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Mapping of the Sedimentary Facies of the Bottom of the Ouladine Lagoon in Grand-Bassam (Ivory Coast_West Africa)

Bi Kassia Francis Koffi, Samassy Rokyatou Epouse Yeo, Kouassi Kouamé Alfred

Laboratory of Environmental Sciences and Technologies, Department of Earth Sciences, Jean Lorougnon Guédé University, Daloa, Ivory Coast
Email: kassiaty1@gmail.com

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Abstract

The Ouladine lagoon has an irregular bottom lined with different substrates. The lithological characteristics make it possible to observe sediments ranging from silts to sands and mixed sediments of variable color. These different fractions have varying proportions. The coarse fraction (>63 μm) has percentages ranging from 0 to 77% and the fine fraction (<63 μm) from 22.46 to 100% in the different sediments collected. The minority fraction of fine sands occupies the northern banks where the greatest depths of the section parallel to the coastal strip are observed. On the other hand, the sandy fractions occupy the southern shore up to the vicinity of the Azuretti mangrove island. This sandy fraction is also present on almost the entire section from the Comoé-Ebrié lagoon confluence to the closed mouth. The grain size characters of the sediments, such as the diagram of the classification coefficient So and the mean Mz, show well-classified sands. These sediments are deposited in a slightly agitated environment coming mainly from dunes and rivers. The sands of the estuarine complex were emplaced by saltation for most samples and by rotation.

Keywords

Substrate, Lithology, Silts, Sediments, Barrier Beach, Mouth, Granulometric, Estuarine, Saltation

1. Introduction

The Ivorian lagoons are expanses of brackish water which occupy a main fault called the fault of the lagoons, which separates the mainland and a coastal strip in the form of a lunar crescent. This sandbank very often has estuaries or mouths (Lankford, 1977; Nichols & Allen, 1981) which allow exchanges between the ocean and the continent. This article, representing one of the objectives to be achieved in my thesis, stipulates that lagoons are highly evolving coastal ecosystems dependent on multiple natural and anthropogenic factors. They are the receptacle for contributions of all kinds from the continent. These lagoons reveal a great variability of hydrodynamic and sedimentary conditions, a rapid evolution of their morphological framework, a great vulnerability as well as a considerable density in the ecosystems they shelter. Their degradation is an inescapable problem of national and international scope.

The spectrum of spatial and temporal variability being complex, we can only follow and understand these variations by having systematic observations to separate the different scales of space and time, and to understand the processes of transformation and their causes, that they are of natural or human origin. The monitoring, future and protection of these areas of capital importance (Guelorget and Perthuisot, 1983; Clavier et al.; 2005) now constitute a sustainable management issue. It is of certain interest to understand and try to explain the sedimentological processes that take place there in order to better manage and exploit them. Knowledge of sedimentary dynamics in estuaries makes it possible to understand the processes of siltation and clogging of which these environments are very often the seat.

The Ouladine lagoon in Grand-Bassam forms an estuarine complex with the Comoé River. Varied natural space with a strong ecological and economic richness (fishing, tourism), the estuary complex of Grand-Bassam, by its hydro-sedimentary dynamics and by the littoral drift, has its mouth subjected to an accelerated filling. Following this closure and its impact on this ecosystem, we undertook through this present study, to carry out work to make a sedimentary characterization of this estuary. This will allow us to follow up and bring some clarity to the processes of sedimentary dynamics. Also this study will allow to apprehend the processes of siltation and clogging of which these environments are the seat. At the end of our study, we will establish a spatial distribution map of bottom sediments.

2. Materials and Methods

2.1. Location of the Study Area

The Ouladine lagoon in Grand-Bassam is located between longitudes 30N 408,645 mE and 421,166 mE and latitudes 57,376 mN and 577,315 mN (**Figure 1**) with an area of 8271 km^2. This area is located on the sedimentary basin like the other mouths except the mouths of the Sassandra and Cavally rivers which are on the Precambrian base. It is laid out longitudinally, parallel to the loose coastline which isolates it from the sea like the other West African lagoons (Pinot, 1998). It is connected to the Atlantic Ocean by an estuary that is occasionally closed under the effect of coastal drift.

