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Hydromorphological and physicochemical characterization of water properties in the lagoon Porto-Novo (Benin Republic)

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Abstract

Porto-Novo lagoon is surface water attached to a municipality with a high human population density. Human populations living around it are depending upon various uses with negative repercussions on its quality. The aim of this work is therefore to study the hydrological, morphometric and physicochemical parameters of this hydrosystem towards its characterization. The study was conducted from June 2015 to February 2016 including so the duringfour seasons in the year in West Africa. Probes were sampled between the water surface and 0.50 m depth at 15 different stations, taking into account the most anthropized zones. Samples taken in plastic bottles were transported to the laboratory andanalyzed using appropriate techniques. 16 physicochemical parameters were investigated. Principal Component Analysis (PCA) and hierarchical classification method (simple and Euclidean) served to characterize and classify the 15 stations under consideration. Results show that the lagoon of Porto-Novo is a shallow surface (1.68 m on average) without apparent thermal stratification. Water turnover time is inferior to an hour (18.04 mn) for an average outlet flow rate which correspond to1.94.10^{8} m^{3}/hour. The physicochemical data allowed to diagnose the eutrophication phenomenon and to characterize the eutrophic state of the water fluid of this lagoon. This eutrophication was caused by an excessive supply of compounds in particular those rich in nitrogen and phosphorus, and was manifested by an increased development of phytoplankton organisms and aquatic macrophytes. These nutrients are originally from human activities on the watershed as well as from industry, hotel complexes and other punctual sources of pollution linked to this lagoon. Classification tests permitted to group the 15 stations, and S6, S4 and S3appeared to be characterized by high organic loads, whereas S5, S8, S9 and S14 indicated high degrees of mineralization.

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Introduction

Quality deterioration of surface water is one of the major problems and challenges that humankind is facing to (Zalewski, 2002). Throughout the world, surface water reserves (lakes, reservoirs, rivers, wetlands, etc.) are threatened by eutrophication due to pollution from punctual and non-punctual sources. This phenomenon, the main problem associated with degradation of surface waters in the tropics (Hill, 2008), is characterized by asphyxia, a consequence of the anarchic proliferation of algae that consume all the oxygen necessary for the maintenance of these ecosystems (Oguthu *et al.*, 1997; Mama, 2010).

Benin Republic, through its hydrographical network, dispose over a large number of aquatic ecosystems whose quality is still deteriorating day after day. The lagoon Porto-Novo belongs to the lagoon complex "Lake Nokoué-lagoon of Porto-Novo" which degradation is the results of both natural and anthropoid factors (Leite *et al.* 2004). Because of its geographical location, this water reserve appears as a receptacle for a great part of the pollutants coming from the city and around localities in the outskirts. Several punctual sources of pollution have been identified and located near and on the downstream neighbourhood vicinity of the lagoon and on its slope basin.

However the issue is not peculiar to this ecosystem. It is noticeable in other cities in the country and seems to be due mainly to the absence of a real waste management strategy coupled with the lack in civic senses of the populations who consider the aquatic environment as the receptacle for all wastes coming from their diverse activities (Madjiki *et al.*, 2013).

Chitou (2011) concluded that the lagoon Porto-Novo is hypereutrophic according to the OECD norms. Changes in the degree of trophy in watershed result often from a decrease in morphometric (Kemka, 2000), and hydrological parameters. Hence, decreasing water flow and its renewability leading so to vulnerability insights an eutrophication.

The main objective of this study is therefore to study the hydrological, morphometric and physicochemical parameters related to the eutrophication of this hydrosystem with a special emphasis on their characterization in order to set up priorities towards actual strategies for a real management of this important surface water, and hence to establish by the way the needs for environmental sustainability of the lagoon Porto-Novo and contribute to its conservation

Materials and methods

Description of the study area

The lagoon Porto-Novo covers about 35 km^2 and is located in the South-eastern of Benin Republic between parallels 6° and 6°30 N and the meridians 2°30 and 2°38 E. It stretches up to about 18 km (Adam and Boko, 1983).

In the Northern part of the study area, it is connected to the Ouémé River via a multitude of branches, from which fresh water and alluvial inputs by flooding periods are received. In its Southern part, the lagoon communicates on the one hand with the lake 'Nokoué' through the channel 'Totché', and farer in the South-eastern with the Atlantic Ocean in Lagos on the other hand in its Southern part. From there, the watershed receives saline water in the dry season (Adam and Boko, 1983).

The lagoon Porto-Novo is influenced by the warm and wet subequatorial climate of Southern Benin, with precipitations following a two-season rainfall regime, a large (April-May-June-July) and a small season (October) intercalated by dry seasons (November-February) and then (August-September).

Sampling techniques

The sampling survey was carried out in the four seasons of the year (GSP=long rainy season; PSS=short dry season; PSP=short rainy season; GSS=long dry season). The choice of sampling sites (equated here to the stations) is carried out taking into account the most anthropoid zones (Figure 1). To that end, two zones were cleared depending on the physical disturbance of the environment, the ripple area that is much more disturbed and the less disturbed central zone.

In each of these two zones, areas where habitats such as "acadjas" and macrophytes are installed were taken into consideration. Free water was sampled. Fifteen sampling stations named S_1 to S_{15} were thus identified and their geographical coordinates generated by GPS. Six stations are located on the Northern rive and sampling sites comprised there: S1 by the village Djassin chosen to evaluate influence of household waste discharge in the Zounvi depression, and to estimate effects of water hyacinth mechanical destruction as well as all influences of human good and sand traffics over the lagoon; S7 to S9 located in Southern part of Douane-Tokpa and Sokomey districts were considered to measure supply from collector clearing a certain number of districts situated on the slope basin; S10 is in tight relation with the factory IBCG ("Industrie Béninoise des Corps Gras") producing soaps and located near the lagoon where it is being supplied by refrigeration water for its machinery, and afterwards the waste waters are rejected back into the lagoon; S14 let appreciating water waste supply from the hotel complex "Beaurivage"; S15 receives underground waters from a source appearing around it.

Four further stations are located on the left rive and consisted of S5, S6 and S8 situated by villages Tori Agonsa, Bokpa and Houinta, respectively; S3 is bordered to the village Donoukpa, and can allow evaluating the influence of Ouémé River which tributary to that lagoon.

Five other stations were in the central zone of the lagoon and consisted of: S2, S11 and S12 in villages Wèdji, Lokpodji and Ponton, respectively, and correspond together to the area with "acadjas" concentration; such sites could permit then to measure any impact of this fishing technique on parameters affecting the lagoon Porto-Novo, those parameters being the main subjects causing eutrophication analyzed in the present study; S4 is located in Totché and allows estimating lake Nokoué influence given that the lagoon Porto-Novo communicates with the lake through this chanel called Totché; S13 is the village Tchakou and let characterizing the phenomenon analyzed at the outlet flow of the water surface under investigation.

Three of these sites were used to measure the water outlet flow speed. These were S1, S2 and S13 located respectively on the left bank, the central part of the lagoon with free water level and at the outlet of the watershed. Water probes were sampled at about 20 cm depth, ie between the surface and 0.50 m depth, as indicated by Izydorczyk (2004) for shallow lakes (maximum depth less than three meters).

Sampling are carried out with a periodicity matching with variation in the climatic regime, ie rainy, dry season and flooding period whenever water pollution in tropical areas is submitted to wide seasonal variations. Thus the months of February, June, September and November were retained as sampling times.

Sample analysis methods

Morphometry

The depth, area, perimeter, shape and volume of the lagoon were the main morphometric parameters determined in this study. Lagoon depth was measured at each sampling station using a graduated cord (instrument) supporting the Secchidisk and at an average depth obtained using the 3D Analyst module of the Arc GIS software.

Data on the watershed surface area, perimeter and shape were obtained from satellite data given its extent and the difficulties to access the surrounding parts due to the congestion caused by water hyacinths. Lagoon volume is given and calculated by applying the equation $V = Zm \times S$, where Zm is the mean depth measured and S the area of watershed.

Hydrology

Water flow rate, velocity, and turnover time were the main hydrological parameters examined. Surface water velocity (Vs) was measured in the field using a float. The float speeds were determined according to the following diagram proposed by Aldegheri (1979):

It is assumed that the AB and CD beacons are perpendicular to the direction of flow and that AC is parallel to the same direction. If the lines AB and CD make an angle α with the perpendicular to the direction of the courant, it is necessary to correct the position of the floats by multiplying the values found by $\cos\alpha$.

From Figure 1 we have:

AC = L travelled during the times T measured by the observer C, with Ta # Tc

EF = lc (distance) corresponding to a time Tc

EG = the distance la corresponding to time Ta

FF '= Xc (abscissa of the float determined using the measurements of the observer C)

. GG '=Xa(the abscissa of the float determined using the measurements of observer A).

If V is the float speed supposed to be constant between the two sections AB and CD, we have:

Va = L/Ta and Vc = L/Tc

To measure errors, Va = Vc with V = (Va + Vc) / 2

Water flow speed Vc (cm/s) is determined according to the relationship:

K = Vc / Vs (Vs is the mean surface velocity) from Aldegheri (1979). (1)

Agbossou (2005) estimated the value of K at 0.80 for rivers and lagoons.

Vc = 0.80 × Vs (2)

* The flow of the lagoon.

The general formula of the water flow is given by the relation:

Q = S x V (3)

With Q = flow rate (m^3/s), S (m^2) = wetted cross sectional area, and V = average fluid velocity (m/s)

The wetted section has been obtained from the average depth of the water shed by its width. Arfib (2001).

* The water turnover time (T) in the lagoon is given by the equation:

T = V / Q (4)

with V being the volume of the lake.

Physicochemical parameters

Following physicochemical parameters: pH, Temperature, Predox, Transparency, electric conductivity (EC), salinity, Turbidity, Suspended Matters in Water (MES), Dissolved Oxygen (DO), Dissolved Oxygen Saturation present (DO sat), Total Nitrogen (NTK), Total Phosphorus (TP), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD)Total Dissolved Substances (TDS), Depth, Chlorophyll a (Chl a) were determined.

Measurement of pH, Temperature, Predox, Transparency, electric conductivity (EC), salinity, Turbidity, Suspended Matters in Water (MES), Total Dissolved Substances (TDS) and Depth were carried out in situ in the morning between 8am and 10am. A WTW 3110 SET 1 portable pH-meter was used to measure pH and Predox with an accuracy of ±0.01. A Hach DR 800 colorimeter was used to determine turbidity and MES. Both dissolved oxygen concentration and its saturation rate were recorded with WTW TetraCon 325 Oximeter. The WTW Cond 3210 was useful for measuring CE, salinity, TDS and temperature with an accuracy of ±0,1. A Secchi disc was necessary to estimate water transparency and depth. Water column chemical parameters were determined in the Laboratories of Applied Hydrology (LHA) at the UAC, Benin and those of the Directorate of Hygiene and Basic Sanitation (DHAB), Benin. Water sampled at about 20 cm depth was stored in a 1.5 liter bottle after carefully washing and rinsing that bottle many times and washing it again with the water to be collected. These bottles were kept in a cooler and immediately conveyed to these laboratories for further analyses. Measurement of the Biochemical Oxygen Demand (BOD) was carried out using a BOD meter of the model Oxytop system while that of the COD by a Hach 2800 spectrophotometer. Chlorophyll a content has been measured according to AFNOR NFT 90–117 norm (1984). Total phosphorus and Kjeldahl nitrogen were assayed by a Hach 2800 spectrophotometer according to AFNOR NFT 90-023 and NFT 90-110 norm (AFNOR, 1984), respectively.

Statistical analyses

Data collected were analyzed for variability between seasons and stations by principal component analysis (PCA) in order to determine the spatial and temporal heterogeneities of the data. All these analyzes were carried out using the MINITAB (2014) and JMP software (SAS Institute, 2007). Mean values of the different parameters were compared by the Tukey-Kramer test. Variability of the various characteristics in the Porto-Novo lagoon was analyzed by ANOVA and the variances between and within seasons as well as stations were compared by the F test at 5% confidence limit. All these tests are implemented in the same softwares.

Results and discussions

Morphometrical elements

The depth values of the Porto-Novo lagoon determined during the sampling periods (June 2015 to February 2016) are represented in Figure 3.

The depth of the lagoon varies according to sampling sites and seasons. It is smaller during the rainy season.

Table 1. Surface velocity values.

Sites	GSP	PSS
S15	19.58	20.46
S7	28.41	12.86
S13	34.87	19.21
Season Mean (cm/s)	27.62	17.51
Overall Mean Surface velocity (cm/s)	22.56 (cm/s)	

Table 2. Specific flow rates of the lagoon.

Periods	Flow rate (m^3/s)	Flow rate (m^3/h)
GSP	66075.88	2.37 10^8
PSS	41889.52	1.50 10^8
Middle flow of the lagoon	53928.70	1.94 10^8

The depth is relatively smaller at the S4 site during the long rainy season, while the S11 site with about 438 cm is the deepest. The average of the lagoon depth is estimated at 168.50 cm. This decrease in the depth value can be explained by the loading of wastes and various particles, erosion and leaching of the banks, which lead to an accumulation of sediments and other elements at the lagoon bottom, reducing thus its depth. Using the channels of this watershed as receptacles for household wastes should also be a major cause. The increase in population size in the municipality of Porto-Novo, with consequently an increment in waste-generating activities, let forecasting in the long term or even in short time, a drastic decrease in the depth of the lagoon, if not its disappearance. However, the extraction of lagoon sand, which is occupying a large part of the active riparian population, is a factor that significantly reduces the decrease in sediment accumulation and depth.

