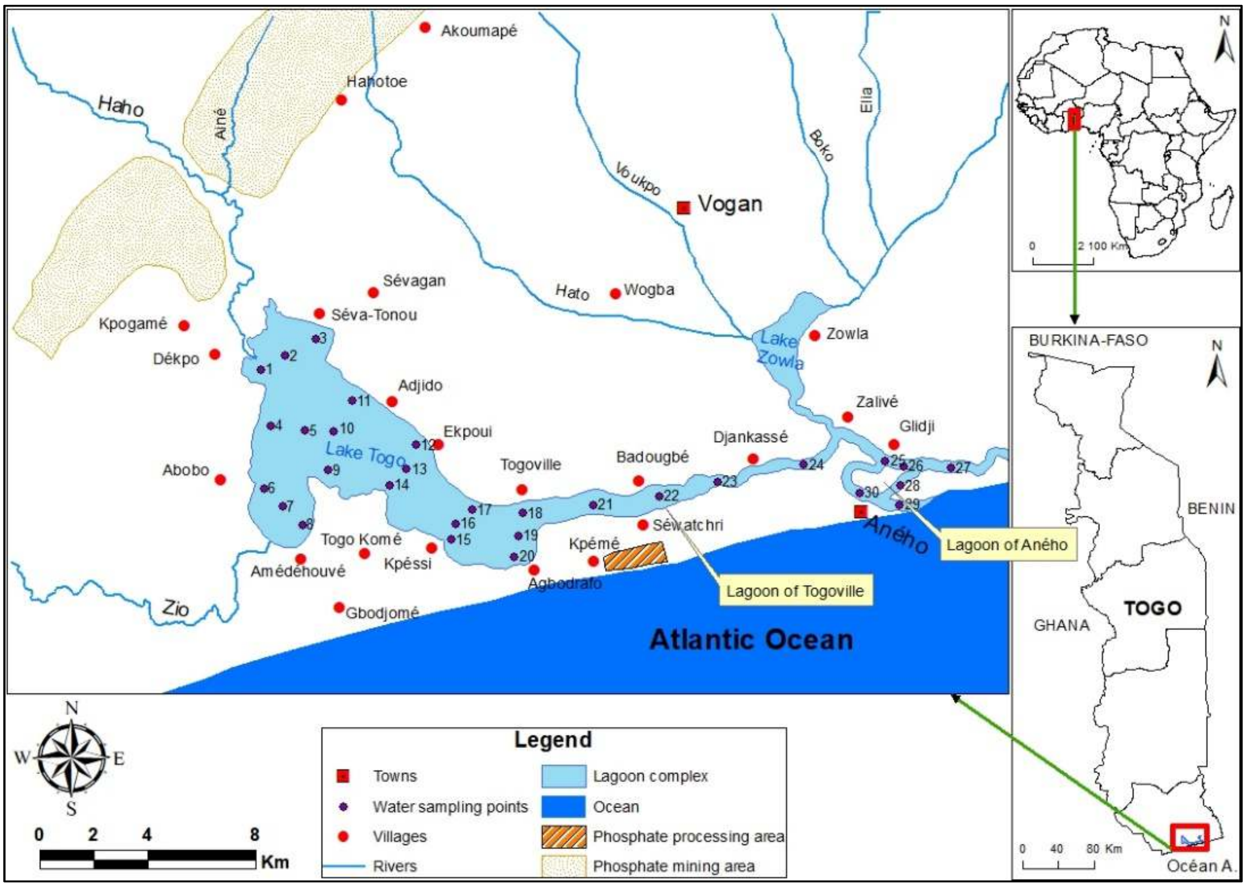

Fig. 1. Location map of the study area showing sampling points

2.2 Sampling and analysis methods

The water samples were randomly collected at 30 sites in the dry season (March 2016) and in the rainy season (October 2016). The sampling was carried out according to AFNOR methods described by [18]. A total of 30 water samples per season were collected 30 cm from the surface in 1.5 L polyethylene bottles previously washed with nitric acid (10%) and then rinsed with distilled water and later with the site water during the sampling. The samples were then chilled in coolers, and transported to the Laboratory where they were refrigerated at 4°C until analysis. Temperature, transparency, pH, electrical conductivity (EC), salinity (Sa) and dissolved oxygen (DO) were measured *in situ*. Total dissolved solids (TDS), Total suspended solids (TSS), turbidity, phosphorus and nitrogen components (PO_4^{3-}, P, NH_4^+, NO_3^-) and major anions (SO_4^{2-}, HCO_3^-, Cl^-) were analyzed in the laboratory within 48 hours. The major cations (Ca, K, Na, Mg) were determined after water acidification with of nitric acid (1%). The measuring devices were calibrated and the standards measured at each set of ten samples to verify the accuracy of the results [19], [18]. Table 1 below summarizes the analyzed parameters and the materials and methods used.

Table 1. Material and Methods for physicochemical parameters analysis

Parameters	Methods	Equipements
Temperature	Electrometry (NFT 90-100)	pH-meter Crison PH 25
pH	Electrometry (NFT 90-008)	
Electrical Conductivity	Conductimetry (NF EN 27888)	Multimeter, type Knick Portamess
TDS	Electrometry (NFT 90-031, NFT90-111)	
Salinity	Electrometry (NFT 90-031)	
Turbidity	Turbidimetry (NFT 90-033)	Turbidimeter ''Type DRT100B model 20012''
Disslved Oxygen	Oximetry (NF EN 25814)	Oxymeter HANNA
TSS	Photometry (Method 8006, HACH)	Spectrophotometer HACH DR 3800
Transparency	Secchi (NF EN ISO 7027)	Secchi's disc
PO_4^{3-}, P, SO_4^{2-}, NH_4^+, Cl^-, NO_3^-	Molécular Spectrophotometry, NFT90-023, NFT90-009, NFT90-015, NFT90- 012)	Spectrophotometer HACH DR 3800
HCO_3^-	Titrimetry (Acidimetry) NFT 90-036	Laboratory glassware
Ca, Mg, K, Na	Atomic Absorption Spectrometry (NFT 90-005, NFT90-020)	AAS Spectrometer Thermo Electron S Series

2.3 Statistical analysis of data

The Principal Component Analysis (PCA) was performed on a matrix of 30 samples and 20 parameters, for each season, in order to highlight the relationship degree between them [20], [21], [5]. The Pearson correlation test allowed to determine the correlation levels between the different variables. Student's t-test was used to compare parameters between seasons. These statistical analyses were performed using STATISTICA 6.1 software. The hydrochemical classes of waters were determined using Piper diagram, built with Diagram software [22].

3 Results

3.1 Physical parameters of waters

3.1.1 Temperature (T), Hydrogen potential (pH) and Dissolved Oxygen (OD)

Table 2 presents the seasonal values of temperature, pH and dissolved oxygen of waters. Temperatures recorded in the dry season range from 29 to 33.30 °C with an average of 30.62 ± 0.83 °C while they are 26.50 to 28.80°C with an average of 28.04 ± 0.53°C in the rainy season. These values are higher than the French standards for drinking water. There is a significant difference between the seasonal mean temperatures and the highest was observed in the dry season ($t = 14.39$, $p = 0.00001$). There is a high degree of homogeneity for temperature values in both seasons with respective coefficients of variation (CV) of 2.70% and 1.90%.

Average pH values are around neutrality in the dry season (7.00 ± 0.32) and slightly acidic in the rainy season (6.97 ± 0.45). They vary respectively between 6.52 and 7.71 and between 5.90 and 7.70. These values have a homogeneous distribution in the dry season (CV = 4.61%) and in the rainy season (CV = 6.44%). No significant differences were found between seasons. However, the lowest values are recorded during the rainy season. The recorded pH values are compliant with WHO standards for 93.33% of samples.