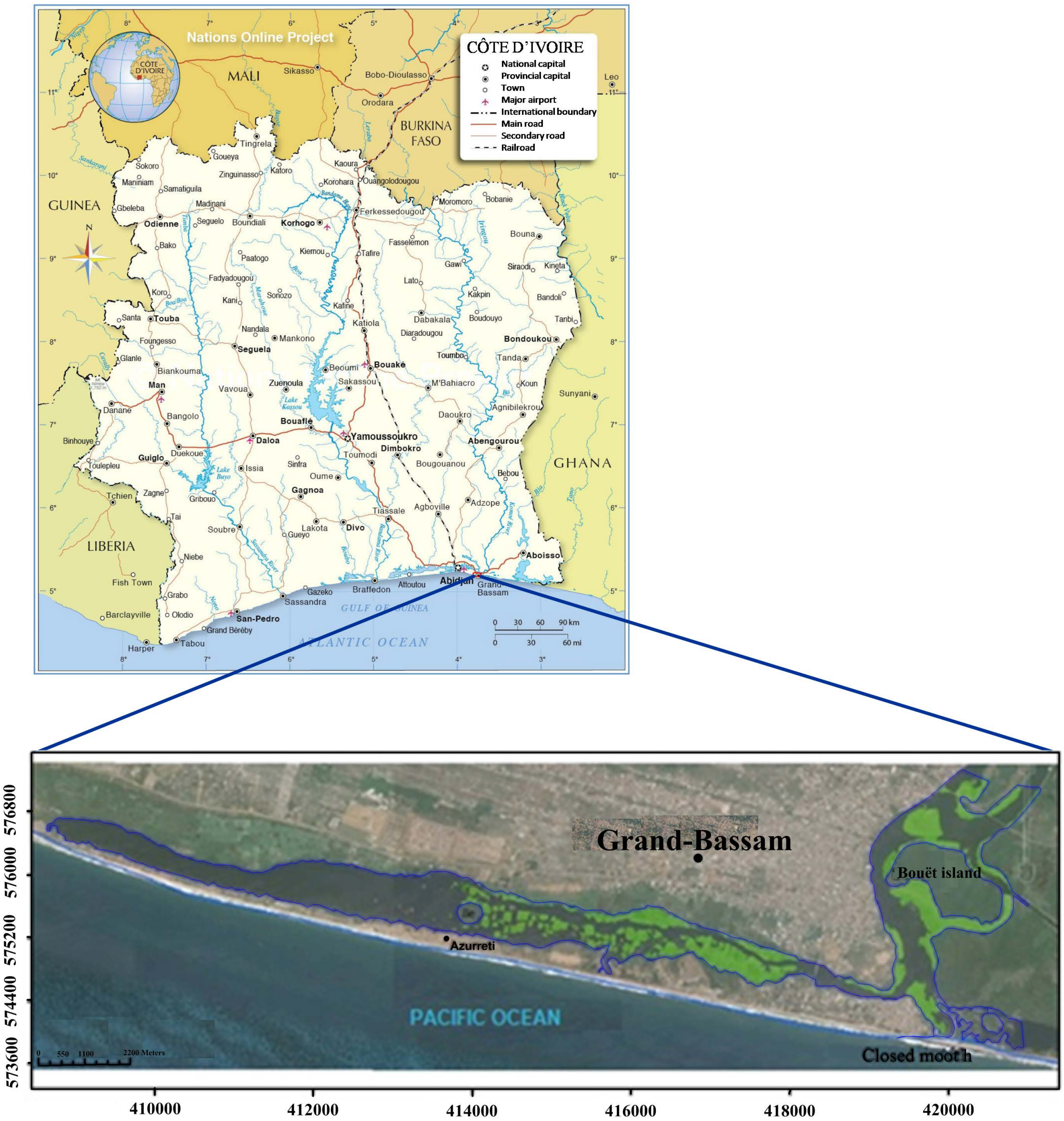

Figure 1. Location of the study area.

2.2. Sedimentological Study Protocol

Two sampling campaigns of the surface sediments of the Ouladine Lagoon were carried out during the months of June 2013 (wet season) and February 2014 (dry season). A total of 136 sediment samples were taken at varying depths covering the entire lagoon (**Figure 2**). Sampling was carried out using a Van Veen grab, which is a one-time sampling instrument. The location of the positions of the sampling points was carried out using a portable Magellan brand GPS.

The sediments are then stored in labeled plastic bags (sample number) for processing in the laboratory. In the laboratory, a lithological description of the sediments is made. It specifies for each sample the lithological nature, the color, the presence or absence of plant and animal debris. Tactile estimation of the abundance and type of grain of sand are present in the sediment. The determination