The lagoon Porto-Novo has an irregular shape, more flatted to the West. Its capacity is estimated at 58,450,000 m^3.

Hydrological elements

Velocity at the surface (Table 1) varies from site to site and is higher during the major rainy season. The mean velocity of the water flow is estimated to be 18,048 m/s.

Flow rate (Q) values for the Porto-Novo lagoon are presented in Table 2. From these values, the renewal time (T) in water of this lagoon has been generated.

The flow rate of the lagoon shows a variation from the rainy season to the small dry season. The highest value is obtained during the rainy. The average flow rate of the Porto-Novo lagoon (53970 m^3/s) is however significantly higher than that observed in most lakes in the neighbourhood of major municipalities.

This may be the result of the large extent of the watershed or due to an overestimation of the average speed and other parameters associated. On Lake Duhamel, it has been estimated to 2.12 years (Anonym 2007, reported by Madjiki *et al.*, 2013) and 0.28 m^3/s on the municipal lake of Ebolowa in Cameroon for example (Madjiki *et al.*, 2013).

Table 3. Means (X̄ ± SD) of the physicochemical parameters as a function of the seasons, Standard deviation.

Parameters	Unit	GSP	PSS	PSP	GSS	Min	Max	Moy	F-test	P>F[$]
pH		6.96±0.35[a§]	6.30±0.245a	6.83±0.22	7.05±0.25	6.00	7.26	6.79±0.29	21.84	**
Transparency	Cm	99.53±54.51a	142.73±82.94a	153.87±88.06a	137±63.75a	20..	370.00	133.28±20.40	1.43	NS
Conductivity	μsem^{-1}	2778±1530.57	135.08±122.13	156±34.01	7040±4295.94	22.6	16950.00	2527.27±2818.38	28.49	**
Salinity		1.27±0.89 a	0.013±0.05b	0±0 c	3.09±1.90 c	0±0	4.60	1.09±1.26	26.99	**
Temperature	°C	27.55±0.49	25.91±0.76	30.73±1.24	31.93±1.04	25.7	31.10	29.03±2.41	96.64	**
Turbidity	NTU	12.93±7.10 a	58.20±12.41 b	13.27±3.47 b	3.73±2.46 c	0.00	87.00	22.03±21.23	151.24	**
TDS	mgL^{-1}	2740.47±1588.69 a	148.65±120.16 a	156±34.02 b	3478.67±2204.58 b	63.00	8470.00	1630.93±1501.46	27.74	**
MES	mgL^{-1}	7.8±5.075 a	41.53±8.97 b	9.27±3.75 b	2.53±1.26 c	1.00	62.00	15.28 ±15.36	144.50	**
Predox	mVolt	-15.05±20.31 a	27.97±13.003 b	-3.99±13.23 c	-24.45±8.53 c	-33.6	52.80	-3.88±19.76	35.14	**
DO	mgL^{-1}	1.61±0.65 a	1.49±0.64 b	0.87±0.46 b	2.80±1.21 c	0.53	5.70	1.69±0.70	14.53	**
% sat	%	20.05±8.04 a	17.46±6.32 b	11.28±5.96	36.79±16.21	6.80	75.2	21.39±9.44	16.52	**

(Con.) **Table 3.** Means (X̄ ± SD) of the physicochemical parameters as a function of the seasons, Standard deviation.

Parameters	Units	GSP	PSS	PSP	GSS	Min	Max	Moy	F-test	P>F[$]
DCO	mgL^{-1}	33.93±15.89 a	27.77±16.64 a	30.80±31.59 a	22.21±24.25 a	2.73	92.82	28.675±4.33	0.66	NS
DBO	mgL^{-1}	15.27±5.95 a	11.87±6.82 a	14.466±13.30 a	9.8±8.62 a	1.00	48.00	12.85±2.16	1.04	NS
NTK	mgL^{-1}	1.58±0.58 a	1.92±0.76 ab	1.74±1.25 b	2.527±1.05 b	0.075	4.31	1.94±0.36	2.67	NS
PT	mgL^{-1}	1.32±1.08 a	2.18±0.64 ab	1.93±0.87ab	1.93±0.87 b	0.01	6.47	1.81±0.31	2.55	NS
Chl a	mgL^{-1}	5.078±2.78 a	4.36±2.91 a	4.05±2.48 a	4.19±3.21 a	1.073	9.545	4.42±0.39	0.35	NS

([$])** p<0.01: Differences between mean and variance of parameters of various stations significant to 1% error, respectively; NS: No significant differences. On the same line or for the same parameter, the means followed by different letters are significantly different (p<0.05).

The renewal time value corresponds to T = 18.04 minutes. Water turnover time of this lagoon is inferior to an hour and makes it normally less vulnerable to eutrophication, due to its small recovery capacity. On Lake Ebolowa, it has been estimated to 1.62 10^{-11} year (Madjiki *et al.*, 2013).

Table 4. Means (X̄ ± ET) of the physicochemical parameters as a function of the stations (ET = Deviation-Type).

Stations	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	F-test	Significant (P>F)
pH	6.63±0.30a	6.76±0.19a	6.91±0.36a	6.85±0.19a	6.84±0.55a	6.96±0.25a	6.73±0.59a	6.94±0.36a	6.83±0.49a	6.84±0.48a	6.84±0.51a	7.01±0.45a	6.74±0.26a	6.81±0.24a	6.08±0.21a	0.258	NS
Transparence	80.75± 11.06 a	126.80±67.50ab	108.00±85.50ab	196.00±139.60bc	103.80±59.10a	83.75±4.79 a	215.50±39.10bc	102.00±9.80 a	150.00±4.00 ab	194.80±53.60b	245.00±112.70bc	110.30±36.00ab	87.50 ±11.00 a	128.50±81.20ab	66.75 ±19.55 a	0.003	**
CE	1769± 2814a	1877±3025a	2304±3427a	4434 ±8345a	5242±6837a	3425±4282a	2609±3487a	2966±3683a	2572±3160a	2337±2700a	2146±2402a	1391±1882a	896±1043a	3346±4093a	596±675a	0.969	NS
Salinity	0.80±1.35a	0.85±1.45a	1.10±1.71a	0.02±0.05a	2.78±3.73a	1.73±2.20a	1.27±1.75a	1.42±1.79a	1.25±1.58 a	1.25±1.55a	1.25±1.55a	1.07±1.24a	0.37± 0.57a	1.10±2.13a	0.12±0.25a	0.865	NS
Depth	111.75 ± 2.87 a	124.50 ± 11.90 ab	110.80± 96.20 a	266.50± 144.50 c	90.25± 13.57 a	103.50± 10.63 a	252.00± 21.70c	128.50± 12.77 ab	175.00± 19.90 ac	239.80 ± 30.80 c	299.80 ± 168.00 c	232.80± 152.00 bc	114.00± 17.66 a	150.00 ± 83.70 ac	104.00± 13.37 a	0.001	**
Temperature	29.28 ± 2.79a	29.48±2.76a	29.53±2.78a	28.47±1.85a	28.20±2.16a	28.85±2.61a	29.23 ±2.50a	29.35±2.71a	29.28±2.71a	29.60±2.21a	30.15±2.56a	29.65 ±3.02a	29.88 ±2.57a	29.18±2.28a	29.13±3.16a	1	NS
Turbidity	18.50 ± 17.60a	23.00±28.90a	29.00±38.80a	26.80±30.00a	23.50±21.60a	27.50±29.00a	19.00±19.44a	25.00±37.00a	18.50±22.20a	18.00±23.50a	20.80±21.70a	18.00±23.60a	20.75±19.36a	21.30±22.80a	21.00±17.45a	1	NS

(Con.) **Table 4.** Means (X̄ ± ET) of the physicochemical parameters as a function of the stations (ET = Deviation-Type).

Stations	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	F-test	Significant (P>F)
TDS	1024± 1347	1079± 1455a	1389 ± 1690a	2314 ± 4105a	3385± 3586a	2283± 2461a	1669 ± 1840a	2039± 2109a	1730± 1855a	1632± 1757a	1508 ± 1652a	1106± 2003a	773± 1058a	2271 ± 2507a	263 ± 339a	0.925	NS
MES	12.50± 11.56a	16.30± 20.70a	19.80± 28.20a	17.80± 21.00a	16.00± 15.87a	20.00± 20.40a	12.75± 15.15a	17.80± 26.90a	15.75± 17.35a	12.25± 17.88a	12.75± 15.02a	13.75± 17.15a	15.00 ± 13.56a	13.75± 16.42a	13.25± 13.52a	1	NS
Predox	3.45± 16.28a	5.62± 25.40a	11.80± 21.10a	-0.67± 27.60a	-7.98± 31.40a	-14.50± 14.53a	-1.73± 35.4a	14.00± 22.70a	-6.93± 29.5a	-7.23 ± 28.40a	-7.45± 30.70a	17.20± 26.00a	15.00 ± 13.56a	-3.40± 14.28a	25.20± 34.00a	0.8	NS
02	2.01± 1.06a	1.70± 0.61a	1.74± 1.37a	2.29± 1.48a	1.91± 1.10a	2.29± 2.31a	1.73± 1.69a	1.74± 0.89a	1.60± 1.15a	1.33± 0.70a	1.29± 0.54a	1.21± 0.47a	1.24±0.76a	1.95± 0.80a	1.33± 0.73a	0.971	NS
%sat	25.30± 12.54a	21.98± 8.15a	22.75± 18.61a	29.60± 20.10a	24.30± 14.60a	29.50± 30.90a	22.50± 22.50a	22.35± 11.81a	20.45± 15.25a	16.83± 8.90a	16.45± 6.69a	15.43± 5.93a	15.73 9.62a	20.93± 6.43a	16.83 ±9.45a	0.981	NS
Chla	5.50± 4.15a	6.06± 3.07a	3.70± 3.32a	6.66± 2.70a	4.26± 2.03a	3.18± 1.45a	2.58± 1.43a	3.32± 2.33a	2.55± 1.86a	3.85± 3.48a	5.64 ± 3.66a	5.97± 3.60a	4.72± 3.69a	4.32± 3.34a	4.01± 3.07a	0.715	NS
PT	3.02± 0.98a	2.07± 1.69a	2.78± 2.01a	2.98± 0.79a	2.48± 1.42a	3.77± 1.57a	3.10± 1.63a	2.35± 2.49a	2.63± 2.63a	2.82± 1.66a	2.01± 1.87a	2.31± 2.26a	2.15± 2.56a	2.48± 1.70a	2.97± 2.50	0.997	NS

(Con.) **Table 4.** Means (X̄ ± ET) of the physicochemical parameters as a function of the stations (ET = Deviation-Type).

Stations	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	F-test	Significant (P>F)
NTK	1.33± 0.58a	1.66± 1.32a	2.21± 0.91ab	1.16± 0.49a	1.68± 0.56a	2.25± 0.92ab	2.31± 0.65ab	1.22± 0.73a	1.60± 0.54a	3.38± 1.24b	1.79± 0.97a	1.61± 0.40a	3.14± 1.29ab	1.84± 1.17a	1.92± 1.26a	0.049	*
DCO	41.20± 28.20ac	13.77± 5.83 ac	27.23± 14.60 ac	38.70± 22.00ac	13.92± 5.59 ac	59.70± 30.10a	16.07± 4.55 ac	18.59± 3.70 ac	59.10± 33.90a	35.90± 31.10ac	28.70± 36.0 abc	20.10± 12.17 ac	11.05± 10.34 bc	26.27± 13.14 ac	19.71± 10.74 ac	0.048	*
DCO	41.20± 28.20ac	13.77± 5.83 ac	27.23± 14.60 ac	38.70± 22.00ac	13.92± 5.59 ac	59.70± 30.10a	16.07± 4.55 ac	18.59± 3.70 ac	59.10± 33.90a	35.90± 31.10ac	28.70± 36.0 abc	20.10± 12.17 ac	11.05± 10.34 bc	26.27± 13.14 ac	19.71± 10.74 ac	0.048	*
DBO	16.25± 9.54 ac	7.50± 3.32 ac	7.50 ± 3.32 ac	17.00± 9.31 ac	6.50 ± 2.52 ac	29.25± 15.65 b	8.75± 2.06 ac	7.75± 2.50 ac	20.75± 12.39 ab	15.25± 11.24 ac	11.25± 11.81 ac	11.00± 7.07 ac	5.25± 4.99 ac	12.50± 4.43 ac	10.75± 5.68 ac	0.019	*

* p<0.05; ** p<0.01: Variances for the parameter significantly different at the error threshold of 5 and 1%, respectively; NS: non-significant means values and variances. On the same line or for the same parameter, the means followed by different letters are significantly different (p<0.05).

Table 5. Coefficient of variation (%) of the water physicochemical parameters studied in the four seasons known in the year in the Porto-Novo lagoon.

