



Seasonal and spatial variability of physicochemical parameters of a semi enclosed lagoon system: the complex of Lake Zowla-Aného Lagoon

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Article History

Received 28 June, 2018
Received in revised form 30 July, 2018
Accepted 03 August, 2018

Keywords:

Physicochemical parameters, Waters, Lagoon system, Lake Zowla, Togo.

Article Type:

Full Length Research Article

ABSTRACT

The semi-closed lagoon ecosystems such as the complex of Lake Zowla-Aného Lagoon are ecosystems whose functioning are influenced by the inflow of fresh continental water and marine water. In order to determine the seasonal variations of the physico-chemical parameters of the waters, a study was made during the dry and the rainy seasons of 2017, on 18 samples of water collected from the complex Lake Zowla-Aného Lagoon. For this study, 17 physico-chemical parameters were evaluated using standard methods according to AFNOR. The pH and the temperature gave averages of 7.59 and 31.02°C respectively, in the dry season, as against 7.2 and 27.46°C in the rainy season. The conductivity and salinity, and Ca²⁺, Na⁺, and Cl⁻ values were found to be 37466.66 µS/cm, 21.34 g/L, 246.43 mg/L; 4205.25 mg/L and 11811.95 mg/L respectively, in the dry season; and were higher than the values obtained from samples collected in the rainy season, which were 3640.22 µS/cm, 1.9 g/L, 14.31 mg/L, 31.74 mg/L and 1104.07 mg/L, respectively. These results show the influence of marine and continental waters on the lagoon system. The values of nitrates, phosphates and ammonium obtained from samples collected in the dry season which were 1.42, 0.72 and 0.06 mg/L were lower than the values of the rainy season (2.65, 1.24 and 0.42 mg/L, respectively). These results confirmed their continental origin.

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INTRODUCTION

The waters of the Lake Zowla-Aného Lagoon complex, located in the Sedimentary Basin of Togo, like any aquatic ecosystem, are affected by pollution problems. Its collection of pollutants comes from streaming and seepage of water which carry with them residuals of pesticides and herbicides on the ground; acid rain and dry depositions that bring pollutants from the atmosphere. Previous studies in the area have shown that surface

water in the sedimentary basin of Togo is threatened by pollution from phosphate mining in the basin, to which could be added pollution from household waste, agricultural inputs, telluric origin (erosion of the grounds and the rocks of the basin) and with fuel from traffic transits by the Lake Togo (Ouro-Sama et al., 2014, 2018; Atanle et al., 2012; Gnandi, 1998; Gnandi et al., 2006). In the municipality of Aného, the system of management of wastewater and garbage is absent, which makes the population to channel wastewaters directly into the lagoon system. Several dumping sites also border the lagoon system. All of these contribute to the degradation

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of the lagoon water quality. Studies on the degradation of hydrosystems in Togo, particularly Lake Zowla-Aného Lagoon are very recent and there is no much data available, which makes it impossible to follow the level of degradation of this ecosystem (Bawa et al., 2018; Ouro-Sama et al., 2018, 2014; Atanle et al., 2012). In aquatic ecosystems, the heavy inputs of nutrients related to pollution have very often caused eutrophication, characterized by the proliferation of aquatic plants such as hyacinth (Mama, 2010; Mama et al., 2011; Gulati and Van Donk, 2002; Ogutu-Ohwayo et al., 1997) and the progressive degradation of these ecosystems. The degradation of the water quality of the complex Lake Zowla-Aného Lagoon has a negative effect on the role of this ecosystem. This is because the complex Lake Zowla-Aného Lagoon is of ecological importance as an ecosystem for benthic, eurythermal and euryhaline macrofauna; and for the economy because it is exploited for fishing by the local population. It is therefore necessary to update information concerning the water quality of this lagoon system in order to preserve it. To preserve aquatic ecosystems, the permanent control of their general state of health is a crucial factor to consider. This involves evaluation of the various physico-chemical parameters and concentrations of the pollutants (Tavakol et al., 2017; Noori et al., 2010; Rioux and Gagnon, 2001), as well as the presence or absence of aquatic organisms and microorganisms, using bio-indicators concept for determining water quality (Juliette et al., 2005). This study aimed to evaluate the physico-chemical quality of Lake Zowla-Aného Lagoon as well as seasonal variability and the origin of pollutants in this ecosystem, in order to know the consequences that are associated with the variability of parameters on water quality.

MATERIALS AND METHODS

Study area

The complex Lake Zowla-Aného lagoon is located in the Togolese littoral and consists of Lake Zowla (6.55 km²), and the Aného Lagoon in the Southeast consisting of a network of narrow channels (4 to 11 m). This complex system belongs to the Togolese littoral zone which is between latitudes 6° 17' 37" and 6° 14' 38" North and longitudes 1° 23' 33" and 1° 37' 38" East (Figure 1). This complex, which is the primary source of protein for the local population, communicates downstream with the sea through the Aného pass, which has been open continuously since 1989 (MERF, 2007; Millet, 1983). The hydrological regime of the lagoon system is mainly dependent on the regime of the Zio, Haho, Boco and Mono Rivers (Atanle et al., 2012; MERF, 2007; ONUDI/TGO, 2007; Millet, 1983). It is therefore a partially closed lagoon.

Sampling technique

The water samples were taken from the complex lake Zowla-Aného Lagoon during the dry season (April) and the rainy season (August) 2017. Sampling was done at 18 sites in the Lake Zowla-Aného Lagoon complex. Water samples were taken 30 cm from the surface in a 1.5 L polyethylene plastic bottle for physicochemical analysis previously prepared. They were put directly in a cooler and transported to the laboratory where they were kept in a refrigerator at 4°C.

Physico-chemical analysis

The physico-chemical parameters were determined according standard methods (Rodier et al., 2009; AFNOR, 2001). Conductivity, pH, temperature and salinity were detected *in-situ* using a Knick portamess conductivity meter and Crisson pH meter. The dissolved oxygen was detected using the HANNA oxymeter. The determination of the transparency was made using Secchi disc (Rejsek, 2002). The cations and anions were determined at the Management Treatment and Valorization of Waste (MTVW) Laboratory from Universities of Lome. The bicarbonates were determined by titrimetric method. Cations (Ca²⁺, Na⁺, K⁺, NH₄⁺ and Mg²⁺) and anions (PO₄³⁻, Cl⁻, SO₄²⁻, HCO₃⁻ and NO₃⁻) were assayed using a HACH DR 3800 molecular absorption spectrometer and a Thermo Fischer Solaar S2 flame atomic absorption spectrometer coupled with a cold vapour emitter, Thermo scientific VP 100.

Table 1 summarizes the methods and materials used for the analyses.

Quality control

The validity of the analytical methods was verified using internal control by making extraction blanks prepared like the same conditions as the samples, without the knowledge of the laboratory technician (El Morhit et al., 2012; Ouro-Sama et al., 2014). This quality control concerns the parameters determined in the laboratory.

