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Seasonal variation of some major ions in a tropical lagoon waters, Aby lagoon (Côte d'Ivoire): Relationship with temperature, salinity and pH

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ABSTRACT

In response to continental inputs, the aim of this study was to know some major ions contents in Aby lagoon waters, according to seasons and in relation to temperature, salinity and pH. To do this, concentrations of major ions such as (sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and sulphates (SO_4^{2-}) of Aby lagoon waters are determined, according to seasons and in relation to temperature, salinity and pH. From September 2007 to July 2009, during monthly sampling campaigns, temperature, salinity and pH of lagoon's waters were measured, *in situ*, at twenty (20) stations distributed along lagoon. Water samples were taken at these stations, at the depth of 0.2 m below the surface, to determine in laboratory, concentrations of major ions using standard methods (Atomic Absorption Spectrometry methods for sodium, potassium, calcium and magnesium and Nephelometric method for sulphates). Seasonal variations of sodium, potassium and calcium concentrations are proportional to temperature, salinity and pH. These ions are under influence of oceanic waters inputs. In contrast, magnesium and sulphates are under anthropogenic influence, these concentrations are not proportional to temperature, salinity and pH. There are significant seasonal differences between major ions concentrations of waters from one season to another. Aby lagoon is under strong anthropogenic influence.
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Keywords: Aquatic ecosystem, Aby lagoon, Major ions, Seasonal variations, Salinity, Côte d'Ivoire.

INTRODUCTION

Aby lagoon, like all Ivorian lagoons, is subject to many pressures (Hauhouot, 2004, Akpétou et al., 2010). Indeed, in addition to the large agglomerations of Adiaké, Étuoboué and Tiapoum and lot of villages, banks of Aby lagoon are places to immense peasant and agro-industrial plantations of coconut trees, rubber trees, oil palms such as Héyania plantations of PALM.CI. In addition, according to Coulibaly et al. (2008), 2,720 m^3 of palm oil production effluents from PALMC.I. are discharged every day into Toumandjé River, one of rivers that feed Aby lagoon. This lagoon is therefore receptacle of domestic and industrial effluents and runoff from agricultural areas. According to Singh et al. (2013), water, by means of its physical, chemical and biological characteristics, reflects the significance as potent ecological factor and quality for sustenance. Moreover, water quality of rivers, lakes and lagoons changes with the seasons and geographic areas, even there is no pollution present (Lawson, 2011). Temperature, salinity, pH and rainfall are influential parameters for the aquatic environment.

Temperature has a strong influence on many physical and chemical characteristics of

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water including the solubility of oxygen and other gases, chemical reaction rates and toxicity and microbial activity (Dallas and Day, 2004). It is a necessary parameter for the knowledge and study of mixtures of water bodies (Daniel et al., 2010). Salinity makes it possible to know ocean circulation, to identify bodies of water of different origin and to follow their mixtures offshore as well as at the coast or estuaries (Kouassi, 2005; Daniel et al., 2010).

In estuaries, salinity gives mixing proportions of fresh and salty waters (Lawson, 2011). PH is also an important factor that influences most chemical and biological mechanisms in water (Haddad and Ghoualem, 2014). As for the rains, they collect the substances present in air, drain those present on the continent and govern the rhythm of seasons in tropical zone. This parameter can also have a negative impact of pollution on the aquatic ecosystem. In addition, major ions such as sodium, potassium, calcium, magnesium and sulphates may have an agricultural or anthropogenic origin (Haddad and Ghoualem 2014) and they could therefore be source of water pollution. In response to continental inputs, the aim of this study was to know, according to seasons and in relation to temperature, salinity and pH, some major ions (sodium, potassium, calcium, magnesium and sulphates) contents in lagoon waters,

