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Sedimentary Dynamics of the Bay of Béago in Yopougon (Abidjan, Côte d'Ivoire): Morph-Bathymetric, Lithological, and Morphoscopic Approaches

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Abstract

The bay of Béago, like the entire Ebrié lagoon, is considered to be a relatively stable environment and an environment conducive to anthropogenic activities, of both biological and socio-economic interest. However, the discharge of water and garbage caused by the population as well as the dredging of sand can pollute and degrade the bay of Béago. The objective of this study is to characterize the sediments and conduct the bathymetric study of the bottom of this bay. Morphologically, the lagoon has a regular relief that is rugged in places and a strong depression to the northeast and northwest. It has the greatest depths of more than 18 m and shoals at the level of the banks. The bathymetry of the bay of Béago highlights three types of channels: the "V" "U" and intermediate channels. These channels reflect intense erosion, a balance between the agents of accumulation and erosion, and an imbalance between the agents of erosion and accumulation. The particle size study of the sediments highlights two types of lithologies: the sandy facies and the muddy facies. Two main classes are contained in the sands. These are coarse sands (20%) and medium sands (80%). Most of the sediment was deposited in a fluvial environment from a variety of feeder sources, including rivers and coastal dunes. Quartz grains have various shapes (angular to sub-angular, rounded to subrounded, and dull rounds, the most dominant of which are those of sub-angular) with a more blunt shiny appearance, which indicates transport in an aqueous medium over a relatively short distance. The samples of vases taken made it possible to determine two lithologies: silts and clays. All of these vases are dominated by silts with a rate of 87.5% compared to 12.5% of clays.

Keywords

Bathymetry, Sediments, Béago Bay, Côte d'Ivoire

1. Introduction

The Ebrié lagoon, the largest in West Africa abounds in several bays, including the bay of Béago, which is the subject of this study [1] [2]. The lagoons are the transit point for most of the continental inflows. Understanding the interrelations between the continent and the ocean requires the study of brackish environments, which play an essential interface role since they are the site of complex phenomena related to exchanges between fresh and marine water [3]. Côte d'Ivoire has a lagoon system located in the coastal zone to the south. The Bay of Béago and the other Ivorian lagoons, along with the adjacent ecosystems, constitute real livelihood supports for the surrounding populations. These populations settled on the shores of the lagoons have, among other things, fishing, dredging sand quarries, tourist facilities, hotel complexes, a sawmill on one of the banks of the bay, and navigation. These activities result in an unfavourable change in the natural characteristics of these brackish environments. In addition, the dredging of the seabed and the discharge of wastewater into the bay of Béago disrupt the hydrology and ecology of the environment. The Ebrié lagoon, including the bay of Béago, the subject of this study, is the receptacle of many urban and industrial effluents and runoff water from the city of Abidjan [4]. Previous work on the Ebrié lagoon has focused on hydrodynamics, morph-bathymetry, sedimentology, water mass circulation, geochemistry, hydroclimate, and salt and freshwater dispersion modelling [5]-[9]. Recent work on the Ebrié lagoon has focused on the sedimentology, geochemistry, and palynology of the bedrock of Banco Bay [10]. Studies on morphosedimentology have not been carried out on Béago Bay, but socio-economic activities such as dredging, sawmills, and hotels could alter the morphology and distribution of sediments. This study will deal with the bathymetry, sedimentology, and depositional environment of the surficial sands of this bay.

2. Materials and Methods

2.1. Presentation of the Study Area

Béago Bay (**Figure 1**), located in the western branch of the Ebrié lagoon, is situated between latitudes 5˚87' and 5˚62' North and longitudes 3˚82' and 3˚81' West. This shallow bay, oriented in the WE direction, is about 1725 km long and between 435 m and 855 m wide, with an area of about 1.5 km^2. The shape of Béago Bay is approximately quadrilateral. The banks are generally sandy, but above 1 meter, there is black and putrid mud covered by abundant plant debris (branches and leaves in the process of decomposition). The village that houses this bay is located in the southern part of the commune of Yopougon, more precisely to the northeast of Azito village and to the south of Kouté village. It is also 25 km from the commune of Plateau.

