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Research Article

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Spatio-temporal variation of the physicochemical parameters of waters from the hydrosystem Lake Togo-Lagoon of Aného (South-East of Togo)

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Abstract The objective of this study is to assess and identify the cause of the spatio-temporal distribution of the physicochemical parameters of waters from the hydrosystem Lake Togo-Lagoon of Aného in order to better plan its management. For this purpose, two sampling campaigns were carried out (March and October 2016) and 30 water samples per campaign were collected from 30 sites. The physicochemical parameters were analyzed using standard methods of the French Association of Standardization (AFNOR). The spatio-temporal variation of parameters was evaluated using maps which were performed by Ordinary Kriging Interpolation Method of ArcGIS 10.2.2 software. It appears that apart from the temperature, pH and dissolved oxygen which showed a low spatial variation, the other parameters strongly varied spatially. Thus, an increase of values from upstream to downstream was noted for conductivity, salinity, TDS, SO_4^{2-}, Cl^-, Ca, K, Mg and Na parameters during both seasons and for PO_4^{3-} and P during dry season. This gives them a predominantly marine origin due to the intrusion of marine waters polluted by phosphate effluent. On the other hand, NH_4^+ and NO_3^- parameters in both seasons and PO_4^{3-} and P during rainy season showed a decrease of their concentrations from upstream to downstream. This gives them an essentially continental source. The hydrosystem Lake Togo- Lagoon of Aného is both under continental and marine influence. The relative importance of each influence, according to seasons, determine the spatial distribution of physicochemical parameters.

Keywords Physicochemical parameter, water, spatial distribution, Lake Togo, Aného lagoon

Introduction

Industries located at the edge of aquatic ecosystems are a source of water pollution due to effluent discharges without prior treatment [1]. Apart from industrial discharges, domestic discharges and leaching of agricultural soils are also involved in the pollution of lagoon waters [2]. Thus, these aquatic ecosystems are those which undergo the greatest variations of abiotic factors [3]. It is known that anthropogenic activities are the main causes of the degradation of natural waters quality [4]. Coastal aquatic ecosystems are therefore subject to strong anthropogenic pressures that contribute to the release of various organic and inorganic pollutants leading to the degradation of their quality [5], [2]. This deterioration of water quality leads to the eutrophication phenomena whose consequences are proliferation of algae and aquatic plants, the highest risk of cyanobacteria (blue algae) occurrence, siltation of lakes, loss of the water transparency, biodiversity and interest species for fishing [6], [2]. This is mainly due to external inputs of nutrients (nitrogen, phosphorus) and polluted waters [7].

The hydrosystem Lake Togo- Lagoon of Aného is located in a phosphate mining area whose activities result in the rejection of various types of untreated wastes. Indeed, it is exposed to the mining effluents dumped into the sea at Kpémé through its embouchure at Aného. In addition, urban waste and the leaching of mining and agricultural soils throughout the watershed contribute to the deterioration of water quality and impede the proper functioning of this ecosystem. However, the study of the physicochemical parameters variability of this water body dates from the 80s [8]. The most recent study in this area dates from the year 2012 and only concerned Lake Zowla located in the North-East of the present lagoon complex [9]. However, regular monitoring of the physicochemical quality of this water body on which the productivity of aquatic species and the socio-economic well-being of local populations depend, is essential for its sustainable management. This study aims to assess the spatial distribution and to identify the possible sources of the physicochemical parameters of Lake Togo-Aného lagoon complex waters for better management planning.

2. Material and Methods

2.1. Study area

The hydrosystem Lake Togo- Lagoon of Aného occupies the largest area of a lagoon system in the South-Eastern Togo. It is located between latitudes 6° 17 '37" and 6° 14' 38" North and longitudes 1° 23'33" and 1° 37' 38" East. This lagoon system occupies a total area of 64 km^2 and is composed of Lake Togo which is the largest (46 km^2), lagoon of Togoville which is a 13 km length channel parallel to the coast with a width varying between 150 and 900 m, Lake Zowla with an area of 6.55 km^2 and lagoon of Aného which is a network of narrow channels [10]. The entire lagoon system communicates with the sea at Aného and with the Mono river further East through a channel called Gbaga. This water body is fed by two main tributaries which are Zio river with a length of 176 km and a flow rate of 9.9 m^3/s and the Haho river with a length of 140 km and a flow rate of 5.8 m^3/s [8]. The Lake Togo watershed enjoys a subequatorial or Guinean climate with two rainy seasons and two dry seasons. The most popular economic activities around the lagoon system are fishing, agriculture and livestock.