Stations	GSP	PSS	PSP	GSS
pH	5.11	3.29	4.03	3.69
Transparency	56.69	59.24	60.15	48.16
EC	57.03	93.58	22.57	63.16
Salinity	72.61	387.39	00.00	63.64
Depth	73.23	51.64	50.77	61.25
Temperature	1.81	2.94	4.16	3.37
Turbidity	56.85	22.06	27.09	68.26
TDS	60.00	83.65	22.57	65.59
MES	67.35	22.36	41.88	51.39
Predox	-139.69	48.12	-343.55	-36.16
OD	41.78	44.22	54.22	44.76
OD sat	41.52	37.45	54.73	45.59
Chla	56.72	68.92	63.26	79.05
PT	85.53	30.27	45.64	45.64
NTK	38.08	41.21	73.97	43.06
COD	48.46	62.03	106.18	113.05
BOD	40.33	59.49	95.13	91.03

Physicochemical parameters

pH

Results of the physicochemical parameters are presented in Table 3 and are showing that the waters of the Porto-Novo lagoon are of acid nature and the pH is not significantly different from one site to another. Indeed, the pH average value is equivalent to 6.79 and the highest value (7.27) is obtained at the sites S6 and S12. According to Table 6, the highest coefficient of variation is observed at Station 7 and the lowest at Station 4.

Table 6. Coefficient of variation (%) of the water physicochemical parameters studied in 15 stations investigated in the Porto-Novo lagoon.

Stations	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
pH	4.48	2.79	5.19	2.76	8.14	3.65	8.82	5.25	7.15	7.06	7.42	6.40	3.83	3.47	3.52
Transparency	13.69	53.27	79.18	71.24	56.95	5.72	18.16	9.61	2.67	27.51	46.01	32.62	12.57	63.19	29.29
EC	159.14	161.18	148.73	188.20	130.43	125.03	133.64	124.18	122.86	115.55	111.93	135.30	116.37	122.32	113.25
Salinity	168.33	170.08	155.35	200.00	134.27	127.66	136.96	125.32	126.74	124.19	124.19	115.53	151.44	193.99	200.00
Depth	2.57	9.56	86.83	54.21	15.04	10.27	8.60	9.94	11.37	12.84	56.04	65.32	15.49	55.82	12.85
Temperature	9.52	9.35	9.43	6.48	7.65	9.06	8.56	9.23	9.26	7.46	8.51	10.19	8.61	7.80	10.86
Turbidity	95.12	125.76	133.82	112.33	92.09	105.41	102.33	147.87	120.18	130.60	104.51	130.92	93.31	107.20	83.12
TDS	131.57	134.84	121.63	177.41	105.96	107.83	110.21	103.43	107.22	107.67	109.53	181.11	136.81	110.38	128.97
MES	92.49	127.45	142.88	118.48	99.22	102.06	118.84	151.83	110.14	145.93	117.80	124.75	90.43	119.41	102.07
Predox	471.81	450.77	-179.09	-4088.47	-394..13	-100.20	-2051.00	-162.23	-426.36	-393.35	-411.65	-151.24	4255.39	-419.90	134.82
DO	52.93	36.03	78.96	64.50	57.85	100.63	97.18	51.34	71.66	52.48	41.54	38.84	61.21	40.97	55.15
DO sat	49.58	37.07	81.79	68.02	60.10	104.58	100.08	52.85	74.58	52.89	40.68	38.45	61.20	30.74	56.15
Chla	75.46	50.68	89.61	40.53	47.59	45.50	55.19	70.08	72.81	90.33	64.84	60.41	78.02	77.16	76.70
TP	32.42	81.59	72.54	26.47	57.26	41.58	52.79	106.27	100.32	58.73	92.98	97.92	118.65	68.54	84.16
NTK	43.64	79.32	40.94	42.53	33.21	40.77	27.95	59.67	34.07	36.70	54.15	24.72	41.19	63.44	65.44
COD	68.45	42.36	53.63	56.85	40.15	50.37	28.35	19.91	57.34	86.48	125.42	60.52	93.59	50.04	54.48
BOD	58.68	44.22	44.85	54.76	38.72	53.50	23.56	32.26	59.72	73.68	105.02	64.28	95.08	35.48	52.83

At all stations, it is always less than 10% indicating certain homogeneity of the sampling methods in each station. The comparison of the pH averages according to the Dunnett method applied in a controlled factor variance analysis (station factor) showed that mean values were not significantly different from pH = 7 (pH of station S6 = 6. 99 in the GSP) at 95% confidence intervals, since the variance comparisons revealed negative values (absolute value of variance-LSD difference) whatever the station considered (with $p > 0.05$), with the exception of station S15 at the same season ($p = 0.023 < 0.05$).

Table 7. Correlation of physicochemical parameters with main components.

Variables	CP1	CP2	CP3	CP4	CP5
pH	0.344	-0.186	0.210	-0.057	0.143
Transparency	0.007	0.002	-0.122	-0.469	0.545
EC	0.367	0.089	-0.267	0.191	0.099
Salinity	0.353	0.068	-0.212	0.045	0.074
Turbidity	-0.336	0.134	-0.373	0.075	0.184
TDS	0.358	0.014	-0.181	0.254	0.154
MES	-0.333	0.118	-0.393	0.068	0.165
Predox	-0.368	0.154	-0.210	0.074	-0.009
DO	0.265	0.164	-0.370	0.164	0.063
Chla	-0.015	0.093	0.274	-0.090	0.695
TP	0.239	0.201	-0.318	-0.340	-0.192
NTK	0.072	0.240	-0.063	-0.690	-0.242
COD	-0.033	-0.614	-0.275	-0.123	0.017
BOD	-0.025	-0.622	-0.249	-0.124	0.002

The highest seasonal mean value (7.05 ± 0.25) is obtained in GSS and the lowest value (6.30 ± 0.24) in PSS. GSP and PSP record the intermediate values with respectively 6.96 ± 0.35 and 6.83 ± 0.22.

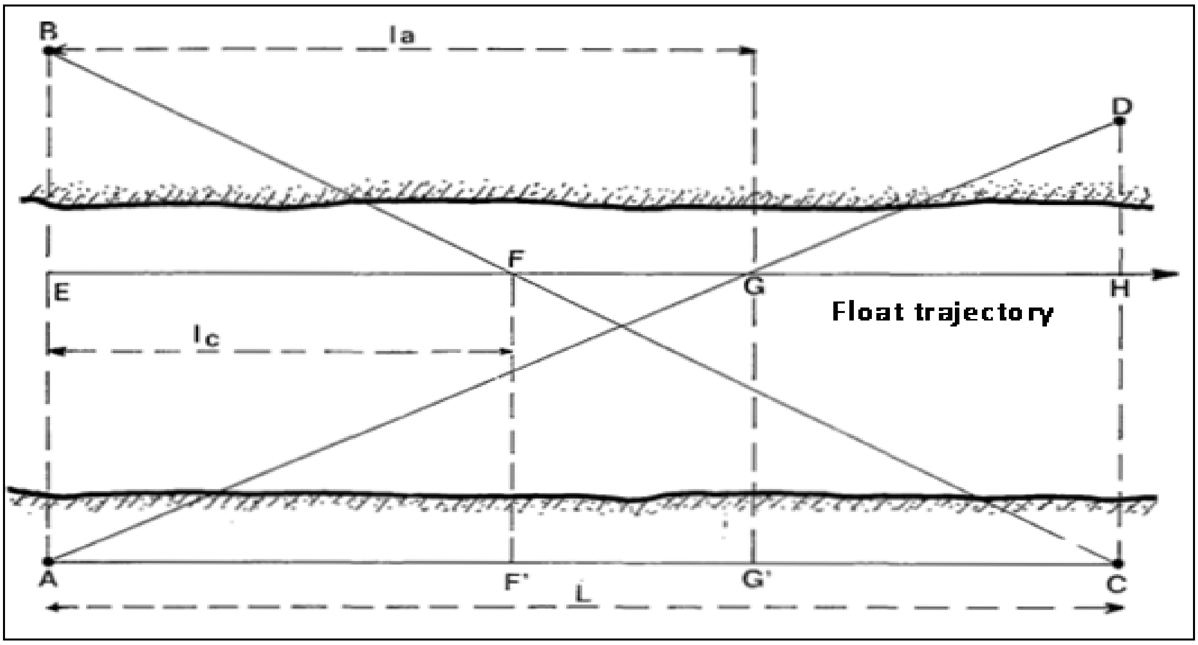

Fig. 1. Determination of the speed of the floats.

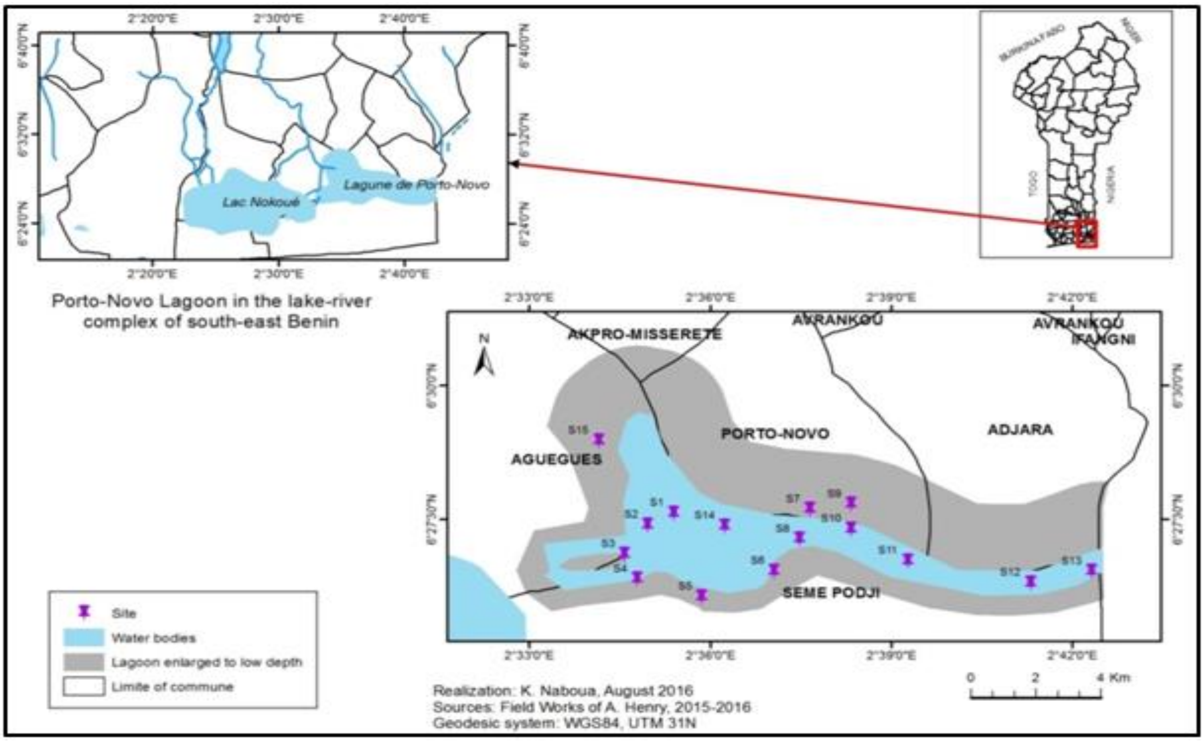

Fig. 2. Localisation of the Porto-Novo lagoon in the lagoon complex of South-Eastern Benin.

The acid pH of this water from GSP to PSP can be justified the direct effects of acid rainwater and inland waters through the flood induced by the Ouémé River from rainfall in the north of the country. According to Korfali and Davies (2003), the acidity of continental waters is related to the supply of humic acids from the leaching of soils.

The persistence of the acidity of the waters of the lagoon during these seasons, should be attributed to the preponderance of rain and continental waters over those from the marine area through Lake Nokoué.

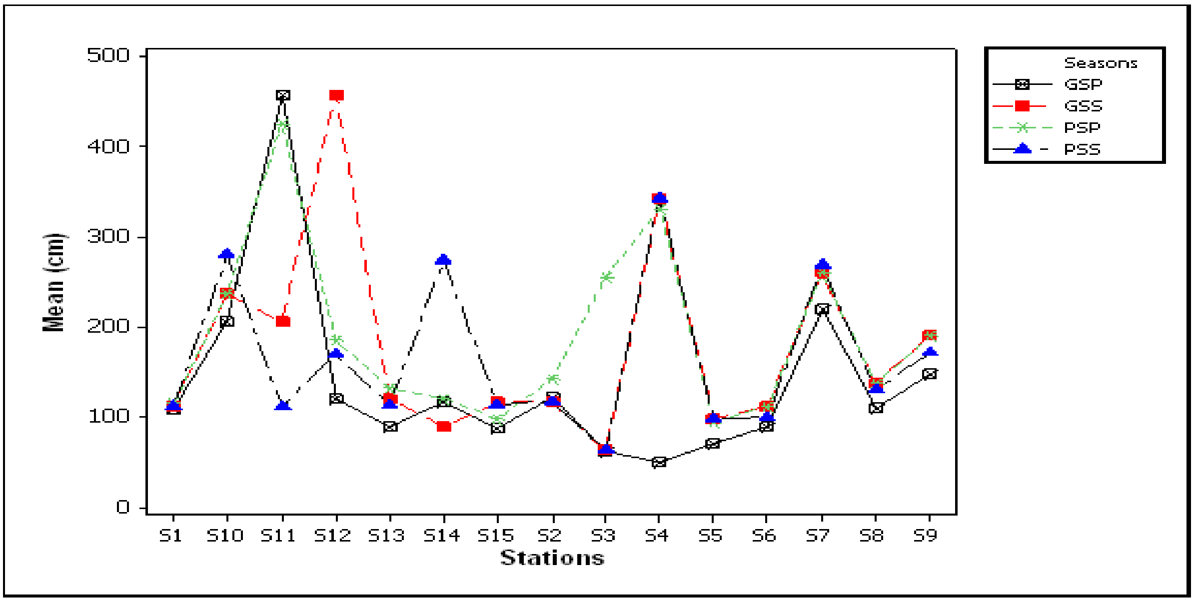

Fig. 3. Average depth variation curve between sites and seasons.