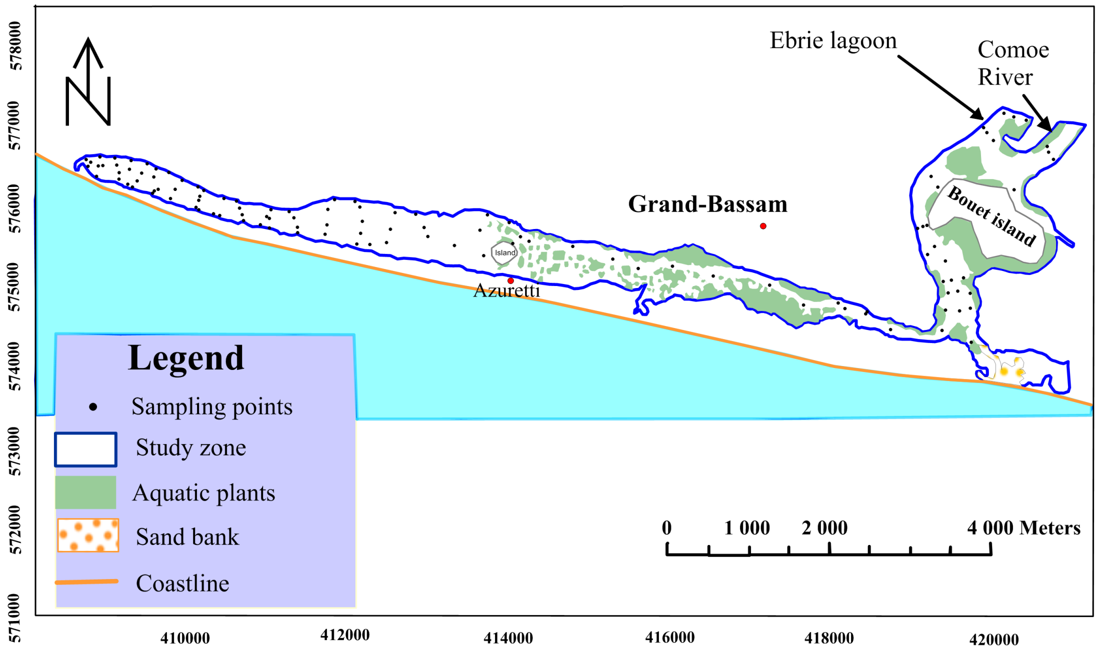

Figure 2. Ouladine lagoon sediment sampling plan.

of the color is an important data in the description of the sedimentary data. It was done using the standard color scale published by "the Geological Society of America" (McManus, 1988). After these steps, washing with tap water is carried out on a sieve with a mesh equal to 63 µm. This wet sieving made it possible to separate the coarse fraction (grain diameters > 63 µm) from the fine fraction (grain diameters < 63 µm). The washed samples are then attacked with 30% hydrogen peroxide then with 50% hydrochloric acid to eliminate organic matter and carbonates respectively. The samples are dried in an oven at a temperature of 100˚C for 24 hours. A fraction of 100 g of dry sediment is taken from each sample using an electric scale and placed at the top of a series of 16 AFNOR type sieves superimposed in order of decreasing mesh size between 5mm and 63µm. After stirring for 20 minutes, the sieve oversizes are successively recovered and weighed. The results obtained are noted in a spreadsheet made on Excel in order to deduce the percentage by weight of each dimensional class compared to the starting sample. For each sample, we established a grain size curve on a semi-logarithmic diagram. A few numerical ordering indices and parameters are determined. These parameters are obtained using the methods of Friedman (1967) and Folk (1974). From these indices and parameters, the mapping of the facies, the mode of transport and the deposition environment of the surface sediments of the Ouladine lagoon and its estuarine complex will be known.

3. Sedimentology of the Superficial Deposits of the Ouladine Lagoon

The sedimentology of the Ouladine lagoon bottom is characterized by a diversity of sediments which are distributed according to the morphology of the bottom.

3.1. Lithologic Characteristic of the Collected Sediments

The superficial lithologic facies observed at the estuary of the Ouladine lagoon-Comoé river complex made it possible to distinguish essentially muds, sands and mixed sediments consisting of sandy muds and muddy sands of variable color distributed as follows (Figure 3). These fractions are represented in different proportions. The results obtained show a significant variation in the rate of the coarse fraction (>63 µm) and the fine fraction (<63 µm). Indeed, the percentage of the fine fraction varies between 22.46 and 100% and that of the coarse fraction is between 0 and 77%. Their observation also shows that the sediments are very heavily loaded with organic matter.

The particle size distribution of the Ouladine lagoon is grouped into 4 coarse fractions: 63 - 125 µm, 125 - 250 µm, 250 - 500 µm and >500 µm and that <63 µm represents the fine fraction. The contents of these different grain size fractions show notable variations within the lagoon, making it possible to distinguish four types of facies distributed in Figure 3.

