

# Hydrology and Eutrophication State of Sassandra River Estuary in Ivory Coast (Gulf of Guinea)

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**Abstract:** Variations in the physico-chemical and chemical parameters of the Sassandra estuarine zone are greatly influenced by the dynamics of the Sassandra River. The waters are heavily loaded during periods of flood. Salinity is very low or zero during the flood and increases slightly to 0.1 to 2.93‰ in the dry season. The values of physico-chemical parameters and those of the nutrient salts measured in the Sassandra estuary are characteristic of water of good quality. However, highly charged waters and high levels of phosphate during the high flow period make this estuary an environment vulnerable to pollution.

**Keywords:** Sassandra River, Estuary, Physico-Chemical, Nutrient Salts

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## 1. Introduction

The estuaries are mixing environments between watermarines and freshwater brought by rivers. Because of their location at the junction of terrestrial and marine ecosystems, these estuarine environments constitute important transition ecosystems (recreational, fishing and production areas fish). However, these frontal media are subject to significant anthropogenic pressure leading to disturbances in their equilibrium and natural functioning [1].

In Ivory Coast, due to population activities, estuaries are experiencing environmental problems. These problems include pollution [2]. The Sassandra estuary, a place of exchange between the Sassandra River and the Atlantic Ocean, is subject to both natural and anthropogenic pressures. The Sassandra river crossing from north to south, cereal crops (maize, sorghum, etc.) and agricultural areas (coffee, cocoa, rubber and oil palm) is responsible for residues of fertilizers and pesticides and transports them to (wastewater, untreated household refuse) "Figure 1", directly into the estuary. All these contributions give rise to concerns about the environmental quality of this plan water. Faced

with this concern, analyzes of physico-chemical parameters and the determination of nutrient salts, as well as their seasonal evolution, are necessary.



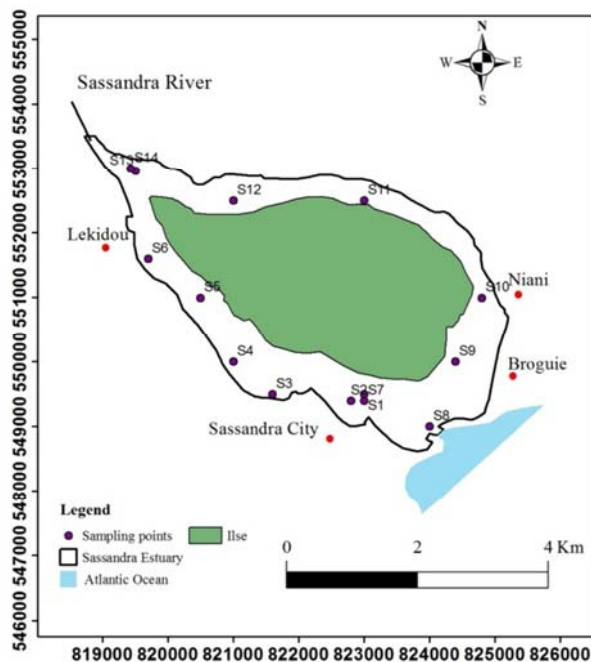
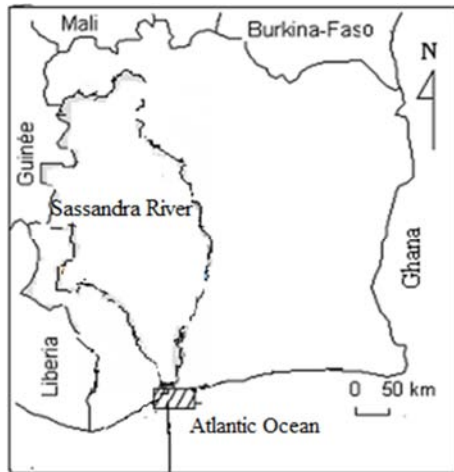
**Figure 1.** Garbage dumps on the edge of south- west of the estuary.

The objective of this study is to characterize the current state of the Sassandra estuary by highlighting the influence of seasonal variations and human activities.

## 2. Material and Methods

### 2.1. Study Site and Water Sampling

The Sassandra estuary is located southwest of the Ivory Coast between latitudes 4°99' N and 4°70' N and longitudes 6°25' W and 5°80' W. It extends 7 km long and 2 km wide with an area of 14 km<sup>2</sup>. It has a maximum depth of 8.5 km [3]. It is divided into two non-identical branches by an island, with the large part to the west and the small part to the east "Figure 2".



**Figure 2.** Geographical location of the Sassandra estuary and distribution of sampling points.

Water samples were collected from 14 stations in this estuarine area using a Niskin bottle. This bottle is dipped under the surface of the body of water manually. A quantity of about 500 ml of water is collected in the bottles previously cleaned. All samples are carefully stored at a low temperature (4°C) in a cooler to avoid photochemical reactions.

Temperature, dissolved oxygen, salinity, conductance, pH and TDS were measured "in situ" using a multi-parameter probe.

### 2.2. Measurement of Physicochemical Parameters

The measurements of the physicochemical parameters were carried out in two ways: in-situ measurements and laboratory analyzes.

#### 2.2.1. In Situ Measurements

The temperature, dissolved oxygen and pH were measured using a multi-parameter type Orion Star 4, salinity, TDS and conductance were measured with a multi parameter of type HACH Sension 5. The measurements were made by immersing the probe in the water. The parameter values are displayed directly and simultaneously on the screen. The temperature is displayed in degrees Celsius, salinity in percent per thousand, and oxygen in milligrams per liter and conductance in microsiemens per centimeter.

#### 2.2.2. Laboratory Analyzes

##### i. Measurements of Suspended Matter

The levels of Suspended Matter were measured according to the method described by [4]. Before filtration, filters were dried at 70°C for 2 hours and then weighed. For each water sample, a quantity 0.50 ml was taken and filtered through a filtration pad. The loaded filters were dried at 105°C for 2 hours, weighed and the load in Suspended Matter has been calculated according to the following formula:

[Suspended Matter] =  $(m_2 - m_1) / V$ , with  $m_1$ : the mass of the filter before filtration;  $m_2$ : the mass of the filter after filtration;  $V$ : the volume of filtered water.