Data processing

Microsoft Excel 2007 and STATISTICA version 5.1 Software were used for data processing. Thus, a principal component analysis (PAC) was carried out in order to highlight inter-specific variations in the contents of physico-chemicals parameters. Student's *t*-test at the 5% threshold was used to compare the seasonal variability of the physicochemical parameters of the waters of the

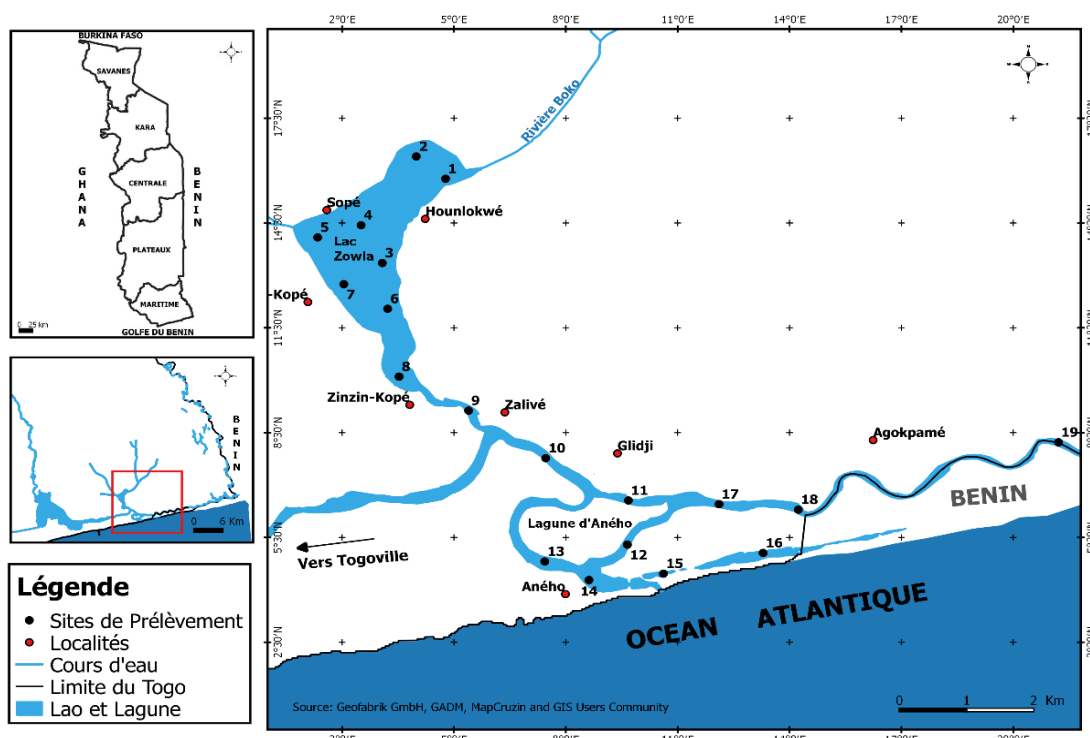


Figure 1. The study area showing the sampling sites.

Table 1. Material and methods for analysis of physicochemical parameters.

Parameters	Methods	Equipment
Temperature	Electrometry (NFT 90-100)	
pH	Electrometry (NFT 90-008)	pH-meter Crison Basic 20+ PH 25
Electrical Conductivity	Conductimetry (NF EN 27888)	
Salinity	Electrometry (NFT 90-031)	Multimeter, type Knick Portamess
TDS	Electrometry (NFT 90-031, NFT90-111)	
TSS	Photometry (Method 8006, HACH)	Spectrophotometer HACH DR 3800
Dissolved oxygen	Oximetry/electrochemistry (NF EN 25814)	Oxymeter HANNA
Transparency	Secchi (NF EN ISO 7027)	Secchi Disc
PO_4^{3-} , SO_4^{2-} , NH_4^+ , Cl^- , NO_3^-	Molecular spectrophotometry, NFT90-023, NFT90-009, NFT90-015, NFT90-012)	Spectrophotometer HACH DR 3800
Ca^{2+} , Mg^{2+} , K^+ , Na^+	Atomic Absorption Spectrometry (NFT 90-005, NFT90-020)	Atomic Absorption Spectrometer, Thermo Electron S Series
HCO_3^-	Titrimetry (Acidimetry) NFT 90-036	Laboratory glassware

complex of Lake Zowla-Aného Lagoon. Pearson's correlation was made in order to know the correlations between the different parameters.

RESULTS

The results of the physical and chemical parameters

analysis are recorded in the Figures 2 and 3. The analysis in Figure 2 shows a small variation of pH and temperature between sampling sites and also between the two seasons. The pH values in the dry season ranged between 7.1 and 8.4 while in rainy season it was between 6.6 and 7.8. For conductivity and water salinity, there is a big difference between the dry and rainy seasons. The conductivity in dry season varies between 17500 and

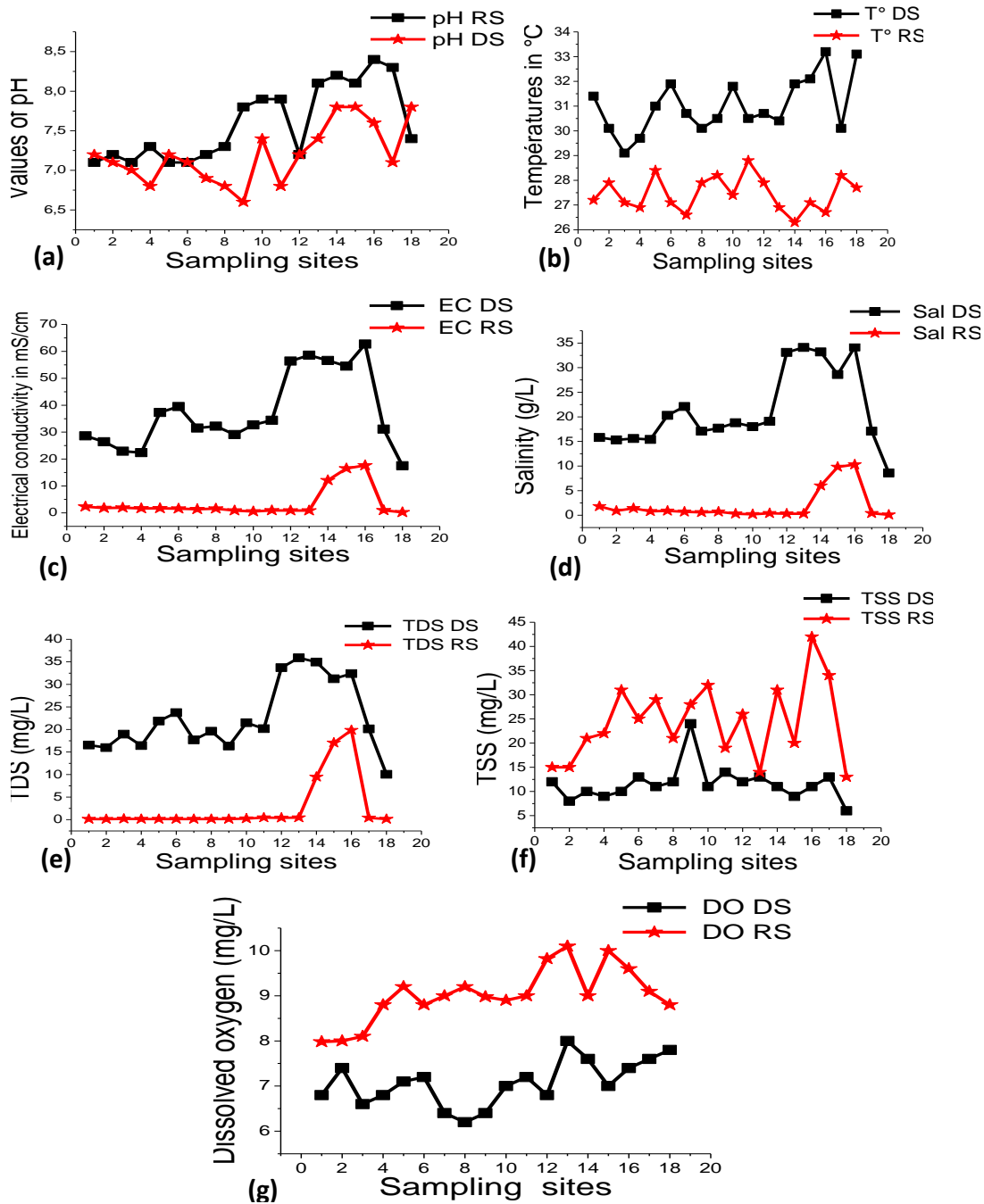


Figure 2. Spatial and seasonal (DS, dry season; RS, rainy season) variation curves for pH. (a), temperature; (b), conductivity; (c), salinity; (d), total dissolved salts; (e), total suspended solids; (f), dissolved oxygen; (g), from the waters of the Lake Zowla-Aného Lagoon system.

