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RELATIONS BETWEEN MAN AND NATURE AND ENVIRONMENTAL DYNAMICS AT THE MOUTH OF THE KOMOÉ RIVER, GRAND-BASSAM (IVORY COAST)

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Abstract: The mouth of the Komoé River is situated in south-eastern Ivory Coast. The entire shoreline is composed of a sequence of partially or totally closed coastal barriers and lagoons. The maximum depth during the lowest water level is 12 m, but it increases to 14 m during high waters. In 1979, the maximum depth was 18 m. The estuary that communicates with the Gulf of Guinea through a natural opening was permanently blocked due to massive clogging; it is currently a lagoon. The most important hydrotechnical project in the area is the Vridi channel, which was inaugurated in 1951 and is located in the Ebrié lagoon (situated west of the mouth of the Komoé River). This study focuses on the relations established between the dynamics of the aquatic setting and the economic activity conducted by the local population. During the period 2005–2007, the bottom of the Komoé lagoon cuvette suffered extensive erosion or deposition alterations: mean variations of -5 cm were recorded for erosive surfaces and 15–20 cm for deposition surfaces. The channel, which is influenced by fluvial runoff, features three morphological types of riverbed: the "U"-shaped channels are in balance with depositional and erosive agents; the "V"-shaped channel is specific to erosive sectors; the intermediary morphology marks the change from erosion to deposition. A 3‰ increase of the salinity has been recorded. During the period 2006–2007 the total volume of deposited sand was 760,458 m^3. The granulometry is directly related to the shape of the particles and decreases upstream to downstream, from 765μm to 240μm. The closure of the opening to the sea and the accentuation of the clogging process at the mouth of the Komoé River require the implementation of new hydrotechnical projects: the artificial reopening of the communication with the sea; the elimination of harmful economic activities (e.g., the semi-wild animal breeding, the elimination of household waste, etc.); channelling the old inlets; refreshing the waters and eliminating the eutrophisation process, etc.

Keywords: barrier spit, bathymetry, coastal lakes and lagoons, coastal geomorphology, dynamic beach

1. INTRODUCTION

An estuary is a space of both confrontation and consensus. It is a hybrid environment located at the interface between the river and the sea. It is an intermediate space seeking an identity. The characteristics of estuaries give one the impression that they have unlimited space and are places where water and land fuse at an undefined horizon. The estuary is the place where eternity meets the ephemeral. It is the permanent and contrasting expression of the relations between man and nature. The physical-geographical and anthropogenic conditions lead to the occurrence of highly varied processes at the mouths of large rivers. The most important factors are the liquid and solid discharge transported by the river and the water mass moved by the tide. Furthermore, there are active or passive factors that act on this environment, such as climate, neotectonics, lithology, geologic structure, etc. Hence, the solid particles transported by the two environments-fluviatile and maritime-permanently model the morphostructure of the landscape. The mouths of the main water streams are subjected to on-going transformations, due to both natural and anthropogenic factors.

Globally, most estuaries that are situated in economically developed regions have been significantly altered: St. Lawrence, Thames, Rio La Plata, Gironde, Tajo, Elba, Loire, etc. Human interventions may have positive or negative consequences. Some work at the river basin or near the shorelines may lead to a partial or total closure of the river mouths. In this case, lagoons may emerge that are created by humans (Allison, 1998; Battacharya & Giosan, 2003; Buynevich, 2007; Byrne & McCann, 1990; Galloway, 1975; Giosan et al., 2006; Hesp, 2002; Nordstrom, 1994; Oertel, 1985; Romanescu, 2014; Stutz & Pilkey, 2002). Because of the recent changes to the environment, such events have occurred on the coast of Ivory Coast.

The attraction to the river mouths for navigation development has led to the elaboration of numerous interdisciplinary studies, on both an international (Colin, 1988; Guira & Ferhi, 1992; Hossain et al., 2014; Romanescu, 2013a,b; Romanescu et al., 2012a,b) and a national level (Abe et al., 1996; Adopo et al., 2008a,b; Caulibaly et al., 2011; Hauhouot, 2008; Koffi & Abe, 1991; Kouakou et al., 2007; Kouassi et al., 1995; Monde et al., 2007, 2011; Sankare & Etien, 1991; Sankare et al., 1991).

The purpose of this study is to reveal the spatial-temporal dynamics of the morphological parameters within the estuary and on the corresponding littoral barrier: bathymetry, nature and granulometry of sediments, thickness of lagoon and river deposits, solid discharge carried by the river, erosion and progradation rates, determination of the annual sedimentary budget of the Komoé River, etc. The main objective is related to understanding the hydro-sedimentary phenomena at the mouth of the Komoé River and their related issues: alluviation, eutrophisation, development of aquatic vegetation, transportation issues, reduction in the amount of fish, etc. The research stages are summarised according to a simplified plan (Table 1).