##### ii. Determination of Nutrient Salts

In the laboratory, the nutrient salts were measured on these water samples. The nitrite concentration ( $\text{NO}_2^-$ ) was evaluated by the colorimetric method. The ammonium concentration was evaluated by the Nessler method. The determination of phosphate and nitrate was carried out according to the method Spectrophotometer of molecular absorption described by [4].

### 2.3. Statistical Methods

The spatial distributions of the various parameters are mapped using ArcGIS version 10.2.2 software. The method used is the IDW. This spatial analysis method reconstructs the estimation and interpolation distribution of the variable at all points of space. Principal Component Analysis (PCA) was chosen to study correlations between the different parameters. This method proceeds by reducing the size of the variable space by taking advantage of the correlations between the initial variables [5].

## 3. Results and Discussion

### 3.1. Results

#### 3.1.1. Physico-Chemical Characteristics of Waters

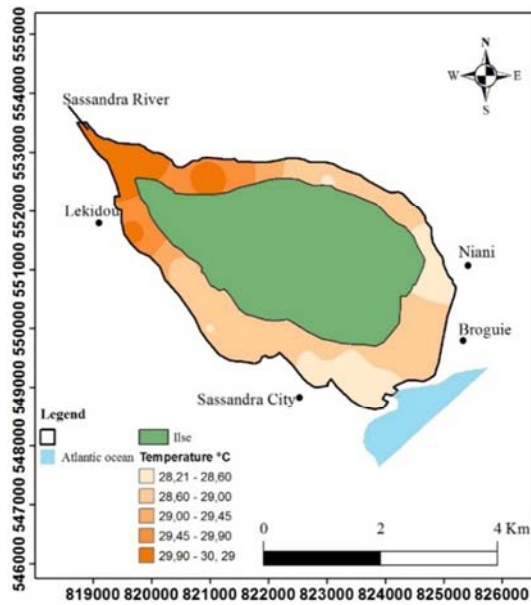
##### Temperature

During flood periods, the temperature values range from 28.21°C to 30.29°C "Figure 3a" with an average of 29.6°C. In the dry season, there is a rise in temperature. The values range from 29.11°C to 31.17°C "Figure 3b", with an average of

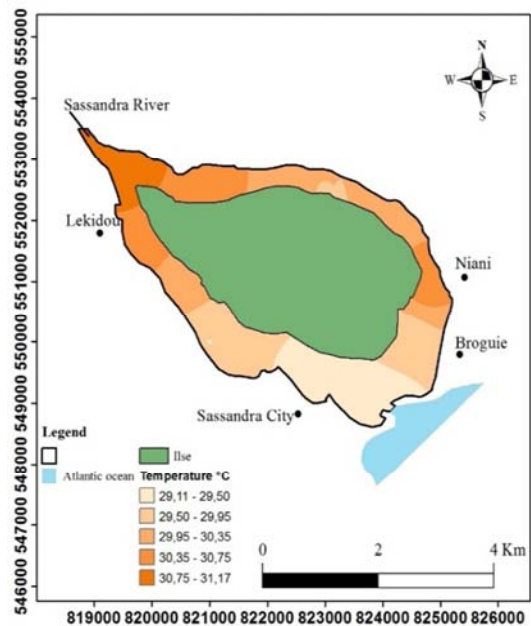
30.02°C. The waters near the mouth are colder, because this part of the estuary is subject to the influence of marine waters.

#### *Dissolved Oxygen*

During flood periods, dissolved oxygen contents ranged from 5.08 mg/L to 7.48 mg/L “Figure 4a”. In the dry season, they range from 4.71 mg/L to 6.56 mg/L “Figure 4 b”. During the flood period, the average dissolved oxygen content is about 6.52 mg/L whereas it is about 5.6 mg/L in the dry season. There is therefore a low variability between the flood season and the dry season. On the other hand, we note the presence of relatively heterogeneous contents on the whole of the body of water “Figure 4a and b”.

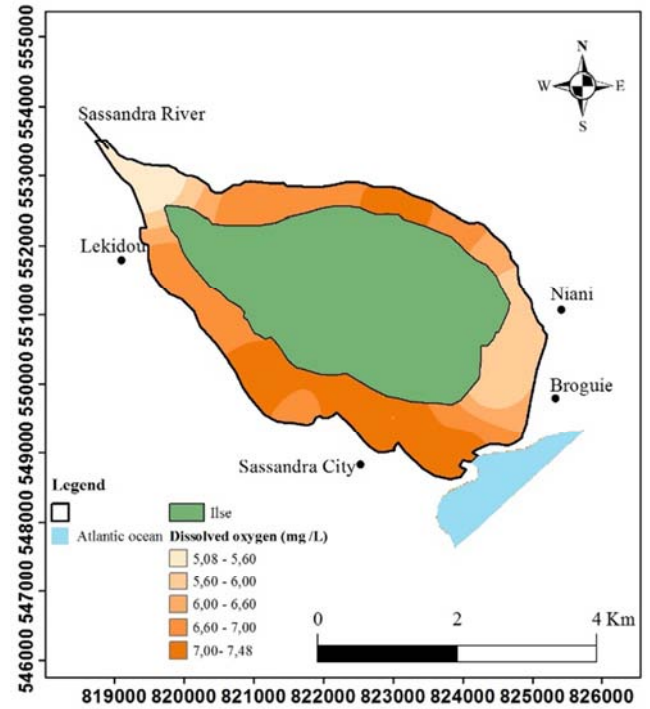


(a)