MATERIALS AND METHODS

Study area

Located at far south-east of Côte d'Ivoire, between the longitudes 2 ° 50 ' W and 3 ° 21' W and the latitudes 5 ° 04 ' N and 5 ° 22' N, Aby lagoon covers an area of 424 km^2 and has 3.8 meters in average depth (Wango et al., 2014) (Figure 1). In eastern part, it constitutes a natural border between Côte d’Ivoire and Ghana (Assemian-Niango et al., 2014). Aby lagoon contains three straits broad of 4.5 km, 2 km and 1.25 km. These straits allow the subdivision into four parts with different hydrological regimes due to variable marine, fluvial and atmospheric influences from one part of the lagoon system to another. These are, from North to South and from West to East, Aby north lagoon and Aby south lagoon, which constitute Aby part of the lagoon complex, Tendo lagoon and Éhy lagoon (Assemian-Niango et al., 2014). This lagoon also contains many islands. Six (6) of them (Assokomonobaha or, Balouate, Meha, Nyamouan, Éloamin and sacred island Bosson-Assoun) constitute the national park of the Éhotilé islands (Malan et al., 2007). Aby lagoon is fed by two main forest rivers, Bia at the north and Tanoé at the east. There are also several smaller rivers so important such as Éholié at the north and Toudoum at Eplémlan. Lagoon is still connect with Atlantic Ocean through the grau of Assinie Mafia. However, exchanges are reduced because of a set of channels that constitute barrier islands located in Aby south lagoon (Koné et al., 2009). Aby lagoon is in Adiaké region whose climate is transitional equatorial type characterized by the following seasonal division (Seu-Anoï, 2012; Eblin, 2014):

- long dry season from December to March;
- long rainy season from April to July;
- short dry season from August to September
- short rainy season from October to November.

Sampling

Samples were collected from twenty (20) stations distributed along Aby lagoon system (Figure 2). Selection criteria of stations are on one hand representability of whole Aby lagoon system and on other hand zones close to big cities (Adiaké, Tiapoum), mouths of main rivers (Bia, Éholié and Tanoé) that feed lagoon, agro-industrial plantations and Aby lagoon system mouth in Atlantic Ocean. The positions of sampling stations were accurately located by using GARMIN Geographical Positioning System (GPSMAP 64 SC) (Table 1).

In situ measurements as well as monthly water sampling were made from September 2007 to July 2009. Water samples were taken, using a Niskin bottle, at the depth of 0.20 m below the surface of lagoon. Statistical treatments were made from XLSTAT 7.5 (Addinsoft, 2004) software. Data were processed using Friedman test to compare parameters during seasons. Table 2 presents analyzed parameters and methods of analysis.