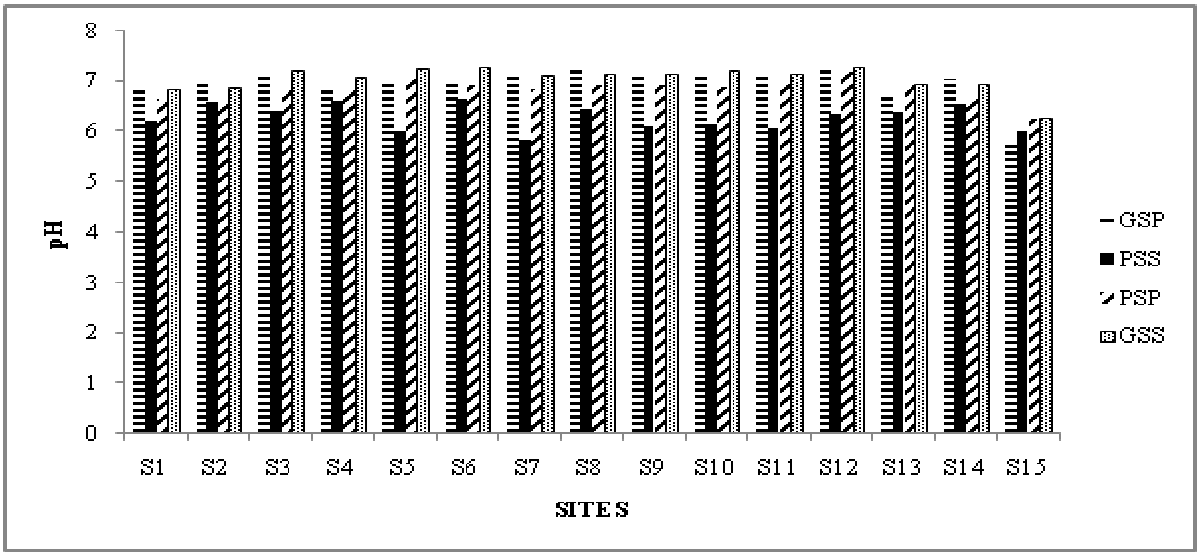

Fig. 4. Change in pH according to sampling sites and seasons.

The basic character of surface water in the dry season is the evaporation and influence of ocean waters (Kouassi and Adingra, 2005). pH can vary depending on several factors such as the physical environment (soil geology), aquatic organisms (respiration and photosynthesis), the extent of acid precipitationetc (Richer-Bond, 2013),. Thus, the spatial and temporal variations of the salinity, depending on the relative importance of the continental and oceanic contributions, also determine the seasonal variation of the pH of the waters.

Temperature

Water temperature is a measure of heat accumulation and varies within the water column depending on various factors such as time of day, water flow, latitude, altitude, season, turbidity, etc. (Richer-Bond, 2013). In this study period, temperature does not vary significantly from one season to another. GSS showed the highest temperatures with an average of 31.93 ± 1.04, while the lowest temperatures are recorded in the PSS (mean = 25.91 ± 0.76).

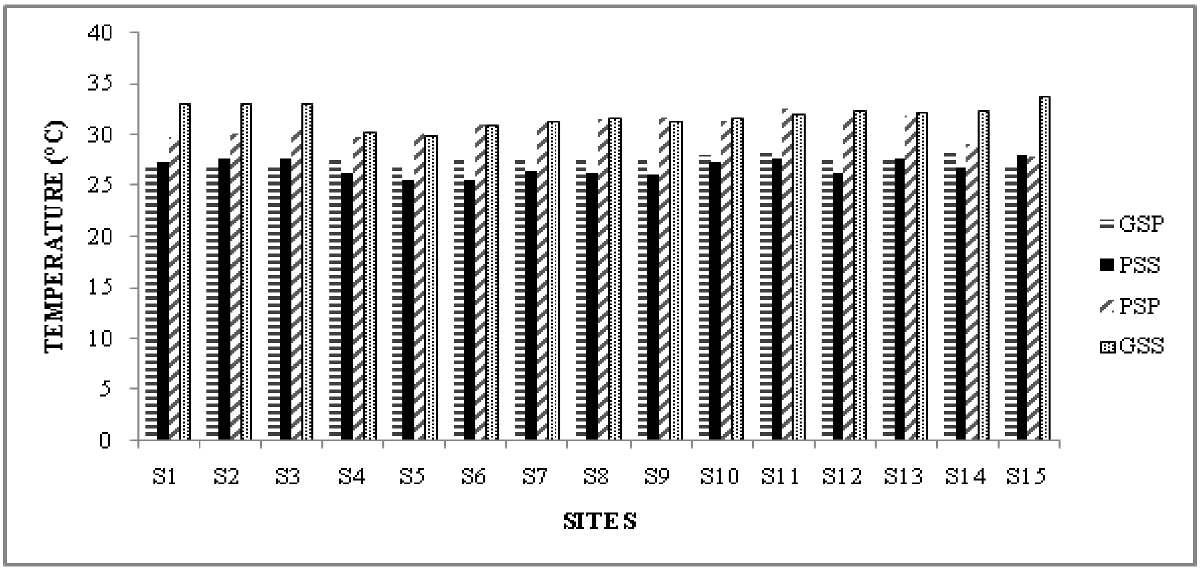

Fig. 5. Variation of temperature (° C) according to sampling sites and seasons.

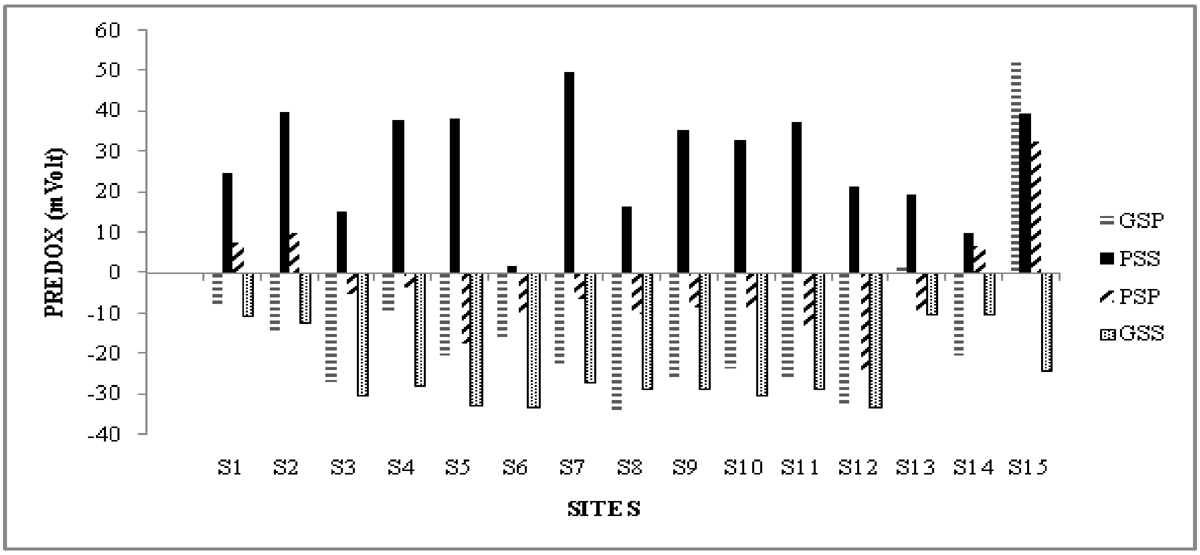

Fig. 6. Predox variation according to sampling sites and seasons.

Intermediate means, 30.73 ± 1.24 and 27.55 ± 0.49 are respectively recorded during PSP and GSP. The highest value (33.8) is obtained at S15 and the lowest (25.7) at S5 and S6. At station level, the mean values indicate absence of significant difference from one site to another (ANOVA, Ficher, p = 1>0.05). The seasonal variations in the mean temperature of the waters of the Porto-Novo lagoon are not large enough. This thermal stability has been observed elsewhere such as in the Fresco lagoon in Ivory Coast.

The low seasonal variation could be explained by hydrodynamics, lagoon activities, tidal actions, floods and low water flows, but also runoffs and precipitations (Issola *et al.*, 2008). The low values observed during the dry season are due, on the one hand, to the effects of climate changes, which result in no longer clear demarcation between rainy seasons, and, on the other hand, to the stirrings of water mass which penetrate the lagoon in that rainy season as it also corresponds to the hydrological season.

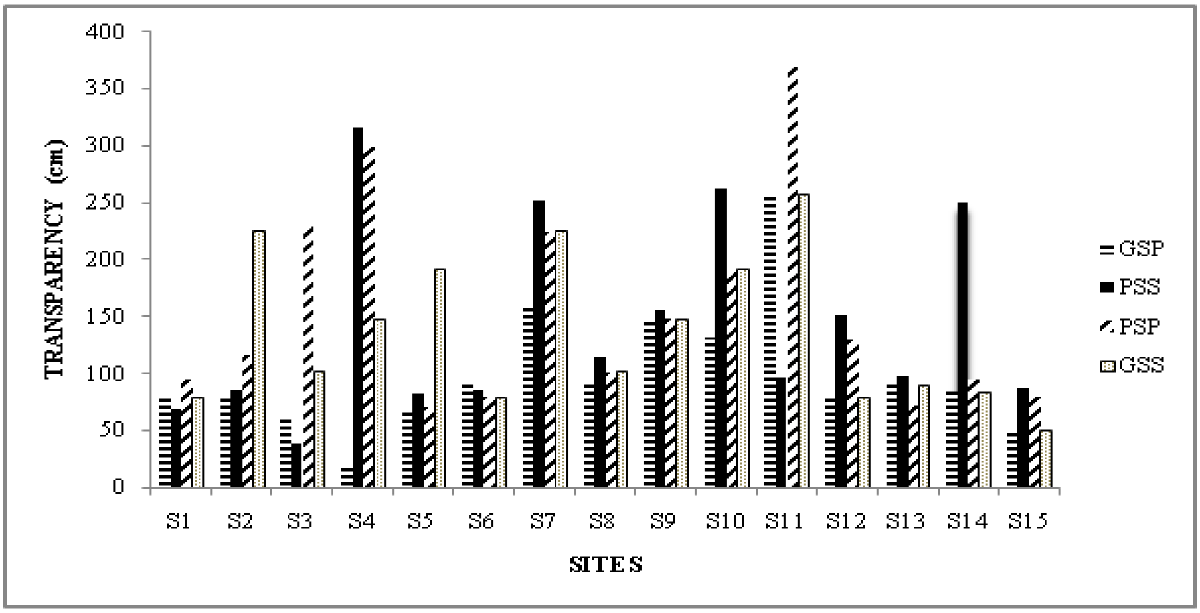

Fig. 7. Variation of transparency according to sampling sites and seasons.

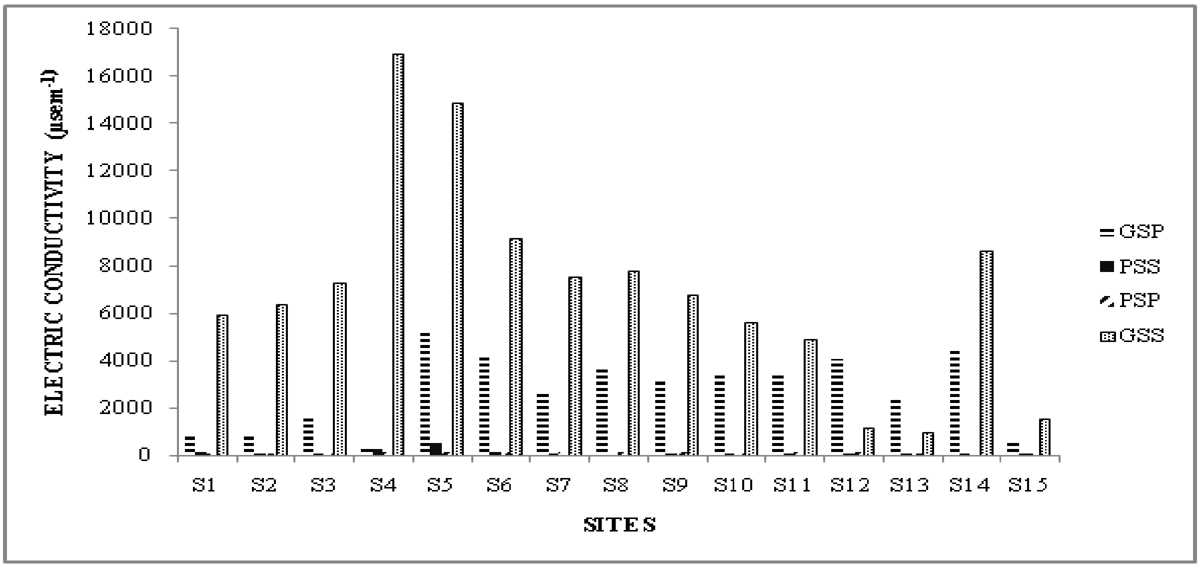

Fig. 8. Change in conductivity according to sampling sites and seasons.