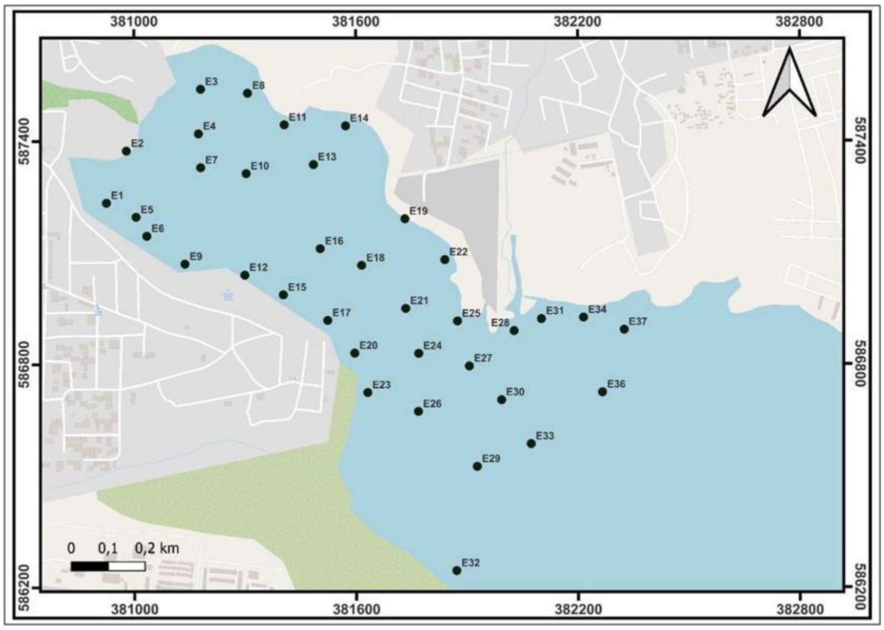

Figure 1. Location of the study area.

2.2. Methodology

2.2.1. Bathymetric Analysis Methods

A conventional acoustic echo sounder (**Figure 2**) emits a sound pulse through a beam directed along the vertical of the ship and measures the time it takes for this signal to travel the ship-bottom and bottom-ship path. The moment of detection results in a strong echo from the bottom. For each transmission, the sounder provides a value of the water level under the ship by analyzing the return signal. Knowing the speed of propagation of sound in water (C: The speed of sound in water is on the order of 1450 m/s) and then the time (dt: seconds) between the emission of the signal at the surface of the water and the reception of the echo from the bottom of the water, the depth (Z in meters) of the water column is obtained using the formula:

$$Z = C * dt/2$$

2.2.2. Sedimentometric Analysis Methods

1) Sediment sampling techniques

Work carried out in Béago Bay aboard a motorboat enabled several samples to be taken. These samples were taken along lines perpendicular to the shore and at a few points between these lines. Using a Van Veen dredge, the jaws of the dredge were opened and then, using a rope, it was gradually lowered into the lagoon until it reached the bottom. Once the bottom was reached, the dredge was pulled upwards to allow it to close and collect the sediments, which were then stored in numbered plastic bags. As currents made this operation difficult in some places, the use of GPS made it possible to identify and position the sampling points.