62700 $\mu\text{S}/\text{cm}$ while in the rainy season it varies between 237 and 17640 $\mu\text{S}/\text{cm}$. on the other hand, the salinity in the dry season is between 8.6 and 34.2 ‰ while in the rainy season it is between 0.1 and 10.3 ‰. For total dissolved salt, the results show that total dissolved salt (TDS) values range from 10050 to 35900 mg/L in the dry

season while in the rainy season they range from 122 to 19850 mg/L. Concerning total suspended solids (TSS) they oscillate between 6 and 24 mg/L in dry season whereas in rainy season they oscillate between 13 and 42 mg/L. In the dry season the dissolved oxygen values found is between 6.2 and 8 mg/L; on the other hand in

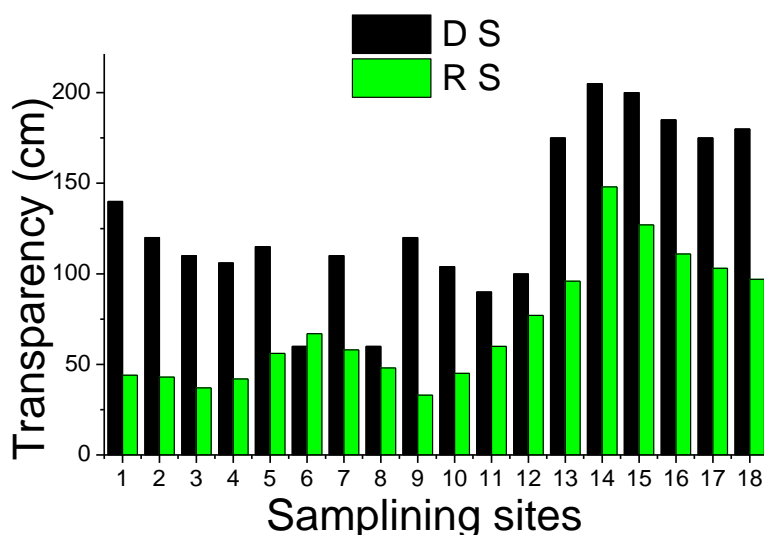


Figure 3. Histogram of spatial and seasonal variation of transparency according to sites and seasons (DS, dry season; RS, rainy season).

the rainy season it varied between 7.98 and 10.01 mg/L. The transparency of the water was very high in the dry season; it oscillates between 60 and 205 cm; meanwhile, in the rainy season it was weak and varied between 33 and 148 cm.

Cations and anions in water samples

The results of analyzes of the cations and anions in the samples of water taken are recorded in Figures 4 and 5. The results of analysis of the cations and anions in the water samples taken are recorded in The levels of Ca^{2+} , Na^+ , K^+ and Mg^{2+} are at all elevated sampling sites in the dry season comparing to the levels found in the rainy season. For NH_4^+ ions, the dry season concentrations were lower than the rainy season levels. For Ca^{2+} ions the levels range in dry season from 136.77 to 627.53 mg/L and from 7.71 to 38.08 mg/L in the rainy season. Potassium ions ranged from 228.08 to 499.48 mg/L in the dry season and from 8.02 to 37.87 mg/L in the rainy season. Magnesium ion levels ranged between 468.48 and 677.57 mg/L in the dry season while in the rainy season they ranged from 12.79 to 44.39 mg/L. The sodium ions with the highest levels among the cations vary from 3353.28 to 6264.13 mg/L in the dry season. In rainy season they were between 17.64 and 44.39 mg/L. Ammonium values noted are between 0.019 and 0.13 mg/L in the dry season. On the other hand, during the rainy season, there was an increase of the concentration which varied from 0.13 to 1.48 mg/L. The analysis results of the anions in water are summarized in Figure 5.

The chloride ions which are most abundant among the

anions range from 4760.65 to 18931.11 mg/L in the dry season. On the other hand, during the rainy season the values are between 55.35 to 5701.47 mg/L. For sulphates and bicarbonates, the levels range respectively from 240 to 3080 mg/L and from 196.86 to 261.31 mg/L in the dry season. In the rainy season, they range from 120 to 340 mg/L and 99.2 to 179.8 mg/L respectively. At all sampling sites, these three anions have high levels in the dry season and low levels in the rainy season. For nitrates and phosphates, the levels vary respectively from 1.04 to 1.97 mg/L and from 0.25 to 1.37 mg/L in the dry season. In the rainy season, the levels vary respectively from 1.93 to 3.42 mg/L and from 0.32 to 3.15 mg/L. The results show that nitrate and phosphate levels are high in the rainy season than in the dry season.

Spatial analysis shows an increase in upstream levels downstream. In fact, sampling sites located in Lake Zowla are low in content while those located in the Aného Lagoon have high levels for these cations and anions.

Sites 12, 13, 14, 15 and 16 have the highest levels. Site 18 located in Gbaga channel is less influenced by marine waters and is the site with low levels for all parameters. Tables 2 and 3 showed the statistical analysis of the different studied parameters.

The results of the *t*-test carried out made it possible to highlight the differences between the average values of the different parameters studied between the dry season and the rainy season. These results are reported in Tables 4 and 5. These results showed differences between the results of the dry season compared to those of the rainy season. The values of *t* obtained for pH, temperature, conductivity, salinity and dissolved salts are positive with respective values of *t* which are 2.76, 11.39,

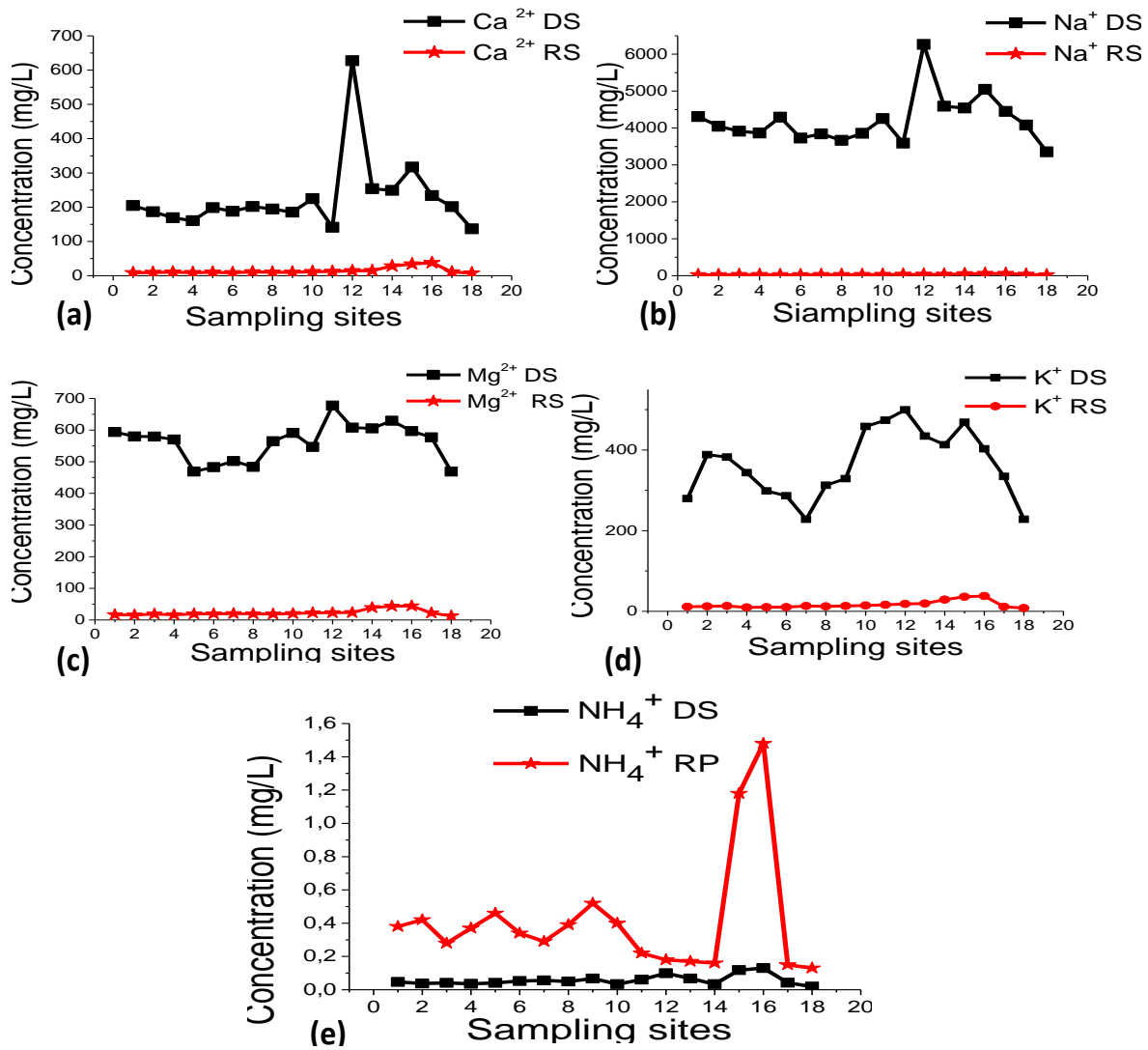


Figure 4. Curves of spatial and seasonal (DR, dry season; RS, rainy season) variation of the concentration of ions. (a), Calcium; (b), sodium; (c), magnesium; (d), potassium; (e), ammonium in water samples.