Predox

Redox potential measures the reducing or oxidizing power of water. The data obtained showed the highest mean value during PSS (27.97 ± 13.003 mVolt), while during the PSP and GSP recorded values were -3.99 ± 13.23 and -15.05 ± 20.31, respectively. GSS indicated the lowest estimated mean of -24.45 ± 8.53 mVolt. Further seasonal dynamic was observed with respect to this parameter. PSS records positive values and therefore is very oxidizing unlike GSS, GSP and PSP which were almost characterized by negative values and therefore are reductive.

In natural waters, relative comparisons of the redox potential (Predox) evolution may be useful in monitoring changes in the aquatic system. When oxygen concentrations decrease, environment becomes more reductive, resulting in the reduction in redox potential (De Villers *et al.*, 2005). Inza and Yao (2015) observed a significant inverse correlation between the Predox and iron in the Ebrié lagoon in Ivory Coast, which would be linked to a process of complication and flocculation taking place in the bay under the effect of an increase in ionic strength induced by the pH elevation and salinity.

According to Figure 6, S15 site records the highest value of the Predox (52.8) during the GSP. However, groundwater supplies this point sufficiently (Chitou *et al.*, 2010); these ground waters would be heavily mineralized during this period.S8 registers the smallest value (-33.6). However, there is no significant difference from one site to another (ANOVA, Ficher, P = 0.8>0.05).

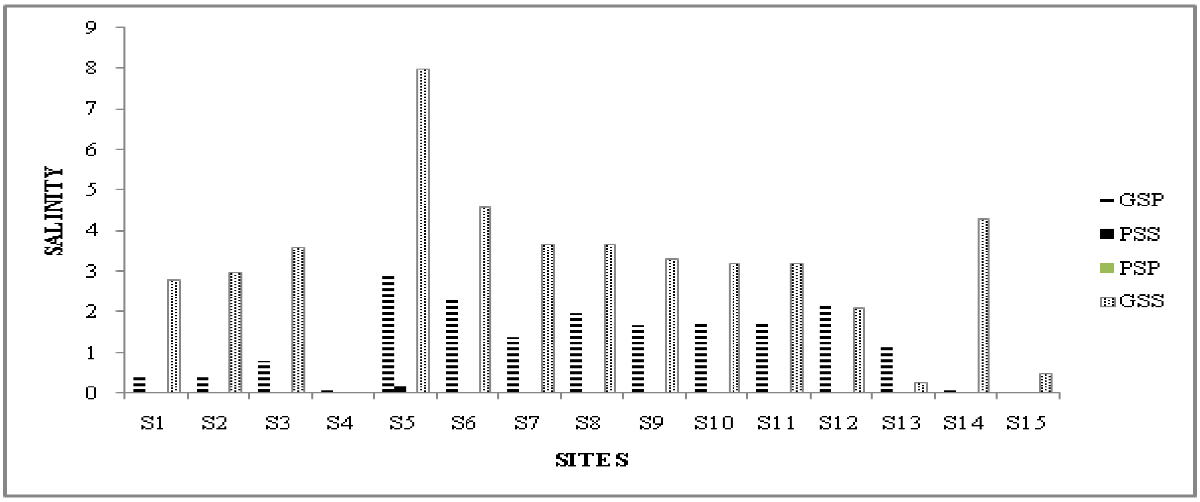

Fig. 9. Change in salinity according to sampling sites and seasons.

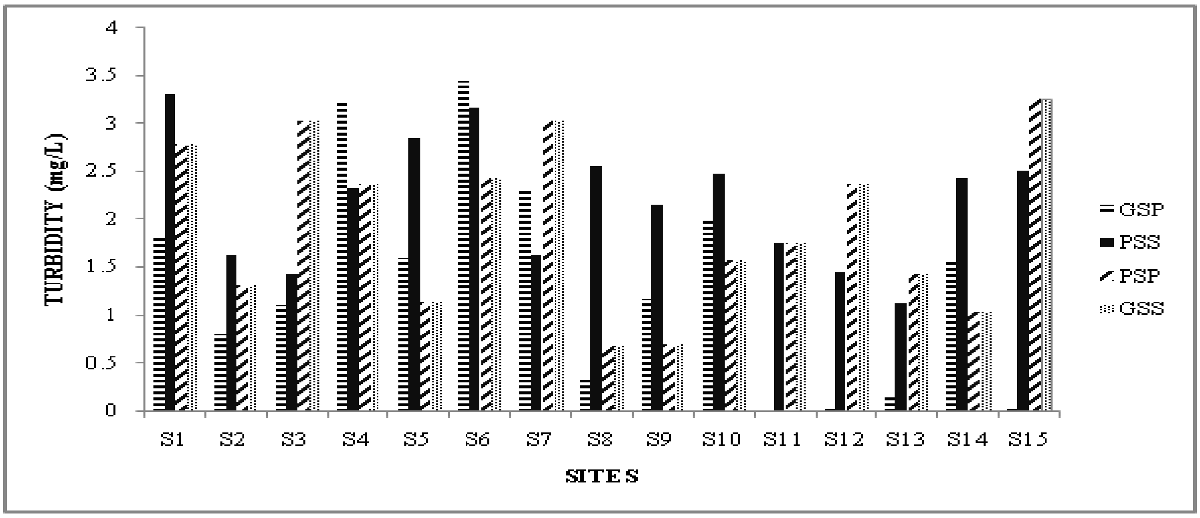

Fig. 10. Variation of turbidity according to sampling sites and seasons.

Transparency

Primary producers need light to ensure their autotrophic metabolism. The ability of light to penetrate the water column is therefore a vital phenomenon for the aquatic photosynthetic biomass production that depends upon it (Richer-Bond, 2013). In the Porto-Novo lagoon, it presented its highest value (370 cm) at S11 site during the PSP. S11 has the particularity of being the most transparent during GSP as well as GSS, when it shows highest values equalling to 257.00 cm in each of these seasons (Figure 7).

During the study period, S11 site had the highest mean (245.00 cm) and was significantly different from sites 4 and 7, (ANOVA, Ficher, P<0.01). Remaining stations are not significantly different from one another, and S15 shows the lowest mean value. S4 registered lowest values in the entire study period, ie 20 cm. GSP recorded the least transparent waters (99.53 ± 54.51 cm) while PSP presented the highest transparency (153.87 ± 88.06 cm).

PSS and GSS showed the intermediate mean values, respectively 142.73 ± 82.94 and 137 ± 63.75 cm. Low transparency is often associated with high turbidity and this condition may be symptomatic of high biological production in an aquatic environment.

High concentrations of suspended solids and turbidity in the dry season could be the result of water evaporation. Indeed, during this period, the high temperature of the water, as a consequence of the atmospheric heating would cause an accumulation of particles in suspension in the water.

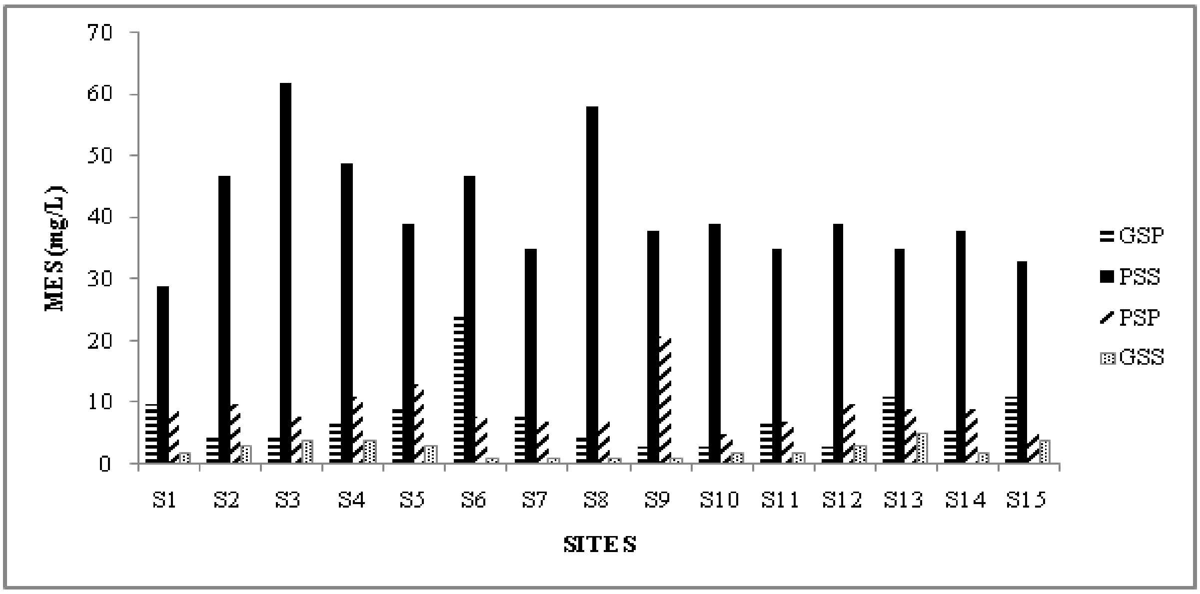

Fig. 11. Variation of MES in relation to sampling sites and seasons.

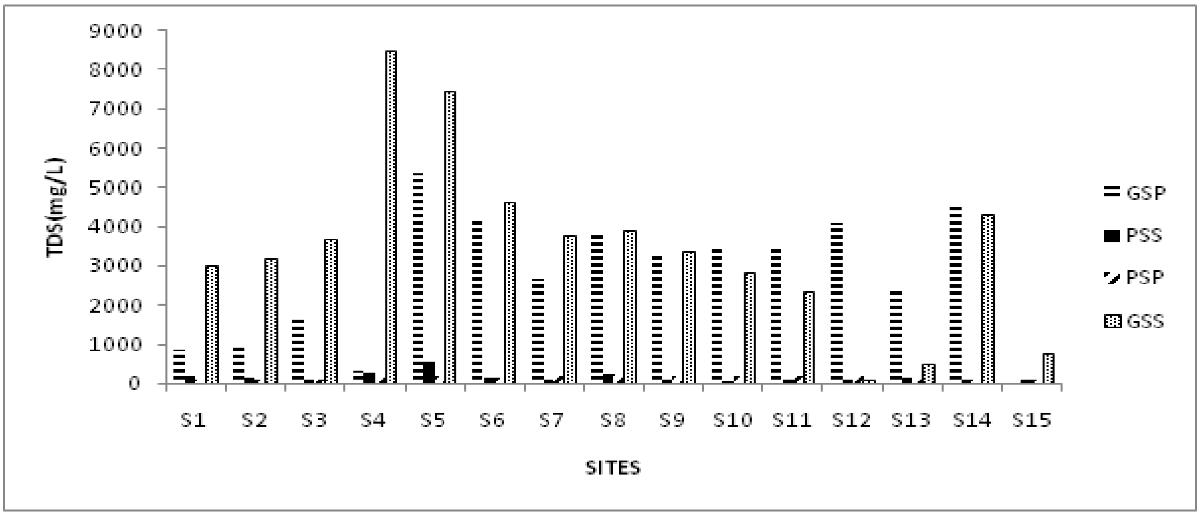

Fig. 12. Variation of TDS in relation to sampling sites and seasons.

This is in agreement with the conclusions of Dongo *et al.* (2013) in Abidjan, Côte d'Ivoire, which believes that the decrease in temperature would be responsible for the increase in viscosity and the reduction in the sedimentation rate of the receiving environment. Several other factors may also influence water transparency and turbidity, such as the water flow regime, the type of soil and surrounding vegetation cover, different natural events (erosion, rain, wind, snowmelt etc.) (Madjiki *et al.,* 2013) as well as various human activities (recreational tourism, resort, industrial, urban, etc.). These elements contribute mainly to the intake of suspended particles of inorganic nature (clay, silt).