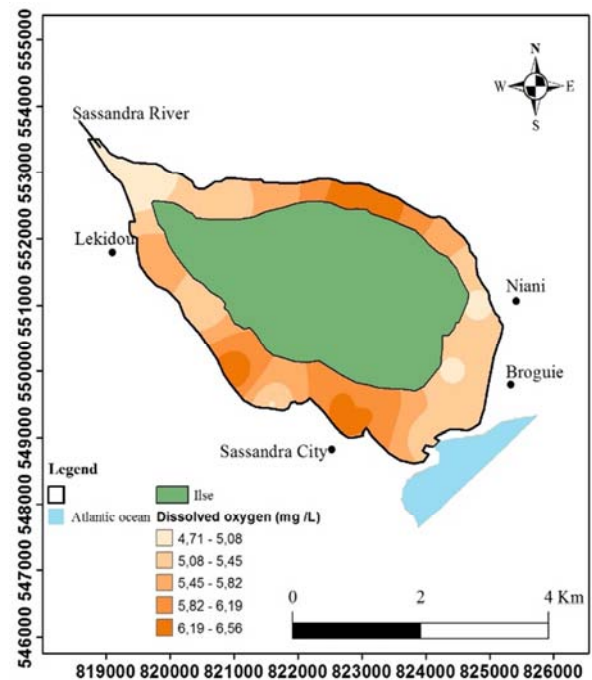


(b)

**Figure 3.** Spatial and seasonal variation in the temperature of the Sassandra estuarine waters.



(a)



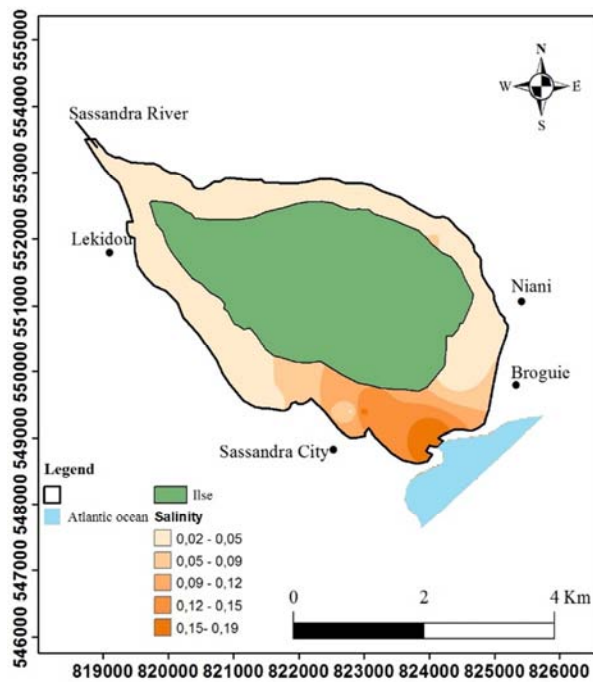
(b)

**Figure 4.** Spatial and seasonal distribution of dissolved oxygen.Salinity.

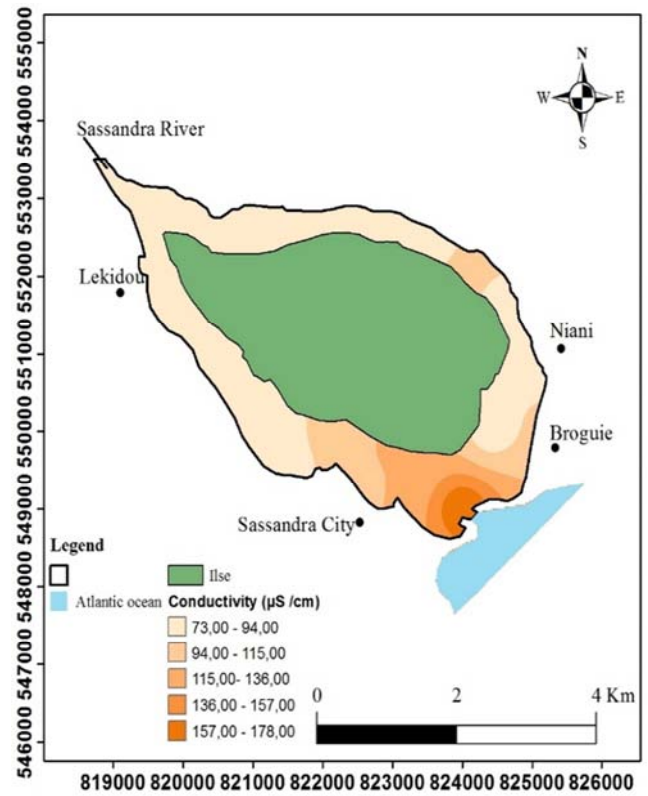
In the flood season, salinity varies from 0.02‰ to 0.19‰ “Figure 5a”, whereas in the dry season it varies from 0.1 to 2.93‰ “Figure 5b” with an average of 0.95‰. At the spatial level, during both seasons, surface salinity tends to decrease as one moves away from the mouth “Figure 5a and b”. This decline in salinity is due to the remoteness of the contact of the river with the sea. On the other hand, it is found that the estuarine waters of the Sassandra estuary are much less salty, reflecting a



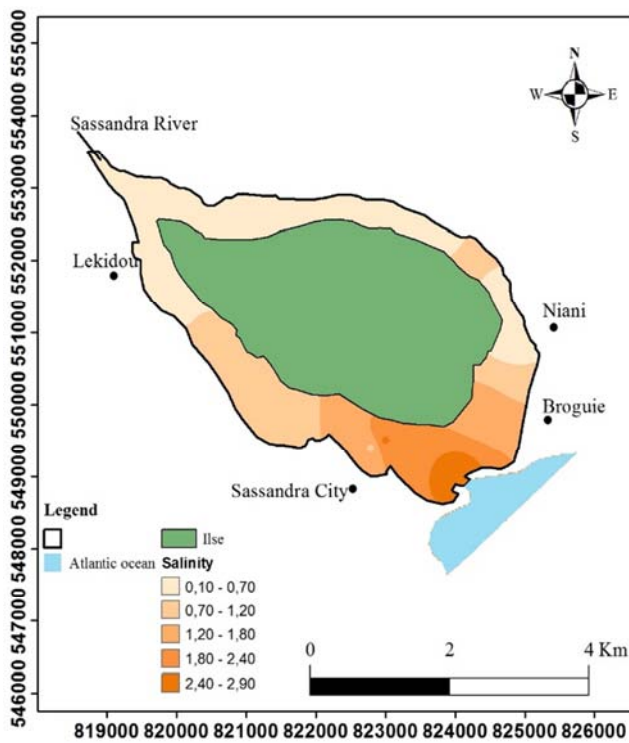
less important contribution of water marine.