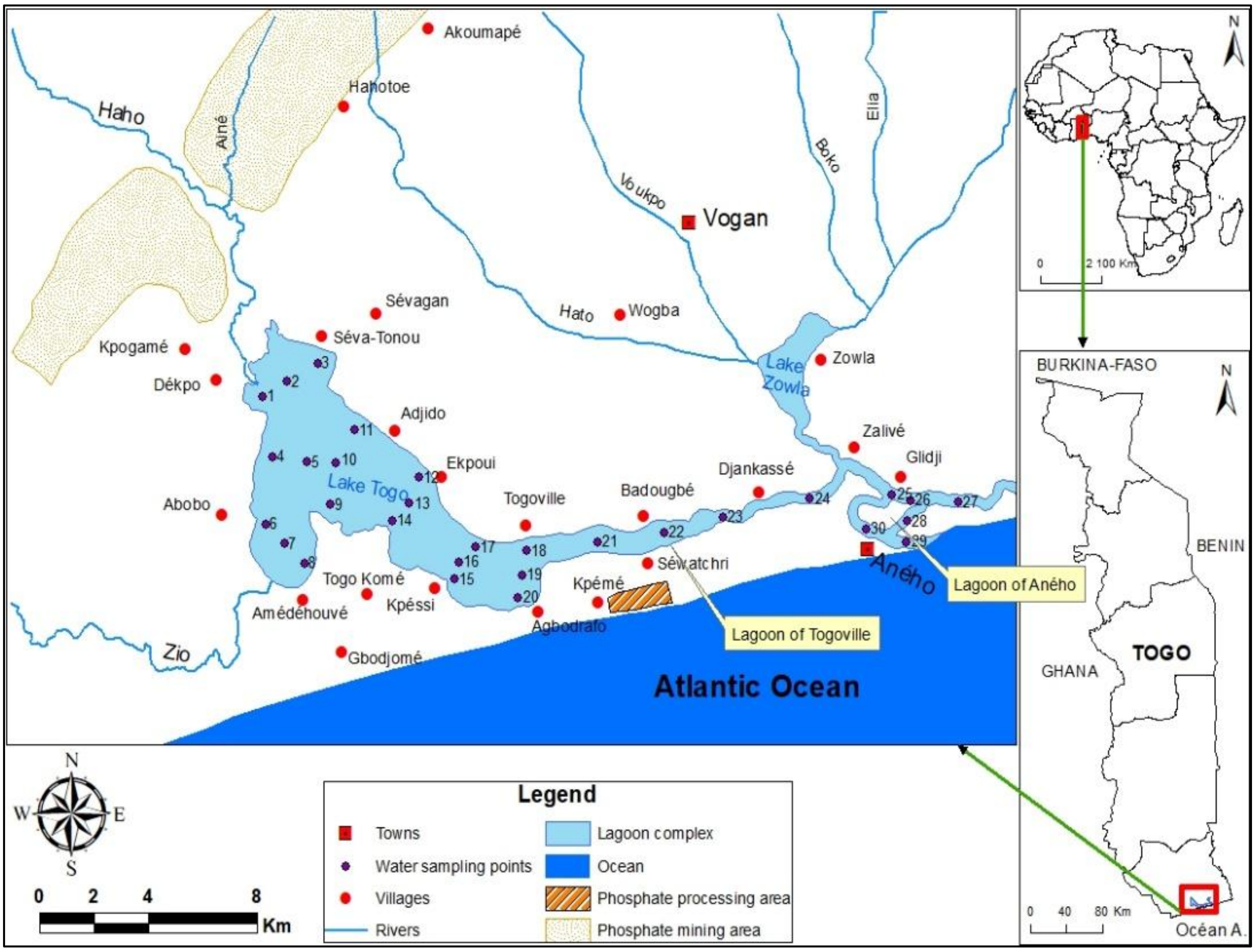

Figure 1: Location map of the study area showing the sampling points

2.2. Sampling and analysis methods

The water sampling was carried out in two seasons: dry season (March 2016) and rainy season (October 2016). Sampling were carried out according to French Association of Standardization (AFNOR) standards as described by Rodier *et al.* [11]. A total of 30 sites were randomly selected and 30 water samples per season were collected at 30 cm from the surface in 1.5 L polyethylene bottles washed with 10% nitric acid and then rinsed with distilled water. These bottles were later rinsed with water of the site before sampling. The samples were put in coolers and transported to the laboratory where they were kept in the refrigerator at 4 °C until the analyzes. *In situ* measurements included temperature, transparency, pH, electrical conductivity (EC), salinity (Sa) and dissolved oxygen (DO). The parameters analyzed in the laboratory are Total Dissolved Solids (TDS), Total Suspended Solids (TSS), turbidity, phosphorus and nitrogen nutrients (PO_4^{3-}, P, NH_4^+, NO_3^-) major anions (SO_4^{2-}, HCO_3^-, Cl^-) and major cations (Ca, K, Na, Mg). Before any measurement, the devices have been calibrated and the standards regularly measured to check the accuracy of the results [12], [11]. The table 1 summarizes the methods and materials used for the analyzes.

Table 1: Material and Methods for Analysis of Physicochemical Parameters

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

2.2.3. Statistical analysis and mapping

The spatio-temporal variation of physicochemical parameters was evaluated through distribution maps which were performed using Ordinary Kriging Interpolation Method of ArcGIS 10.2.2 software. Indeed, it is a geostatistical method which consists in estimating the values of the unsampled surfaces by the interpolation methods of the available values in order to produce prediction maps of spatial distribution of the studied parameters. The Ordinary Kriging Interpolation method is the most used in geostatistical analysis and has the particularity to produce a better prediction of data [13], [14], [15], [16], [17]. Cluster analysis (CA) was used to determine the degree of similarity among physicochemical parameters and among sites [18], [19]. The STATISTICA 6.1 software was used for this analysis.

3. Results

3.1. Physical parameters of waters

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

The Figure 2 (a1, a2) indicates that the hydrosystem is dominated by values ranging from 30.38 to 33.30 °C in dry season and from 26.50 to 28.28 °C in rainy season. However, the warmest waters were located in Lake Togo both in dry and rainy seasons. The lagoon of Aného records the lowest values in dry season while in rainy season, low values occurred in the North-West and South-East of Lake Togo. Thus, there was a slight decrease in temperature values from upstream to downstream during both seasons.

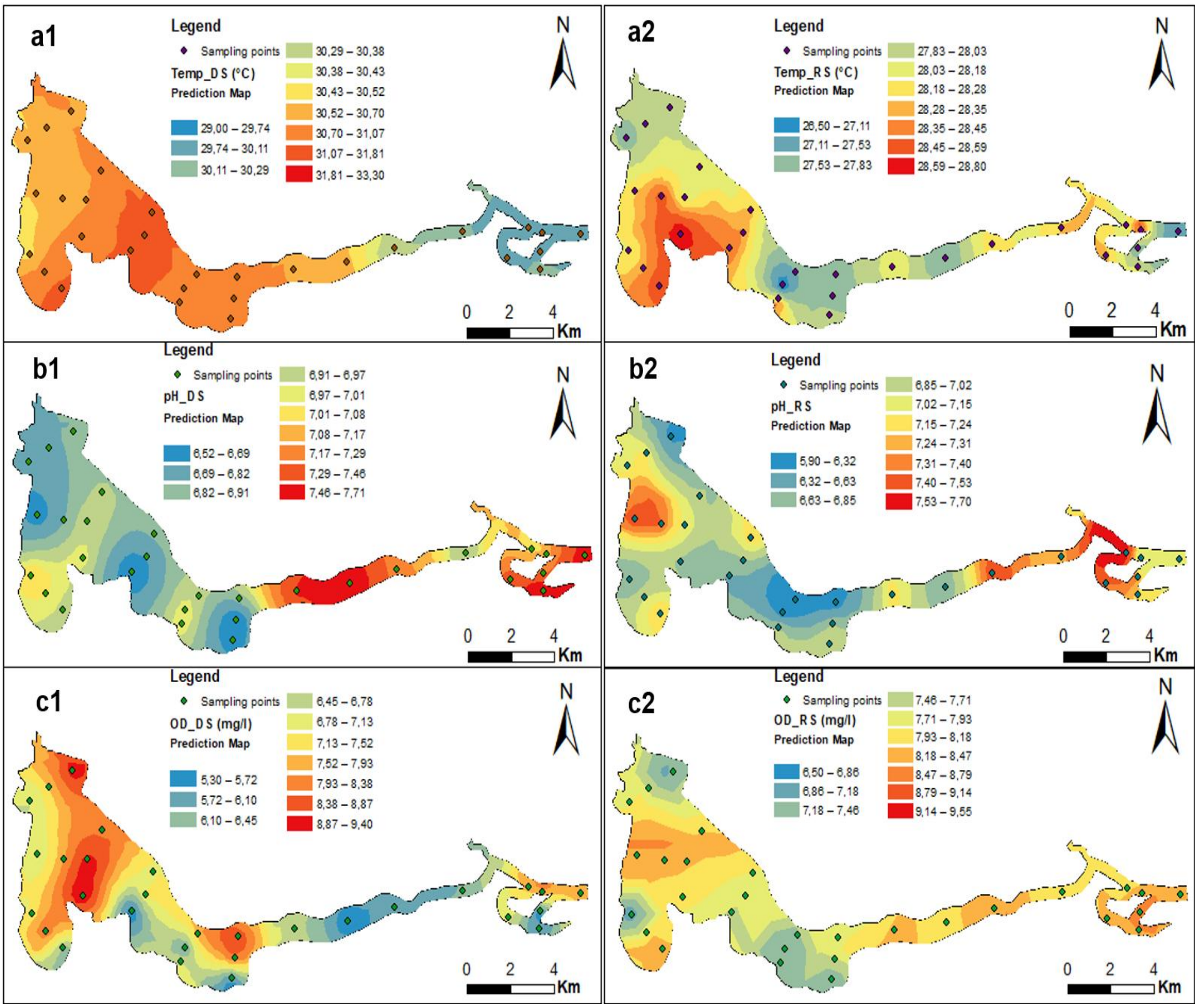

Figure 2: Spatial distribution map of temperature, pH and dissolved oxygen in dry (a1-c1) and rainy season (a2-c2)

The pH showed a slight increase in its values from the North-West to the South-East during both seasons (Figure (2b1, b2)). The water body was largely covered by values between 6.52 and 7.08 in dry season and between 5.90 and 7.24 in rainy season. These values were mainly located in Lake Togo. The highest values were recorded in lagoons of Togoville and Aného during both seasons with a peak noticed in the North-West of Lake Togo during the rainy season.