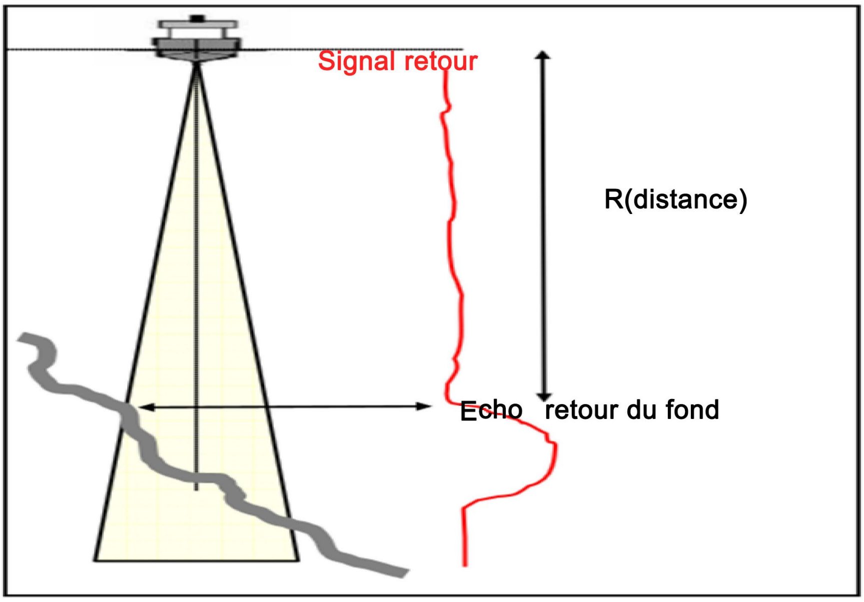

Figure 2. Echo sounder.

2) Lithological description of the surface sediments of Béago Bay

The description consisted of making a visual and tactile observation of the sediments. Thus, the lithological nature, the colour indicated by the Munsell code, and the presence or absence of plant and/or animal debris in the sediments are determined.

3) Particle size analysis of sands

This analysis makes it possible to determine the respective percentages of the different particle size classes present in the sands. In the laboratory, 5 out of 37 samples were sand. Only these five samples of sandy sediment could be collected from the environment. These sands have undergone a pre-treatment to allow us to determine the particle size.

After the pre-treatment of the samples, the sieving is carried out on a sieve column following the Udden-Wentworth progression (US standard). The technique consists of taking 100 g of the dried sediment using an electronic scale (B) to sieve it through a column of seven (07) sieves with meshes of (A): 4000 µm; 2000 µm; 1000 µm; 500 µm; 250 µm; 125 µm; 63 µm. (1000 µm = 1 mm). The sieves are arranged in descending order from top to base. After pouring the material into the column, the lid is attached to it and the mechanical vibrator is turned on for 10 minutes. The grains will go down the sieves until they are blocked by the mesh corresponding to the diameter of the grain. The rejection of each sieve is then weighed to determine the proportion of the fraction in the sample.

The particle size parameters sought are: quantiles, mean, standard deviation, asymmetry, and kurtosis. The calculation of the parameters will be done by the method of moments [11] [12]. These parameters were determined using the Gradistat 8.0 software [11].

The determination of the particle size facies is carried out according to the shapes of the cumulative curves. This method makes it possible to characterize the curves by referring to the particle size facies defined [13].

The study of the mode of transport is carried out using the test [14]. It relates the grain size to the mode of transport.

Deposition environments are determined from the So-Md and Md-Sk diagrams [15].

Morphoscopic grain analysis involves determining the size, appearance, and shape of quartz grains using a binocular magnifying glass attached to a computer.

3. Results

3.1. Morphology of Béago Bay

3.1.1. 2D Bathymetric Map of Béago Bay

Analysis of the bathymetric map of Béago Bay shows that the depths vary from 0 m to 18 m, with an average of 3.78 m (**Figure 3**). The channel is NW-SE. The greatest depths are in the southeast. On the other hand, the shallowest depths are located in the NW and in the center of the bay. This great depth can be explained by the intensity of the dredging carried out in these places. There is an irregular relief.