3.2. Granulometry of the Coarse Fraction of the Sediments

The granulometric of the sandy fraction makes it possible to characterize the deposits and to learn, consequently, about the nature, the factors governing the transport of the sediments, and the conditions of their installation. And also, to identify the factors and phenomena that control the sedimentary dynamics in the lagoon. Thus, from the grain size distribution of a given sample and using the cumulative curves, we were able to calculate different "particle size parameters".

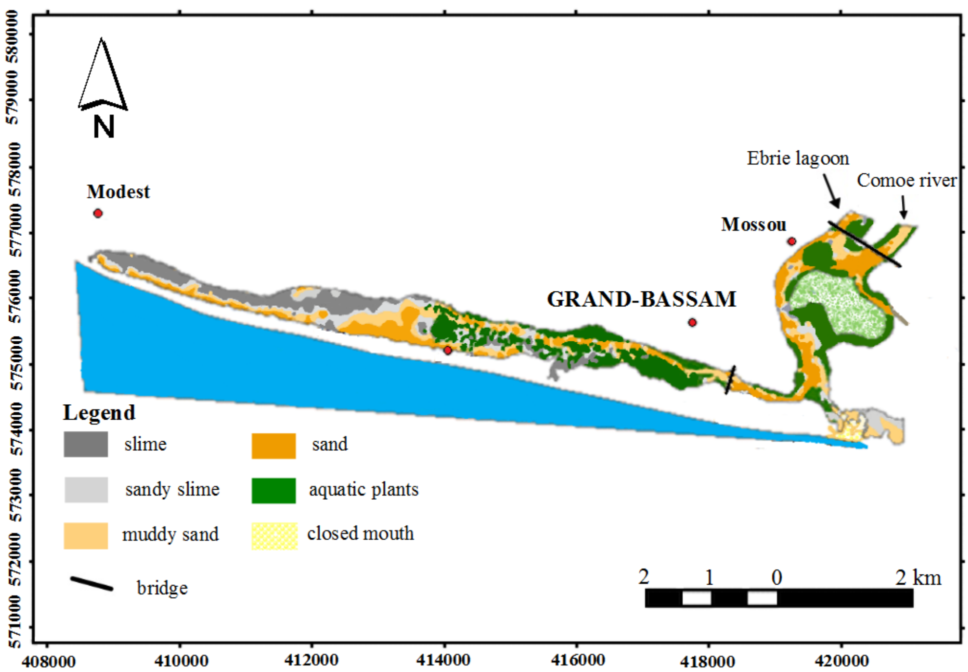

Figure 3. Distribution map of sediment proportions in the Ouladine lagoon.

3.3. Analysis of Cumulative Curves

The sediments taken from the Ouladine Lagoon are characterized almost entirely by cumulative curves having the shape of an S and parabolic curves (**Figure 4** and **Figure 5**). The curves having the shape of an S with a steep slope, well straightened and very regular despite the existence of slight differences in their appearance reflect a homogeneous sedimentary stock and the energy conditions adopted for the transported load (Brahim et al., 2008).

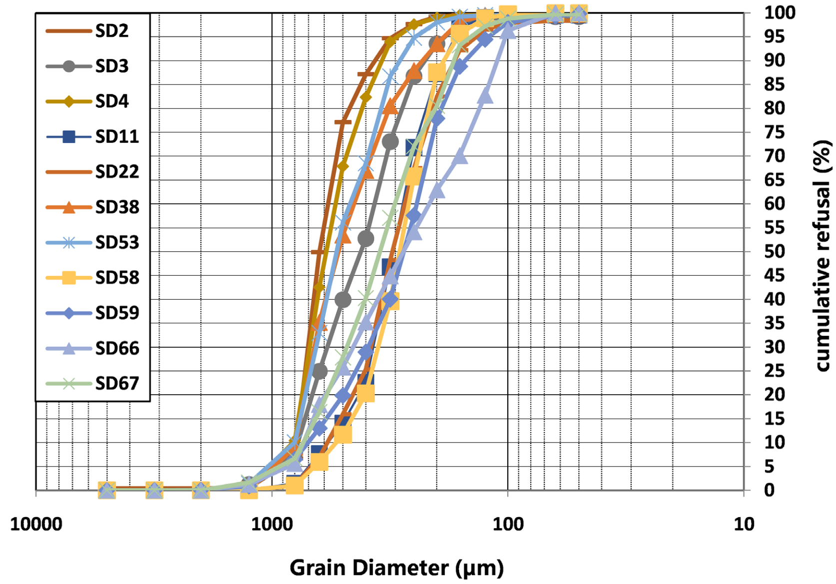

Figure 4. Granulometric curves of the superficial sediments of the Ouladine lagoon presenting an S shaped facies.