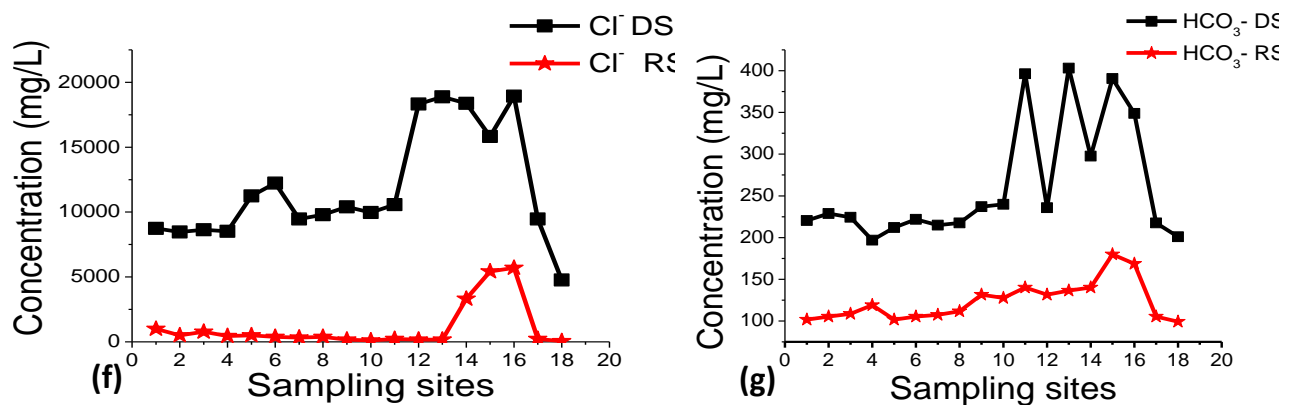


Figure 5. Spatial and seasonal (DR, dry season; RS, rainy season) variations of anions concentration. (f), Chloride; (g), bicarbonates; (h), sulphates; (i), phosphates; (j), nitrates in water samples.

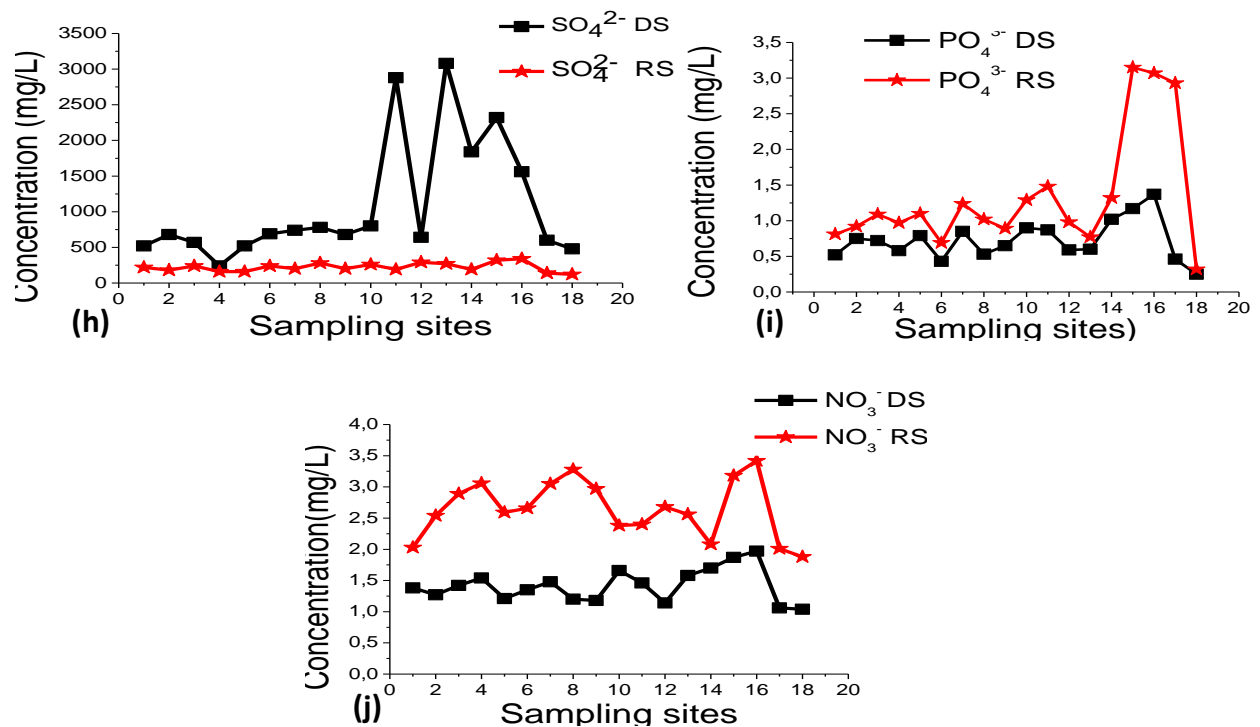


Figure 5. Contd.

9.31, 9.74 and 8.58. This shows that, it is therefore a significant difference between the dry season levels which are higher than those of the rainy season. For total suspended solids and dissolved oxygen, the values of t are negative correlation. The values of t are respectively -6.16 and -10.46 and these results show that total suspended solids and dissolved oxygen values in the rainy season were higher than the dry season values. For Ca^{2+} , Na^+ , Mg^{2+} , K^+ , Cl^- , SO_4^{2-} and HCO_3^- ions the values of t are positive values. These values are respectively 8.23, 26.8, 38.24, 17.49, 9.74, 4.24 and 7.75. These positive values show that the average concentrations of these ions in the dry season are higher than those found in the rainy season and further explain the results found for salinity, conductivity and dissolved salts. For the PO_4^{3-} , NO_3^- and NH_4^+ ions, the results give negative t -values; this shows that the average concentrations of these ions obtained in the rainy season are higher than those of the dry season. The values of t found are respectively -2.37, -9.93 and -2.5.

Principal component analysis

The analysis of the main components (ACP) was done according to the three first factors and, that made it possible to project the variables (studied parameters) and the individuals (sampling sites) in the plans. In the dry

season the three factors express 73.51%; which are 49.23% for the first factor (F1) 15.33% for the second (F2) and 8.95% for the third (F3). In the rainy season, the three factors express 82.33%; which are 64.5% for F1; 11.07% for F2 and 6.76% for F3. The results of the analysis according to the F1 \times F2 and F1 \times F3 plans in the dry season highlight the F1 axis which is defined on the negative side by almost all the physico-chemical parameters. The axis F2 meanwhile defines on the negative side the Ca^{2+} , Mg^{2+} , K^+ and Na^+ ions; on the positive side by phosphate, nitrates, sulfates, pH and transparency. Axis F3 is defined on the negative side by suspended solids and on the positive side by dissolved oxygen and transparency. The projection of the sampling sites on the F1 \times F2 and F1 \times F3 planes highlights the F1 axis which defines a decreasing distribution from the negative side to the positive side of the sites with respect to salinity and alkaline element. Figures 5 and 6 show the results of the projections in the dry season.