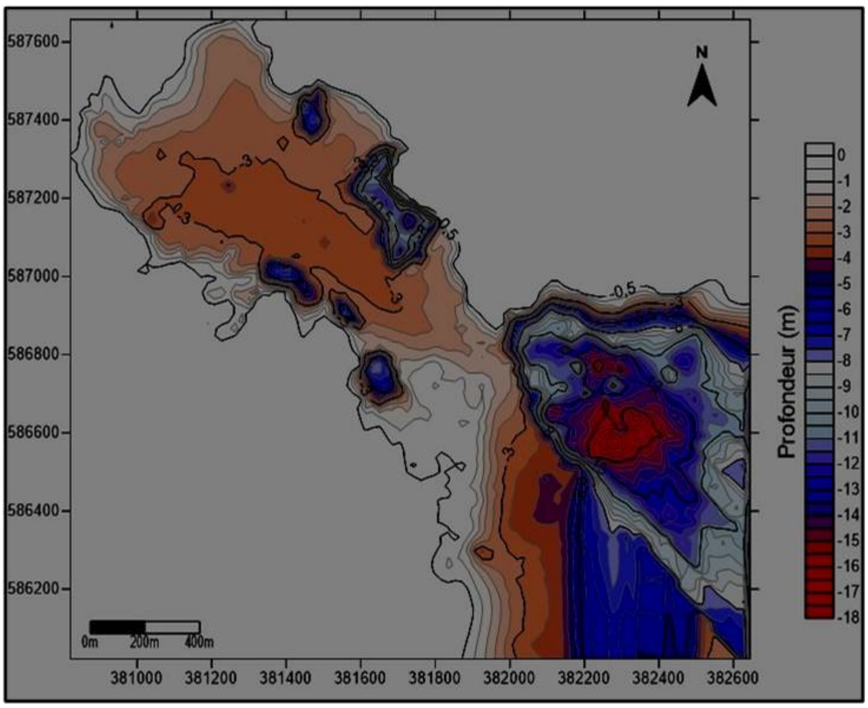

Figure 3. 2D bathymetry map of Béago Bay.

Characterization of Channels and Bathymetric Profiles

Analysis of the bathymetric profiles of Béago Bay shows the "V" "U" and intermediate type profiles (**Figure 4**). The profiles (P1 to P8) were drawn in a parallel direction NE-SW and perpendicular to the main channel of the bay.

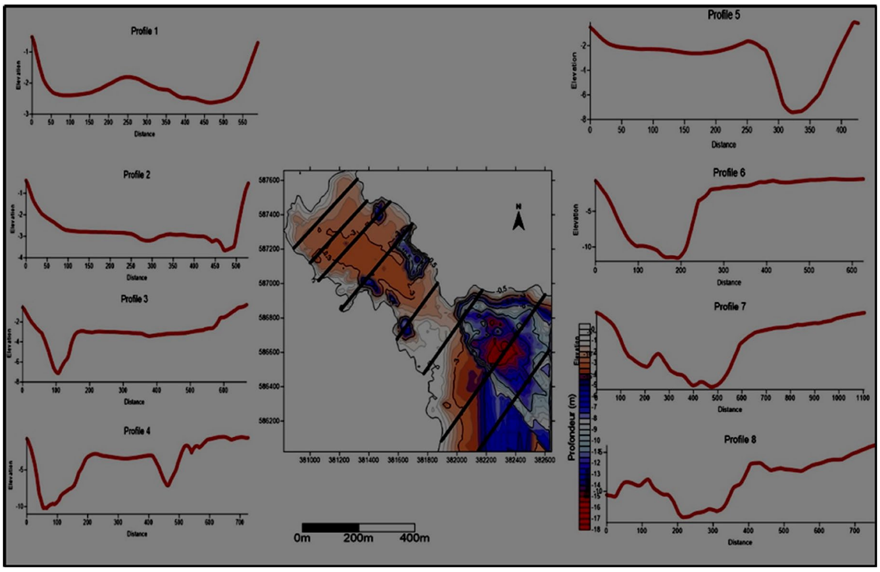

Figure 4. Channel positioning map.