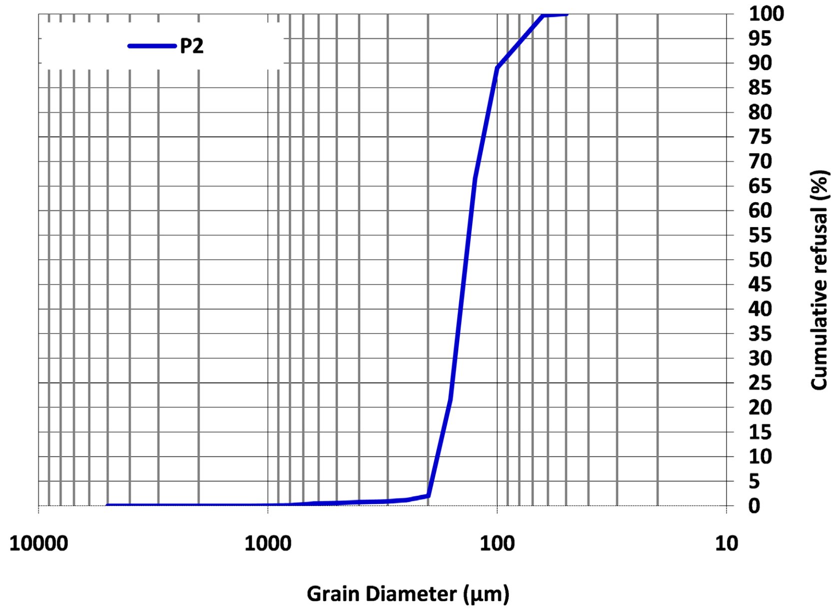

Figure 5. Granulometric curves of the superficial sediments of the Ouladine lagoon with a parabolic facies.

3.4. Particle Size Indices

3.4.1. The Mean and the Median

The mean (M) defines the average grain size (Folk & Word, 1957). The median is the size corresponding to 50% of the grains on the cumulative curve. They reflect the particle size distribution of the sediment and the average kinetic energy during sediment deposition.

$$M = \frac{Q16 + Q50 + Q84}{3} \quad (1)$$

Over the extent of the lagoon basin, the average of the sediments collected varies between 109.67 and 1033.67 µm, i.e. in phi (ϕ) units, from 0.21 to 3.23 ϕ indicating a spatial presence of fine to coarse sands. According to the distribution of Folk (1966),

- Medium sands are the most represented of the samples taken, i.e. 52.63%;
- Coarse sands have almost the same frequency of presence (44.73%);
- The fine sands have the lowest frequency (2.63%) and are located mainly to the east of the lagoon towards the closed mouth and at a depth of almost 5m where current turbulence is weak allowing settling by gradient.

3.4.2. The Standard Deviation

The standard deviation gives an idea of the dispersion from the mean. It characterizes the degree of classification of the sample studied.

$$Sd = \frac{Q84 - Q16}{4} + \frac{Q95 - Q5}{6.6} \quad (2)$$

We note that the standard deviation of the cumulative curves of the sands of the Ouladine lagoon varies from 0.13 to 2.74 with a trend less than 1. Thus, according to the classification of Friedman (1962 and 1967) (**Table 1**), the sand sediments are very well classified to very poorly classified with a majority of the moderately classified sediments. The very poorly classified sediments are located at the entrance to the Ebrié lagoon. Those very well classified meet at the western end of the lagoon and around the bridge in the France district towards the northern shore.

Table 1. Distribution of the classification of sedimentary facies according to the average.

Standard Deviation	classification
Sd > 4	Extremely misclassified
4 > Sd > 2	very poorly rated
2 > Sd > 1	Misclassified
1 > Sd > 0.7	Moderately Rated
0.7 > Sd > 0.5	Moderately well ranked
0.5 > Sd > 0.35	Well rated
0.35 > Sd	Highly rated

3.4.3. Skewness

The asymmetry of a distribution reflects a better (or worse) classification of fine particles compared to that of large particles. It results in the following report:

$$Sk = \frac{Q84 + Q16 - 2Q50}{2(Q84 - Q16)} + \frac{Q95 + Q5 - 2Q50}{2(Q95 - Q5)} \quad (3)$$

This parameter is often presented as an indicator of the sediment deposition environment (**Table 2**).

Overall, the skewness distribution map between −0.65 and 1.12 µm shows a range of deposits: very asymmetrical sands towards the ends represent 20%, positive asymmetry sands towards the ends, 34.28%, very asymmetrical sands towards the coarse, 17.14% and almost asymmetrical sands represent 25.71%. Their installation was done by a generally weak current.