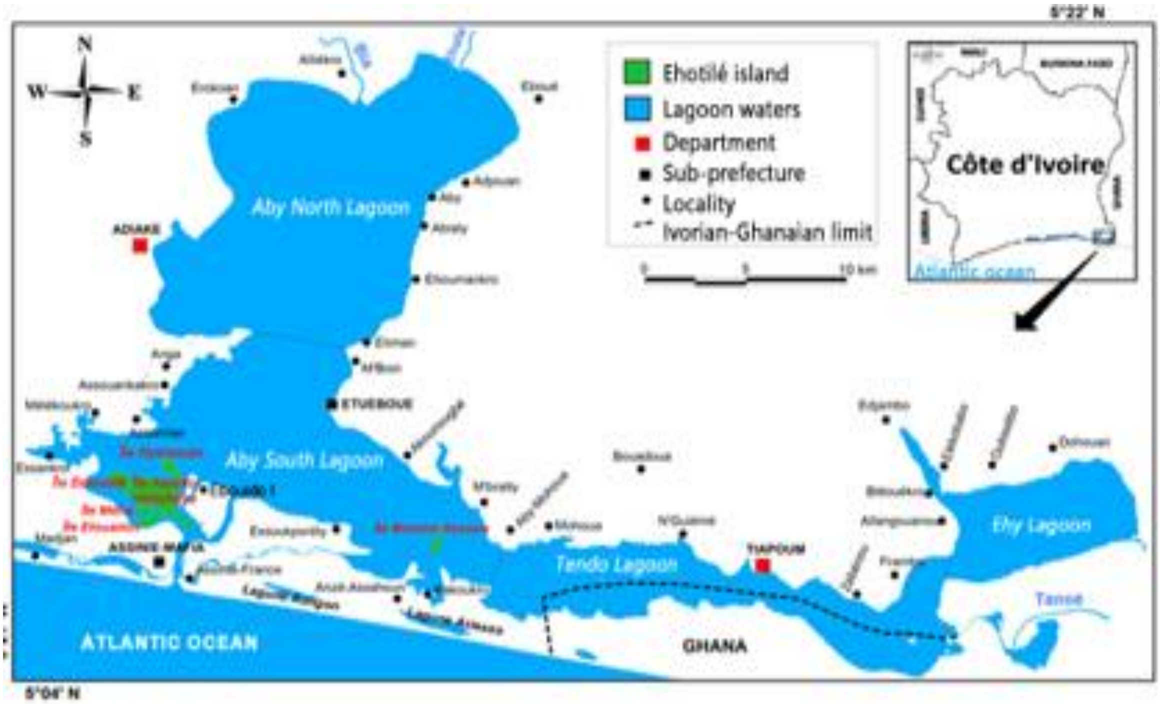

Figure 1: Aby lagoon system (Source: Oceanological Research Center Abidjan/ Côte d'Ivoire).

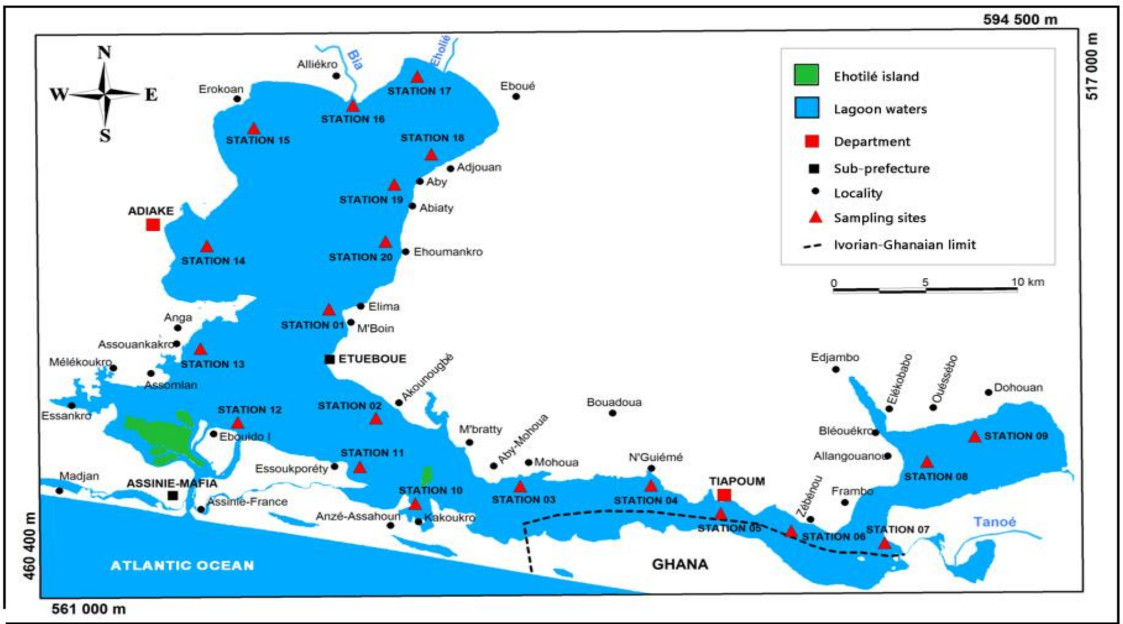

Figure 2: Aby lagoon system and sampling sites (Source: Oceanological Research Center Abidjan/ Côte d'Ivoire).

Table 1: Geographical coordinates of sampling stations.

Stations names	Stations numeros	geographical Coordinates (UTM)		Stations names	Stations numeros	geographical Coordinates (UTM)	
		X	Y			X	Y
Éléman-M'boin	1	476200	578100	**Angboudjou**	11	477800	568700
Akounougbé	2	478700	571600	**Éboïndo I**	12	471200	571400
Mowa	3	486500	567500	**Assouankakro**	13	469200	575800
N'guiémé	4	493600	567500	**Adiaké**	14	469600	581900
Tiapoum	5	497300	565600	**Érokoan**	15	472200	588900
Zébénou	6	501100	564600	**Bia**	16	477600	590200
Tanoé	7	506100	565300	**Éholié**	17	481100	591900
Allangouanou	8	508600	568800	**Adjouan**	18	482300	58800
Ouessébo	9	511200	570300	**Aby-Abiaty**	19	479800	585500
Kakoukro	10	480800	566500	**Éhoumankro**	20	479300	582100

Table 2: Analyzed parameters and methods of analysis.