3.1.2. 3D Bathymetric Map of Béago Bay

The 3D map facilitates the observation of depressions and shoals (Figure 5). The largest depressions are located in the southeast between latitudes 586,400 to 587,000 m and longitudes 382,200 to 382,600 m. This may be due to anthropogenic pressure from intense sand dredging activity or intense erosion. As for the shoals, they have shallow depths and are located in the northwest between latitudes 587,200 to 587,800 m and longitudes 381,000 to 381,800 m. They can be caused by the deposition of sediment from runoff.

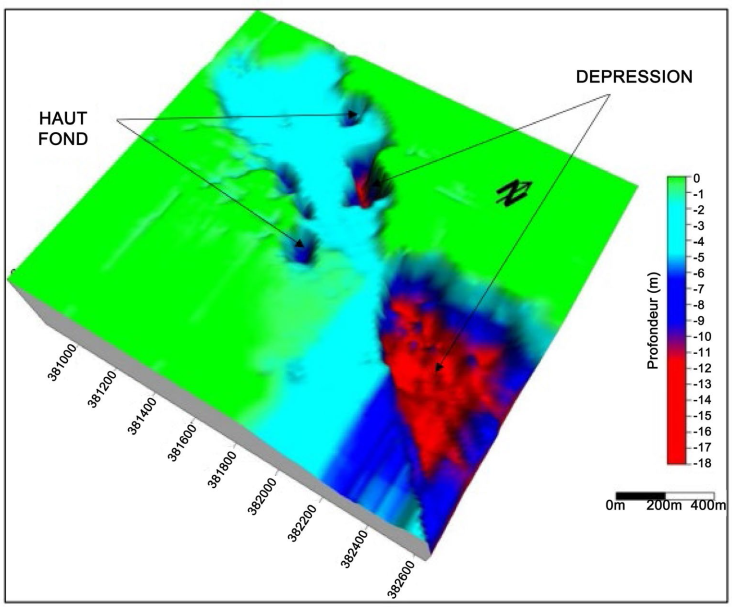

Figure 5. 3D bathymetric map of Béago Bay.

3.2. Sedimentology of Béago Bay

3.2.1. Lithology of Surface Sediments

The macroscopic description of the sediments highlights two main lithological facies. A muddy facies occupies most of the bottom of the bay of Béago. These are vases of varying colours rich in shell and plant debris. Indeed, they range from olive black (5Y2/1) to olive grey (5Y3/2). The sandy facies vary from yellowish-brown to varying degrees (10YR 2/1) to greyish-brown

£(N2), according to Munsell's code. The bay of Béago is mainly covered by mud, which represents about 86.49% of the sediments of the bay, *i.e.*, 2/3, and about 13.51% for the sands, *i.e.*, 1/3 (Figure 6). The sands are located on the banks and the mud at the bottom of the bay of Béago.

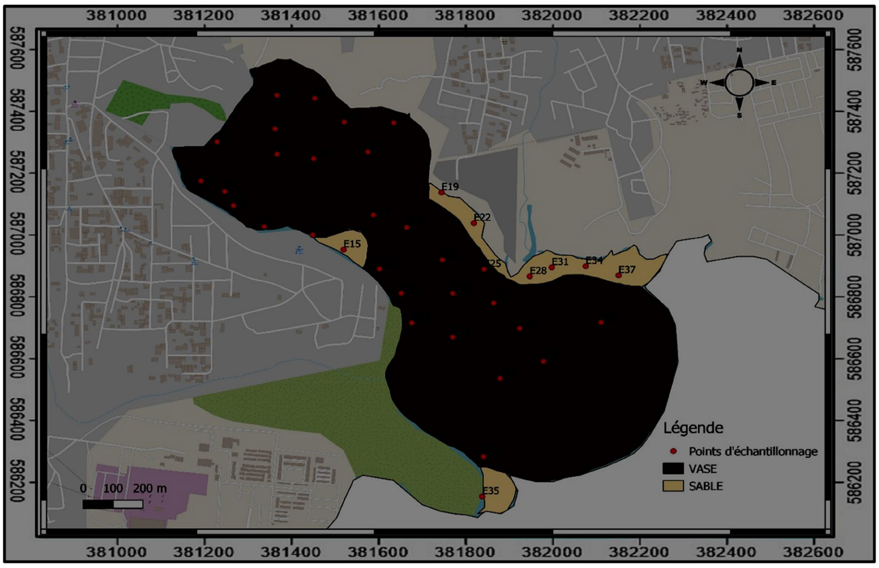

Figure 6. Map of the spatial distribution of sediments in Béago Bay.