The results of the analysis of the principal components according to the F1 \times F2 and F1 \times F3 plans in the rainy season highlight the F1 axis which is defined on the negative side by almost all the physicochemical parameters and on the positive side by the temperature. The F2 axis is defined on the negative side by nitrates and sulphates and on the positive side by pH and transparency. The F3 axis defines on the negative side the pH and on the positive side phosphates and

Table 2. Average levels of pH, temperature, electrical conductivity, salinity, total dissolved salts, total suspended solids, dissolved oxygen and transparency in the Water of Lake Zowla-Aného Lagoon system according to the seasons (DR, dry season; RS, rainy season).

		pH	T°C	EC µS/Cm	Sal ‰	TDS g/L	TSS mg/l	DO mg/L	Trp (cm)
DS	Av	7.59	31.02	37466.66	21.34	22.62	11.61	7.01	130.8
	SD	0.48	1.12	14031.77	7.79	7.66	3.68	0.56	45.35
	Min	7.1	29.1	17500	8.6	10.05	6	6	60
	Max	8.4	33.2	62700	34.2	35.9	24	8	205
	CV	6.31	3.64	37.45	36.49	33.89	31.7	8.04	34.66
RS	Av	7.2	27.46	3640.22	1.99	2.76	24.33	8.94	83.94
	SD	0.37	0.69	5538.15	3.22	6.13	7.95	0.7	54.86
	Min	6.6	26.3	237	0.1	0.122	13	7.98	33
	Max	7.8	28.8	17640	10.3	19.85	42	10.1	210
	CV	5.13	2.52	152.14	131.31	221.83	32.69	7.83	65.35

Av, Average; SD, standard deviation; Min, minimum; Max, maximum; CV, coefficient of variation; T, temperature; Sal, salinity; TDS, total dissolve salt; TSS, total suspended solids; DO, dissolved oxygen; Trp, transparency; DR, dry season; RS, rainy season.

Table 3. Average levels of Ca²⁺, Na⁺, Mg²⁺, K⁺, Cl⁻, SO₄²⁻, HCO₃⁻, PO₄³⁻, NO₃⁻ and NH₄⁺ ions in the waters of the Lake Zowla-Aného Lagoon system depending on the season (DR, dry season; RS, rainy season).

		Ca ²⁺	Na ⁺	Mg ²⁺	K ⁺	Cl ⁻	SO ₄ ²⁻	HCO ₃ ⁻	PO ₄ ³⁻	NO ₃ ⁻	NH ₄ ⁺
DS	Av	226.43	4205.24	562.6	364.49	11811.95	1090	261.35	0.72	1.42	0.06
	SD	108.88	660.04	59.14	83.92	4310.9	864.69	71.78	0.28	0.27	0.03
	Min	136.77	3353.28	468.89	228.08	4760.65	240	196.86	0.25	1.04	0.019
	Max	627.53	6264.13	677.57	499.48	18931.11	3080	403.08	1.37	1.97	0.13
	CV	48.09	15.69	10.51	23.02	36.5	79.33	27.46	38.88	19.01	50
RS	Av	14.31	31.71	22.96	16.5	1104.07	222.22	123.4	1.33	2.65	0.42
	SD	9.16	11.31	9.29	8.84	1780.92	62.08	23.31	0.83	0.45	0.35
	Min	7.71	17.64	12.79	8.02	55.35	120	99.2	0.32	1.93	0.13
	Max	38.08	57.36	44.39	37.87	5701.47	340	179.8	3.15	3.42	1.48
	CV	64.01	35.66	40.46	53.57	161.3	27.93	18.89	62.41	16.98	83.33

Av, Average; SD, standard deviation; Min, minimum; Max, maximum; CV, coefficient of variation; DR, dry season; RS, rainy season.

Table 4. The result of *t*-test for the physical parameters.

	pH	T	CE	Sal	TDS	TSS	Ox D
t	2.76	11.39	9.51	9.74	8.58	-6.16	-10.46
p	0.009	0.001	0.001	0.001	0.001	0.001	0.001

Table 5. Result of *t*-test for cations and anions.

	Ca ²⁺	Na ⁺	Mg ²⁺	K ⁺	Cl ⁻	SO ₄ ²⁻	HCO ₃ ⁻	PO ₄ ³⁻	NO ₃ ⁻	NH ₄ ⁺
t	8.23	26.8	38.24	17.49	9.74	4.24	7.75	-2.37	-9.93	-2.5
p	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.02	0.001	0.017

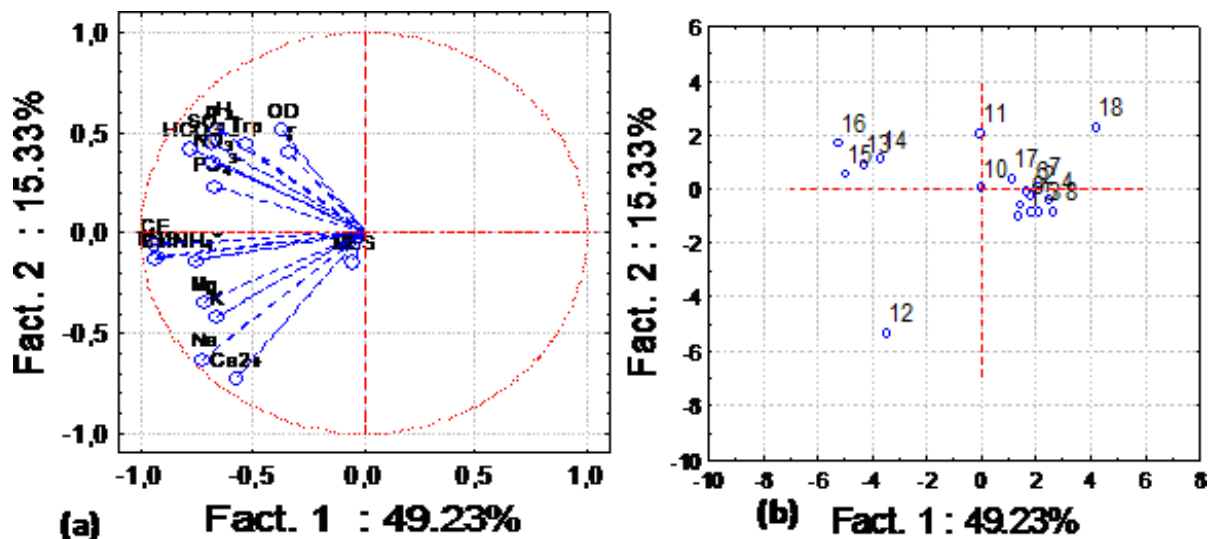


Figure 5. (a), Projection of variables; (b), individuals in F1 x F2 factorial design in the dry season.