(a)

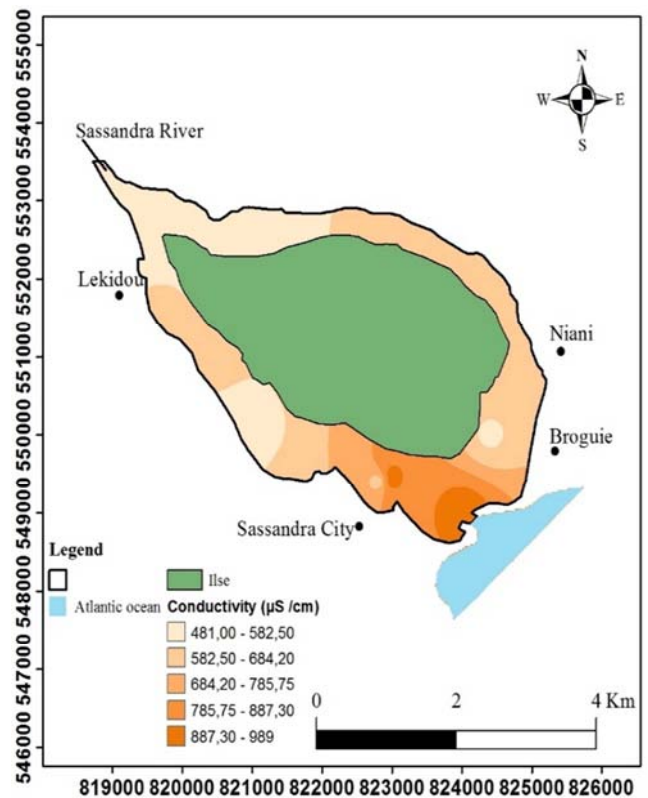


(a)



(b)

**Figure 5.** Spatial and seasonal variation in the salinity of the Sassandra estuarine waters.



(b)

**Figure 6.** Spatial and seasonal variation in the conductance of the Sassandra estuarine waters.

### Conductance

As regards conductance, it oscillates between  $73\mu\text{S} / \text{cm}$  and  $178\mu\text{S} / \text{cm}$  during a flood period “Figure 6a”, with an average value of  $96.43\mu\text{S} / \text{cm}$ . In the dry season, it increases from  $481\mu\text{S} / \text{cm}$  to  $989\mu\text{S} / \text{cm}$  “Figure 6b”, with an average value of  $642\mu\text{S} / \text{cm}$ . On a spatial plane, the conductance is unequally distributed. The maximum values are observed downstream while the minimum values are located upstream “Figure 6a and b”. This could be explained by the fact that the sector is influenced by seawater with high conductance at the mouth of the water. The exchanges between fluvial and sea water induce an increase in conductance.

### Hydrogen potential (pH)

For pH, it is between 6.98 and 6.05 with an average of 6.29 during the flood period “Figure 7a”. During the dry season, it varies between 6.19 and 7.76 with an average of 6.66 “Figure 7b”. These values do not show significant variations from one season to the next. On a spatial basis, the pH is relatively homogeneous except at the mouth and in the southwest of the estuary where the highest values are recorded “Figure 7a and b”. The mean values obtained reflect an acidic environment. This acidity can therefore be interpreted as the result of the massive presence of fresh water from the Sassandra River.

### Total dissolved salts (TDS)

As for TDS, it ranges from  $0.041 \text{ g} / \text{L}$  to  $0.266 \text{ g} / \text{L}$  with an average of  $0.078 \text{ g} / \text{L}$  during the flood period “Figure 8a”. In the dry season, it increases slightly and is in the range  $0.133 \text{ g} / \text{L}$  to  $0.377 \text{ g} / \text{L}$  “Figure 8b” with an average of  $0.22 \text{ g} / \text{L}$ . At the spatial level, the mouth and its surroundings are characterized by maximum values. These higher values would be due to the presence of marine waters. Upstream, the lowest values are observed and their distribution is almost homogeneous “Figure 8a and b”.

### Suspended Matter

At the level of the Suspended Matter, there are both significant seasonal and spatial variations. It varies between  $15.10 \text{ mg/L}$  and  $30.01 \text{ mg/L}$  during a flood period “Figure 9a” with an average of  $19.65 \text{ mg/L}$ . In the dry season, there is a very large variation. It decreases from  $4.4$  to  $1.2 \text{ mg/L}$  “Figure 9b” with an average of about  $2.7 \text{ mg/L}$ . This very great reduction of suspended solids can be justified by the absence of the intense flow of the Sassandra river (low flow) during dry periods. On the other hand, they can be explained by the rarity of the rainy events or not at all during the dry season. From the spatial point of view, the Suspended Matter is distributed heterogeneously in the estuary. The maximum values are observed in the west branch at the mouth “Figure 9a and b”. The high loads observed in the west channel suggest a more intense flow of water. At the mouth, the maximum concentration of Suspended Matter is probably due to the action of the waves.