3.2.2. Particle Size Parameters

The dynamic conditions of the environment at the time of deposition determine the particle size of a sediment. The results obtained (Table 1) show that the E15 sample has an average (Mz) between 0 ϕ and 1 ϕ, which means that the sands are coarse, while the E19, E28, E35, and E37 samples have an average in the range of 1 ϕ to 2 ϕ, so these sands are average. Samples E15, E19, and E37 have a classification (SO) between 0.71 and 1.00; therefore, they are moderately ranked, whereas E28 and E35 have their SO between 0.50 and 0.71, so are quite well ranked. The skewness (ski) of samples E15, E19, E35, and E37 is less than 0 and therefore has a negative asymmetry. Therefore, there is a preponderance of coarse sizes in relation to the average of the sample. As for E28, its ski (g1) is greater than 0, and there is a positive asymmetry. Thus, fine sizes are abundant compared to the sample average. The grain size of the sands of the bay of Béago is average on the whole, with an asymmetry towards the coarse elements. Indeed, the divergence of the swell in this area leads to lower energy, thus putting the coarse, medium, and fine elements on the spot, which gives a sand that is moderately classified and fairly well classified.

Table 1. Particle size parameters of the Béago sediments.

Samples	Mz (Φ)	S	Ski	Interpretation
E15	0.887	0.896	−0.197	Coarse, moderately graded sand, negative asymmetry.
E19	1.066	0.931	−0.418	Medium-sized, moderately graded sand, negatively asymmetric.
E28	1.619	0.546	0.251	Average sand, fairly well ranked, positively asymmetrical.
E35	1.226	0.695	−0.019	Average sand, fairly well graded, negative asymmetry
E37	1.595	0.986	−0.360	Medium-sized, moderately graded sand, negative asymmetry.

3.2.3. Morphoscopic Quartz Grains of the Bay

The morphoscopic analysis of the quartz grains of the bay focused on five (5) grains from each sandy sample. A total of twenty-five (25) samples were analyzed and revealed four (4) forms, dominated by the subangular forms (**Table 2**) and two (2) aspects, the most abundant of which are the blunt and shiny aspects (**Table 3**), which highlights the influence of a short water transport time and a fluvio-marine dynamic process.

Table 2. Shapes of the entire quartz grains of Béago Bay.

Quartz grain shape	Subangular	Angular	Subarrondies	Rounded	Total
Number of samples	17	2	5	1	25
Proportions (%)	69.36	6.48	20.14	4.02	100

Table 3. Aspects of the Béago Bay quartz grain set.

Appearance of the grains	Blunt Glossy	Round-Mat	Total
Number of samples	21	4	25
Proportions (%)	85.37%	14.63%	100

3.2.4. Mode of Transport of Sandy Sediments

The application of the Visher test (1969), illustrated in **Figure 7**, makes it possible to distinguish three (3) sand populations in Béago Bay as of 29/01/2022. These are:

- Population C of coarse sand with grains transported by bedload, with a proportion of 90%;
- Population A of medium sand, whose grains are transported by saltation, with a proportion of 10%;
- Population B of fine sand with grains transported by suspension, with a proportion of 0%.

It is clear that the most dominant mode of transport in the Bay of Béago is bedload.