3.4.4. The Uniformity Coefficient

The uniformity coefficient which is equal to the ratio of d60 (grain diameter corresponding to 60% of the cumulative weight) to d10 (representing 10% of the cumulative refusal) is less than 2 for all the samples analyzed. This shows a uniform sediment granulometry in the Ouladine lagoon. Note that a single sample (Sd38) has a coefficient greater than 2 (i.e.: 2.27) reflecting, so to speak, a varied or spread grain size.

3.4.5. The Particle Size Mode

The analysis of the particle size modes shows two types of deposit:

- a bimodal sand with main modes of 315 µm and 630 µm, it is a medium to coarse sand which characterizes the sandy zone of the southern shore from the western end to the island of Azuretti;
- a unimodal sand with main modes of 125 µm, it is a medium sand, which is located both at the level of the main channel of sections II and III of the lagoon and coarse sands which are located in the eastern section of the lagoon.

3.4.6. The Passega Diagram

The position of the representative points of surface sediments on the Passega diagram (**Figure 6**) made it possible to show the different modes of sediment transport:

Table 2. Distribution of sedimentary facies according to the index of asymmetry (Folk, 1966).

Skewness	classification
1 > Sk > 0.3	very asymmetrical sands towards the ends
0.3 > Sk > 0.1	Asymmetrical towards the ends
0.1 > Sk > −0.1	Almost asymmetrical
−0.1 > Sk > −0.3	Asymmetric towards coarse
−0.3 > Sk > −1	Very asymmetrical towards the coarse

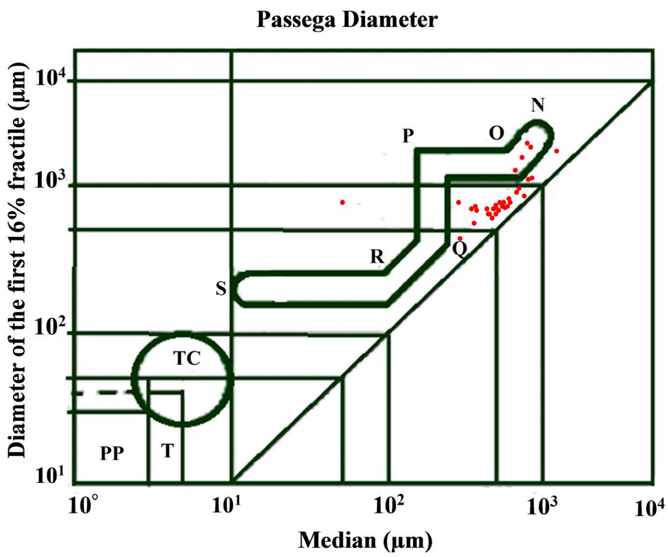

Figure 6. Position of the representative points of the sands taken from the Ouladine lagoon in the Passega diagram translating their mode of transport.

- transport by saltation presenting the majority of the samples to which are added a few grains transported by rolling for the Sd65 samples; 62; 61 represented by the segment (QP) of the Passega diagram,
- transport exclusively by rolling (ON branch) characterizing coarse sediments, example of sediments P17; 16; 13; 12; 8.

4. Determination of the Deposition Environment

The grain size index diagram shows the different origins of the lagoon sands (Figure 7). The sands are mostly dune or river sands, beach sands (Sd1, Sd2, Sd3, Sd4, Sd11, Sd17, Sd18). These multiple origins of the sediments reveal the estuarine character of the Ouladine lagoon.

5. Discussion

Since the closure of the Grand-Bassam estuary, the water balance in the Ouladine lagoon is mainly controlled by water inflows from the Comoé, the Ebrié lagoon system (Ebrié, Potou and Adjin) and seasonal waters from the rainfall. The estuary directly receives precipitation, which represents 5% of continental inputs. The annual averages recorded for the period from 1950 to 1998 are 1890 mm. This average marks a decrease in the volume of precipitation since 1950, which fell from 2359 mm between 1949 and 1958 to 1513 mm between 1989 and 1998 (Kouassi, 2005).