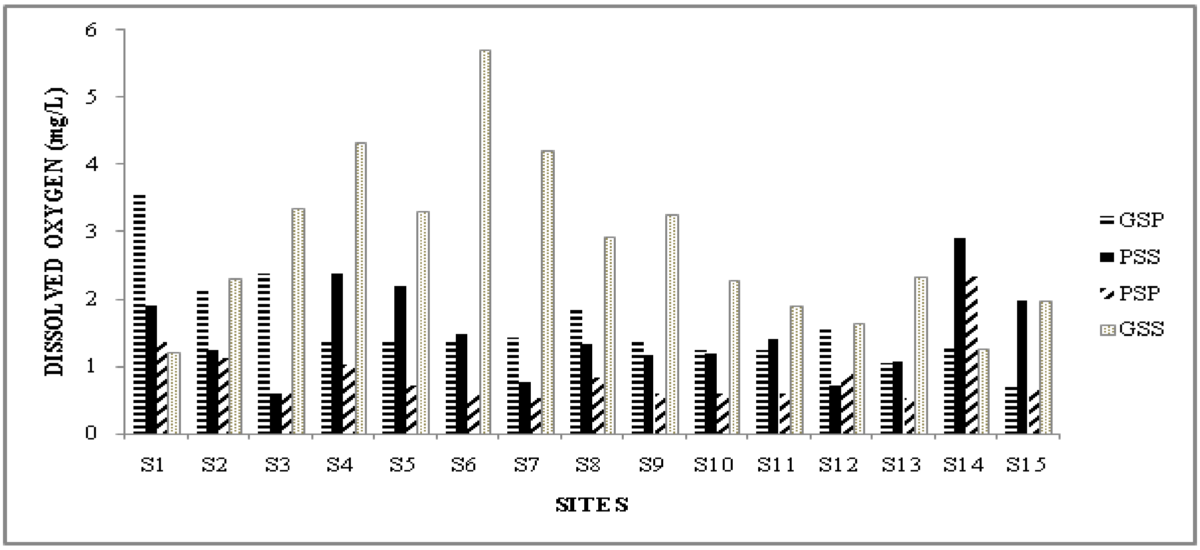

Fig. 13. Variation of dissolved oxygen as a function of sampling sites and seasons.

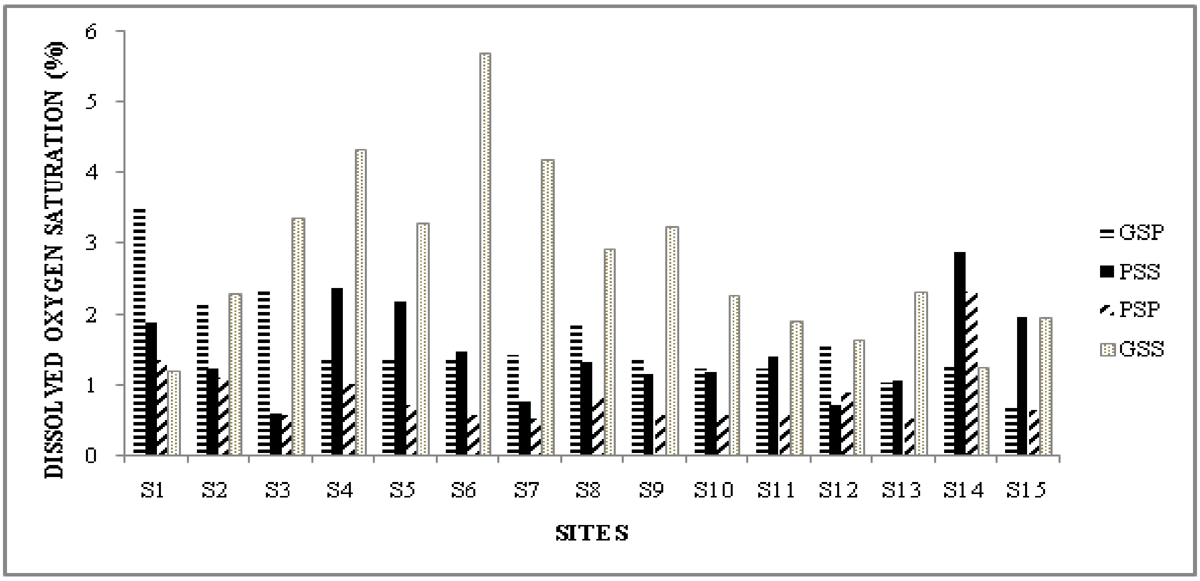

Fig. 14. Changes in dissolved oxygen saturation by sampling sites and seasons

Electric conductivity (EC)

According to Figure 8, the EC values show a fluctuation from one site to another as well as from a season to another. These values are indicating strong mineralization during GSS with an average of 7040 ± 4295.94 µsem^{-1} followed by GSP (2778 ± 1530.57 µsem^{-1}) while PSS and PSP have the lowest EC values with 135.08 ± 122.13 µsem^{-1} and 156 ± 34.01 µsem^{-1}, respectively. From one site to another, this variability is also remarkable.

The EC ranges between 345 µsem^{-1} at site S4 and 5360 µsem^{-1} at S5 in GSP, and between 110 µsem^{-1} at sites S1-2-3-15 and 200 µsem^{-1} at sites S5-8 in PSP. In GSS, values range from 980 µsem^{-1} at S13 to 16950 µsem^{-1} at site S4 and then from 22.6 µsem^{-1} at S8 to 539 µsem^{-1} at S5 in PSS. S5 showed the highest EC values in almost seasons with an average of 5242 ± 6837 µsem^{-1} per season and therefore seems to be the most heavily mineralized station on the lagoon area. In general, averages do not show significant differences between stations.

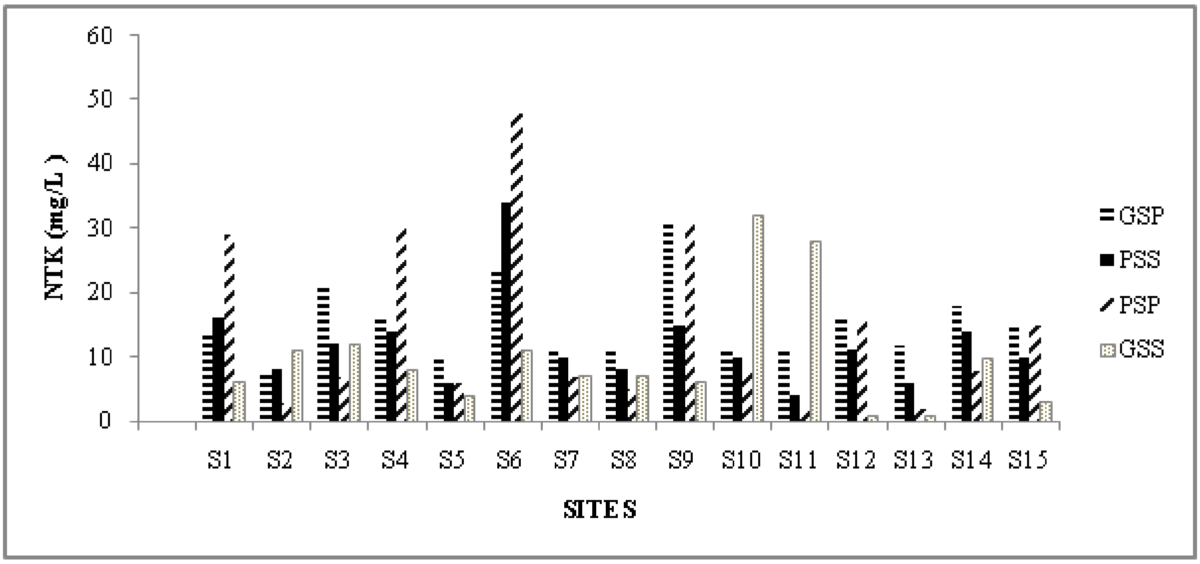

Fig. 15. Change in NTK content according to sampling sites and seasons.

This conductivity values recorded in this study are higher than those for freshwater values at 50 to 1500 µS.cm-1 according to Canadian standards (Richer-Bond, 2013), those recorded on Wetlands in Cameroon (938-1500 µS/cm) and the reports of Zandagba *et al.* (2016) on Lake Nokoué in Benin (70 µS/cm in February during the GSS), but lower than those measured (6000-8000 µS.cm-1) by Claon (2004) in the Aby lagoon in Ivory Coast and those (310-9000 µS.cm-1) from Affian *et al.* (2002) in the Ebrié lagoon in the same country.

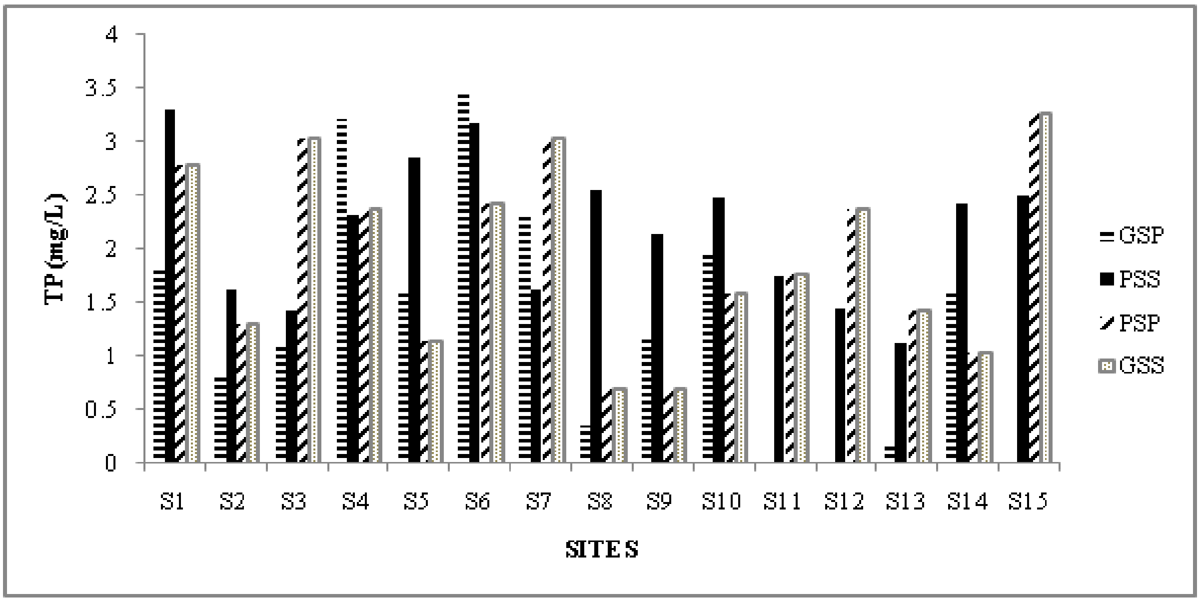

Fig. 16. Changes in total phosphorus content by sampling sites and seasons

The conductivity value observed in our study could be related to the strong influence of inland waters and the reduction of marine influence across Lake Nokoué. The increase of this GSS content could correspond to the results of a strong evaporation.

Chitou *et al.* (2010) recorded on the same lagoon that the EC is correlated with turbidity and TDS. TDS are thus species that increase the ionic power of the waters of the lagoon and consequently it's EC.

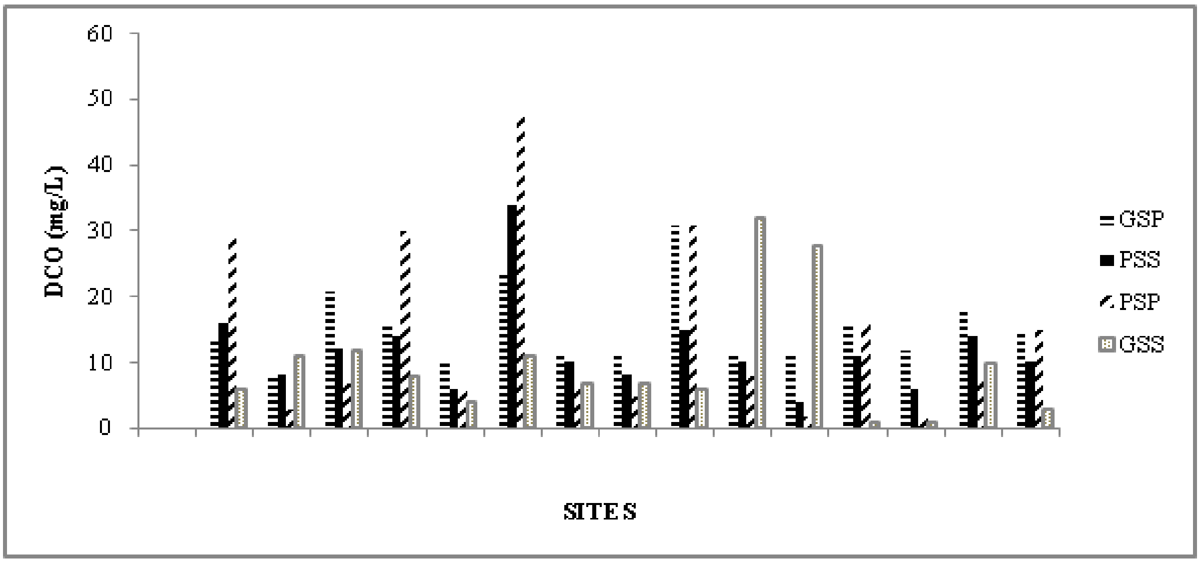

Fig. 17. Changes in COD content by sampling site and season

Salinity

Water salinity in the Porto-Novo lagoon is strongly influenced by that arising from lake Nokoué and the Ouémé River as well as by other environmental conditions. Thus, throughout the PSP and PSS, this salinity is zero but has an average value of 3.09 ± 1.90 during GSS followed by GSP (1.27 ± 0.89). Within S5, the highest salinity values were recorded in GSS and GSP with rates corresponding to 8 and 2.9, respectively. Averages at the different sites are not significantly different from one another, but from the biological point of view, differences between salinity levels from a site to another were sufficient to explain macrophytes distribution and the high mineralization observed at S5.This fluctuations linked to the seasons such as that of the lagoon of Fresco in Ivory Coast (Issola *et al.*, 2008). Increase in salinity during the dry season resulted from a significant evaporation and the arrival of marine waters (Kambiré *et al.*, 2014). Such arrival of marine waters increases salinity of Lake Nokoué which flows in the lagoon. These results are similar to those obtained by Chitou *et al.* (2010) on the same lagoon and those of Maslin and Bouvet (1986), andNiyonkuru (2007) on Lake Ahémé and Gnohossou (2006) in Lake Nokoué. Also, studies on other tropical lagoons as reported by Bazaïri *et al.* (2003) in the Merja-Zerga Lagoon in Morocco, Rosa and Bemvenui (2006) in the Patos Lagoon in Brazil and Kouadio *et al.* (2008) in the Lagoon Aby in Ivory Coast attest our findings. The particularly high salinity value at S5 should be the consequence of its proximity to Lake Nokoué.