Analyzed parameters	Methods of analysis and/or measuring devices
Temperature (T), Salinity (S)	*In situ* with Multiparameter TURO T-611 (Turo technology, 1996)
pH	*In situ* with pH-meter HI/98/150 brand HANNA
Sodium (Na^{+}) and	Atomic Absorption Spectrometry (AAS method) (NF T 90 020, 1984),
Potassium (K^{+})	reading 589.6 nm and 766.5 nm, respectively
Calcium(Ca^{2+}) and	Atomic Absorption Spectrometry (NF EN ISO 7980, 2000), reading 422.7
Magnesium (Mg^{2+})	nm and 285.2 nm, respectively
Sulfates (SO_4^{2-})	Nephelometric method (NF T 90 040, 1986), reading 650 nm

RESULTS

Table 3 presents means, extreme values (minimum, maximum) and coefficients of variation of analyzed parameters of lagoon's waters during seasons. With refference to parameters studied, Aby lagoon waters showed the following characteristics: average temperatures, pH, salinities and sodium and potassium contents are lowest in the short dry season and highest in the long dry season. Average temperature ranged from 27,72 °C to 30,73° C, salinities from 0,17 ‰ to 1,65 ‰, pH from 7,12 to 7,87, sodium contents from 214,67 mg/L to 453,55 mg/L and potassium contents from 30,2 mg/L to 84,9mg/L. Average calcium contents ranged from 6,97 mg/L in the short rainy season to 25,67 mg/L in the long dry season. Average magnesium contents ranged from 3,78 mg/L in the long dry season to 21,86 mg/L in the short rainy season. Average suphate contents ranged from 4,85 mg/L in the short rainy season to 26,62 mg/L in the long rainy season. Whatever season, calcium contents of waters are higher than magnesium contents. In short dry season, potassium and calcium levels are low. Coefficients of variation of average temperatures and pH below 15 % are low.

Table 4 presents results of Friedman test for comparison of K paired samples, from XLSTAT 7.5 (Addinsoft, 2004) software. In terms of intra-seasonal variations, physico-chemical parameters and major ions contents of lagoon waters in the long rainy season differ from those in the short rainy season, except for sulphate contents. Difference between the long dry season and the short dry season is due to the salinity of waters and their magnesium and sulphate contents. With regard to inter-seasonal variations, composition of lagoon waters in the long rainy season differs from that in the long dry season in terms of temperature, salinity and sulphate contents. However, with exception of sulphate contents, difference is significant between charasteristics of lagoon waters in the long rainy season and in the short dry season. The short dry season differs to the short rainy saison in terms on temperatue and levels of potassium, magnesium and sulphates.

Table 5 presents correlation matrix of parameters. There are positive correlations between temperature and salinity, pH and the levels of sodium and calcium. The salinity has positive correlation with the pH and the sodium and calcium contents of lagoon waters. However, it has negative correlation with the potassium and sulphates contents. The pH has positive correlation with the sodium and calcium contents and negative correlation with the magnesium content. The sodium content has positive correlation with the calcium content and negative correlation with the magnesium content. The Potassium content has positive correlation with the magnesium content and negative correlation with the calcium content. The calcium and magnesium contents have negative correlation.

Table 3: Means, extreme values (Min, Max) and Coefficients of Variation (CV) of temperature (T), salinity (S), pH and major ions (Na^+, K^+, Ca^{2+}, Mg^{2+} and SO_4^{2-}) during seasons.