The morphology of the bottom of the lagoon at the entrance to the Comoé River and the Ebrié Lagoon is greatly shaped by the currents during the rainy and flood season of the Comoé with a maximum depth of 13.7 m. We note, compared to the bathymetric studies of Adopo (2009), that the depths have

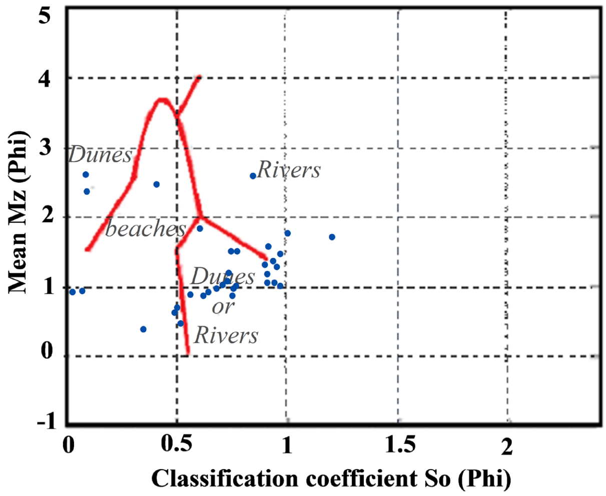

Figure 7. Distribution of sands according to So-Mz showing their origins.

changed very little. A difference in depth of 0.3 m at the confluence of the Comoé River and the Ebrié lagoon shows overall that the area is getting richer. This fattening is supported by the work of TASTET since 1979 where the maximum depths were 18 m. Since the closure of the mouth, the Comoé River-Ouladine lagoon estuary complex now behaves like a sediment receptacle. Thus, it is subject to the accumulation of all kinds of sediments (sand and silt).

On the section parallel to the coastline, the Ouladine lagoon has several depressions with a major SE-NW direction. They are sub-parallel to the fault of the lagoons called "Major accident" of Côte d'Ivoire. This oceanic fracture would be at the base of the establishment of the depressions of the Ouladine lagoon that the covering formations would fill with difficulty because of the lagoon currents which run through them. This is why we will say, since the bathymetric work of Coulibally in 2008 on this portion of the lagoon, that the observed depths hardly vary. Only the depression at the level of the bridge which joins the colonial district observes a variation in depth. His work shows a depth of 5.5 m while our work measures this depression at 7.2 m deep, a difference of 1.7 m. This area is subject to a vortex movement that promotes erosion and digging. To these swirling movements, we must add the mechanisms generating lagoon currents which would be the thermohaline forces, that is to say linked to temperature and salinity. These analyzes harmonize with the work of Allenbach (1989) which shows that when two large masses of water of different density (different temperature and different salinity) are present, they tend not to mix except very partially with the level of their contact zone. As a result, the one with the highest density tends to pass below the less dense one, which generates a current.

The distribution of the superficial sediments of the Ouladine lagoon to the west is essentially shaped by winds and storms: During tides and storms, seawater reaches the lagoon through the passes and/or through the sub-lowered areas of the sand bar. Thus the coarse sands are deposited in the vicinity of the southern shore and the finer elements migrate towards the northern edge. during non-rainy seasons or during heavy storms before the dunes are wet, the fine sand particles are carried by the wind to settle on the northern edge of the lagoon. these fine, clayey particles also reach the lagoon by runoff and leaching from the land bordering this shore. Siltation all along the north shore is favored by the weak current, negligible to strip the surface of the lagoon bottom. The aquatic plants that have invaded most of the lagoon in this section favor the establishment of muddy sediments very rich in plant organic matter.

The North-South section, that is to say, from the Ebrié lagoon-Comoé river confluence to the closed mouth, is animated by the current from these two water inlets. As a result, most of this section is periodically remobilized (ABE, 2005) to present a mostly coarse to medium sedimentology compared to the mud which is always located at the level of aquatic plants and in areas where the current is very low.

6. Conclusion

The sedimentological study carried out on the estuary complex of the Ouladine lagoon-Comoé river revealed different characteristics of this hydrosystem.

It should be noted that a bathymetric study was carried out to characterize the deposit zones of the different sediments. It reveals depths that vary between 0 and 13.71 m, an average of about 6.85 m. The great depths are located at the entrance to the Comoé River and the Ebrié lagoon. The west side of the lagoon is shallower. There are west-east and north-south direction channels which are cut by depressions and shoals. With the closure of the mouth, the depths on the North-South section decrease from upstream to downstream to constitute a reception basin for the sediments which pass through it.

On the sedimentological level, the surface samples studied made it possible to distinguish muds of variable colors which occupy approximately 43.79% of the total area of the study area. These muds are mobilized because of the weak current in the western section of the lagoon and also because of the aquatic plants which favor their deposit. They are mainly found along the northern shore of the western section. The sedimentary fraction > 63 µm represents the majority with 56.21% of the study area. They are located along the southern bank of the western section and along the north-south section from the entrance of the Comoé River to the closed mouth.

The particle size analysis of the fraction greater than 63 µm shows the presence of coarse sediment representing 44.73% and 52.63% for the medium sands. Fine sands, very little represented with a percentage of 2.63%, are located at the closed mouth where there is a deposit of sediments by decantation.