Turbidity, Suspended particulate matter (MES) and Total Dissolved Solids (TDS)

Turbidity assesses the amount of suspended matters in water. According to Figure 10, the variability of the turbidity is high from one site to another. From 33 NTU within S6 during the GSP for the lowest overall value (2 NTU) at this season, turbidity reached 87 NTU at S3 in PSS the general lower value equalling to 44 NTU at S1 and 20 NTU at site S8 during the PSP with a bottom value of 9 NTU at site S15. This later site recorded paradoxically the highest turbidity consisting in 9 NTU during the GSS, whereas a zero (0.00) value at the S8 site in this season was measured. PSS corresponds to the period when water in the lagoon contained more suspended matters with an average of 58.20 ± 12.41 NTU (Table 3). GSS delivered the lowest mean value (3.73 ± 2.46 NTU) and intermediates averages for turbidity were obtained in PSP and GSP with 13.73 ± 2.46 NTU and 12.93 ± 7.10 NTU, respectively. No significant differences in turbidity averages were noted within a given site as well among them.

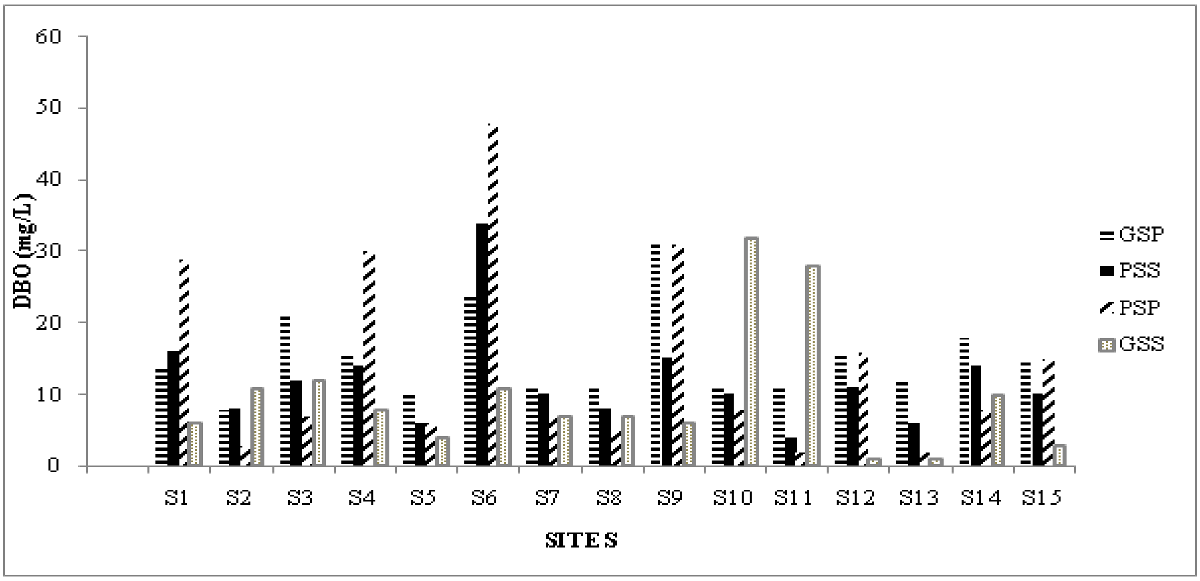

Fig. 18. Changes in BOD content by sampling site and season.

Results from the measurement of MES levels in the lagoon Porto-Novo during the whole study period as showed in Table 3 and Figure 11 are indicating particularly high values in PSS, the overall average being 41.53 ± 8.97 mg/L in that season and 2.53 ± 1.26 mg/L, the lowest in the study period during the GSS. Intermediate means (9.27 ± 3.75) and (7.8 ± 5.075 mg/L) were respectively recorded in PSP and GSP.

The highest MES value (62 mg/L) across the study period is obtained at S3 during the PSS with an overall lowest value of 29 in this season. Within GSS, MES values ranged from 1 mg/L (lowest in the study period) at S7, S8 and S9 and 5 mg at site S13. The rainy seasons presented values ranging from 5 mg/L in S15 to 21 mg/L in S9 for the small and 24 mg/L in S6 to 3 mg/L in S9and S10-12for the long season. Like turbidity, MES averages per site show that there is no significant difference from one site to another.

As for *Total Dissolved Solids (TDS),* values during the whole experimentation period show as turbidity variations among sites and seasons. GSP and GSS register the highest mean values with averages ranging from 2740,47±1588,69 mg/L to 3478,67±2204,58 mg/L, respectively, while PSP and PSS recorded the lowest values with means equalling respectively to 156±34,02 mg/L and 148,65±120,16 mg/L(Table 3 et Figure 12).

S4 during GSS launches the higher value of the whole study period (8470 mg/L) for the lower value (63 mg/L) in S15 during GSP. TDS means per site show no significant difference among sites. The average annual TDS concentrations of the surface waters in the Porto-Novo lagoon are lower than those of the Fresco lagoon (25.06 mg/L to 47.69 mg/L) measured by Issola *et al.* (2008), and those of the Ebrié lagoon (21.90-52.30 mg/L) measured by Guiral *et al.* (1993), which are even higher than those observed in Lake Nokoué in Benin and Ebrié in Ivory Coast with concentrations of 18.50 and 7.00 mg/L, respectively, according to Villanueva and Concepcion(2004). These differences, as reported by Kambiré *et al.* (2014), could be related either to hydro-dynamism or the characteristics of the study area, but also to the anthropogenic pressure around each of the hydrosystems analysed TDS are raised in GSS and are mainly the result of evapotranspiration. Indeed, Adandédjan (2012) observed that conductivity, TDS, salinity and pH in the surface water under investigation show very high values during the same season and equated it with the concentration of ions present in the water as a consequence of the reduction of its volume and of the greater tidal amplitudes at certain seasons. Kambiré *et al.* (2014) also found an identical evolution of TDS and conductivity on the Aby lagoon in Ivory Coast.

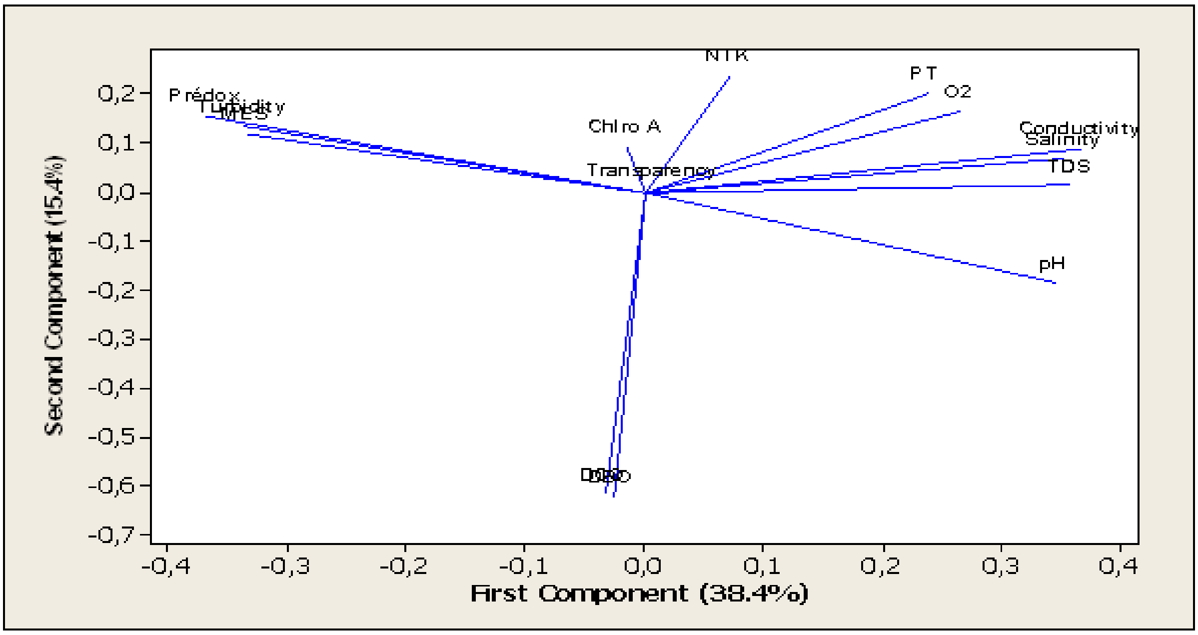

Fig. 19. Projection of the various parameters in the axis system CP1 and CP2.

The lowest seasonal average values are recorded in PSS. These low values according to Boni (2005) explain a reducing or anthropoid environment often leading to an anaerobic situation.

An important algal development follows in the lagoons and indeed limits the water transparency as signalized by Rougerie (1960). Site S3 has the highest TDS value in PSS.

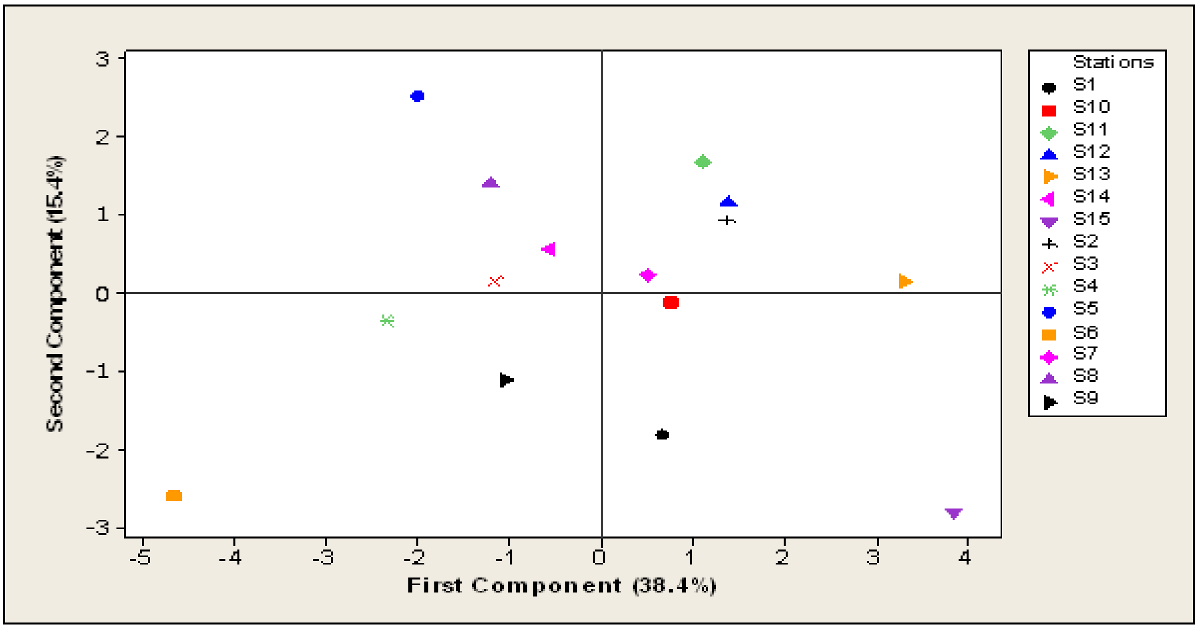

Fig. 20. Projection of stations in the CP1 and CP2 axis system.

It should be noted that this site is the one in contact with the tributary Ouémé River, and that the PSS corresponds to the hydrological season when a large quantity of water coming from the North of the country carries the suspended matters into the lagoon. This is in agreement with several studies conducted elsewhere (Makhoukh *et al.*, 2011).

As this result, the waters of the Lagoon Porto-Novo would be subjected to a double mineralization, natural and organic. In fact, according to Dufour (1982) and Konan *et al.* (2008), exchanges with the ocean, freshwater inputs by rivers, precipitations and evapotranspiration that undergo significant spatial and temporal variations cause natural mineralization originally. Organic mineralization, on the other hand, is linked to the decomposition of organic matters, which is influenced by environmental parameters such as pH, temperature, redox potential and dissolved oxygen.