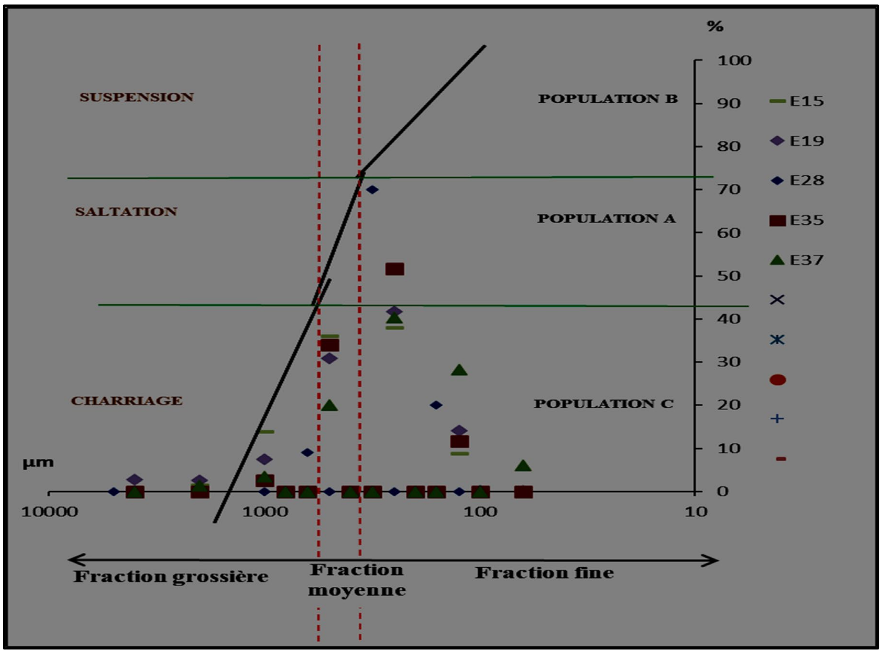

Figure 7. Mode of sediment transport in Béago Bay.

3.2.5. Repository Environments

The distribution of points in the Md-So diagram reveals that 75% of the sediment comes from the river domain and 25% from the beach domain. In addition, the Sk-Md diagram shows a scatter plot mainly concentrated in the coastal dune domain. This distribution of grains highlights that the sediments located on the edge of Béago Bay are mainly river and coastal dune sands.

3.2.6. Particle Size Classes of Vases

In the 32 muddy samples, 16 samples were chosen according to different facies to define the particle size classes. The particle size study of the sedimentary fraction below 63 µm revealed two proportions of particle size classes. These are silts and clays (Table 4).

Table 4. Particle size classes of the muds of the bay of Béago.

ECH	Years (m)	Long (m)	%SILTS	CLAYS
E2	380,979	587,374	62.5	37.5
E3	381,180	587,540	40.93	59.07
E5	381,005	587,196	58.34	41.66
E9	381,137	587,070	52.61	47.39
E10	381,303	587,313	79.59	20.41
E13	381,485	587,337	75	25
E16	381,503	587,111	78.57	21.43
E18	381,615	587,066	65.38	34.62
E21	381,734	586,950	64.47	35.53

Continued

E22	381,840	587,081	62.96	37.04
E25	381,874	586,916	65	35
E26	381,768	586,673	58.34	41.66
E27	381,906	586,795	73.9	26.1
E29	381,927	586,525	75	25
E33	382,073	586,586	73.91	26.09
E34	382,215	586,926	44.82	55.18

Silts are most numerous in the muddy facies of Béago Bay, except in samples E3 and E34, where the percentages of clays are dominant compared to silts.