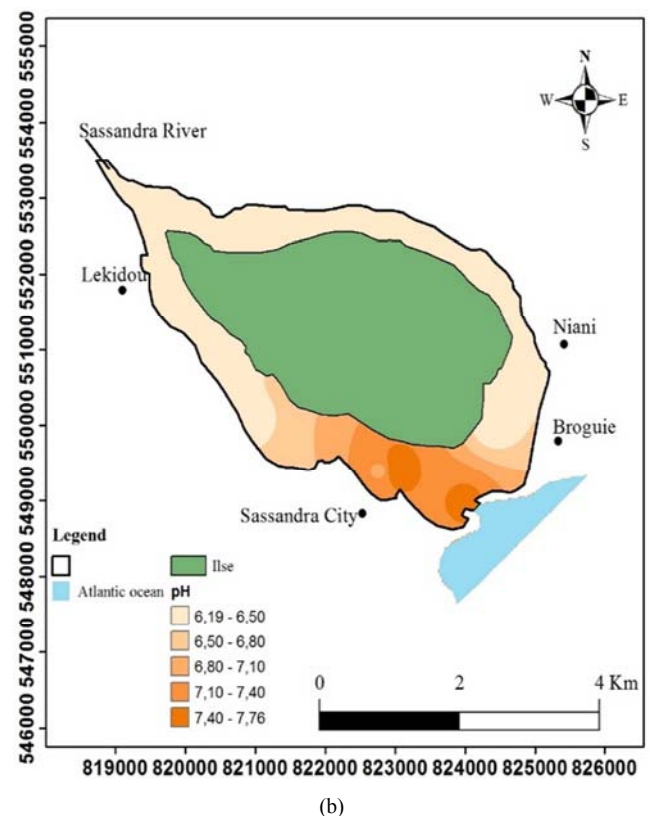
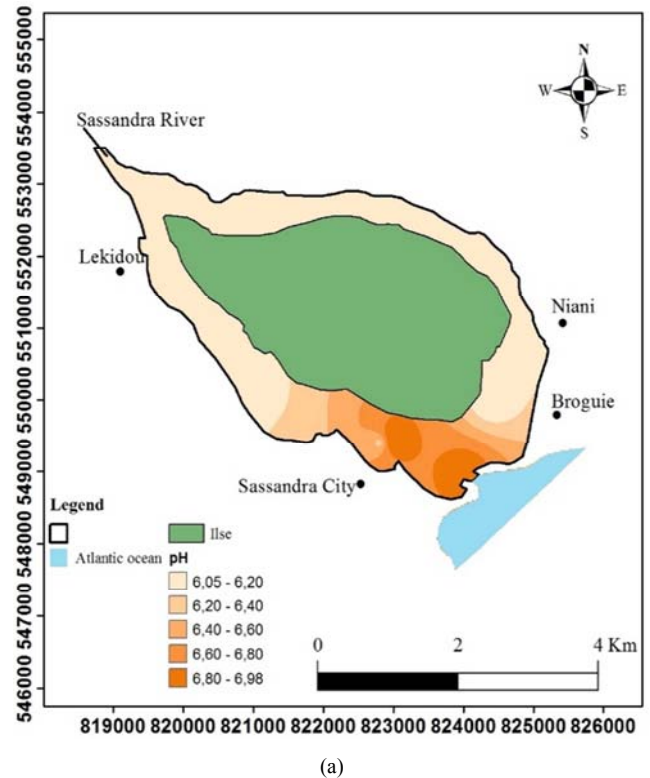
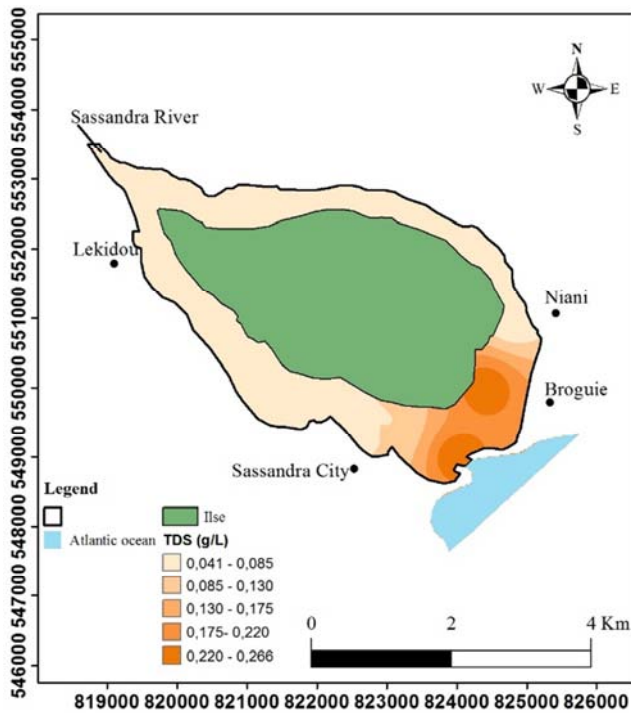
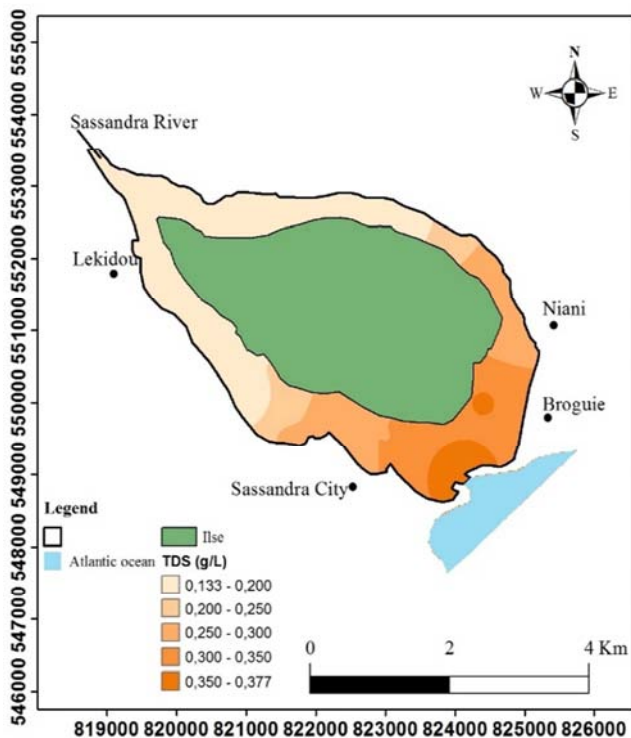


Figure 7. Spatial and seasonal variation of the pH of the estuarine waters of Sassandra.