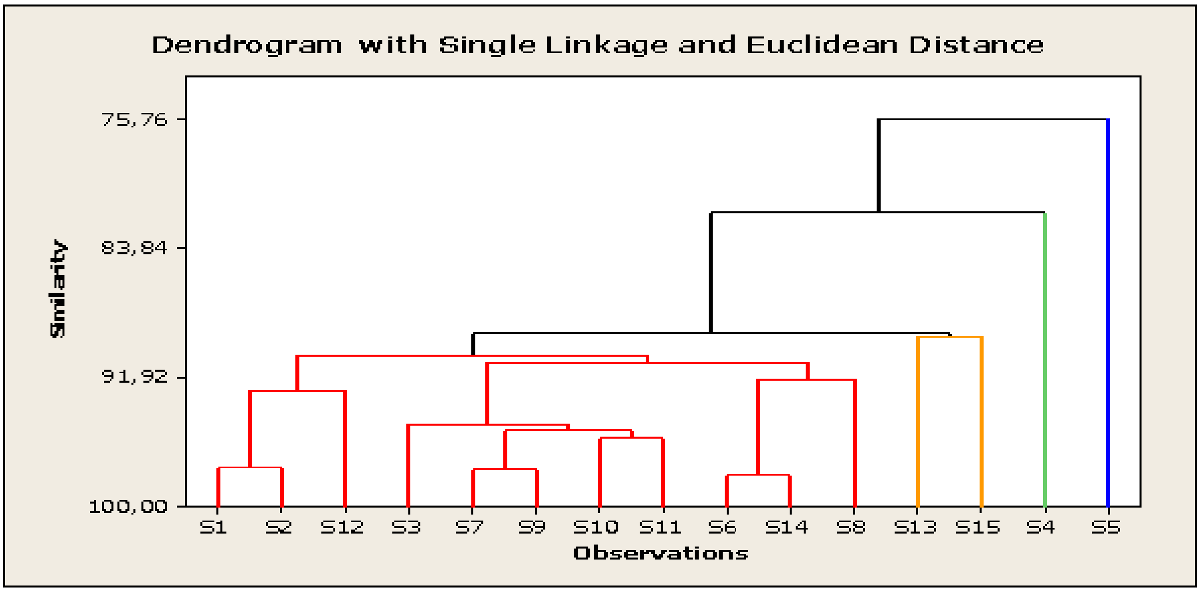

Fig. 21. Hierarchical classification of sites.

Dissolved oxygen (DO) and its saturation (DO sat)
Dissolved oxygen (Figure 13) highest concentrations in the lagoon are recorded in GSS with an average of 2.80 ± 1.21 whereas it is only 1.61 ± 0.65 mg/L in GSP compared to 1.49 ± 0.64 mg/L in PSS and 0.87 ± 0.46 mg/L within PSP. These DO contents also vary from site to site. Thus, it oscillates between 5.7 at S6 and 1.22 mg/L at S3 during GSS and between 0.72 at S15 site and 3.54 mg/L at S1site during GSP.

In PSS, it ranges from 0.6 at S3 site to 2.9 mg/L at S5 site. Concerning PSP, the OD content varies between 0.53 at S13 and 2.33 mg/L at S14. No significant differences were found between averages recorded at the different sites. Water oxygen regenerates from its contact with the atmospheric air; its dissolution being facilitated by water stirring. It has also a biological origin due to the chlorophyll function of periphyton plants, planktonic algae and aquatic phanerogams in hydrosystems (Arrignon, 1998; Onyema, 2013).

The increase in dissolved oxygen content during dry seasons is consistent with the observations of Seu-anoi *et al.* (2014) on the Grand-Lahou lagoon in Côte d'Ivoire. This increase can be explained by the activity of the biological processes of proliferated phytoplankton (Mouradi *et al.*, 2009). Results on nutrient contents such as NTK and PT during the dry seasons show highest values, leading to a multiplication of the phytoplankton and consequently a production of dioxygen by photosynthesis.

The lowest values have been identified in rainy seasons because of the dilution effect by the influential loads.

Voulion (2004) also showed a reduction in dissolved oxygen under water hyacinths stress. But, these invasive plants cover much the lagoon principally in the short dry season. It follows that macrophytes constitute a second source of reduction of dissolved oxygen in the water of the lagoon studied.

According to Kenneth (1974), at 20 °C the saturation of oxygen in the water of a river is 8.57 mg/L. But, for a water rich in organic matters, this value can decrease considerably, or even cancel out. It can be concluded that except temperature, the loading of organic matters contributes to the reduction of oxygen saturation in the water.

The negative correlation between oxygen content and chlorophyll a can be explained by the fact that a high level of chlorophyll a should result whenever other ever required environmental conditions are fulfilled (light, high CO_2, transparency of Water, etc.) in a high photosynthetic activity, thus a high level of DO at the beginning, and then, from a certain given time, the fact (e.g. high DO) should inhibit photosynthetic intensity by feed-back, and then, accelerate respiration and use of available DO and a drop in its rate in the environment. These are simple metabolic regulations at the biocenosis level in its relations with the biotope or the environment. Dissolved oxygen saturation according to Figure 14 shows a variation almost identical to that of the dissolved oxygen.

Total nitrogen (NTK) and Total phosphorus (TP).

Examination of the NTK temporal distribution within the lagoon (Table 3) reveals that the highest averages are recorded in GSS and PSS with 2.527 ± 1.05 mg/L and 1.92 ± 0.76 mg/L, respectively. The lowest value is noted during GSP and corresponds to 1.74 ± 1.25 mg/L, while in PSP, NTK is equivalent to 1.58 ± 0.58 mg/L. Figure 15 shows that S13 in GSS registered the highest value (4.9 mg/L) with a value of 0.98 mg/L in PSP, the lowest in this season when S2 in the same period records the lowest value among all sites (0.075 mg/L) whereas S3, S7 and S13 show high values at the same time (3.19 mg/L). This point S13 is not significantly different from the others except for S10 (ANOVA, Ficher, $P<0.05$). S6 shows the highest value for NTK (3 mg/L) in GSP, while the lowest (0.92 mg/L) is obtained at S11. During PSS, S10 presents the highest mean value (4.31 mg/L) and lowest (1.13 mg/L) is obtained at S9.

As for *Total phosphorus (TP),* PSS showed the highest mean value with 2.18 ± 0.64 mg/L, whereas GSP had the lowest of 1.32 ± 1.08 mg/L. GSS and PSP recorded the intermediate value, the same amount equivalent to 1.93 ± 0.87 mg/L. According to Figure 16, the highest TP content is recorded within GSP, ie 3.44 mg/L at S6 and lowest at the same season 0.01 mg/L at S11. S3 site displayed the lowest TP value during the PSS, ie 1.42 while the highest value at that time (3.3 mg/L) was found at S1. A similar observation was made in the PSP wherever site S15recorded the highest mean value (4.16) for a value of 0.69 mg/L, the smallest during that season at S8. The GSS showed at S8 the highest value of the entire campaign (6.47) while the S3 displays the smallest mean (3.99 mg/L). No significant differences were found between means recorded at the diverse sites. These concentrations (1.32 to 2.18 mg/L) are lower than those observed by Abubakar and Yakasai (2012) on the Salanta River in Nigeria with 3.78 to 19.50 mg/L, and Zandagba *et al.* (2016) on lake Nokoué with 3.45 mg/L but much higher than those of the Fresco lagoon in Ivory Coast with ranges from 0.07 to 0, 09 mg/L. S9 site in the rainy season records the highest value of PT and testifies on the one hand the pollution of this water with those nutrients at this point, and on the other hand the domestic origin of phosphorus. Indeed, according to Rodier *et al.* (1996) and Garnier *et al.* (2015), contamination of surface waters by PT may be induced by industrial (agro-food) and domestic discharges or through the leaching of cultivated land containing phosphate fertilizers and other pesticides. The nutrient concentrations of water bodies are strongly influenced by the nature of the sediments (Karikari *et al.* 2007). Wetzel (2001) and Labrecque *et al.* (2012) stated that the level of phosphorus released into water can be doubled when sediments are frequently disturbed. It follows that a good part of the phosphorus contained in the water column is provided from the release during the extraction of the lagoon sand by the numerous operators in this sector.

Soluble phosphorus from agriculture is of paramount importance because it is an immediately available source for biological phenomena, thus accelerating eutrophication of surface waters (Matagi, 1996).

Chemical oxygen demand (COD), Biological oxygen demand (BOD)

COD and BOD levels recorded at the different sites and during the different seasons show identical patterns. These parameters are higher in rainy than in dry seasons. From 33.93 ± 15.89 and 30.80 ± 31.59 mg/L, respectively in the large and small rainy seasons, averages COD of 22.21 ± 24.25 mg/L in GSS and 27.77 ± 16.64 mg/L during PSS were observed. S6 in PSP displayed the highest value while S11-13showed the lowest values in the same season. S9 with its 77.16 mg/L in GSP is the richest in COD, and the smallest (15.46 mg/L) in this season was recorded at S2. The COD mean value was 71.24 at S9 and 9.5 mg/L at S11 during PSS. Sites S12 and S13 in GSS are those with the lowest COD and BOD as showed in Figures 17 and 18.

The highest COD value (81.9 mg/L) was observed at S10 and S11. Apart from S15 (ANOVA, Fischer, $P<0.05$ and $P<0.01$), all others are not significantly different. High values for COD and BOD in the rainy season can only be explained by the enrichment of this aquatic environment in organic matters. Indeed, according to Amadi *et al.* (2006), the increase in BOD is attributed to the amount of organic matters and other pollutants present in the water. Chemical or biological degradation of organic matters in water depletes the lagoon in oxygen (Chitou *et al.* 2010). This is confirmed by the low values of dissolved oxygen observed during the rainy seasons in our study.

Chlorophyll a is correlated with NTK. The lagoon is therefore relatively loaded with nitrogenous nutrients and by the action of specialized bacteria, under sufficient oxygenation conditions, they will be oxidized. This process of oxidation is highly disturbed within the lagoon, due to the input of domestic and industrial wastewater, but also by the high phytoplankton load (Abidi *et al.*, 2014). PT is also correlated with COD, BOD, TDS, turbidity, and DO. The large biomass amounts and organic matters are biologically and/or chemically degraded in an aerobic environment, that resulting in high dissolved oxygen consumption.

A high organic matters load also reflects the exceeding of the lagoon's self-purifying capacity, which causes ecosystem malfunctioning. The high chlorophyll a values observed in the central zone of the lagoon should be related to the absence in this zone of macrophytes in contrast to the most anthropoid zones as pointed out by Mama (2010).

In general, means of almost parameters under investigation (pH, salinity, temperature, turbidity, TDS, MES, Predox, OD, % Sat) are significantly different between seasons according to Tukey-Kramer significance test performed with JMP software at 5% error ($p<0.001$ *) as indicated in Tables 3 and 4. Also, those of transparency, COD, BOD, NTK, PT, Chla were not found significantly different from one another ($p\geq0.05$). These results are confirmed by results presented in Tables 5 and 6 showing coefficients of variation among seasons and stations. Differences in physicochemical and hydromorphological properties of different stations or parts in the lagoon Porto-Novo are showing moreover all possible interactions among and within seasons and sites investigated on the lagoon Porto-Novo as presented in Figures 4-18.

Principal component analysis (PCA) (Figures 19, 20) and hierarchical cluster analysis (Figure 21) revealed a high variability in the physicochemical and hydrological properties of the waters of the Porto-Novo lagoon, depending on the sites considered. The simultaneous projection of the variables and the sites on the system of factorial axes allows classifying these sites according to their physicochemical characteristics. Thus, S6, S4 and S3 appear to be characterized by high organic loads, while high mineralization levels are characterizing S5, S8, S9 and S14 sites. S1, S2, S6, S7, S9, S11,S12,S14 presented high mean values for EC, TDS, DO, and PT as shown in Figure 19. Cluster analysis (single Euclidean) performs the classification delivered in PCA with regards to stations S13 and S15 (Figure 21). Hence, Figures 19 and 20 indicated the grouping of these sites together with all eight (8) aforementioned. S4 and S5 displayed single characteristics with relatively high Predox, Turbidity, MES and pH; the later parameter being higher at S4 than S5. This observation is in accordance with findings of Abidi *et al.* (2014) on the waters of the Tunis lagoon. On the Porto-Novo lagoon, analysis by these statistical tools shows that the first two components illuminated 53.3% of the total diversity observed. Particular attention to this variability is necessary as it should influence the diversity of phytoplankton and benthic populations, as well as fauna in the Porto-Novo lagoon.

Conclusion

The results of this work allow obtaining data on the water quality of the lagoon of Porto-Novo in Benin Republic. Porto-Novo lagoon is a shallow surface. The average flow rate of the Porto-Novo lagoon is significantly higher than that observed in most lakes in the neighbourhood of major municipalities. Furthermore, water turnover time of this lagoon makes it normally less vulnerable to eutrophication. Nevertheless, waters of this lagoon are in eutrophic state according to physicochemical parameters analyzed. The lagoon is polluted both by urban wastewater and particularly rain runoffs. They are the main sources of nutrient intake in the hydrosystem. In addition, there is anthropogenic pressure by the installation of "acadjas" and other wild dumps on and in the environment close to this water body. Consequences are macrophyte development including water hyacinths at various places or points on the lagoon making it difficult to be navigated.

Thus, appropriate and adequate solutions involving all stakeholders must be adopted in terms of the protection and safeguarding of this lagoon environment as it is very important and used for different purposes by human populations of Porto-Novo and the surrounding communes, even in the whole Benin country.However, the methods of investigation of morphological and hydrological parameters deserve to be revisited in order to better understand the difference of the results with those brought according to the physicochemical parameters.

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