Table 2. Seasonal variation of T, pH and OD values in waters

Statistics n = 30/season	Temperature (T°C)		pH		DO (mg/l)	
	DS	RS	DS	RS	DS	RS
Minimum	29.00	26.50	6.52	5.90	5.30	6.50
Maximum	33.30	28.80	7.71	7.70	9.40	9.55
Average	30.62	28.04	7.00	6.97	7.16	8.01
Median	30.60	28.12	6.97	7.07	7.05	8.00
SD	0.83	0.53	0.32	0.45	1.20	0.80
CV (%)	2.70	1.90	4.61	6.44	16.82	10.04
Skewness	0.78	-1.25	0.72	-0.86	0.15	0.06
Kurtosis	3.05	1.76	0.10	0.25	-1.00	-0.77
t-test (t ; p)	14.39 ; 0.00001		0.33 ; 0.73999		-3.18 ; 0.00235	
Standards	< 25		6,5-9,5		5 - 7	

__DS__: Dry season; __RS__: Rainy season; __CV__: Coefficient of variation; __SD__: Standard deviation

The concentrations of dissolved oxygen are in accordance with European quality standards for fish life. They range from 5.30 to 9.40 mg/l in the dry season and from 6.50 to 9.55 mg/l in the rainy season with respective averages of 7.16 ± 1.20 and 8.01 ± 0.80 mg/l which are significantly different with the lowest recorded in the dry season (t = -3.18, p = 0.0024). The coefficients of variation in the dry season (16.82%) and rainy season (10.04%) indicate that the values are fairly homogeneous in both seasons.

3.1.2 Electrical Conductivity (EC), Salinity (Sa) and Total Dissolved Solid (TDS)

The electrical conductivity, salinity and TDS values of waters are summarized in Table 3. The measured conductivities are all higher than the French standards. They vary from 14.43 to 58.10 mS/cm in the dry season and from 1.5 to 13.72 mS/cm in the rainy season. These values show heterogeneity in their distribution both in the dry season (CV = 43.03%) and rainy season (CV = 83.52%). The respective seasonal averages of 27.42 ± 12.35 mS/cm and 3.61 ± 3.01 mS/cm are significantly different and the highest is obtained in the dry season (t = 10.26, p = 0, 0000).

The salinities values vary from 7.20 to 34.80 g/l (CV = 50.74%) with an average of 14.84 ± 7.53 g/l in the dry season and from 0.90 to 7.60 g/l (CV = 72.01%) with an average of 2.19 g/l in the rainy season. Thus, we note a heterogeneous distribution of salinities and a very significant difference between their seasonal averages, the highest of which is obtained in the dry season (t = 9, p = 0.0000). All salinity values are above WHO standards for drinking water in both seasons.

Total dissolved solids (TDS) values range from 76.70 to 718 g/l with an average of 235.75 ± 200.91 g/l in the dry season and between 7.70 and 71 g/l with an average of 18.49 ± 15.42 g/l in the rainy season. The respective coefficients of variation (85.22% and 83.37%) are high. These values are all above WHO standards for drinking water. The average value in the dry season is very significantly greater than the rainy season’s one (t = 5.91, p = 0.0000).

Table 3. Seasonal variation in EC, Sa and TDS values of waters

Statistics n = 30/season	EC (mS/cm)		Salinity (g/l)		TDS (g/l)	
	DS	RS	DS	RS	DS	RS
Minimum	14.43	1.50	7.20	0.90	76.70	7.70
Maximum	58.10	13.72	34.80	7.60	718.00	71.00
Average	27.42	3.61	14.84	2.19	235.75	18.49
Median	26.40	2.42	13.90	1.65	136.95	12.50
SD	12.35	3.01	7.53	1.58	200.91	15.42
CV (%)	45.03	83.52	50.74	72.01	85.22	83.37
Skewness	1.35	2.14	1.46	2.03	1.30	2.18
Kurtosis	1.45	3.90	1.83	4.01	0.55	4.16
t-test (t ; p)	10.26 ; 0.00000		9.00 ; 0.00000		5.91 ; 0.00000	
Standards	0,18-1		0,1		1	

***DS**: Dry season; **RS**: Rainy season; **CV**: Coefficient of variation; **SD**: Standard deviation*

3.1.3 TRANSPARENCY (TRAN), TURBIDITY (TURB) AND TOTAL SUSPENDED SOLIDS (TSS)

The results of transparency, turbidity and SS are reported in Table 4. The transparency values range from 38.43 to 100% with an average of 75.17 ± 19.39% in the dry season and range from 16.92 to 77.32% with an average of 41.43 ± 16.25 % in rainy season. There is a very significant difference between the seasonal averages with the highest in the dry season (t = 7.30, p = 0.0000). The transparencies vary quite homogeneously in the dry season (CV = 25.80%) and in the rainy season (CV = 39.23%).

Mean turbidity values are 15.19 ± 3.92 NTU in the dry season and 37.36 ± 6.23 NTU in the rainy season. They range from 8.60 to 26.90 NTU and from 26.50 to 51.50 NTU, respectively, and are above WHO standards for drinking water. These variations are fairly homogeneous in the dry season (CV = 25.81%) and in the rainy season (CV = 16.68%). A significant difference (t = -16.50, p = 0.0000) was noted between seasonal averages the lowest in the dry season.

Table 4. Seasonal variation in Transparency, Turbidity and TSS of waters

Statistics n = 30/season	Transparency (%)		Turbidity (NTU)		TSS (mg/l)	
	DS	RS	DS	RS	DS	RS
Minimum	38.43	16.92	8.60	26.50	1.00	55.00
Maximum	100.00	77.32	26.90	51.50	32.00	108.00
Average	75.17	41.43	15.19	37.36	13.88	77.73
Median	78.94	36.58	14.78	35.95	11.00	75.50
SD	19.39	16.25	3.92	6.23	8.30	13.35
CV (%)	25.80	39.23	25.81	16.68	59.78	17.17
Skewness	-0.53	0.38	1.27	0.87	0.93	0.76
Kurtosis	-0.81	-0.92	2.29	0.54	0.32	0.47
t-test (t ; p)	7.30 ; 0.00000		-16.50 ; 0.00000		-22.26 ; 0.00000	
Standards	-		5		25	

***DS**: Dry season; **RS**: Rainy season; **CV**: Coefficient of variation; **SD**: Standard deviation*

Total suspended solids (TSS) contents range from 1 to 32 mg/l with an average of 13.88 ± 8.30 mg/l in the dry season and from 55 to 108 mg/l with an average of 77.73 ± 13.35 mg/l in the rainy season. The distribution of TSS is quite heterogeneous (CV = 59.78%) in the dry season and homogeneous (CV = 17.17%) in the rainy season. The average dry season content of TSS is significantly lower than the rainy season's one (t = -22.26, p = 0.0000). In the dry season, 83.33% of the values are lower than the French quality standard for fish life while in the rainy season, all values exceed this standard.

3.2 CHEMICAL PARAMETERS OF WATERS

3.2.1 NITROGEN (NO_3^-, NH_4^+) AND PHOSPHORUS (PO_4^{3-}, P) NUTRIENTS

Table 5 shows the orthophosphates (PO_4^{3-}), total phosphorus (P), nitrate (NO_3^-), and ammonium (NH_4^+) contents in water. Average phosphate concentrations (PO_4^{3-}) are 1.0 mg/l in the dry season and 0.6 mg/l in the rainy season. They vary respectively from 0.61 to 2.20 mg/l and from 0.25 to 0.94 mg/l. These values vary heterogeneously in the dry season (CV = 49.53%) and quite homogeneously in the rainy season (CV = 33.31%). The average dry season content is significantly higher than the rainy season's one (t = 4.09, p = 0.0001). In the dry season, all PO_4^{3-} contents are higher than the French standard for drinking water against 70% in the rainy season.

Total phosphorus (P) concentrations range from 0.20 to 0.73 mg/l with an average of 0.33 ± 0.17 mg/l in the dry season against 0.08 to 0.30 mg/l with average of 0.21 ± 0.06 mg/l in the rainy season. Contrary to the dry season (CV = 49.92%), these values show a fairly homogeneous variation in the rainy season (CV = 27.51%). All contents are above the French standard for drinking water in the dry season against 90% in the rainy season. There is a significant difference between seasonal average contents and the highest was obtained in the dry season (t = 3.85, p = 0.0003).