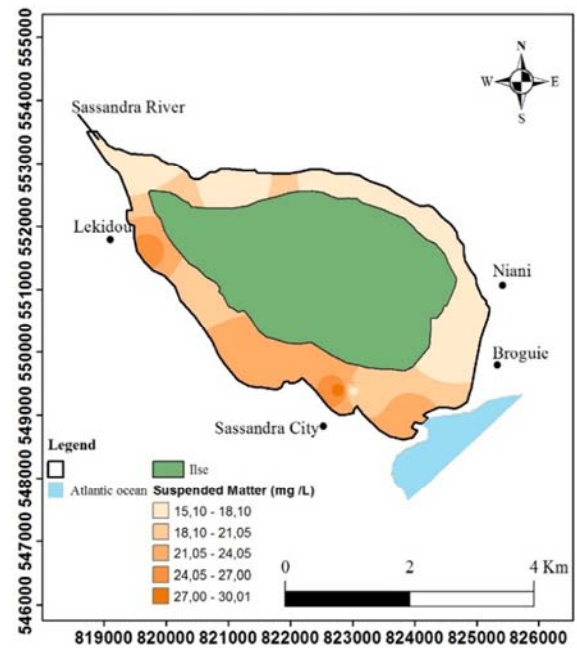


(a)

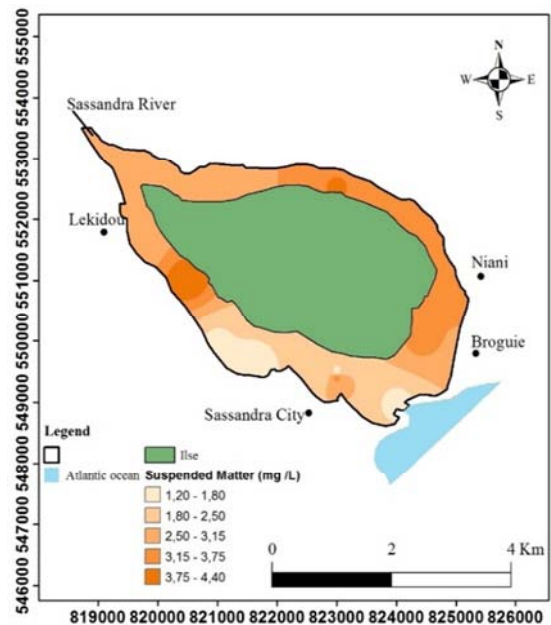


(b)

Figure 8. Spatial and seasonal variation of TDS in the estuarine waters of Sassandra.



(a)



(b)

Figure 9. Spatial and seasonal distribution of Suspended Matter concentrations.

### 3.1.2. Nutrient Salts

#### Nitrate

"Figure 10a and b" shows the variations of nitrate in the Sassandra estuary. During the flood period, the levels range from 0.1 mg/L to 0.4 mg/L "Figure 10a", with an average of 0.24 mg/L. In the dry season, they decrease and range from 0.052 mg/L to 0.193 mg/L "Figure 10b", with an average of 0.11 mg/L. This observation is due to the fact that during the flood the Sassandra River The distribution of the nitrate concentration is almost homogeneous in the eastern branch. The western branch, on the contrary, is marked by a



heterogeneity of seasonal concentrations with the maximum values not far from the deposits of The maximum levels encountered in the western branch can therefore probably be interpreted as the result of the leaching of garbage dumps and the discharge of domestic wastewater.

#### Nitrite

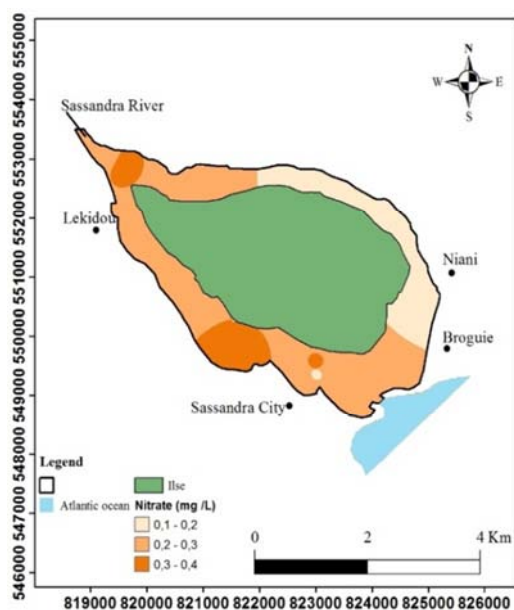
Nitrite concentrations in the Sassandra estuarine zone vary between 0.0015 mg/L and 0.007 mg/L with an average of 0.003 mg/L during the flood period “Figure 11a”. In the dry season there was a slight decrease in measured concentrations. They range from 0.001 mg/L to 0.003 mg/L “Figure 11b”. The highest values are observed in the western branch “Figure 11a and b”. The spatial distribution indicates concentrations, by the location of the maxima measured, an anthropogenic origin from refuse deposits and the discharge of domestic wastewater.

#### Ammonium

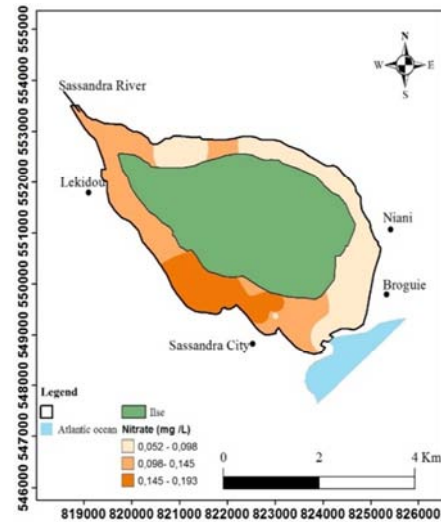
The ammonium concentrations measured in the Sassandra estuary range from 0.1 mg/L to 0.52 mg/L during flood periods “Figure 12a”, between 0.06 mg/L and 0.15 mg/L in the dry season “Figure 12b”. Their spatial distributions “Figure 12a and b”, generally show higher concentrations in the west channel and near garbage deposits.