Figure 2 (c1, c2) indicate that in dry season, the hydrosystem was dominated by dissolved oxygen contents ranging from 6.78 to 9.40 mg/l with the highest concentrations measured in the center and North-West of the lake Togo while the lowest values occupy the South-East of Lake Togo, lagoons of Togoville and Aného. During the rainy season, the hydrosystem was dominated by contents varying between 7.71 and 9.55 mg/l. The lowest contents were measured in the North-West and South-East of Lake Togo.

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

The spatio-temporal distributions of conductivity (Figure 3 (a1, a2)), salinity (Figure 3 (b1, b2)) and TDS (Figure 3 (c1, c2)) were similar. These distributions presented a gradient characterized by an increase in values from upstream (North-West) to downstream (South-East) in both dry and rainy seasons. However, in the rainy season the appearance of increasingly high values of conductivity and TDS was noticed along the Northeastern bank of Lake Togo.

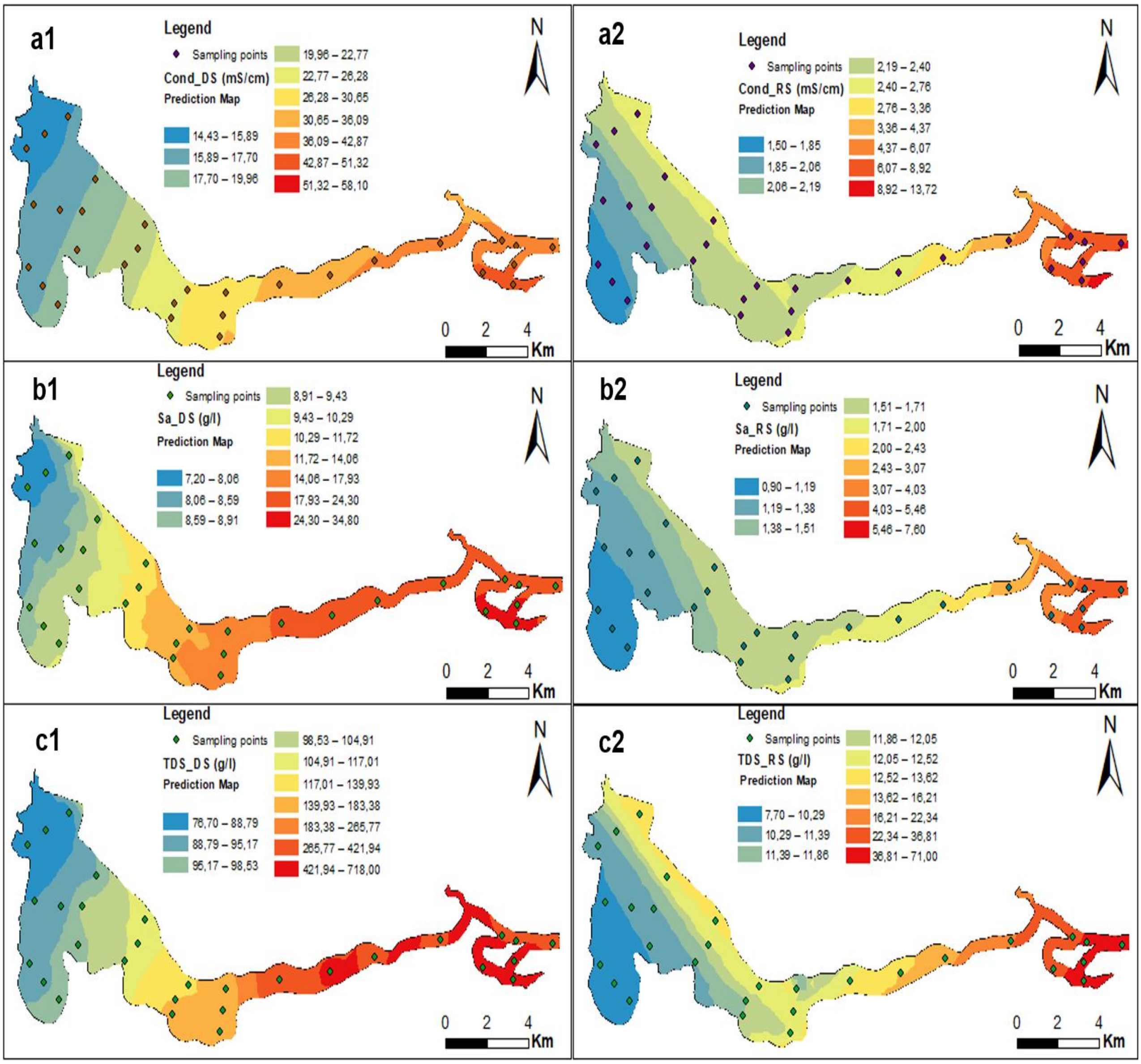

Figure 3: Spatial distribution map of conductivity, salinity and TDS values in dry (a1-c1) and rainy season (a2-c2)

The conductivity, salinity and TDS values which dominate the hydrosystem in dry season were the highest and respectively ranged from 22.77 to 58.10 µS/cm, from 9.43 to 34.80 g/l and from 104, 91 to 718 g/l. On the other hand, in rainy season, it is rather the lowest values which dominated the water body and were respectively varying from 1.50 to 2.40 µS/cm, from 0.90 to 1.71 g/l and from 7.70 to 12.05 g/l. These values were all located in Lake Togo.

3.1.3. Transparency (Tran), Turbidity (Turb) and Total Suspended Solid (TSS)

The Figures 4 (a1, a2) show the spatio-temporal distributions of water transparency. The values between 69.05 and 100% and between 32.30 and 77.32% dominated the hydrosystem respectively in dry season and in rainy season. These values showed a decrease from upstream (North-West) to downstream (South-East) during both seasons. However, there was a slight increase at the sites S28 to S30 in lagoon of Aného during the rainy season. It appears that the most transparent waters were located in Lake Togo.

Turbidity (Figure 4 (b1, b2)) and total suspended solids (Figure 4 (c1, c2)) exhibited similar spatial distributions in both dry and rainy seasons. Turbidity values which dominated the lagoon complex ranged from 8.60 to 15.17 NTU in dry season and from 35.47 to 51.50 NTU in rainy season.