According to the Passega diagram, grain size indices, "Sorting" (So) and average (Mz), the sands of the estuarine complex were set up by saltation for most of the samples and by rotation. The diagram of the classification coefficient So and the average Mz, allowed us to determine the different origins of the sands which line the lagoon bottom. Thus, the average of the sediments comes from dunes or rivers and seven other samples have the characteristics of beach sands. This diversity of origin reflects the estuarine character of the Ouladine lagoon which is a complex bringing together a river, a lagoon and the Atlantic Ocean.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Abe, J. (2005). *Contribution à la connaissance de la morphologie et de la dynamique sédimentaire du littoral Ivoirien (cas du littoral d'Abidjan): Essais de modélisation en vue d'une gestion rationnelle* (309 p.). Thèse de Doctorat d'Etat ès Sciences Naturelles, Université de Cocody.

Adopo K. L. (2009). *Caractérisation du fonctionnement hydro-sédimentaire d'un environnement estuarien en zone tropicale: Cas de l'embouchure du fleuve Comoé à Grand-Bassam (sud-est de la Cote d'Ivoire)* (154 p.). Thèse Doctorat Université Cocody.

Allenbach, M. (1989). *Les méthodes de l'océanographie géologique du littoral. Applications au domaine méditerranéen: Zone littorale est algéroise en baie de Zemmouri-el-Bahri (Algérie)* (366 p.). Thèse de Doctorat d'Etat ès Sciences Naturelles, Université de Nice.

Brahim, M. et al. (2008). *Etude de l'hydrodynamique sédimentaire de la lagune de Bizerte*. Bull. Inst. Natn. Scien. Tech. Mer de Salammbô, Vol. 35.

Clavier, J., Boucher, G., Chauvaud, L., Fichez, R., & Chiffletd, S. (2005). Benthic Response to Ammonium Pulses in a Tropical Lagoon: Implications for Coastal Environmental Processes. *Journal of Experimental Marine Biology and Ecology, 316,* 231-241. https://doi.org/10.1016/j.jembe.2004.11.004

Folk R. L. (1974). *Petrology of Sedimentary Rocks* (170 p). Hemphill Publishing Co.

Folk, R. L. (1966). A Review of Grain-Size Parameters. *Sedimentology, 6,* 73-93. https://doi.org/10.1111/j.1365-3091.1966.tb01572.x

Folk, R. L., & Ward, W. C. (1957). Brazos Rivers Bar: A Study in the Significance of Grain Size Parameters. *Journal of Sedimentary Research, 27,* 325-354. https://doi.org/10.1306/74D70646-2B21-11D7-8648000102C1865D

Friedman, G. M. (1962). Comparison of Moment Measures for Sieving and Thin-Section Data for Sedimentary Petrological Studies. *SEPM Journal of Sedimentary Research, 32,* 15-25. https://doi.org/10.1306/74D70C36-2B21-11D7-8648000102C1865D

Friedman, G. M. (1967). Dynamic Processes and Statistical Parameters Compared for Size Frequency Distribution of Beach and River Sands. *Journal of Sedimentary Petrology, 37,* 327-354. https://doi.org/10.1306/74D716CC-2B21-11D7-8648000102C1865D

Guelorget, O., & Perthuisot, J. P. (1983). *Le domaine paralique Expressions géologiques, biologiques et économiques du confinement* (136 p.). Travaux du Laboratoire de Géologie, Paris, No. 16.

Kouassi, A. M. (2005). *Hydrochimie et qualité des eaux des lagunes Ebrié et de Grand-Lahou de Côte d'Ivoire* (155 p.). Thèse de Doctorat, Université de Cocody.

Lankford, R. R. (1977). *Coastal Logons of Mexico. Their Origin and Classification Estua-*

rine Processes (Vol. II, pp. 182-215). Academic Press Inc. https://doi.org/10.1016/B978-0-12-751802-2.50022-9

McManus, J. (1988). Grain Size Determination and Interpretation. In M. Tucker (Ed.), *Techniques in Sedimentology* (pp. 63-85). Blackwell Scientific Publ.

Nichols, M., & Allen, G. P. (1981). Sedimentary Process in Coastal Lagoon. In *Coastal Lagoon Research Present and Future* (pp. 27-80). UNESCO Technical Papers in Marine Science 33.

Pinot, J. P. (1998). *La gestion du littoral* (2 Vol., 759 p.). Institut océanographique.

Tastet, J. P. (1979). *Environnements sédimentaires et structuraux quaternaires du littoral du golfe de Guinée (Côte d'Ivoire, Togo, Bénin)* (181 p.). Thèse de Doctorat d'Etat Sc. Nat, Univ. Bordeaux I.