The average ammonium content in the dry season (0.08 ± 0.05 mg/l) is significantly lower (t = -9.92, p = 0.0000) than the rainy season's one (0.30 ± 0.11 mg/l). These contents vary respectively from 0.02 to 0.19 mg/l and from 0.10 to 0.53 mg/l and show a fairly homogeneous variation in the rainy season (CV = 37.13%) contrary to the dry season where it is heterogeneous (CV = 57.31%). It appears that 26.67% of the ammonium contents are higher than the French standard for drinking water in the dry season contrary to 90% in the rainy season.

Table 5. Seasonal variation of nutrient (PO_4^{3-}, P, NH_4^+ and NO_3^-) contents in waters

Statistics	PO_4^{3-} (mg/l)		P (mg/l)		NH_4^+ (mg/l)		NO_3^- (mg/l)	
n = 30/season	DS	RS	DS	RS	DS	RS	DS	RS
Minimum	0.61	0.25	0.20	0.08	0.02	0.10	0.44	1.59
Maximum	2.20	0.94	0.73	0.30	0.19	0.53	1.30	3.99
Average	1.00	0.60	0.33	0.21	0.08	0.30	0.82	2.26
Median	0.76	0.64	0.25	0.22	0.09	0.31	0.87	2.25
SD	0.50	0.20	0.17	0.06	0.05	0.11	0.20	0.49
CV (%)	49.53	33.31	49.92	27.51	57.31	37.13	24.87	21.61
Skewness	1.43	-0.24	1.31	-0.60	0.25	-0.10	0.13	1.60
Kurtosis	0.65	-1.08	0.31	-0.23	-0.35	0.00	-0.32	4.43
t-test (t ; p)	4.09 ; 0.00013		3.85 ; 0.00029		-9.92 ; 0.00000		-14.84 ; 0.00000	
Satndards	0,5-		0,1		0,1		50	

***DS**: Dry season; **RS**: Rainy season; **CV**: Coefficient of variation; **SD**: Standard deviation*

Nitrate concentrations range from 0.44 to 1.30 mg/l with an average of 0.82 ± 0.20 mg/l in the dry season and from 1.59 to 3.99 mg/l with an average of 2.26 ± 0.49 mg/l in the rainy season. They show fairly homogeneous variation for the respective seasons (CV = 24.87 and 21.61%). The average dry season content is significantly lower than the rainy season one (t = -14.84; 0.0000). All values are below the WHO standard for drinking water which is 50 mg/l.

3.2.2 MAJOR ANIONS (SO_4^{2-}, CL^- AND HCO_3^-)

Table 6 summarizes the results of sulphate (SO_4^{2-}), chloride (Cl^-) and bicarbonate (HCO_3^-). Sulphate contents (SO_4^{2-}) are between 190 and 2580 mg/l with an average of 681.43 ± 594.45 mg/l in the dry season and between 38.70 and 706.70 mg/l with an average of 131.12 ± 138.59 mg/l in the rainy season. These values are distributed very heterogeneously with CV = 87,23% and CV = 105,70% respectively. The seasonal average contents are significantly different and the highest was obtained in the dry season (t = 4.94, p = 0.0000). During the dry season 83.33% of the values are above the WHO standard for drinking water against 13.33% in the rainy season.

The average chloride concentrations are 8208.98 ± 4168.97 mg/l in the dry season and 1212.26 ± 872.97 mg/l in the rainy season. There is a very significant difference between them and the highest was obtained in the dry season (t = 9, p = 0.0000).

These concentrations vary respectively from 3985.49 to 19263.2 mg/l and from 498.19 to 4206.91 mg/l. The contents are heterogeneously distributed in the dry season (CV = 50.79%) and in the rainy season (CV = 72.01%). All reported values are above the WHO drinking water standard in both seasons.

Table 6. Seasonal variation of major anions (SO_4^{2-}, Cl^-, HCO_3^-) concentrations in waters

Statistics n = 30/season	SO_4^{2-} (mg/l) DS	SO_4^{2-} (mg/l) RS	Cl^- (mg/l) DS	Cl^- (mg/l) RS	HCO_3^- (mg/l) DS	HCO_3^- (mg/l) RS
Minimum	190.00	38.70	3985.49	498.19	197.21	90.52
Maximum	2580.0	706.70	19263.2	4206.91	384.30	133.22
Average	681.43	131.12	8208.98	1212.26	233.86	112.22
Median	430.00	75.35	7694.23	913.34	221.43	113.58
SD	594.45	138.59	4168.97	872.97	38.86	11.58
CV (%)	87.23	105.70	50.79	72.01	16.62	10.32
Skewness	1.85	2.86	1.46	2.03	2.27	-0.20
Kurtosis	3.12	9.86	1.83	4.01	6.77	-0.49
t-test (t ; p)	4.94 ; 0.00001		9 ; 0.00000		16.43 ; 0.00000	
Standards	250		250		200	

***DS**: Dry season; **RS**: Rainy season; **CV**: Coefficient of variation; **SD**: Standard deviation*

The bicarbonate content ranges from 197.21 to 384.30 mg/l with an average of 233.86 ± 38.86 mg/l in the dry season and from 90.52 to 133.22 mg/l with an average of 112.22 ± 11.58 mg/l in the rainy season. They are homogeneously distributed in the dry season (CV = 16.62%) and rainy season (CV = 10.32%). Seasonal averages contents indicate a very significant difference and the highest one was observed in the dry season ($t = 16.43$, $p = 0.0000$). All values recorded in the dry season are above the WHO standard for drinking water contrary to the rainy season where they are all lower.

3.2.3 MAJOR CATIONS (CALCIUM, POTASSIUM, MAGNESIUM AND SODIUM)

Table 7 presents calcium (Ca), potassium (K), magnesium (Mg) and sodium (Na) contents. The mean concentration of calcium (Ca) in the dry season (175.97 ± 111.66 mg/l) is significantly higher ($t = 4.01$, $p = 0.0002$) than that obtained in the rainy season (83.04 ± 60.46 mg/l). These contents vary from 40.04 to 452.36 mg/l and from 35.40 to 299.05 mg/l, respectively. They have a heterogeneous distribution in the dry season (CV = 63.46%) and rainy season (CV = 72.80%). The results show that 63.33% of the samples are above the WHO standard for drinking water in the dry season against 20% in the rainy season.

Potassium (K) levels range from 189.86 to 606.57 mg/l with an average of 297.42 ± 112.14 mg/l in the dry season and from 16.38 to 188.26 mg/l with average of 56.21 ± 40.91 mg/l in the rainy season. The seasonal averages contents are significantly different and the highest was observed in the dry season ($t = 11.07$, $p = 0.0000$). Concentrations are distributed fairly homogenously in the dry season (CV = 37.70%) and heterogeneous in the rainy season (CV = 72.79%). All potassium contents are above the WHO standard for drinking water in both seasons.

The average concentration of magnesium (Mg) in the dry season (766.86 ± 447.81 mg/l) is significantly higher ($t = 7.36$, $p = 0.0000$) than the rainy season's one (162.58 ± 38.19 mg/l). These values vary respectively from 145.02 to 1557.29 mg/l and from 117.01 to 252.10 mg/l. Mg contents are distributed heterogeneously in the dry season (CV = 58.39%) and fairly homogeneous in the rainy season (CV = 23.49%). All recorded values are above WHO standards for drinking water.

Sodium (Na) concentrations are very high in the dry season with an average (2368.06 ± 555.60 mg/l) very significantly higher ($t = 20.8$, $p = 0.0000$) than the rainy season's one (249.95 ± 49.19 mg/l) They vary respectively between 1801.02 and 4540.41 mg/l and between 185.08 and 391.63 mg/l with a fairly homogeneous distribution in the dry season (CV = 23.46 mg/l) and rainy season (CV = 19.68 mg/l). All values recorded in the dry season are above WHO standards for drinking water against 90% in the rainy season.