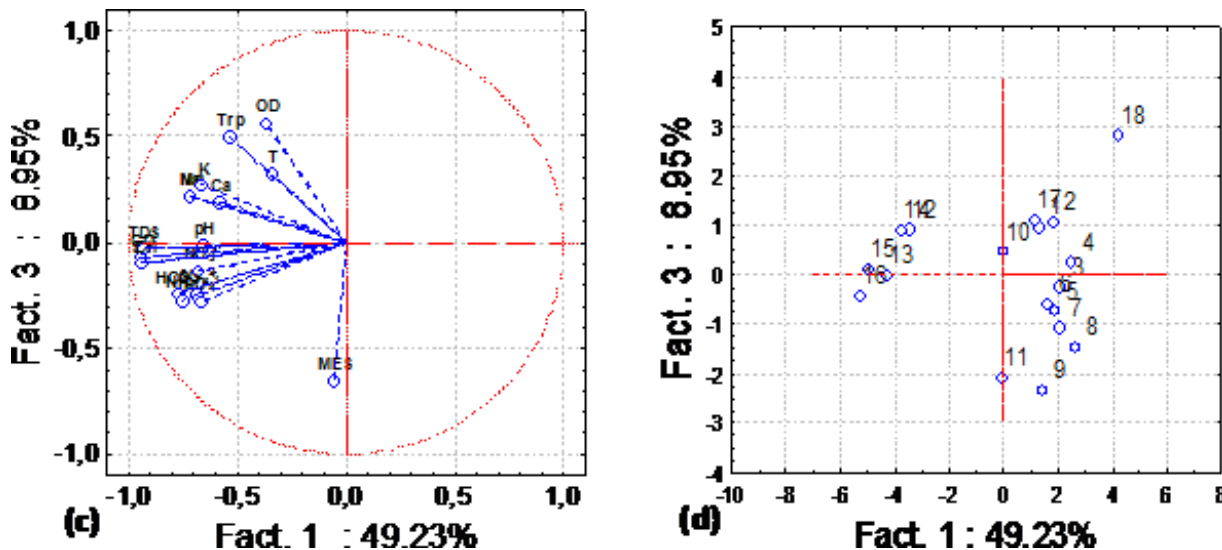


Figure 6. (c), Projection of variables; (d) individuals in the F1 x F3 Factorial Plan in the dry season.

transparency. The projection of the sites with respects to the axis F1 defines a negative side marked by the sites having high content of salinity and nutritive salts; a positive side marked by points having low levels. The projection of the different concentrations of the cations and anions and the sampling sites in the rainy season is summarized in Figures 7 and 8.

The PAC revealed two zones in the complex Lake Zowla-Aného Lagoon during the dry season and the rainy season. In dry season, we distinguish the zone Z1 with high levels of Cl⁻, Na⁺, SO₄²⁻, HCO₃⁻, K⁺, Mg²⁺, salinity, conductivity and total dissolved salts. This zone consists

of sites S12, S13, S14, S15, S16; located in Aného and near the pass are permanently influence by marine water, which provokes the rise of Cl⁻ and Na⁺ ions. A second zone Z2 is composed of sites S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S17 and S18. These sites located in the center and on the north side of the lagoon system have average contents compared to the Z1 sites. These sites are moderately influenced by marine waters because of their remoteness from the pass, so that the waters of this zone have low levels of alkaline salts responsible for the salinity obtained in the waters samples of this zone. In rainy season, we have the first

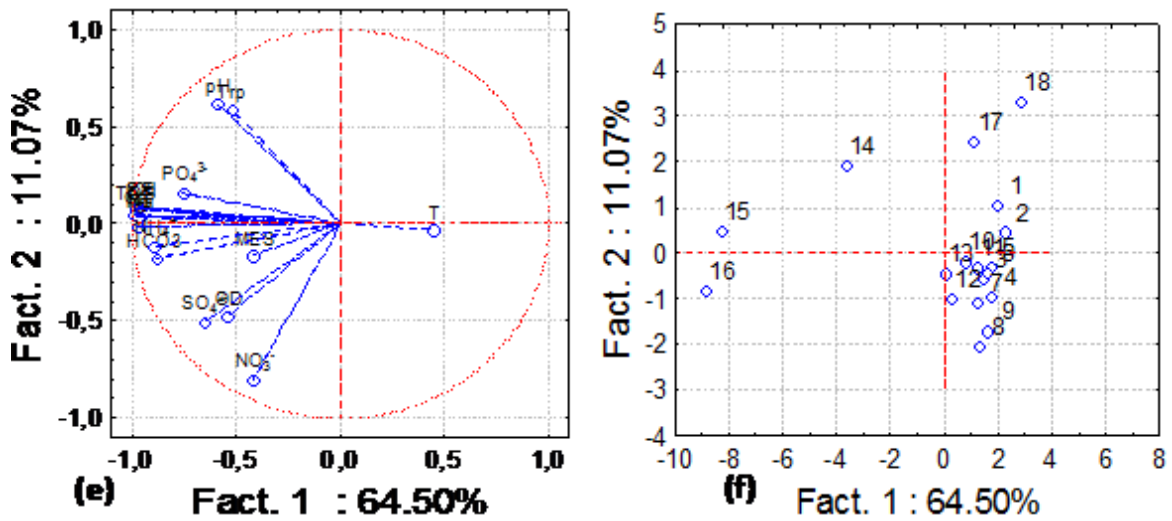


Figure 7. (e), Projection of variables; (f), individuals in the F1 x F2 factorial design during the rainy season.

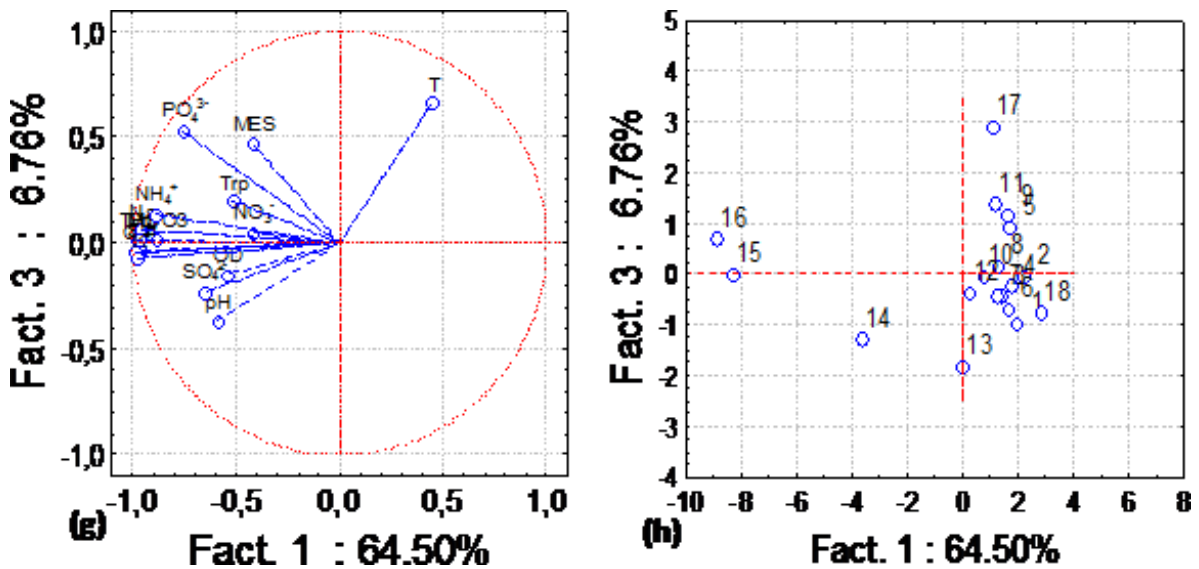


Figure 8. (g), Projection of variables; (h), individuals in the F1 x F3 factorial design during the rainy season.

zone Z1 which is composed of sites S14, S15 and S16. These sites showed high levels of Cl^- , NO_3^- , PO_4^{3-} , NH_4^+ ions, salinity and electrical conductivity. The increase in NO_3^- , PO_4^{3-} and NH_4^+ levels is due to urban wastewater discharges from the city of Aného, to the leaching of urban land. The second zone Z2 is composed by sites S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12, S13, S17 and S18. These sites were influenced by continental fresh water. Thus, the parameters that contribute to marking the factors F1, F2 and F3 are the Cl^- , Na^+ , NO_3^- , PO_4^{3-} , NH_4^+ ions, the salinity, the conductivity and total dissolved salts.

The PAC highlights the correlation existing between the majorities of the different parameters. This correlation is illustrated in Table 6.

In the dry season there is a correlation between pH with salinity, conductivity, total dissolved salts and Cl^- , SO_4^{2-} , HCO_3^- , PO_4^{3-} and NO_3^- ions; but in rainy season it is correlated with conductivity, salinity, dissolved salts and Cl^- , Ca^{2+} , Na^+ , K^+ , Mg^{2+} ions. Conductivity, salinity, total dissolved salts and chlorides are correlated with each other and also correlated with Ca^{2+} , K^+ , Na^+ , Mg^{2+} , SO_4^{2-} , PO_4^{3-} , NO_3^- , HCO_3^- and NH_4^+ ions in the dry season and in the rainy season. Calcium, sodium,

Table 6. Correlation between the different parameters during the study seasons.