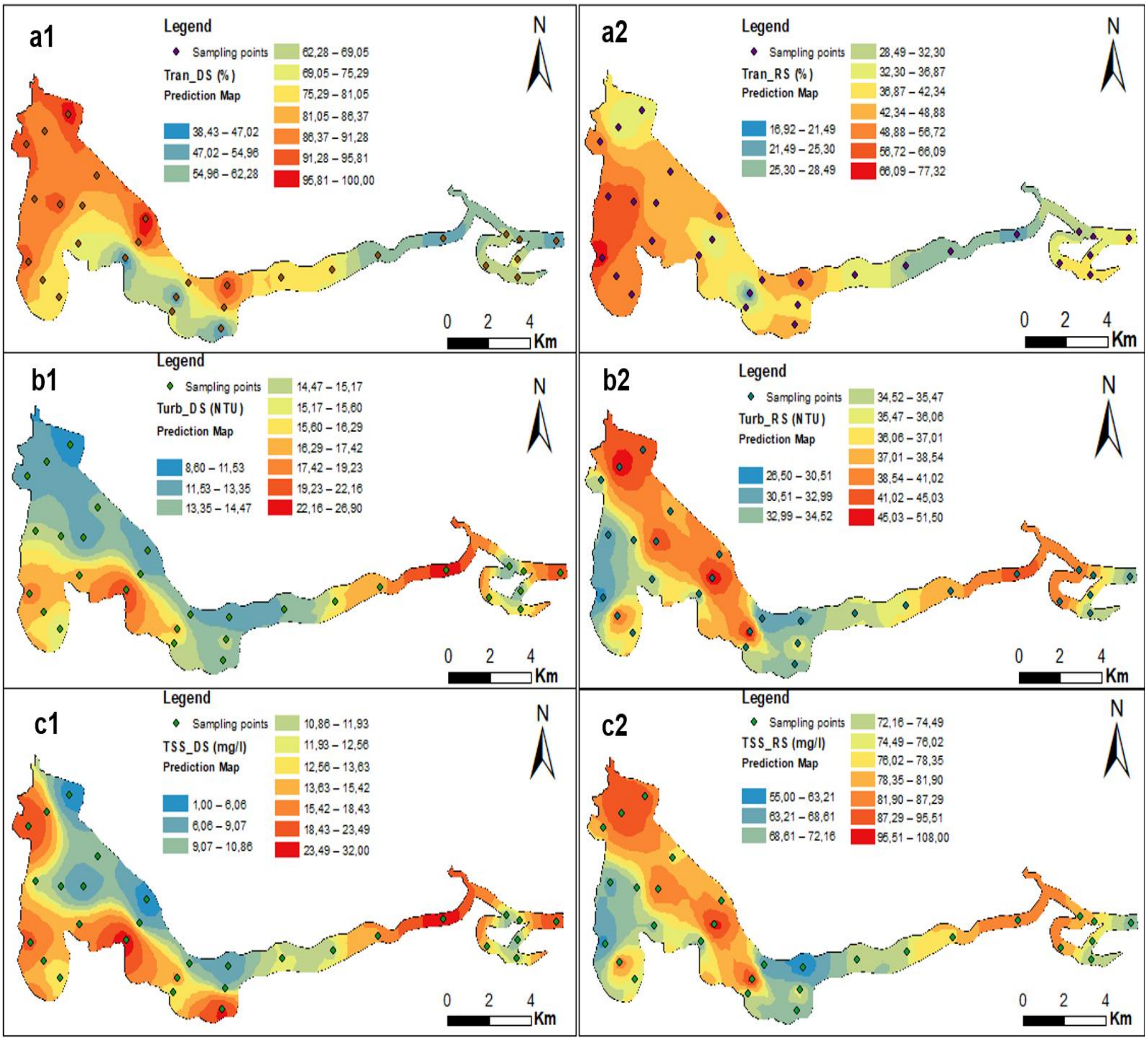

Figure 4: Spatial distribution map of Transparency, Turbidity and TSS values in dry (a1-c1) and rainy season (a2-c2)

For Total Suspended Solid (TSS), these values were respectively between 11.93 and 32 mg/l and between 74.49 and 108 mg/l. During the dry season, the most turbid waters and the most concentrated waters in TSS were located in South-West of Lake Togo, from the site S22 in lagoon of Togoville to the confluent at Zalivé and in lagoon of Aného. The rainy season was characterized by an inversion of this orientation in Lake Togo following the SW-NE direction, while the spatial distribution in the lagoons of Togoville and Aného were the same to the dry season's one.

3.2. Chemical parameters of waters

3.2.1. Phosphorus (PO_4^{3-}, P) and nitrogen (NO_3^-, NH_4^+) nutrients

The spatio-temporal distributions of phosphate (PO_4^{3-}) (Figure 5 (a1, a2)) and total phosphorus (P) (Figure 5 (b1, b2)) are similar. In fact, PO_4^{3-} and P contents increased from upstream (North-West) to downstream (South-East) in dry season. In rainy season, there was an increase in concentrations in Lake Togo following the NW-SE direction and the persistence of high concentrations around the confluent receiving waters from Lake Zowla at Zalivé. During the dry season, the hydrosystem is mostly covered by lower contents of PO_4^{3-} and P which were between 0.61 and 0.73 mg/l and between 0.20 and 0.25 mg/l, respectively. They were all located in Lake Togo. During the rainy season, the hydrosystem was dominated by the highest PO_4^{3-} and P concentrations which were respectively between 0.53 and 0.94 mg/l and between 0.19 and 0.30 mg/l.

The spatio-temporal distributions of ammonium (Figure 5 (c1, c2)) and nitrate (Figure 5 (d1, d2)) showed a decrease in concentrations from upstream (North-West) to downstream (South-East) whatever the season is. Thus, the highest contents of ammonium (NH_4^+) and nitrate (NO_3^-) were recorded in the Northwestern areas of Lake Togo during both seasons. The water body is dominated by the highest NH_4^+ concentrations and ranged from 0.07 to 0.19 mg/l in dry season and from 0.3 to 0.53 mg/l in rainy season. The contents of NO_3^- which dominated the hydrosystem in dry season were the lowest, ranging from 0.44 to 0.84 mg/l, while in rainy season they were the highest and ranged from 2.05 to 3.99 mg/l.