4. Discussion

4.1. Morph-Bathymetry of Béago Bay

The bathymetric soundings carried out in the bay of Béago show depths of up to 18 m. The characterization of the channels of the bay of Béago has highlighted profiles of "V," "U," and the intermediate shape. Channels with a "V" profile are the result of an intense erosion process; this type of channel has a concavity with an acute bottom. This type of morphology can be observed in the South-East and North-Centre. The intermediate profile is a profile that has not yet reached its equilibrium shape, which is the "U" shape. Overall, the "V" shape is in the majority, which is in line with the results obtained [16] [17]. These authors state that in Côte d'Ivoire, the channels of fluvial, lagoon, and estuarine origin encountered are of the "V" type. The presence of "U" type channels naturally in the bay of Béago shows that this bay has been affected by glaciation. Similarly, if we admit the existence of "U" type channels artificially, this would mean that the "V" type channels would have been modified into "U" type channels following sand dredging or following the filling of sandy and muddy sediments. The silt is deposited by simple settling, while the sand is the result of the remobilization of sandy sediments from the banks, which, thanks to the steep slopes of the bay (up to 20% and more), slide into the axis of the bay during periods of agitation of the water body. Since the sediments trapped in the lagoons far exceed in volume those that escape, hence their tendency to fill, it is conducive to dredging activities. Given the number of intermediate profiles obtained that tend to form the "U" type channels, these show by their great depths that the existence of the "U" type channels in the bay is artificial. In this case, it would be due to the heavy dredging activities carried out in this bay.

4.2. Particle Size and Morphoscopy

The particle size study of the sedimentological data collected shows that the sands of the bay of Béago are, on the whole, coarse to medium, with a particle size that is a function of the hydrodynamics of the environment. These results are in line with the descriptions made, for whom the sands of the main channel are generally coarse to medium [18]-[20]. In addition, the values of the ranking index and the asymmetry do not go beyond 1. These results indicate that the sandy fractions of the surface sediments of the Comoé River estuary have a fluvial paleoenvironment [21]. The nature of the modal appearance of the lagoon indicates that there are various sources of supply, or that there is a mixture of sediments by the confluence of rivers or an irregularity of water flows [22]. The sediments would therefore be brought into the bay by runoff, the rivers, and the Agnéby River.

Morphoscopy has revealed shiny blunt quartz grains with a predominantly angular shape, reflecting a relatively short transport in an aqueous medium [23]. The main mode of sediment transport in the eastern channel of the Ebrié lagoon is saltation, with 60.89%, and a beach-type or coastal depositional environment. However, our results present bedload as the main mode of transport and a river-like deposit. This difference in results can be explained by the sampling period. Indeed, the samples used in this work were taken in the dry season on January 29, 2022, while used were sampled in the rainy season (July 2015) [24].

4.3. Sedimentology of the Muds

The bottom of the waters of the bay of Béago is largely lined with mud. This could be explained by the feeding of the Ebrié lagoon system, which is essentially suspended by rivers and by runoff water on the banks [25] (Tastet and Guiral, 1994). The predominance of quartz grains (sand) in the sediments would mean that these sediments are supplied with quartz by wind inputs, erosion of boundary formations, and detrital terrigenous fluvial inputs [26].

5. Conclusion

The sedimentary dynamic study of the bay of Béago has made it possible to highlight the morph bathymetry, allowing the analysis of the channels, followed by a study of the sandy sediments and muds. The morphological study carried out during the low water period shows depths that vary from 0 to 18 m, with an average of 3.78 m. The greatest depths are in the southeast, the medium depths in the north-centre at the level of the banks, and the shallow ones are located in the northwest. The bay evolves on a main channel in a NW-SE direction, marked by major depressions to the southeast and shoals to the northwest. The analysis of the channels shows "U" type channels in places, reflecting a deposition on the radial. However, we note the presence of "V" type channels resulting from erosion processes, and intermediate type channels indicating an evolution of the "V" type into "U" type or vice versa. The sediments sampled are of two different types: sand and mud. The particle size of the sandy sediments revealed two particle size classes. These are coarse and medium sands. These sands are mostly moderately to well classified. Three modes of transport have been distinguished: saltation, bedload, and suspension. The sands are mostly angular to sub-angular, with a more blunt, shiny appearance. Silts are more abundant than clays in the muddy facies.

Conflicts of Interest

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

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