#### Phosphate

“Figure 13a and b” shows the evolution of phosphate concentration during the flood and dry season. During floods, concentrations range from 1.1 mg/L to 2.8 mg/L “Figure 13a”, with an average of 1.60 mg/L. In the dry season, concentrations drop. They range from 1.31mg/L to 0.81mg/L “Figure 13b”. The fall in phosphate concentrations in the dry season can be explained by the action of the aquatic microfauna which could use them for the synthesis of new organic molecules [6]. Overall, the contents are high. These high grades can be interpreted as the result of leaching of agricultural land around the Sassandra River basin. The highest values are generally observed in the western branch, indicating a significant contribution of anthropogenic inputs.

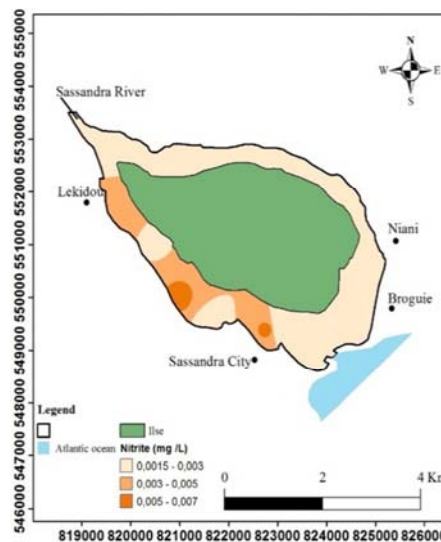


(a)

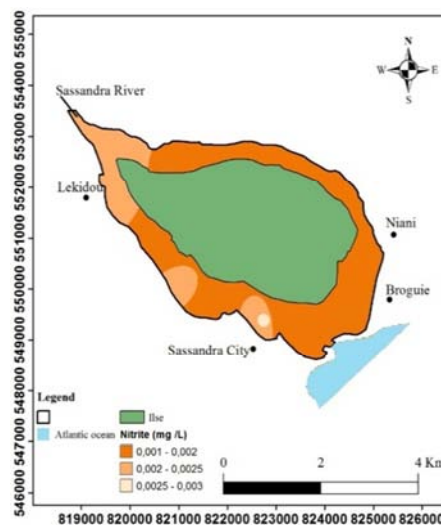


(b)

Figure 10. Spatial and seasonal distribution of nitrate concentrations.

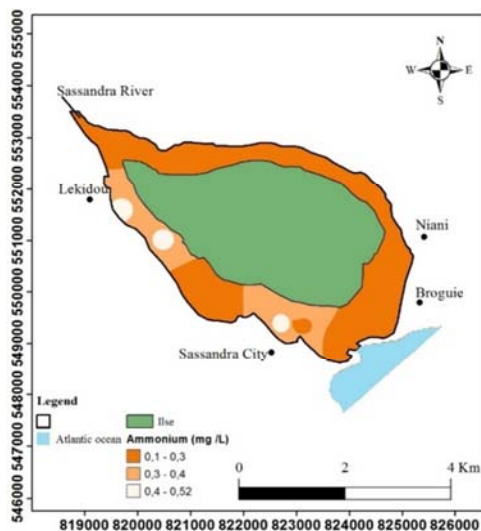


(a)

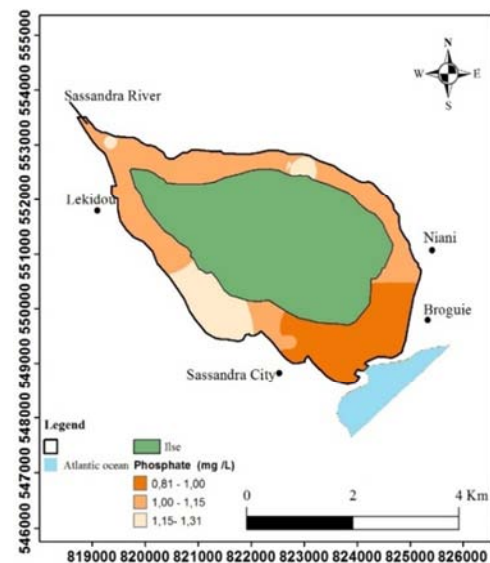


(b)

Figure 11. Spatial and seasonal distribution of nitrite concentrations.



(a)

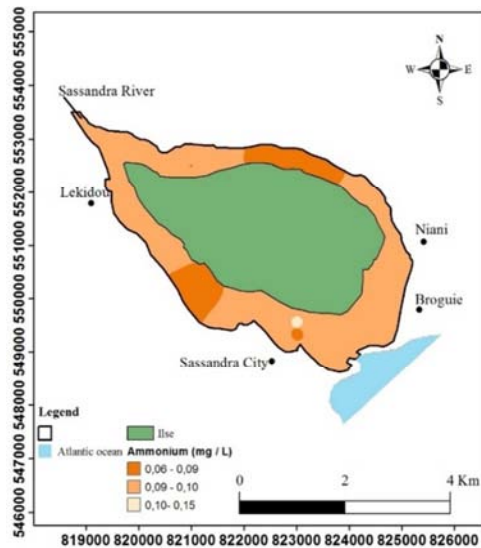


(b)

Figure 13. Spatial and seasonal distribution of phosphate concentrations.