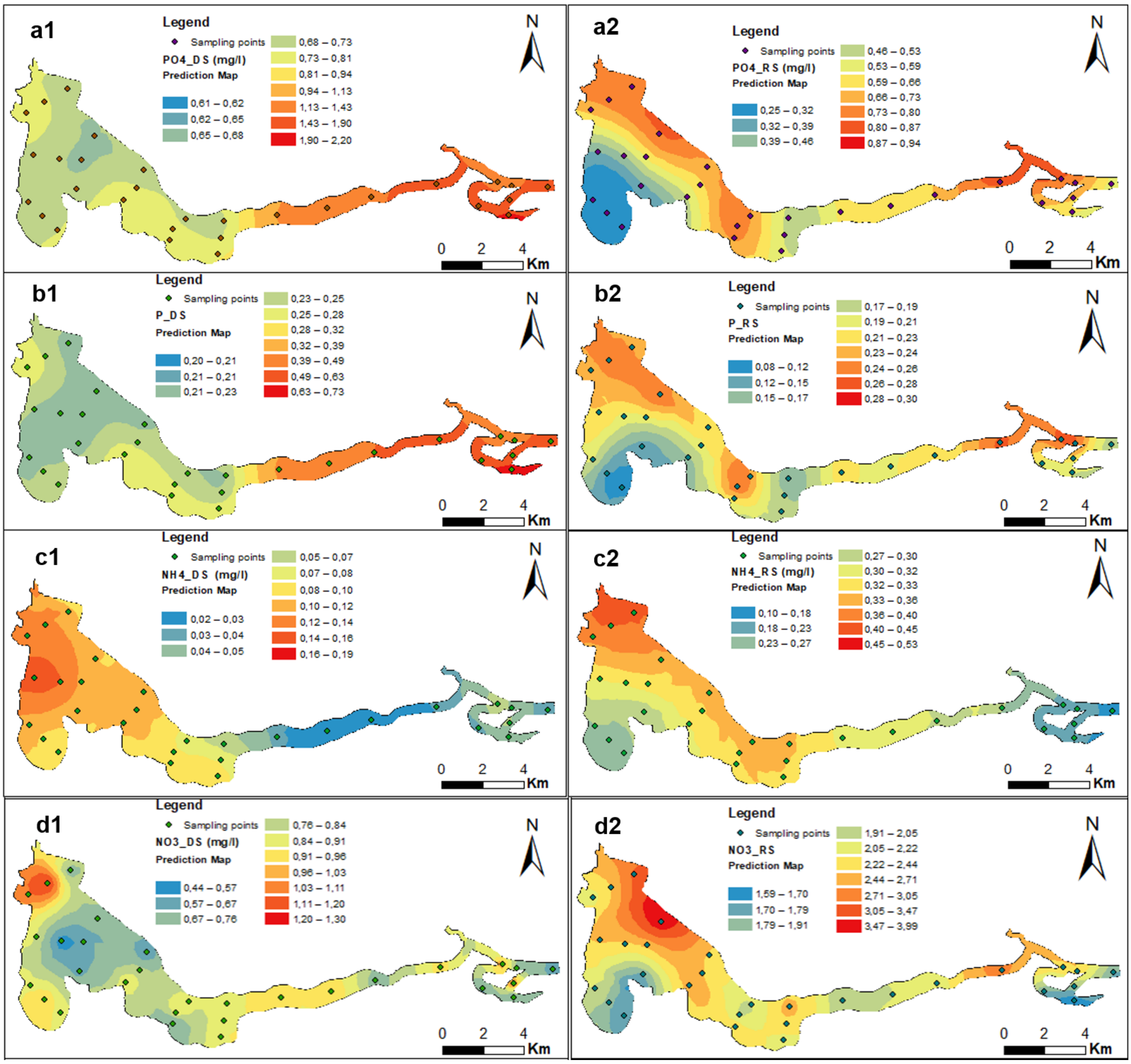

Figure 5: Spatial distribution map of phosphates, total phosphorus, ammonium and nitrate in dry (a1-d1) and rainy season (a2-d2)

3.2.2. Major anions (SO_4^{2-}, Cl^- and HCO_3^-)

The spatio-temporal distribution of sulfates (SO_4^{2-}) (Figure 6 (a1, a2)) and chlorides (Cl^-) (Figure 6 (b1, b2)) were similar in both seasons. An increase in concentrations from upstream (North-West) to downstream (South-East) is noted during both seasons. In dry season, the hydrosystem was dominated by the highest contents of SO_4^{2-} and Cl^- which were respectively between 325.99 and 2580 mg/l and between 4929.28 and 19263.24 mg/l. In rainy season, these contents were respectively between 59.52 and 706.70 mg/l and between 837.79 and

4206.91 mg/l. The lowest concentrations were recorded in the upstream areas of the water body during both seasons.

The spatio-temporal distributions of bicarbonates (Figure 6 (c1, c2)) were fairly homogeneous and showed bidirectional orientation. Indeed, during dry season, the lowest contents were located in the Southeastern part of Lake Togo, from where they increased towards upstream (North-West) and downstream (South-East). The highest concentrations occupied most part of the water body and ranged from 210.79 to 384.30 mg/l. In rainy season, the lowest levels were located in the Southwestern part of Lake Togo and most part of the water body was covered by the highest concentrations, which range from 105.69 to 133.22 mg/l.

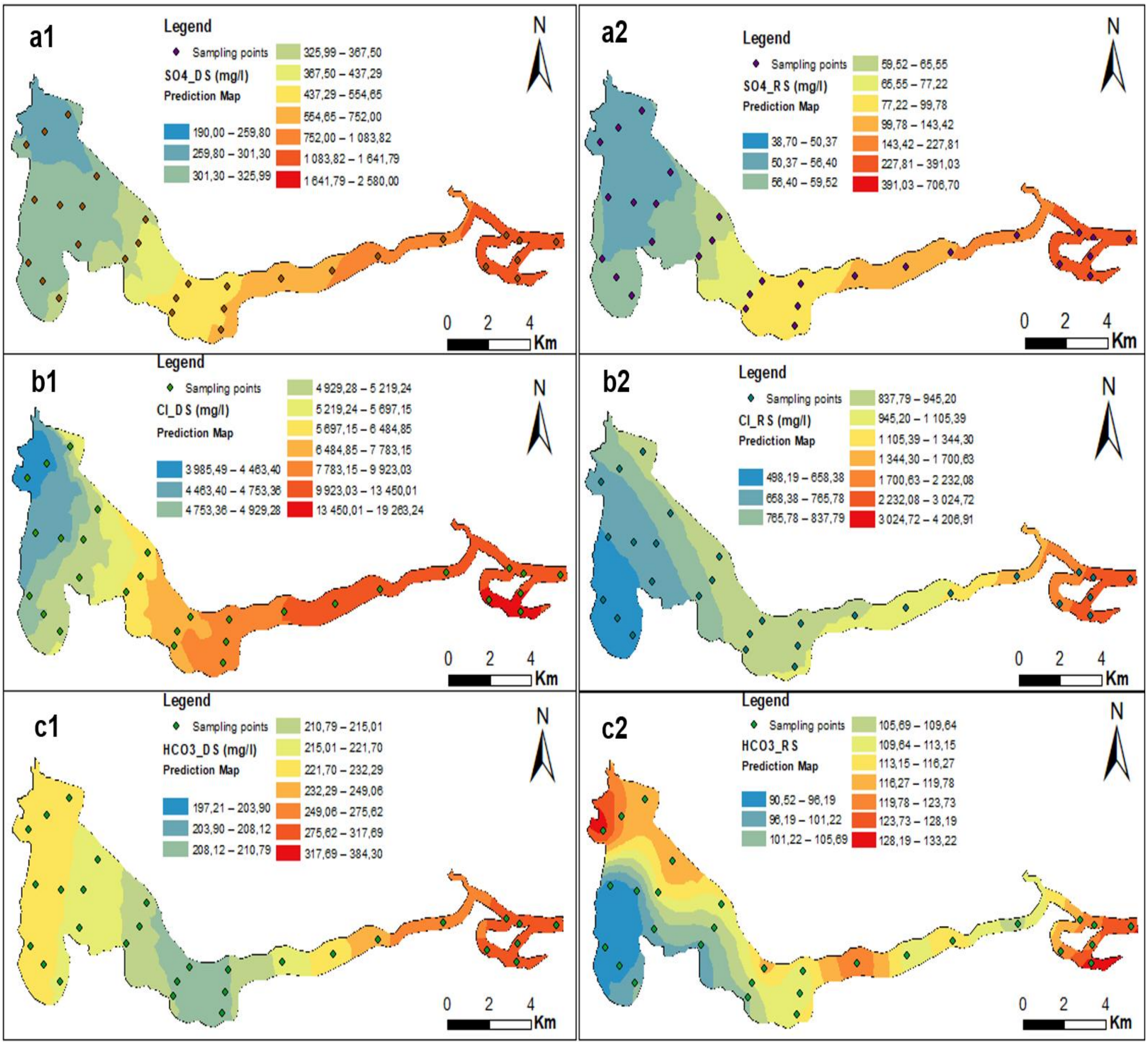

Figure 6: Spatial distribution map of sulphates, chlorides and bicarbonates in dry (a1-c1) and rainy season (a2-c2)

3.2.3. Major cations (Ca, K, Mg and Na)

The spatio-temporal distribution maps of major cations (Figure 7) show an increase in concentrations from upstream (North-West) to downstream (South-East) during both seasons. The highest major cations contents were recorded in the lagoon of Aného while the lowest were generally located in upstream areas in the North-West and South-West of Lake Togo during both seasons. However, a gradual increase of concentrations was noted particularly for K and Na along the Northeastern shore of Lake Togo.