Analyzed Parameters								
	T (°C)	**S (‰)**	**pH**	Na^+ **(mg/L)**	K^+ **(mg/L)**	Ca^{2+} **(mg/L)**	Mg^{2+} **(mg/L)**	SO_4^{2-} **(mg/L)**
Long Dry Season (LDS)								
Means	30,73	1,65	7,87	440,55	71,6	25,67	3,78	6,57
Min	29,25	0	6,4	11,5	11	1,24	0,84	0,17
Max	32,65	3,5	8,9	597	170	92,25	16,56	24,23
CV	3,2	81	10,45	47,83	71,47	107,7	104,37	99
Long Rainy Season (LRS)								
Means	29,82	0,36	7,17	327,87	71,1	16,25	6,61	26,62
Min	27,1	0	5,44	13	9,7	0,52	0,05	0,06
Max	33,35	1,6	8,47	597	170,5	78,4	24,96	86,3
CV	5,81	122,9	8,93	56,92	60,5	146,42	121,17	82,66
Short Dry Season (SDS)								
Means	27,72	0,46	7,12	214,67	71,4	9	8,61	6,18
Min	26,4	0	5,65	11	3	0,2	1,32	1,3
Max	28,73	4,75	8,08	495	145,3	19,6	18,48	13,4
CV	2,44	227,5	8,02	72,81	59,71	74,04	62,86	63,37
Short Rainy Season (SRS)								
Means	29,32	0,17	7,17	278,75	45,8	6,97	21,86	4,85
Min	28,13	0	6,82	10,5	10,5	1,4	0,96	0,24
Max	29,95	0,68	7,73	497	187,5	18,4	82,88	15,4
CV	1,62	119,22	3,3	70,77	103,76	74,61	90,56	98

Table 4: Matrix of pairs comparisons (difference and conclusion).

	Intra-seasonal variations		**Inter-seasonal variations**			
Parameters	**Seasons**		**Seasons**			
	LDS-SDS	**LRS-SRS**	**LDS-LRS**	**LDS-SRS**	**LRS-SDS**	**SDS-SRS**
T	52,000*	10,000	17,000*	27,000*	35,000*	25,000*
S	29,500*	16,500*	22,000*	38,500*	7,500	9,000
pH	19,000*	9,000	14,000	23,000*	5,000	4,000
Na^+	36,000*	16,000	16,000	32,000*	20,000*	4,000
K^+	40,000*	14,000	7,000	21,000*	33,000*	19,000*
Ca^{2+}	14,000	0,000	15,000	15,000	1,000	1,000
Mg^{2+}	21,500*	35,500*	6,500	42,000*	15,000	20,500*
SO_4^{2-}	15,000	33,000*	29,000*	4,000	14,000	19,000*

Critical value for difference: 16,003 *: Significant values.

Table 5: Correlation Matrix of parameters.

	T	**S**	**pH**	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**SO_4^{2-}**
T	1,00							
S	**0,62**	1,00						
pH	**0,75**	**0,97**	1,00					
Na^+	**0,95**	**0,82**	**0,90**	1,00				
K^+	-0,04	**-0,48**	-0,29	-0,25	1,00			
Ca^{2+}	**0,79**	**0,90**	**0,89**	**0,93**	**-0,59**	1,00		
Mg^{2+}	-0,27	**-0,66**	**-0,51**	**-0,49**	**0,97**	**-0,77**	1,00	
SO_4^{2-}	0,24	-0,24	-0,26	0,12	-0,41	0,19	-0,37	1,00

DISCUSSION

Temperature (> 27 °C), salinity (> 0 mg/L) and pH (7-8) are characteristic of tropical lagoons. These values were significantly observed by Traoré et al. (2012) in Aghien lagoon and Yao et al. 2009 in Ébrié lagoon. However, aby lagoon is more saline than Aghien lagoon and less saline than Ébrié because of its low communication with Atlantic Ocean.

Like temperature, salinity and pH of Aby lagoon waters, highest values of sodium and calcium (440,55 mg /L and 25,67 mg/L, respectively) during long dry season are due to oceanic waters intrusion. High correlations between sodium and calcium levels and salinity and pH confirm oceanic influence. Ouro-Sama et al. (2018) have also reported highest values of sodium and calcium (2368,06 mg/L and 175,97 mg/L, respectively) in waters from hydrosystem Lake Togo-Lagoon of Aného during this period. Indeed, long dry season is a period of maximum oceanic influences, characterized by high ambient air temperatures that favor evaporation phenomenon. In addition, rainfall is also absent and inflow of rivers, with a similar regime to rainfall, is low. However, lower levels of sodium and calcium Aby lagoon waters, compared to hydrosystem Lake Togo-Lagune of Aného, are due to the low communication of Aby lagoon with Atlantic Ocean (Koné et al. 2009).