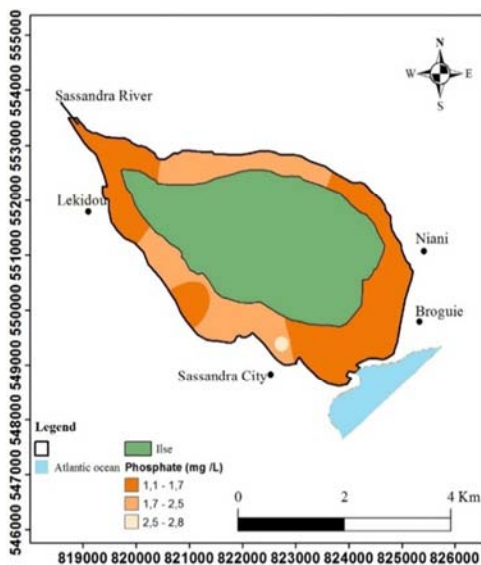
### 3.1.3. Correlation Between Physico-chemical Parameters and Nutrient Salts

At the level of the Sassandra estuarine zone, two groups are distinguished “Figure 14”. The first group consists of physico-chemical parameters (pH, TDS, salinity, conductance) and a second group consisting of chemical parameters (nitrite, nitrate, ammonium, phosphate) and Suspended Matter. With regard to temperature and dissolved oxygen, it is found that they deviate from the two groups.



(b)

Figure 12. Spatial and seasonal distribution of ammonium concentrations.



(a)

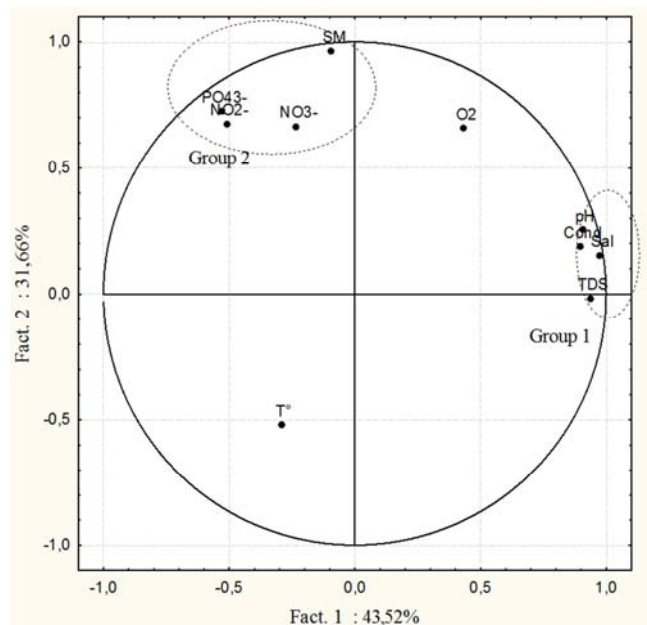


Figure 14. Correlation circle between physico-chemical parameters and nutrient salts.

Table 1 shows very strong correlations between Suspended Matter and nutrients. This can be explained by the fact that by transporting soil particles, the water also carries dissolved



nutrients associated with sediments [7]. There are also very strong correlations

Between certain physicochemical parameters. Others, such

as temperature and dissolved oxygen are negatively correlated ( $r = -0.61$ ).

**Table 1.** Correlation matrix between physico-chemical parameters and nutrient salts.

Variables	O <sub>2</sub>	pH	Sal	TDS	Cond	T°C	NO <sub>3</sub> <sup>-</sup>	NO <sub>2</sub> <sup>-</sup>	PO <sub>4</sub> <sup>3-</sup>	SM
O <sub>2</sub>	1									
pH	0.46	1								
Sal	0.47	0.97	1							
TDS	0.36	0.81	0.92	1						
Cond	0.36	0.88	0.93	0.86	1					
T°C	-0.61	-0.30	-0.29	-0.18	-0.17	1				
NO <sub>3</sub> <sup>-</sup>	0.23	0.06	-0.11	-0.37	-0.05	-0.19	1			
NO <sub>2</sub> <sup>-</sup>	0.22	-0.29	-0.37	-0.39	-0.34	-0.12	0.29	1		
PO <sub>4</sub> <sup>3-</sup>	0.08	-0.29	-0.37	-0.45	-0.20	-0.05	0.52	0.76	1	
SM	0.50	0.16	0.07	-0.04	0.14	-0.36	0.64	0.70	0.80	1

SM: Suspended Matter.

### 3.2. Discussion

Physicochemical parameters are influenced by the waters of the Sassandra River. Relatively high values of nutrient salts and Suspended Matter are recorded during the flood period. High values of salinity, conductance, pH and TDS are measured in the dry season. This observation has also been reported in other Ivorian estuarine areas by [8], [9] and [10]. Compared to previous studies, nitrate levels approximate those obtained by [10] in the Estuary Grand-Lahou. The latter obtained average levels of nitrate varying between 0.01 and 0.83 mg/L. As for the phosphate contents, they are for the most part superior to those found by these authors. They found mean levels varying between 0.05 mg/L in the dry season and 0.4 mg/L during rainy periods. However, nitrite concentrations are much lower than those measured (between 0.03 mg/L and 0.79 mg/L) in the Grand-Lahou estuary by [10]. According to [8], in the rainy season, runoff drainage and water turnover enrich the water columns with nutrient salts. Nitrite, nitrate and ammonium concentrations do not exceed the values from which eutrophication problems occur. Nitrite concentrations are well below 3 mg/L, so they do not pose a threat to aquatic fauna (especially for young fish) [11]. As for ammonium, there is less risk to aquatic life. The concentrations obtained for this nutrient salt are well below 44 mg/L, below which a stream is considered to be of good quality [12]. Unlike nitrate, nitrite and ammonium, the phosphate concentrations are high. They are higher than 50 µg / L. A concentration from which eutrophication can already be demonstrated according [11].

## 4. Conclusion

The monitoring of physico-chemical parameters and concentrations of nutrient salts revealed their high variability. Salinity, conductance, pH, Suspended Matter and nutrient salts vary with the Sassandra River intake. The values observed for most of the variables studied are found in the range of good quality waters. Nutrient salt levels do not show a state of eutrophication of the estuary. However, these values indicate some vulnerability, particularly where average phosphate

levels range between 1.07 mg/L (dry season) and 1.60 mg/L (flood period) and suspended solids during floods.

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