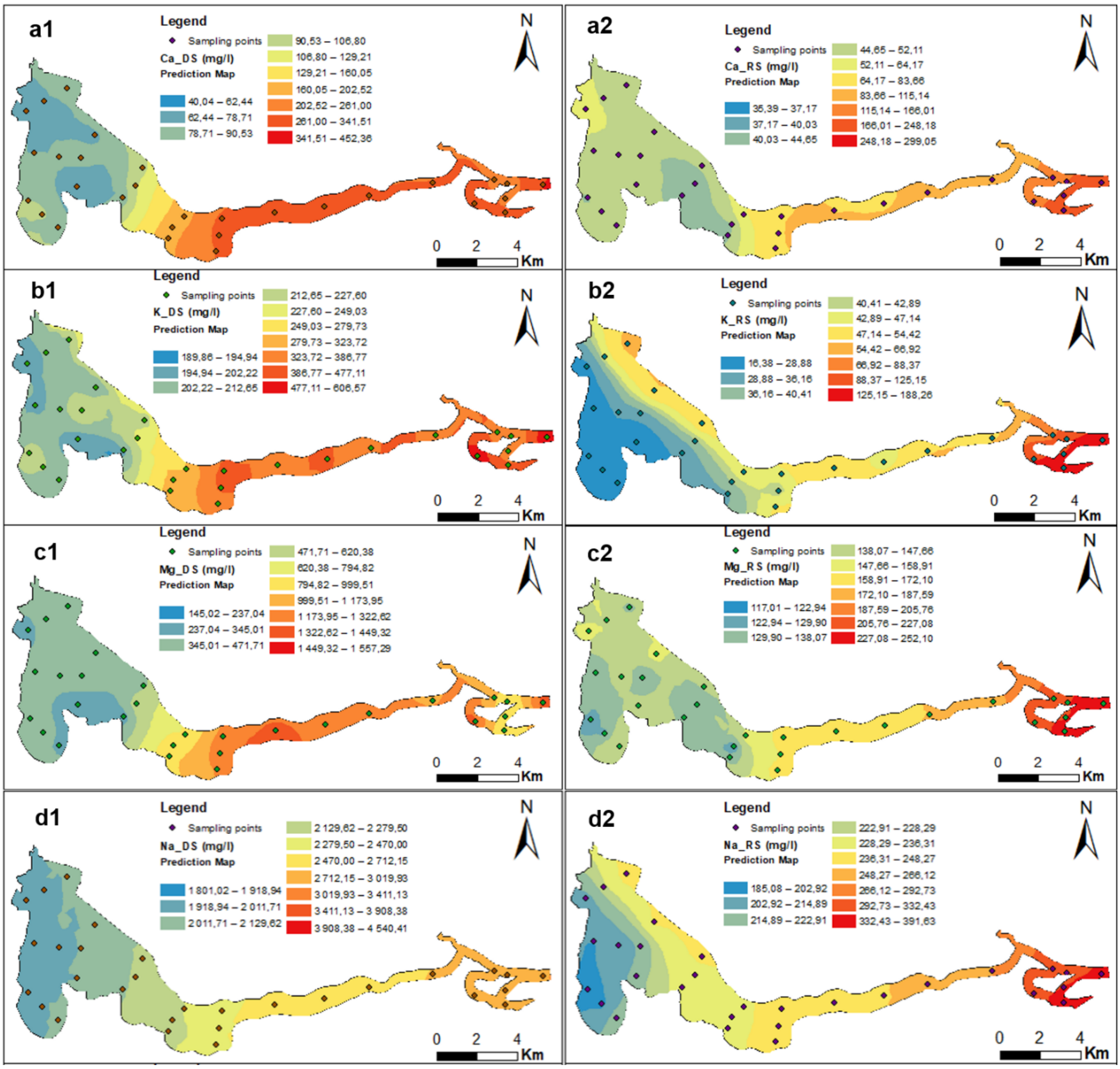

Figure 7: Spatial distribution map of Ca, K, Mg and Na in dry (a1-d1) and rainy season (a2-d2)

3.2.4. Hierarchical Cluster Analysis (HCA)

3.2.4.1. Classification of physicochemical parameters

The dendrograms of physicochemical parameters for the dry and rainy season are shown in Figure 8 (a, b). The analysis of these dendrograms reveals that the physicochemical parameters were divided into two large groups during both seasons. The first groups (G1 and G1') are composed of organic parameters having continental origin and which contribute to the organic and anthropic pollution of the waters during both seasons. The second groups (G2 and G2') include mineralization parameters and dissolved salts having marine origin which represent the indicators of marine pollution and influence on the hydrosystem.

During the dry season, the group G1 is formed by two subgroups. The first subgroup (G1a) which is composed of T°C, NO_3^-, Turb and MES represents the effect of temperature on the decomposition process of organic matters. The second subgroup (G1b) is composed of the parameters Tran, DO and NH_4^+. This indicates that transparency and dissolved oxygen depend on each other and are related to the organic pollution represented by NH_4^+. It appears from these two subgroups that the maximum mineralization of organic matters occurs during low-water periods when the water body is not very active. The second group (G2), also, have two subgroups. The first (G2a) is composed of pH, Na, CE, Sa, Cl^-, TDS, PO_4^{3-}, P, SO_4^{2-} and HCO_3^-. It indicates that, in the dry season, the pH of the water is controlled by the dissolved salts brought by marine waters. The highest degree of similarity obtained between pH and Na shows that the pH of these waters is more controlled by sodium contents. In addition, a high degree of similarity is noted between EC, Sa, TDS and Cl^-. Thus, the degree of mineralization and the salinity are related to the Cl^- content of waters. The source of PO_4^{3-} and P in dry season is anthropogenic and mainly comes from the phosphate effluent. These two phosphorus compounds having a strong similarity with SO_4^{2-}, it appears that SO_4^{2-} in dry season are also anthropogenic and would come from the combustion of heavy fuels and hydrocarbons in the phosphate plant of Kpémé. The isolation of the bicarbonates in this subgroup shows that apart from the marine origin, they would also come from the continent. The second subgroup (G2b) is composed of Ca, K and Mg that would have a common geological source.

During the rainy season, group G1' is subdivided into two subgroups. The first (G1'a) comprises T°C, Tran, pH and DO with a high degree of similarity between T°C and Tran, then between DO and pH. The second subgroup (G1'b) is composed of Turb, MES, PO_4^{3-}, P, NH_4^+ and NO_3^- with a high degree of similarity between Turb and MES, PO_4^{3-} and P as well as between NH_4^+ and NO_3^-. The subgroup G1'b shows that TSS are mainly composed of particulate organic matter and phosphate particles. The presence of PO_4^{3-} and P in this subgroup shows that they are from the continent during the rainy season. The second group (G2') also has two subgroups. The first subgroup (G2'a) includes CE, TDS, Sa, Cl, K, Na, SO_4^{2-}, Ca and Mg which are mineralization parameters mainly brought by marine waters. A high degree of similarity was noted between the parameters CE, TDS, Sa, Cl, K, Na. The isolation of HCO_3^- in the second subgroup (G2'b) confirms its double sources which are marine and continental whatever the season is.