Table 7. Seasonal variation of the major cation (Ca, K, Mg and Na) contents in waters

Statistics n = 30/season	Ca (mg/l)		K (mg/l)		Mg (mg/l)		Na (mg/l)	
	DS	RS	DS	RS	DS	RS	DS	RS
Minimum	40.04	35.40	189.86	16.38	145.02	117.01	1801.02	185.08
Maximum	452.36	299.05	606.57	188.26	1557.29	252.10	4540.41	391.63
Average	175.97	83.04	297.42	56.21	766.86	162.58	2368.06	249.95
Median	139.51	68.58	278.24	45.31	643.75	158.56	2318.41	237.54
SD	111.66	60.46	112.14	40.91	447.81	38.19	555.60	49.19
CV (%)	63.46	72.80	37.70	72.79	58.39	23.49	23.46	19.68
Skewness	0.83	2.13	1.35	1.78	0.31	0.92	2.42	1.35
Kurtosis	0.06	4.92	1.73	2.90	-1.37	0.00	7.79	1.46
t-test (t ; p)	4.01 ; 0.00018		11.07 ; 0.00000		7.36 ; 0.00000		20.8 ; 0.00000	
Standards	100		12		50		200	

***DS**: Dry season; **RS**: Rainy season; **CV**: Coefficient of variation; **SD**: Standard deviation*

The average concentration of magnesium (Mg) in the dry season (766.86 ± 447.81 mg/l) is significantly higher (t = 7.36, p = 0.0000) than the rainy season's one (162.58 ± 38.19 mg/l). These values vary respectively from 145.02 to 1557.29 mg/l and from 117.01 to 252.10 mg/l. Mg contents are distributed heterogeneously in the dry season (CV = 58.39%) and fairly homogeneous in the rainy season (CV = 23.49%). All recorded values are above WHO standards for drinking water.

Sodium (Na) concentrations are very high in the dry season with an average (2368.06 ± 555.60 mg/l) very significantly higher (t = 20.8, p = 0.0000) than the rainy season's one (249.95 ± 49.19 mg/l) They vary respectively between 1801.02 and 4540.41 mg/l and between 185.08 and 391.63 mg/l with a fairly homogeneous distribution in the dry season (CV = 23.46 mg/l) and rainy season (CV = 19.68 mg/l). All values recorded in the dry season are above WHO standards for drinking water against 90% in the rainy season.

3.2.4 HYDROCHEMICAL FACIES OF THE HYDROSYSTEM LAKE TOGO-LAGOON OF ANÉHO WATERS

Figure 2 shows the Piper diagram of the hydrosystem Lake Togo-Lagoon of Aného waters. The analysis of this diagram allowed to identify the different hydrochemical facies of the waters and their variations during the seasons. Indeed, in the cations' triangle, the majority of the waters are oriented towards the sodium potassium pole against a minority (mainly located in the north of Lake Togo) which tends towards a state of equilibrium between the cations in dry season. This last trend is realized in the rainy season where there is no dominant cation in all of the waters. In addition, in the anions' triangle, there is a strong localization at the chlorinated pole both in the dry season and rainy season for all samples. The synthesis of the information contained in the two triangles in the lozenge which includes all ions, shows that in the dry season, the water of the hydrosystem Lake Togo-Lagoon of Aného presents mostly a chloride sodium facies whereas in the rainy season it changes to chloride calcium facies. This confirms the influence of seasons on the chemical compositions dynamic of this hydrosystem waters.

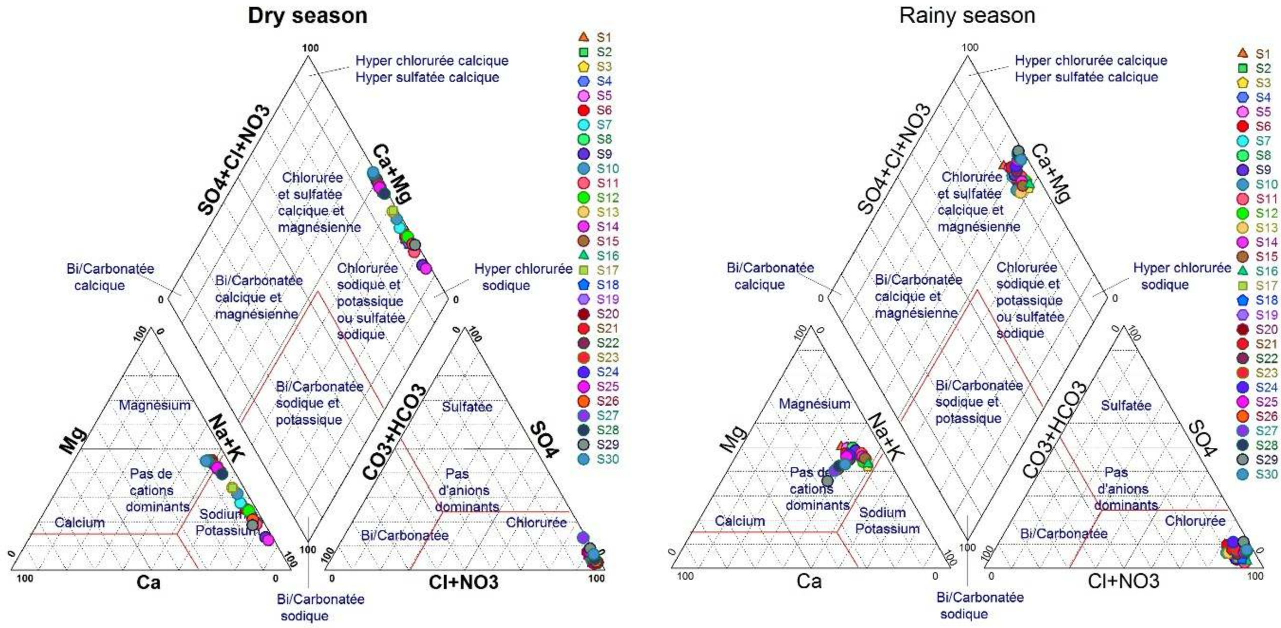

Fig. 2. Piper's diagram of lagoon complex waters in dry season and rainy season

3.3 TYPOLOGY OF THE HYDROSYSTEM LAKE TOGO-LAGOON OF ANÉHO WATER

The typological analysis of the waters allowed to highlight the relationship between the studied variables and their possible common sources as well as the similarities between the different sites prospected. This study was conducted through a Principal Component Analysis (PCA) on a data matrix containing 20 variables and 30 cases per season.

3.3.1 EIGEN VALUE AND TOTAL VARIANCE EXPLAINED

The eigenvalues, the percentages of variances explained and the cumulative variances for the two seasons are presented in Table 8.

Table 8. Eigenvalues and percentage of variance explained for dry and rainy seasons

	Dry season				Rainy season			
	F1	F2	F3	F4	F1	F2	F3	F4
Eigen values	10.51	2.58	1.7	1.3	9.61	3.94	2.06	1.32
% Total variance	52.54	12.92	8.48	6.52	48.03	19.72	10.3	6.6
% Cumulative variance	52.54	65.46	73.93	80.46	48.03	67.75	78.05	84.65

It appears that the 4 factors explain 80.46% of the total variance in the dry season with include F1: 52.54%; F2: 12.92%; F3: 8.48%; F4: 6.52% and 84.65% of the total variance in the rainy season including F1: 48.03%; F2: 19.72%; F3: 10.3%; F4: 6.6%. The variances explained by the couple F1xF2 are 65.46% in the dry season and 67.75% in the rainy season. Thus, it appears that these factorial planes are capable to restore most of the information contained in the data concerning the factors controlling the physicochemical evolution of the waters. The analysis of these factorial planes will be supplemented by the relic information contained in the factors F3 and F4 (Table 9). Table 9 shows the coefficients of correlation between the variables and the factorial axes in the dry season and rainy season.