		Rainy season																	
		pH	T°C	CE	Sal	TDS	MES	OD	Trp	Cl ⁻	Ca ²⁺	Na ⁺	Mg ⁺	K ⁺	SO ₄ ²⁺	HCO ₃ ⁻	PO ₄ ³⁻	NO ₃ ⁻	NH ₄ ⁺
Dry season	pH	1	-0.43	0.61 _b	0.6 _b	0.61 _b	0.05	0.21	0.65	0.6 _b	0.63 _b	0.54 _a	0.57 _a	0.59 _a	0.21	0.4	0.3	-0.29	0.43
	T°C	0.33	1	-0.48	-0.47	-0.43	-0.13	-0.13	-0.05	-0.47	-0.45	-0.37	-0.42	-0.44	-0.33	-0.25	-0.09	-0.20	-0.27
	CE	0.54 _a	0.37	1	0.99 _b	0.98 _b	0.38	0.39	0.46	0.99 _b	0.97 _b	0.9 _b	0.94 _b	0.93 _b	0.53 _a	0.79 _b	0.71 _b	0.35	0.86 _b
	Sal	0.52 _a	0.26	0.98 _b	1	0.99 _b	0.36	0.37	0.47	0.99 _b	0.95 _b	0.89 _b	0.93 _b	0.92 _b	0.55 _a	0.78 _b	0.72 _b	0.37	0.89 _b
	TDS	0.51 _a	0.23	0.97 _b	0.98 _b	1	0.4	0.43	0.52	0.98 _b	0.97 _b	0.92 _b	0.94 _b	0.94 _b	0.57 _a	0.83 _b	0.75 _b	0.39	0.91 _b
	MES	0.22	-0.22	0.07	0.14	0.04	1	0.23	0.07	0.36	0.42	0.43	0.47	0.36	0.19	0.27	0.47	0.25	0.34
	OD	0.55 _a	0.36	0.28	0.26	0.29	-0.24	1	0.17	0.37	0.52 _a	0.54 _a	0.54 _a	0.57 _a	0.62 _b	0.67 _b	0.46	0.51 _a	0.43
	Trp	0.66	0.46	0.41	0.37	0.38	-0.21	0.59 _a	1	0.47	0.5	0.52	0.5	0.45	0.09	0.39	0.59	-0.16	0.46
	Cl ⁻	0.52 _a	0.26	0.98 _b	0.99 _b	0.98 _b	0.14	0.26	0.38	1	0.95 _b	0.89 _b	0.93 _b	0.92 _b	0.55 _a	0.78 _b	0.72 _b	0.37	0.89 _b
	Ca ²⁺	0.01	0.06	0.6 _b	0.62 _b	0.62 _b	0.01	-0.03	0.05	0.62 _b	1	0.97 _b	0.98 _b	0.99 _b	0.6 _b	0.87 _b	0.71 _b	0.34	0.83
	Na ⁺	0.15	0.09	0.7 _b	0.72 _b	0.73 _b	-0.03	0.03	0.24	0.72 _b	0.94 _b	1	0.98 _b	0.97 _b	0.61 _b	0.9 _b	0.77 _b	0.31	0.77 _b
	Mg ²⁺	0.41	-0.07	0.53 _a	0.58 _a	0.59 _a	0.09	0.28	0.38	0.59 _a	0.64 _b	0.77 _b	1	0.98 _b	0.59 _a	0.87 _b	0.73 _b	0.33	0.78 _b
	K ⁺	0.25	0.04	0.52 _a	0.57 _a	0.59 _a	-0.02	0.15	0.29	0.56 _a	0.61 _b	0.77 _b	0.88 _b	1	0.66 _b	0.91 _b	0.68 _b	0.36	0.81
	SO ₄ ²⁻	0.63 _b	0.15	0.62 _b	0.6 _b	0.61 _b	0.1	0.46	0.38	0.6 _b	0.6	0.18	0.31	0.21	1	0.66 _b	0.33	0.61 _b	0.64 _b
	HCO ₃ ⁻	0.67 _b	0.23	0.68 _b	0.65 _b	0.65 _b	0.1	0.43	0.43	0.65 _b	0.12	0.26	0.41	0.31	0.96 _b	1	0.63 _b	0.43	0.77 _b
	PO ₄ ³⁻	0.51 _a	0.3	0.58 _a	0.55 _a	0.52 _a	-0.05	-0.03	0.38	0.55 _a	0.12	0.29	0.38	0.33	0.46	0.58 _a	1	0.24	0.74 _b
NO ₃ ⁻	0.51 _a	0.36	0.57 _a	0.55 _a	0.56 _a	-0.16	0.19	0.38	0.55 _a	0.01	0.21	0.4	0.41	0.55 _a	0.64 _b	0.83 _b	1	0.56 _a	
NH ₄ ⁺	0.4	0.3	0.73 _b	0.69 _b	0.62 _b	0.18	-0.01	0.24	0.69 _b	0.54 _a	0.59 _a	0.5 _a	0.41	0.42	0.6 _b	0.6 _b	0.5 _a	1	

The values of R followed by b, indicate significant correlation at P= 0.01 level; the values followed by a, which indicate significant correlation at P= 0.05 level.

magnesium and potassium ions in the dry season are correlated each other and with salinity, conductivity, total dissolved salts and NH₄⁺ ions; in the rainy season, they were correlated each other and with pH, salinity, conductivity, total dissolved salts and SO₄²⁻, PO₄³⁻, HCO₃⁻ and NH₄⁺ ions.

Sulphate ions were correlated in the dry season with pH, salinity, conductivity, total dissolved salts, and, with Cl⁻, HCO₃⁻, and NO₃⁻ ions; in the rainy season, they were correlated with salinity, conductivity, total dissolved salt, dissolved oxygen and, with Cl⁻, Na⁺, K⁺, Ca²⁺, Mg²⁺, HCO₃⁻, NO₃⁻ and NH₄⁺ ions. HCO₃⁻ ions were correlated with

pH, salinity, conductivity, total dissolved salts and, with Cl⁻, SO₄²⁻, PO₄³⁻, NH₄⁺ and NO₃⁻ ions in the dry season; in the rainy season, these ions were correlated with salinity, conductivity, total dissolved salts, dissolved oxygen and with Cl⁻, Na⁺, K⁺, Mg²⁺, Ca²⁺ ions; SO₄²⁻, PO₄³⁻ and NH₄⁺. The ions PO₄³⁻ and NO₃⁻ show a correlation with the pH, the conductivity, the salinity, the total dissolved salts, and also with the Cl⁻ and HCO₃⁻ ions in the dry season. In the rainy season they were not correlated each other. The PO₄³⁻ ions were correlated with the conductivity, the salinity, the total dissolved salts, the Cl⁻, Na⁺, K⁺, Ca²⁺,

Mg²⁺, HCO₃⁻ and NH₄⁺ ions while the NO₃⁻ ions were correlated with the dissolved oxygen and SO₄²⁻, NH₄⁺ ions. Temperature, transparency and suspended solids were not correlated with other parameters.

DISCUSSION

The pH analysis results show a low pH variation in the rainy season compared to the dry season. In the dry season the average is 7.59 and in the rainy season 7.2. This temporal variation of pH is

due to the action of marine waters during the dry season and continental freshwaters during the rainy season on the waters of the lagoon complex. Studies have shown that marine waters are basic and those of continental origin are acidic (S raphin et al., 2008; Yacoub et al., 2008). The highest pH values for both seasons are found in site 16 with 8.4 for the dry season and site 14 with 7.8 in the rainy season located in An ho near the estuary. The lowest values are found in site 1 with 7.1 in the dry season and site 9 with 6.6 in the rainy season. These sites in Lake Zowla are very far from the pass.