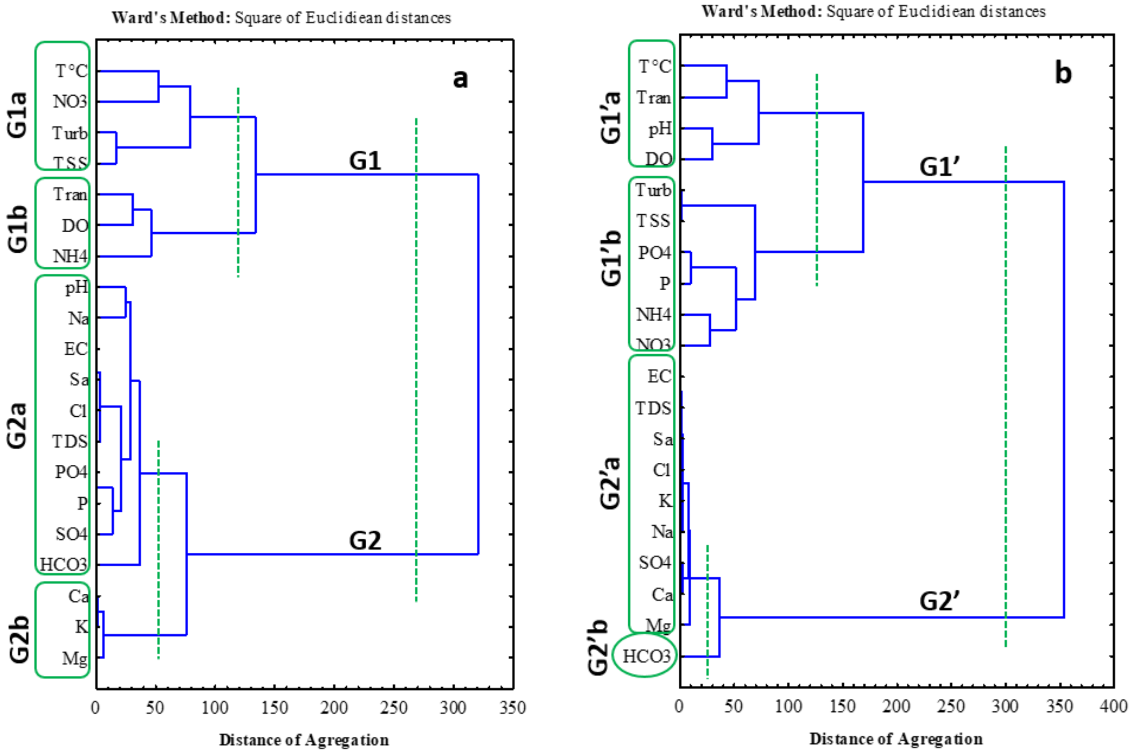

Figure 8: Dendrogram of Physicochemical parameters in dry (a) and rainy (b) season

3.2.4.2. Classification of sites

The Figure 9 shows the dendrograms from the hierarchical cluster analysis of the sites based on the physicochemical characteristics of waters in dry and rainy season. These results show that in dry season, the hydrosystem Lake Togo- Lagoon of Aného can be subdivided into three zones. The first zone (Z1) is composed of sites S1 to S13 located in the Northeastern parts of Lake Togo and whose salinity was between 7.2 and 10.9 g/l. It is the most influenced by continental waters and can be named "continental zone". The second zone (Z2) includes sites S14 to S23, S25 and S26 and covers the South-East of Lake Togo and the lagoon of Togoville with salinities ranging between 10.5 and 20.9 g/l. It is an intermediate zone that is relatively influenced by continental and marine waters. The third zone (Z3) is composed of sites S24 and S27 to S30 mainly located in the lagoon of Aného with salinities ranging from 17.5 to 34.8 g/l. This area is strongly influenced by marine waters and can be named "marine zone". During the rainy season, the hydrosystem was essentially divided into two zones. The first zone (Z1') groups sites S1 to S25 and covers Lake Togo and lagoon of Togoville. The salinities were between 0.9 and 3 g/l. It is an area which is strongly influenced by continental waters during the rainy season. The second zone (Z2') is composed of sites S26 to S30 all located in the lagoon of Aného. These waters remained brackish in rainy season with salinities which varied between 5 and 7.6 g/l. This zone is strongly influenced by marine waters.

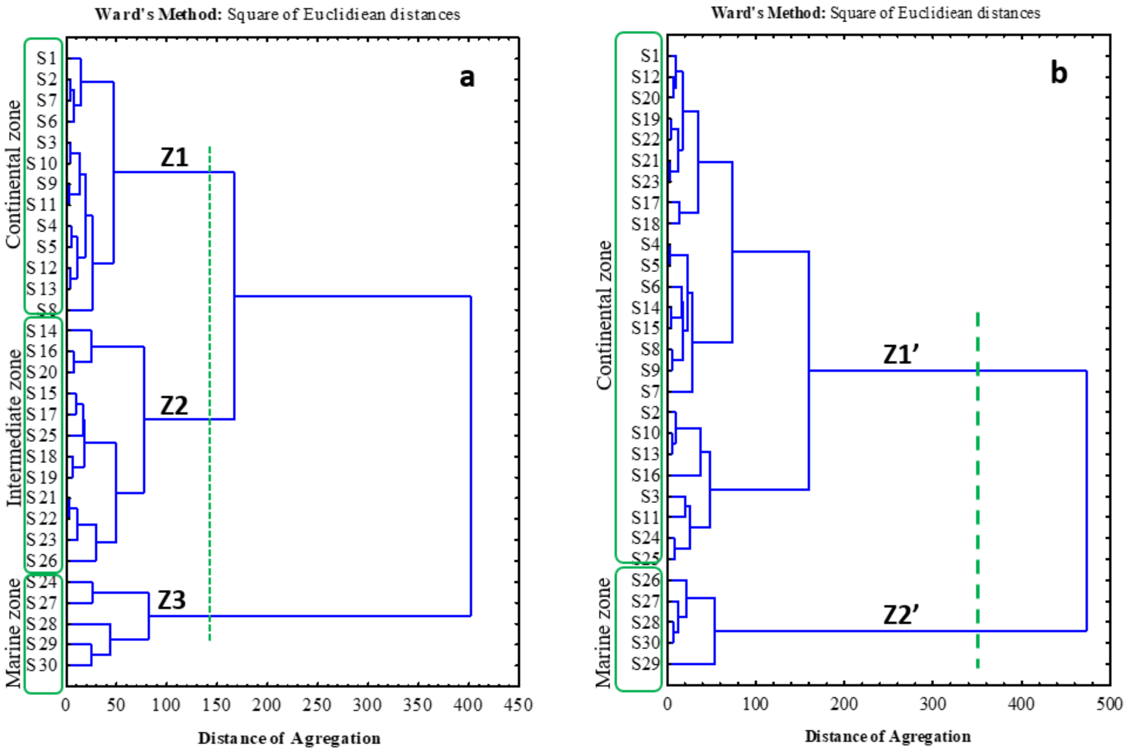

Figure 9: Dendrogram of sites in dry seasons (a) and in rainy season (b)

4. Discussion

Temperature is considered to be one of the most important ecological factors in aquatic ecosystems [20], [21]. Indeed, it influences the physicochemical, biochemical and growth of aquatic living organisms [22], [11]. The low spatial variation of temperature in both seasons would be due to a shallow depth (1.94 ± 0.75 m in October 2016) of the hydrosystem whose waters are easily traversed by solar rays associated with regular mechanical mixing. However, the slight decrease in temperature at downstream is related to the influence of marine waters which are colder [8], [23], [24]. Low spatial variations in temperature have also been obtained in some tropical lagoons [23], [25], [26], [27].

In aquatic ecosystems, pH influences the behavior and distribution of chemical elements [20]. It is one of the important factors in hydrosystems. The slight increase in pH from upstream to downstream can be explained by an intrusion of oceanic waters which are basic. Indeed, the variation of the pH depends on the salinity's one, therefore on the relative importance of the contributions of continental acidic waters and oceanic basic waters [8], [23], [24]. The acidity of the continental waters is due to the addition of humic acids from soil leaching [28]. The basic character of marine waters is due to their high content of dissolved salts [29], [2]. This low spatial variation in pH is consistent with results obtained by other authors in tropical lagoons [8], [23], [9], [27], [30].