Table 9. Correlation coefficients of variables with factorial axes

	Dry season					Rainy season			
	F1	F2	F3	F4		F1	F2	F3	F4
TDS	**-0.95**	-0.09	0.24	-0.01	EC	**-0.99**	0.00	-0.02	0.00
Cl	**-0.95**	-0.14	0.19	-0.07	Sa	**-0.98**	-0.07	0.05	-0.01
Sa	**-0.95**	-0.15	0.19	-0.08	TDS	**-0.99**	0.00	-0.02	0.00
EC	**-0.95**	-0.14	0.19	-0.11	Cl	**-0.98**	-0.07	0.05	-0.01
P	**-0.94**	0.14	0.16	0.07	Ca	**-0.98**	0.08	0.01	-0.03
PO4	**-0.93**	0.15	0.16	0.06	K	**-0.98**	-0.13	0.01	0.03
SO4	**-0.86**	-0.04	-0.05	0.10	Na	**-0.97**	-0.10	0.05	0.05
K	**-0.84**	-0.13	-0.46	-0.14	SO4	**-0.94**	0.03	-0.03	0.04
Ca	**-0.81**	-0.12	-0.47	-0.22	Mg	**-0.93**	0.05	-0.02	0.11
Na	**-0.76**	-0.22	0.03	0.19	HCO3	**-0.66**	-0.41	0.29	0.03
pH	**-0.73**	-0.24	-0.01	0.11	NH4	**0.63**	-0.48	0.27	0.15
Mg	**-0.71**	-0.10	-0.48	-0.33	PO4	-0.14	**-0.89**	0.26	0.18
NH4	**0.70**	0.00	0.31	0.03	TSS	0.16	**-0.82**	-0.41	-0.18
TSS	-0.14	**0.92**	-0.13	0.05	Turb	0.16	**-0.80**	-0.43	-0.19
Turb	-0.30	**0.76**	-0.24	0.34	Tran	0.08	**0.78**	0.32	0.31
Tran	0.50	**-0.66**	0.17	-0.11	P	-0.02	**-0.72**	0.29	0.39
DO	0.42	**-0.53**	-0.32	0.40	DO	-0.10	-0.04	**-0.79**	0.06
HCO3	-0.57	0.01	**0.65**	0.20	pH	-0.26	0.05	**-0.66**	0.45
T°C	0.34	0.02	0.09	**-0.68**	T°C	0.15	0.31	-0.41	**0.63**
NO3	0.06	0.44	0.29	**-0.48**	NO3	0.34	-0.40	0.23	**0.57**

3.3.2 CORRELATION MATRIX

Table 10 presents the correlation matrices between the physicochemical parameters of the water in the dry season (A) and rainy season (B). In the dry season, significant and positive correlations were obtained between pH and EC, salinity, TDS, PO_4^{3-}, P, SO_4^{2-}, Cl^-, Ca, K, Mg and Na. Only NH_4^+ is negatively correlated with pH (r = -0.68). This correlation decreases in the rainy season and is may be related to disturbances caused by river inputs and precipitation. In the dry and rainy seasons, EC, salinity and TDS are significantly and positively correlated with SO_4^{2-}, Cl^-, HCO_3^-, Ca, K, Mg, Na and negatively with NH_4^+. Transparency has a significantly negative correlation with TSS and turbidity, respectively, in both seasons. In the dry season, there are significant and positive correlations between phosphorus (PO_4^{3-}, P) nutrients and SO_4^{2-}, Cl^-, HCO_3^-, Ca, K, Mg, Na. These correlations become very low or even nil in the rainy season except between PO_4^{3-} and HCO_3^-. In addition, the significantly negative correlations observed between NH_4^+ and phosphorus components (PO_4^{3-}, P) in the dry season become positive in the rainy season. This illustrates the influence of seasons on the physicochemical quality of the waters.

Table 10. Correlation matrix between physicochemical parameters

	B : Rainy season																			
A : Dry season	T°C	pH	EC	Sa	TDS	Tran	Turb	TSS	DO	PO4	P	NH4	NO3	SO4	Cl	HCO3	Ca	K	Mg	Na
T°C	1	**0.37**	-0.11	-0.17	-0.12	0.26	-0.09	-0.11	0.15	-0.27	-0.18	-0.06	0.11	-0.04	-0.17	-0.35	-0.16	-0.16	-0.08	-0.12
pH	-0.31	1	0.24	0.19	0.23	-0.02	0.07	0.1	**0.48**	-0.09	0.01	-0.26	-0.15	0.26	0.19	0.07	0.24	0.21	0.35	0.21
EC	-0.24	**0.66**	1	**0.98**	**1,00**	-0.06	-0.12	-0.13	0.1	0.11	0,00	**-0.63**	-0.3	**0.94**	**0.98**	**0.6**	**0.95**	**0.98**	**0.89**	**0.96**
Sa	-0.25	**0.66**	**1,00**	1	**0.98**	-0.1	-0.08	-0.09	0.02	0.19	0.07	**-0.57**	-0.27	**0.94**	**1,00**	**0.62**	**0.94**	**0.98**	**0.88**	**0.97**
TDS	-0.31	**0.74**	**0.96**	**0.96**	1	-0.06	-0.13	-0.13	0.1	0.11	0,00	**-0.62**	-0.3	**0.94**	**0.98**	**0.6**	**0.96**	**0.98**	**0.89**	**0.96**
Tran	0.19	-0.18	**-0.37**	**-0.37**	**-0.37**	1	**-0.72**	**-0.73**	-0.26	**-0.6**	-0.33	-0.17	-0.05	-0.06	-0.1	-0.24	-0.03	-0.16	-0.03	-0.15
Turb	-0.24	0.08	0.11	0.11	0.16	**-0.65**	1	**0.98**	0.24	**0.49**	0.31	**0.39**	0.2	-0.15	-0.08	0.03	-0.24	-0.05	-0.23	-0.08
TSS	-0.09	-0.12	-0.05	-0.04	0.01	**-0.63**	**0.71**	1	0.22	**0.54**	**0.37**	**0.36**	0.17	-0.14	-0.09	0.09	-0.24	-0.06	-0.24	-0.11
DO	-0.16	-0.21	**-0.44**	**-0.43**	**-0.43**	**0.46**	-0.32	**-0.44**	1	-0.15	-0.13	-0.26	-0.04	0.07	0.02	-0.08	0.12	0.1	0.13	0.03
PO4	-0.27	**0.68**	**0.85**	**0.86**	**0.91**	**-0.46**	**0.39**	0.26	**-0.47**	1	**0.83**	**0.36**	**0.4**	0.08	0.19	**0.59**	0.06	0.24	0.13	0.24
P	-0.29	**0.69**	**0.86**	**0.86**	**0.92**	**-0.48**	**0.38**	0.26	**-0.48**	**0.99**	1	**0.39**	**0.43**	0,00	0.07	0.34	-0.05	0.11	-0.01	0.07
NH4	0.18	**-0.68**	**-0.58**	**-0.58**	**-0.62**	**0.39**	-0.31	-0.1	0.14	**-0.58**	**-0.61**	1	**0.52**	**-0.57**	**-0.57**	-0.12	**-0.62**	**-0.54**	**-0.58**	**-0.51**
NO3	0.09	-0.17	-0.05	-0.07	-0.02	-0.07	0.03	0.36	-0.29	-0.02	-0.03	0,00	1	-0.32	-0.27	-0.05	**-0.37**	-0.22	-0.31	-0.22
SO4	-0.25	**0.54**	**0.78**	**0.79**	**0.76**	**-0.39**	0.25	0.16	-0.25	**0.82**	**0.81**	**-0.44**	-0.2	1	**0.94**	**0.53**	**0.95**	**0.92**	**0.83**	**0.88**
Cl	-0.25	**0.66**	**1,00**	**1,00**	**0.96**	**-0.37**	0.12	-0.04	**-0.43**	**0.86**	**0.86**	**-0.58**	-0.07	**0.8**	1	**0.62**	**0.94**	**0.98**	**0.88**	**0.97**
HCO3	-0.33	0.31	**0.64**	**0.64**	**0.69**	-0.22	0.1	0.01	-0.23	**0.63**	**0.64**	-0.15	0.17	**0.47**	**0.64**	1	**0.62**	**0.67**	**0.66**	**0.65**
Ca	-0.25	**0.53**	**0.72**	**0.72**	**0.67**	**-0.36**	0.18	0.06	-0.18	**0.64**	**0.64**	**-0.62**	-0.08	**0.72**	**0.72**	0.19	1	**0.94**	**0.92**	**0.91**
K	-0.25	**0.58**	**0.73**	**0.74**	**0.69**	**-0.36**	0.21	0.07	-0.16	**0.69**	**0.69**	**-0.64**	-0.16	**0.78**	**0.74**	0.2	**0.98**	1	**0.89**	**0.97**
Mg	-0.22	**0.43**	**0.63**	**0.61**	**0.57**	-0.35	0.11	0.03	-0.21	**0.51**	**0.52**	**-0.56**	0.02	**0.55**	**0.61**	0.14	**0.95**	**0.88**	1	**0.92**
Na	-0.35	**0.58**	**0.73**	**0.75**	**0.72**	-0.31	0.08	-0.08	-0.21	**0.62**	**0.65**	**-0.57**	-0.22	**0.73**	**0.75**	**0.39**	**0.55**	**0.59**	**0.41**	1