The average value of the temperature in the dry season (31.02 C) was slightly higher than that of the rainy season (27.46 C). This variation in temperature was due to the interaction between surface water and atmospheric air; and brewing between marine and continental waters. Indeed, the increase of the temperature of the air at the surface of the water in the dry season explains the temperature of the water. This can lead to intense evaporation, thus increasing the basicity of the waters (Karim, 2005). According to Jean-Ren  and Daniel (1994), spatial variations of temperature in water originate in border environments. In addition to tropical lagoons whose average depth is low, the mixing of water due to the winds blowing, fishing activities, navigation on the lake lagoon create a strong hydro dynamism that promotes the mixing of layers of water surface and layers of underlying waters causing a homogenization of the temperature over the entire water column (Traore et al., 2012; S raphin et al., 2008). The pH and temperature values found are similarly to results of Ouro-Sama et al. (2018) in Lake Togo-An ho Lagone, Ayah et al. (2015) in the Lom  lagoon and Atanle et al. (2012) in Lake Zowla.

The salinity, the conductivity and the total dissolved salts found in the dry season whose average values are respectively 21.34 ‰; 37466.66  S/cm and 22.62 g/L are higher than those found in the rainy season which are respectively 1.99 ‰; 3640.22  S/cm and 2.76 g/L. This difference between the seasons is due to the action of the marine waters and continental waters on the system of Lake Zowla-An ho Lagoon. Indeed, in the dry season we note the rise of marine waters in the lagoon waters through the pass to An ho. This rise in marine waters causes an increase in the concentration of alkaline cations and anions in the lagoon waters. This causes the increase of salinity, conductivity and dissolved salts. On the other hand, during the rainy season the arrival of fresh continental waters from the Boco, Haho, Zio and Mono rivers causes a drop in the concentration of cations and anions. This decrease would therefore be at the origin of the decrease in conductivity, salinity and dissolved salts. This seasonal variation was also observed by Mama et al. (2011) in the waters of Lake Nokou  in Benin. The results found in the dry season are much higher than those of Ayah et al. (2015) in the Lom  Lagoon and Atanle et al. (2012) in Lake Zowla but are

similarly for results of Ouro-Sama et al. (2018). On the other hand, during the rainy season, the results found are close to those of Atanle et al. (2012). The results of the *t*-test allow to explain more this difference between the seasons. The values of *t* for these three parameters are positive; this shows that there is a significant difference between the values of the dry season and of the rainy season. At the spatial level, the results show an increasing gradient of salinity, conductivity and total dissolved salts from upstream to downstream. The sites in Lake Zowla have low values while those in An ho near the pass have high values. This difference makes it possible to define a decreasing degree of downstream upstream mineralization as indicated by the analysis results of major cations and anions (Cl⁻, HCO₃⁻, SO₄²⁻, Ca²⁺, Mg²⁺, K⁺ and Na⁺). The spatial evolution of the contents of these elements follows evolution of salinity; this shows their role in determining the salinity of the waters. This decrease in the levels of these cations and anions has also been proved by the results of El Morhit et al. (2012) in the Lukkos estuary in Morocco. The average values of these ions found in the dry season are higher than those found in the rainy season. These results are confirmed by the results of the *t*-test, all of which are positive. These observations make it possible to link the increase of the concentrations of these ions in the waters by the contributions of the marine waters which are mineralized in the dry season. In the rainy season, the arrival of the less mineralized continental freshwater causes a dilution of the waters of the lagoon system resulting in a drop in the contents of these cations and anions (Atanle et al., 2012).

Dissolved oxygen levels are higher in the rainy season than in the dry season with respective averages of 8.94 and 7.01 mg/L. This increase could be due to meteoritic dissolved oxygen influx linked to the long rainy season leading to the rise in concentrations from July. The decreases in dissolved oxygen concentrations observed during the dry season are due to coastal upwelling and therefore an intrusion of ocean waters with low dissolved oxygen (Issola et al., 2008). Among the causes of variation of its content, mention may also be made of the presence of oxidable organic materials, organisms, aerobic germs, fats, hydrocarbons, detergents, as well as the disturbance of atmospheric exchanges at the air-water interface (Rodier et al., 2009). In freshwater in particular, it is especially the temperature of the water that influences the solubility of oxygen. The results obtained are similar to those of Issola et al. (2008) in the Fresco Lagoon but higher than those of Atanle et al. (2012), Ayah et al. (2015) and Traore et al. (2012) respectively in the Lom  Lagoon, Lake Zowla in Togo and in the Aghien Lagoon in C te d'Ivoire.

Suspended Materials are higher in rainy seasons than in the dry season. This increase in suspended solids is due to the telluric inputs of particles from runoff and

rivers feeding the lagoon system. Suspended matter in the dry season would be at the high primary production of the lagoon system as mentioned Issola et al. (2008). Also, the various human activities carried out on the Lake Lagoon including fishing, swimming, navigation can cause the resuspension of the MES throughout the year. In the dry season, the results found are close to those found by Traore et al. (2012) in the Aghien Lagoon, which found an average of 14 mg/L; however, in the rainy season the results are close to those found by Issola et al. (2008) in the Fresco Lagoon. This increase in suspended solids in the rainy season can be explained more by the decrease of the transparency of the water during the rainy season. The suspension of the particles increases the turbidity of the water thus decreasing the transparency.

The analysis of nutrient salts (nitrates, ammonium and phosphates) shows that they are more abundant in the rainy season than in the dry season. The value of nitrates found in the rainy season 2.65 mg/L and in the dry season 1.42 mg/L is lower than that found by Traore et al. (2012) and Ayah et al. (2015), which are respectively 23.4 and 3.37 mg/L. Phosphate ion levels in the rainy season (1.24 mg/L) and in the dry season (0.72 mg/L) are higher than those found by Séraphin et al. (2008), Traore et al. (2012) and Atanle et al. (2012) found 0.24 mg/L, respectively, 0.058 mg/L and 0.4 mg/L. The increase in nitrate and ammonium levels in the waters is believed to have a continental origin. Indeed, the runoff and leaching waters that cross the surface of the villages surrounding the Lake Zowla-Aného Lagoon complex transport with them the pollutants that they pour into the rivers feeding the lagoon complex. According to Hammami et al. (2005), the levels recorded in the studied waters are related to the drainage of agricultural lands in the watershed and the resuspension of sediment nitrate. The increase in phosphate levels during the rainy season may also be due to the leaching of the soil layers in the phosphate mining area, which are brought by the Hato and Voukpo rivers as mentioned in the results of Atanle et al. (2012). Added to this, is the contribution of the rains transporting the dust released in the exploitation zone, the leaching of the agricultural lands, the contribution of the Mono River and the contribution of phosphatic waste discharged into the sea.

PAC revealed two zones in the Lagoon complex. A first zone Z1 consisting of sites 12, 13, 14, 15 and 16 whose waters are permanently influenced by marine waters and which have high levels of salinity, electrical conductivity, total dissolved salt ions such as: Cl^- , PO_4^{3-} , NO_3^- , NH_4^+ and HCO_3^- . These points are located near the pass and were more influenced by human activities, which also explain the high levels of nitrate ions, ammonium and phosphates found in this zone. A second group weakly influenced by marine waters but which is more influenced in the rainy season by inland waters. The correlation

between the different parameters shows a strong correlation between pH, salinity, conductivity, dissolved salts and cations and anions.

Conclusion

The physicochemical analysis of the waters of the Zowla-Aného Lagoon system showed a high water salinity in the dry season proved by the high concentration of chlorides and sodium ions, followed by a large dilution of these ions in the water in the rainy season and an increase of nutrients. In the dry season, the increase of water salinity in the lagoon complex favours the development of mangroves and some species of fish and bivalves especially *Crassostrea gasar* whose collection constitutes a source of income but inhibits the development of water hyacinths. In the rainy season, the case is reverse. This study has made it possible to distinguish two zones in the lagoon complex: the first zone consisted of the sites 12, 13, 14, 15 and 16 which are more influenced by the marine action, located in Aného near the pass while the second zone regrouping the other sites distant of the pass which are more influenced by the waters of the Boko, Voukpo and Mono rivers. To reach the aims of this study, it is necessary to evaluate the levels of trace element in water in order to know the relation between water quality and the variability of physicochemical parameters.

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