Dissolved oxygen of surface waters come mainly from the atmosphere and photosynthetic activity of aquatic chlorophyllous plants [31], [32]. The fairly high levels recorded in northwestern and central Lake Togo during the dry season (Figure 2 (c1)) can be explained by the shallowness of the water body, its position which is more exposed to ocean winds and its larger surface area in contact with the atmosphere. This exposes it to a permanent mechanical mixing which favors the fixation of the atmospheric oxygen according to the contact surface [32]. The low contents recorded in the lagoon of Togoville can be explained by the narrowness of the water body, the low mixing during the low-water period and the use of branches as a fish trap which contributes to the enrichment of organic matters whose degradation consumes oxygen [23], [33]. During the rainy season, the high flow rate of flood waters and the action of the monsoon winds cause a regular mixing of the whole lagoon complex and a homogenization of the dissolved oxygen contents which are relatively higher.

The values of conductivity, salinity and TDS show a high spatial variation with an increase of the values from upstream to downstream during both seasons. This can be explained by the intrusion of very mineralized and salty marine waters, especially during low water and high tides. These waters progressively go up to the North-West of Lake Togo by diffusion favored by the mechanical mixing of the waters [8], [23], [9], [2]. In addition, the entry of less mineralized and unsalted continental waters during floods considerably reduces the marine influence and homogenizes the levels in Lake Togo and Lagoon of Togoville. However, the increasing gradient from upstream to downstream persists in rainy season because of the low marine influence observed in the lagoon of Aného which remained brackish. These spatial variations have also been observed by other authors in tropical estuarine lagoons [8], [2], [27]. During the rainy season, the appearance of increasing values of conductivity and TDS along the northeastern shore of Lake Togo could be explained by the effect of a supply of dissolved salts by Haho river. Millet [8] explains that this area would be the privileged seat of drain flow during floods because it is the most exposed to the wind and characterized by the most important mechanical water mixing of the Lake. However, these inputs generate concentrations very below those from marine waters.

The spatio-temporal distribution of turbidity values (Figure 4 (b1, b2)) and TSS contents (Figure 4 (c1, c2)) show that, during the dry season, TSS enters in the hydrosystem mainly through the Zio river and secondarily by the Haho river. This can be explained by the fact that the Zio river has a permanent course with a higher flow rate unlike the Haho river which has an intermittent course with a lower flow rate [8], [34]. In addition, this water body receives, in both seasons, particles transported by the waters coming from Lake Zowla. This explains the persistence of high levels around the confluent at Zalivé, which receives the waters of Lake Zowla. The high values recorded in the northeastern region of Lake Togo during the rainy season (Figure 4 (b2, c2)) could be explained by an increase in the contents of TSS by the phosphate particles transported by the Haho river. In addition, according to Millet [8], this zone would be the privileged seat of drain flow during floods. Thus, the areas receiving the waters of the tributaries have high turbidity and TSS contents depending on the importance of their inputs and are inversely proportional to the water transparency (Figure 4). This is in accordance with the results obtained by Konan *et al.* [23] in the Grand-Lahou lagoon in Côte d'Ivoire and Zandagba *et al.* [27] in Lake Nokoué in Benin.

The spatio-temporal variations in phosphate and total phosphorus contents show that they are mainly from external source. During the dry season, the increase in their concentrations from upstream to downstream highlights their marine source. In fact, the phosphate effluents discharged into the sea at Kpémé are transported by the coastal drift to Aného. From there, they are introduced into the hydrosystem by diffusion and mechanical mixing of water and reach the northwestern areas of Lake Togo especially during low water and high tides. On the other hand, in the rainy season, the phosphorus compounds which arrive in the hydrosystem are essentially from the continent. They are brought mainly by the Haho river and Zowla Lake which is fed by rivers crossing mining soils. Thus, these phosphorus compounds in the rainy season are due to the leaching of phosphate quarries and agricultural soils [8], [11], [9]. These results obtained in the rainy season are in accordance with those recorded by Kouassi *et al.* [35] and Konan *et al.* [23] respectively in Ebrié and Grand-Lahou lagoons in Côte d'Ivoire.

The spatio-temporal distribution of ammonium (Figure 5 (c1, c2)) shows an essentially continental source through the Haho and Zio rivers. This explains the decrease in concentrations from upstream to downstream. Continental waters are more concentrated in ammonium because of the leaching of agricultural soils and the incomplete degradation of animal and plant organic matters transported by the Zio and Haho rivers [8], [11]. The highest ammonium contents were also recorded by Kouassi *et al.* [35] in Ebrié lagoon in Côte d'Ivoire in areas receiving continental waters.

Nitrates are the most stable forms of dissolved inorganic nitrogen. They constitute the final stage of nitrogen oxidation [11]. The high concentrations recorded in northwestern Lake Togo and their decrease from upstream to downstream associated with the increase in their contents during the rainy season (Figure 5 (d1, d2)) indicate that the nitrates present in the waters of the hydrosystem have continental source. They come from the leaching of agricultural soils where nitrogen fertilizers are used irrationally and brought by Haho and Zio rivers. To this, the release of the nitrate contained in the sediments can be added [8], [36], [11]. These results corroborate those obtained by Kouassi *et al.* [35] and Konan *et al.* [23] respectively in Ebrié and Grand-Lahou lagoons in Côte d'Ivoire.

The spatio-temporal distributions of SO_4^{2-}, Cl^- and HCO_3^- (Figure 6) indicate a strong marine influence on the hydrosystem's waters especially during periods of low water and high tides. This influence is reduced in the rainy season by the massive entry of continental waters with lower contents [8], [37]. However, the bidirectional and homogeneous distribution of HCO_3^- (Figure 6 (c1, c2)) shows that they have double sources of neighboring importance. Indeed, the HCO_3^- come from the mainland as well as the sea whatever the season is. A low marine influence is observed in dry season. This homogeneity was also noted by Millet [8] in the same lagoon complex.

The increase in concentrations of major cations from upstream to downstream during the both seasons (Figure 7) can be explained by an intrusion of marine waters highly concentrated in major cations which progressively go up to upstream in the northwestern part of the lagoon complex. In the rainy season, this evolution is interrupted and pushed back by the arrival of continental waters with low contents of major cations [8], [37] through Haho and Zio rivers. This limits the marine influence on the lagoon of Aného. The concentrations of major elements in coastal aquatic ecosystems generally depend not only on exchanges with the ocean but also on inland water supplies [8], [23]. Thus, in the rainy season, the appearance of increasing major cations contents along the northwestern shore of Lake Togo, can be explained by continental inputs. This is much more marked for K and Na (Figure 7 (b2, d2)) at the Northeastern bank of Lake Togo, which according to Rodier [11], would be the preferred seat of a drain flow during floods. These elements could have an anthropic or natural origin by the alteration of the magmatic rocks [11].

5. Conclusion

This study shows that there is a variation in the spatial distribution of physicochemical parameters of waters from the hydrosystem Lake Togo-Lagon of Aného. Indeed, temperature, pH and dissolved oxygen show a low spatial variation with a slight increase in temperature and pH values from upstream to downstream. In addition, the conductivity, salinity, TDS, SO_4^{2-}, Cl^-, Ca, K, Na and Mg have high spatial variations marked especially by an increasing gradient from upstream to downstream of values recorded both in dry and rainy season. This illustrates the marine influence which lead to a mineral pollution of the lagoon waters especially in dry season. The same concentration gradient was observed for the phosphorus compounds (PO_4^{3-}, P) in dry season followed by a reversal of the concentration gradient during the rainy season. Thus, P and PO_4^{3-} have marine source in dry season due to phosphate effluents and continental origin in the rainy season by leaching of mining and agricultural soils. In contrast, nitrogen compounds (NO_3^- and NH_4^+) showed higher concentrations in upstream and lower in downstream during both seasons. This explains their continental source. A high spatio-temporal variation was noted in TSS, turbidity and transparency. The hierarchical cluster analysis applied to the parameters led to the conclusion that the organic pollution parameters are of continental origin while the mineralization and dissolved salts are of marine origin.

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