3.3.3 VARIABLES AND CASES PROJECTION IN THE F1xF2 PLANE

The analysis of the factorial plane F1xF2 resulting from the projection of the variables and characterized by a correlation circle (Figure 3) reveals that in the dry season the factorial axis F1 is defined in its negative part by CE, Sa, TDS, P, PO_4^{3-}, SO_4^{2-}, Cl^-, K, Ca, Na, pH, Mg and in its positive part by NH_4^+. The factorial axis F2 is defined in its positive part by TSS and turbidity while its negative part is characterized by transparency (Tran) and dissolved oxygen (OD). In the rainy season, the factorial axis F1 is defined by CE, Sa, TDS, Cl, Ca, K, Na, SO_4^{2-}, Mg, HCO_3^-, in its negative part and by NH_4^+ in its positive part. The main contributors of the F2 axis are PO_4^{3-}, TSS, Turbidity (Turb) and P in its negative part and transparency in its positive part. Thus, the factorial axis F1 defines a gradient of mineralization and enrichment in dissolved salts and organic matter both in dry and rainy seasons. In addition, there is a seasonal rhythm with in relation to the factorial axis F2 characterized by a pole inversion of the parameters (TSS/Turbidity) and the Transparency followed by a rapprochement between the couples PO_4^{3-}/P and TSS/Turbidity in the rainy season. In addition, Table 9 indicates that the F4 axis is negatively defined by the NO_3^- and the temperature (T °C) in the dry season and positively in the rainy season.

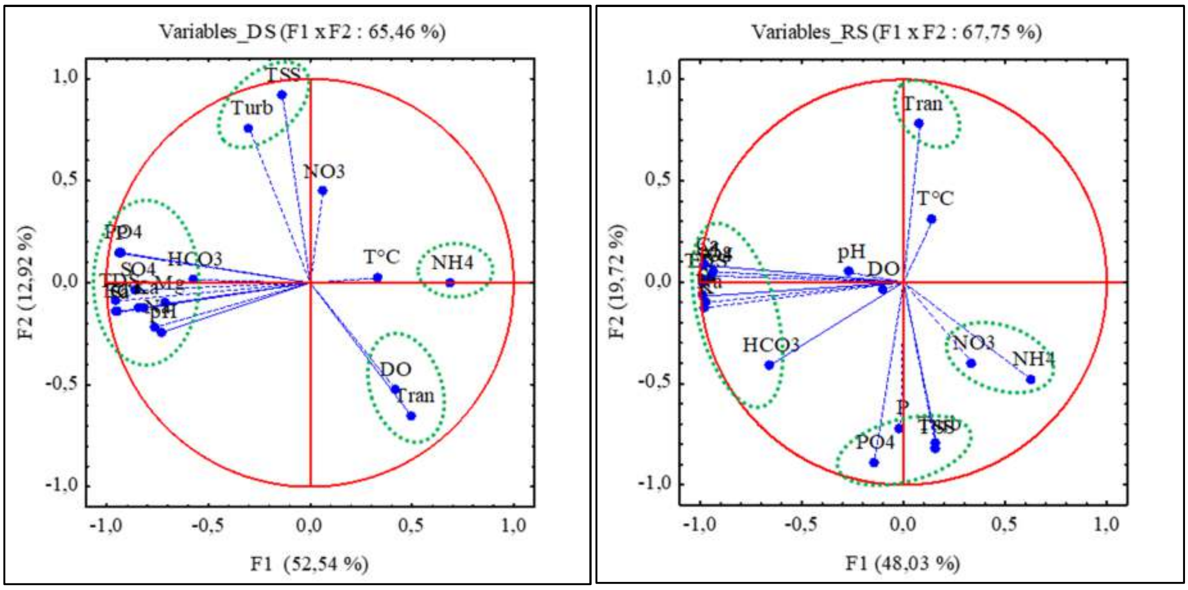

Fig. 3. Variables projection in the F1xF2 factorial plane in the dry season (DS) and rainy season (RS)

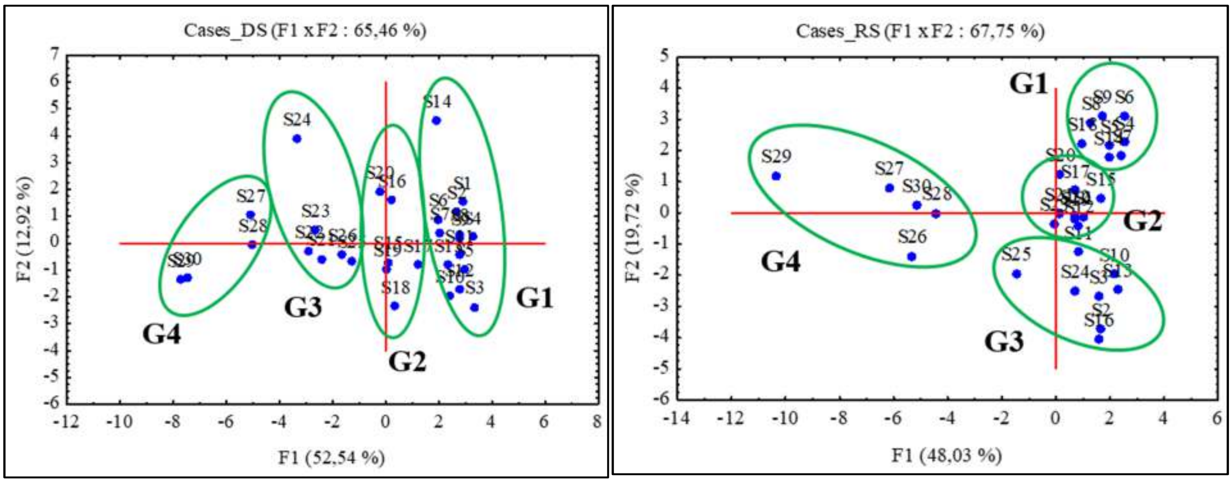

Fig. 4. Cases (sites) projection in the F1xF2 factorial plane in the dry season (DS) and rainy season (RS)

The projection of observations in the F1xF2 factorial plane (Figure 4), in the dry season, allows to distinguish four types of water according to their physicochemical characteristics. The first type (G1) regrouping the sites S1-S14, located in the north-west of Lake Togo, is characterized by weakly mineralized water, more concentrated in ammonium (NH_4^+), in dissolved oxygen and more transparent with particularly the site S14 which is very turbid and concentrated in TSS. The second type (G2) is composed of sites located in South-East of Lake Togo (S15-S20). These waters are moderately mineralized and have fairly high levels of NH_4^+ and dissolved oxygen with medium transparency. The third type (G3) corresponding mainly to the sites of the lagoon of Togoville (S21-S26) is characterized by fairly strong mineralization, low levels of NH_4^+ and dissolved oxygen with lower transparency. However, the site S24 is very turbid and very concentrated in TSS. The fourth type (G4) corresponds to the lagoon of Aného waters. They are highly mineralized, less transparent with low levels of NH_4^+ and dissolved oxygen. In the rainy season four types of water have been identified. The first type (G1) is characterized by weakly mineralized and more transparent waters with low levels of NH_4^+, PO_4^{3-}, P, TSS and low turbidity. The second type (G2) is characterized by low mineralization of water. These waters have medium transparency and turbidity with average contents of NH_4^+, PO_4^{3-}, P and TSS. The third type (G3) includes weakly mineralized and less transparent waters with higher levels of NH_4^+, PO_4^{3-}, P and TSS. The fourth type (G4) is characterized by high mineralized waters with lower levels of NH_4^+, PO_4^{3-}, P. Thus, there is a global gradient of increasing mineralization of the lagoon's waters from upstream to downstream.