In short dry season, minimum potassium levels are due to algal blooms. Potassium is a nutrient of plants. Therefore, algae for their growth (Ohou-Yao, 2010) use it. This observation is confirming by Hauert (2012) and Haddad and Ghoualem (2014). According to these authors, anthropogenic agricultural, mining and industrial activities influence potassium levels. Negative correlation between potassium and salinity confirm its continental origin.

As for calcium, significant photosynthetic activity during short dry season (Konan, 2010) leads to consumption of carbon dioxide (CO_2). This reduction of CO_2 in waters would be at origin of reduction of dissolution of calcium carbonates and consequently of decrease of calcium contents of waters during short dry season.

Maximum sulphates and magnesium levels in waters are recorded during long rainy season and short rainy season, respectively. This is not the case of Coatzacoalcas estuary in Mexico, lagoon of Porto-Novo and hydrosystem Lake Togo – Lagoon of Aného in Benin where Hoz et al. (2003), Mama et al. (2011) and Ouro-Sama et al. (2018), respectively, have reported high sulphates and magnesium levels in dry season or in période of oceanic influence. These high sulphates and magnesium levels during rainy seasons are due to anthropogenic factors (Assemian-Niango et al., 2014). Indeed, according to Gabriel et al., (2008), atmospheric deposition (precipitation, dry deposition), runoff from agricultural areas and urban land are the main sources of sulphates from surface water. High levels of this parameter can also be observed in polluted rivers (Haddad and Ghoualem, 2014). The low sulphates levels of waters during short rainy season are due to algal proliferation. Indeed, according to Fao (2003), sulphates are form of sulfur assimilable by plants, which they promote growth. They enter into amino acid composition such as methionine, cystine and cysteine and are susceptible to leaching.

The levels of magnesium of waters highest during short rainy season may be due to fertilizers applied at beginning of short rainy season. Negative correlation between magnesium and salinity, pH, sodium and calcium confirm its continental origin. Relatively low levels of magnesium during long dry season can be explained by high temperatures leading to precipitation of carbonate forms and reduction of magnesium levels in waters. Moreover, contrary to observations of Mama et al. (2011), Calcium contents higher than magnesium contents confirm weak exchanges between lagoon and Atlantic Ocean and consequently dominance of inland waters.

Aby lagoon waters are characterized by a lower thermal variation as indicated by low coefficients of variation observed (< 6%) during seasons. Like temperature, low coefficients of variation of pH (< 11%) indicate a small variation in pH of waters within different seasons.

Concentrations of major ions (sodium, potassium, calcium, magnesium and sulphates) in waters vary significantly within each season (coefficients of variation > 45%). With regard to intra-seasonal variations, characteristics of waters in long dry season significantly differ from those in short dry season, with exception of sulphates and calcium contents. In rainy seasons, characteristics of waters in long rainy season differ from those in short rainy season in terms of salinity, magnesium and sulphates levels. As for inter-seasonal variations, differences are generally significant.

Conclusion

Temperature, salinity and pH are characteristic of tropical coastal lagoons. Sodium and calcium contents of Aby lagoon waters varie in proportion to temperature, salinity and pH. These levels are highest in long dry season, following intrusions of ocean waters. These ions are therefore under oceanic waters influence. In contrast, magnesium and sulphates are under anthropogenic influence and their contents are high during periods of strong continental influence (rainy seasons). Concentrations of major ions in Aby lagoon waters vary within each season. These concentrations also differ significantly from one season to another, depending on air temperature, precipitation, ocean and continental inflow, and anthropogenic activities. Aby lagoon is under strong anthropogenic influence. Control of continental inputs will help to preserve its ecological quality.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

SA-N has contributed to made the campains, to samples's analyse and to write the manuscript. NA and KGKP have contributed, respectively, to the writing of the manuscript and to the statistical processing of the data of the study.

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