4 Discussion

Temperature is one of the most important ecological factors in aquatic ecosystems. It is involved in most physicochemical and biological processes [23], [24]. Indeed, it acts on pH, density, viscosity, solubility of the gases in the water and dissociation of the dissolved salts [18]. In addition, temperature influences biochemical reactions, development and growth of aquatic organisms [25]. According to [26], an increase in temperature promotes self-purification and sedimentation of total suspended solids. Compared to the French standard for drinking water set at 25 °C, the waters of the lagoon complex are unfit for human consumption [27]. However, they are characteristic of tropical lagoon water temperatures that vary between 25 and 35 °C depending on the season [28], [29], [30]. Favorable temperatures to a good growth of the fish species widely raised are between 24 and 35 °C [31]. The variation in water temperature is directly related to local climatic conditions, water flows, influence of tides and seasons [17], [32], [5]. In fact, the low temperatures recorded in the rainy season are due to the fresh wind of the monsoon while the intense sunshine in the dry season would be the cause of the temperature increase. This is in accordance with other studies in the topical area [3], [4], [5], [33]. The homogeneity of the temperatures distribution in any season would be due to a small thickness of water easily traversed by the solar rays associated with a regular natural and anthropic mixing [17], [34], [29].

pH is one of the important parameters that influences the behavior and distribution of chemical elements in aquatic ecosystems [23]. The pH values obtained during the two seasons are globally in accordance with the WHO standards for drinking water set between 6.5 and 9.5 [35] and with natural water pH which is between 6 and 8, 5 [23] with the exception of S17 in the rainy season. The lowest pH values recorded in the rainy season and the homogeneity of their distributions in both seasons have also been reported in other tropical lagoons [29], [36], [3], [4], [37], [38]. The pH variation is related to salinity's one. Thus, unlike the waters of continental origin which are acidic, those of marine origin are basic [17], [34], [29]. The acidity of the waters in the rainy season is directly due to acid rain and continental waters through the flood of rivers Haho and Zio [29], [37]. Also, [39] indicate that the acidity of inland waters is due to the supply of humic acids from soil leaching. The increase in pH in the dry season is due to evaporation and the influence of more alkaline ocean waters loaded with dissolved salts [40], [37]. This oceanic influence is confirmed by the increase in pH downstream of the lagoon complex. In addition, according to [41], the pH of surface water depends on the concentration of CO_2. Thus, unlike photosynthesis which increases the pH, the phenomenon of respiration and the mineralization of organic matter leads to its decrease by the production of CO_2. The pH values recorded during this study are favorable to a good development of aquatic life. The values between 5 and 9 are compatible with the life of fishes. However, the favorable pH range for most aquatic species is between 6 and 7.2 [42], [18].

Dissolved oxygen from surface water comes mainly from the atmosphere and photosynthetic activity of aquatic chlorophyllous plants [42]. The average dissolved oxygen content in the rainy season is higher than the dry season's one. This variation was observed by [43] and [37] respectively in the Grand-Lahou and Aby lagoons in Côte d'Ivoire. The same observation was made for the surface waters of Oued Moulouya in Morocco [44]. The concentration of dissolved oxygen in the water decreases as the temperature increases. This is due to its lower solubility, but also to its increased consumption by living beings and the multiplying bacteria [45], [18]. Lower levels of dissolved oxygen have been found in some lagoons in tropical areas [3], [4], [37], [5], [33]. The waters of the hydrosystem Lake Togo-lagoon of Aného are relatively aerated. In fact, dissolved oxygen levels are compatible with fish life according to European standards set between 5 and 7 mg/l [18]. These high levels could be explained by a continuous mechanical mixing of the water due to the tide movement during the low water period, the high flow of the continental waters during the rivers floods and the wind. Also, can we mention the photosynthetic activity of phytoplanktonic organisms [17], [20]. The minimum levels for the survival of salmonid fish and cyprinids are 4 mg/l and 6 mg/l, respectively [27]. A dissolved oxygen content which is less than 2 mg/l leads to the death of many aquatic organisms [46].

The conductivity, salinity and TDS variabilities are similar considering that these parameters are very significantly and positively correlated (Table 10). Based on the values of conductivity, salinity and TDS, the waters of the hydrosystem are unfit for human consumption according to the WHO standards for drinking water which are respectively 0.18-1 mS/cm, 0.1 g/l and 1 g/l [47], [27], [48] during the two seasons. The measured values are similar to other coastal lagoons and estuarine ecosystems [20], [4], [49], [33]. The high values obtained during the dry season are due to a strong marine influence during high tides, causing saline and very mineralized water to rise upstream. The significant decrease in values in the rainy season is explained by the entry of fresh continental waters via the rivers Haho and Zio associated with direct rainfall on the lagoon complex [17], [34], [3], [37]. With conductivity values above 1500 µS/cm, these waters are unsuitable for irrigation and watering [42]. However, in times of flooding the salinity ends up canceling associated to low conductivities which make them very favorable to watering and irrigation of crops often practiced on the banks of Lake Togo. According to [50], salinity values greater than 7 g/l cause the inhibition of the growth of *Eichhornia crassipes* (water hyacinths). This explains the colonization of lagoon's waters by this species only during the rainy season when salinity tends to zero.

Suspended matter contents and turbidity values are significantly and positively correlated (Table10). The measured values are similar to those found by other authors according to the seasons [4], [5], [33], [38]. They are, however, superior to those found by [37] in the Aby lagoon in Côte d'Ivoire. The significant difference obtained between the values of the dry season and those of the rainy season could be due to a sudden hydrological manifestation whose load in TSS is attributed to an intense erosion of the watershed, after rains [44]. Thus, the high values of turbidity and TSS recorded during the rainy season are due to the sedimentary particles transported by the Haho and Zio rivers, to the resuspension of the particles deposited at the bottom by strong mechanical mixing of the water due to the winds of monsoon and to high flow rates [17], [30], [3]. According to [18], turbidity is related to the presence of various organic particles, clay, colloids, plankton, etc. The increase in turbidity and levels of TSS causes a decrease in the transparency of the water. Indeed, this prevents the penetration of light, decreases photosynthesis and dissolved oxygen, compromises the development of aquatic life by creating imbalances between the various species. The asphyxiation of the fish, by clogging of the gills, is often a direct consequence of the high levels of TSS [51], [52], [18]. Although acceptable in the dry season, the waters of the hydrosystem Lake Togo-lagoon of Aného are unfit for consumption and are likely to compromise the fish life according to the French standard which is 25 mg/l [27].

Orthophosphates are anions easily fixed by the soil. Their natural presence in the waters is related to the characteristics of the lands crossed and the decomposition of the organic matter [18]. The orthophosphate and total phosphorus contents recorded are positively and very significantly correlated (Table 10) and are higher than those found in Lake Zowla in Togo [3], in Aby lagoon [37] and Aghien lagoon [30], [38] in Côte d'Ivoire. On the other hand, they are lower than the concentrations recorded in Lake Ahémé in Benin [4]. In the dry season, orthophosphates would mainly come from the intrusion of marine waters loaded with phosphate effluents discharged into the sea. However, in the rainy season they would be due to the entry of inland waters via the Haho river, which is responsible for the leaching of mining and agricultural soils. According to [18], surface water can be contaminated by industrial and domestic discharges or by the leaching of agricultural land containing phosphate fertilizers or treated with phosphorus pesticides. The total phosphorus levels found in the hydrosystem Lake Togo-lagoon of Aného are much higher than those of natural waters, which are between 0.005 and 0.02 mg/l [23]. The French standards recommend for PO_4^{3-} and P the respective guide values of 0.5 and 0.1 mg/l for drinking water [27]. Generally, the problems of eutrophication of water are announced starting from the contents oscillating between 0,34 and 0,7 mg/l of phosphorus [23], [5]. This phenomenon is observed in the lagoon complex where there is a proliferation of phytoplankton and macrophytes such as *Eichhornia crassipes* in the rainy season when the salinity is low [50].

Ammonium is often found in water and usually results in a process of incomplete degradation of organic matter. It can originate from plant matter in streams, animal or human organic matter, industrial waste, fertilizers, etc. [18]. The ammonium contents recorded in the hydrosystem Lake Togo-lagoon of Aného are low. However, they degrade the water quality in the rainy season in accordance with the French quality standard for drinking water set at 0.1 mg/l [27]. At corresponding period, they are similar to those found in Zowla Lake in Togo [3], Aby lagoon [37] and Fresco lagoon [29] in Côte d'Ivoire. In addition, these levels are lower than those recorded in the Aghien lagoon in Côte d'Ivoire [30] and in Lake Nokoué in Benin [53], [33]. These low contents can be explained by a good aeration of the hydrosystem (Table 2) which allows a faster oxidation of the animal and plant organic matter of the hydrosystem. Regarding toxicity for fish fauna, it is known that it is ammonia (non-ionized form (NH_3)) which is toxic and not ammonium (ionized form (NH_4^+)) and that the proportion of NH_3 depends on the pH and temperature [18]. According to [54], ammoniacal nitrogen remains in the ionized form (NH_4^+) without major danger to aquatic life, as long as the pH remains below 8. Lavoie *et al*. [55] confirm that ammonium NH_4^+ passes in its toxic form when the pH is high. By comparing the pH values recorded (5.59 to 7.71) with the long-term sensitivity threshold set at 0.3 mg/l of NH_3 regardless of the fish life [18], it appears that the waters of the hydrosystem Lake Togo-lagoon of Aného pose little danger regarding ammonia (NH_3) toxicity.

Nitrates are the final stage of nitrogen oxidation. The nitrate levels found in the hydrosystem Lake Togo-lagoon of Aného are low and are distributed fairly homogeneous over the two seasons. They are favorable for human consumption according to the WHO standard for drinking water which is 50 mg/l [48]. These levels are higher than those obtained in Lake Zowla in Togo [3] and in the Grand-Lahou lagoon in Côte d'Ivoire [49]. On the other hand, they are well below the concentrations recorded in Lake Ahémé [4] and Lake Nokoué [53] in Benin and then in the Fresco lagoon in Côte d'Ivoire [29]. The increase in nitrate levels during the rainy season can be explained by the drainage and leaching of the agricultural soils of the watershed where nitrogen fertilizers are irrationally used and the resuspension of nitrate from sediments [56]. The low levels of nitrate recorded may be related to the action of the aquatic microflora likely to use them for the synthesis of new organic molecules. In excess, nitrates participate in eutrophication phenomena with phosphorus [18].

The sulphate (SO_4^{2-}), chloride (Cl^-) and bicarbonate (HCO_3^-) contents are significantly and positively correlated with conductivity, salinity and TDS (Table 10). The high concentrations recorded in the dry season are due to the intrusion of very concentrated marine waters in major anions, especially during low-water periods of the hydrosystem and high tides. The decrease in the rainy season is mainly due to a dilution of the lagoon waters by those of the Haho and Zio rivers. Indeed, these rivers and their tributaries have lower levels of major anions [17], [21]. For the quality of drinking water, the WHO sets the guideline values for sulphates, chlorides and bicarbonates at 250; 250 and 200 mg/l respectively [48]. Thus, in the rainy season, the arrival of river waters considerably reduces the influence of the sea and favors the decrease of concentrations. There is also a significant and positive correlation between major cations (Ca, K, Mg, Na) and conductivity, salinity and TDS (Table 10). These correlations attribute to them the same variabilities. Indeed, the highest levels recorded downstream in the lagoon of Aného, unlike those found upstream at the mouths of the Haho and Zio rivers, indicate an intrusion of marine waters highly concentrated in major cations [17], [21]. It is known that the major element contents of littoral aquatic ecosystems are generally depend on the inputs of the ocean and inland waters [17], [34]. The levels of Ca, K, Mg and Na recommended by WHO for drinking water are 100, 12, 50 and 200 mg/l respectively [48]. It thus appears that the waters of the lagoon complex are globally unfit for human consumption regarding the levels obtained.

The opposition of ammonium to mineralization parameters on the F1 axis during both seasons (Figure 3) indicates that two different processes explain their presence in the water. Indeed, ammonium would come from the mineralization of organic matter in the hydrosystem and on the continent and brought by the rivers Haho and Zio. As for the parameters of mineralization and dissolved salts, they are mainly brought by marine waters, especially during low water periods [17]. In addition, the main source of total phosphorus and orthophosphate in the dry season is marine whereas in the rainy season it is continental and is due to the leaching of mining and agricultural soils where phosphorus fertilizers are irrationally used. This explains their good correlation with TSS and Turbidity brought by floodwater during the rainy season (Figure 3). The sites that are under the permanent influence of the sea, whatever the season, are located in the lagoon of Aného. During the dry season, the marine intrusion reaches upstream of the lagoon complex while in the rainy season the marine influence is limited to lagoon of Aného because of inland waters (Figure 4). The physicochemical parameters studied show that the waters of the hydrosystem Lake Togo-lagoon of Aného are chloride sodium type in the dry season and chloride calcium type in the rainy season (Figure 2). This variation can be explained by the seasonal dynamics of the hydrosystem hydrology. These results are in accordance with those obtained by [17] in the same hydrosystem and by [5] in the lagoon system of Lomé. According to [17], sodium chloride is the most dominant salt in the waters from the hydrosystem Lake Togo-lagoon of Aného.

5 CONCLUSION

This study allowed to determine the physicochemical characteristics and the level of mineral and organic pollution of the hydrosystem Lake Togo-lagoon of Aného in accordance with quality standards. The hydrochemistry of this ecosystem is strongly influenced by continental and oceanic waters, which are in turn controlled by the seasons. Indeed, in the dry season, there is a mineral and organic contamination due to the intrusion of ocean waters heavily loaded with dissolved salts (Mg, Na, Cl^-, and SO_4^{2-}) and phosphorus nutrient salts (PO_4^{3-}, P) to the north-west of Lake Togo. This is characterized by very high conductivity, salinity and TDS values. These phosphorus elements are mainly due to the discharge of phosphate effluents into the sea. In the rainy season, the contamination is mainly organic with the entry of the continental waters which bring the nitrogen and phosphorus nutrients (PO_4^{3-}, P, NH_4^+, NO_3^-) after leaching agricultural and mining soils. These waters which are less concentrated in dissolved salts considerably reduce their contents by dilution effect. Although nutrient levels are low, they are higher than natural water concentrations. This is a threat of eutrophication of the hydrosystem which is already manifested by the proliferation of water hyacinths on the water surface once the salinity conditions allow it. It is therefore essential to pay particular attention to the quality of this ecosystem for the socio-economic well-being of local populations. This will involve regular monitoring of the physicochemical parameters of the waters and actions limiting the input of phosphorus and nitrogen nutrients and organic matter.

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