Table 1. Breakdown the research stages

No	Research stage
1	Bibliographic documentation
2	Establishing the measurement points
3	Morphometric measurements Topographic Planimetric Bathymetric
4	Elaborating the thematic maps
5	Analysing the data and elaborating the general conclusions

2. PHYSICAL GEOGRAPHICAL CHARACTERISTICS OF THE STUDY AREA

The catchment area of the Komoé River is situated between 3° and 5°30' West longitude and 5° and 11°30' North latitude. The estuarine sector of the Komoé River is situated in the eastern part of the Ebrié lagoon, between 5°12' and 5°14' North latitude and 3°43' and 3°44' West longitude. The old estuary represents the mouth of the Komoé River and part of the surrounding lagoons (Fig. 1).

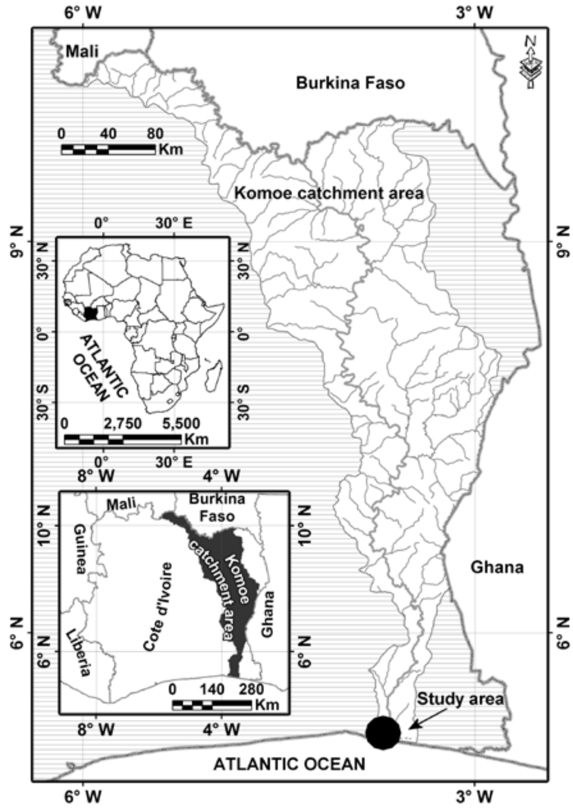

Figure 1. Geographical location of the Komoé hydrographic basin and of the coastal zone near the river mouth

The Ebrié lagoon contacts the lagoon at the level of the Komoé River in the locality of Moossou. A couple of kilometres to the south, the estuary comprises other small-sized lagoons: Ouladine and Mondoukou. The old inlets have remained 11 km away from the current stream, which trends in a north-south direction at the river mouth (Koffi & Abe, 1991). Because of high maximum discharges (historical maximum of 2,300 m^3/s), the Komoé River has managed to break into the littoral barrier in several sectors and has left visible traces near Azureti and around the Ouladine lagoon. The littoral barrier openings are currently closed.

The Komoé River springs from Burkina Faso, near the locality of Péni. It crosses the State of Ivory Coast from north to south. It flows into the Guinea

Gulf (Atlantic Ocean) east of the Ebrié lagoon (approximately 40 km from Abidjan). It has only a few, low-discharge tributaries: Léraba, Iringou, Bayakokoré, etc. It is 813 km long and its catchment area has an area of 82,408 km^2. It lies within a tropical rain regime and has a mean annual discharge at Agniassué (278 km from the river mouth) of 106 m^3/s (for a 70,112 km^2 area surface, which corresponds to 85% of the total surface area). The recorded mean annual discharges significantly increased between the years 1982 and 2006, from 112 m^3/s in 1982 to 2,300 m^3/s in 2006 (Fig. 2).

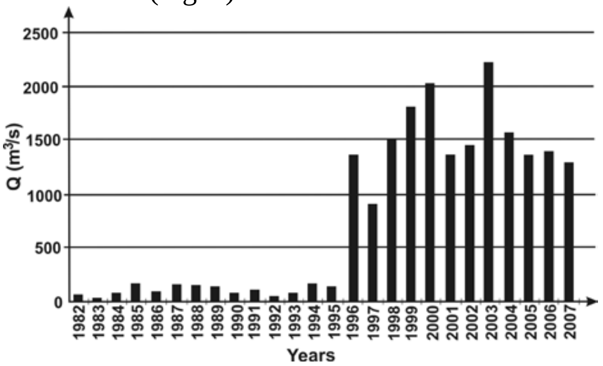

Figure 2. Variation of the annual discharge of the Komoé River in the period 1982–2006

The crystalline basement rocks of the catchment area belong to the West African craton, specifically to the Man shield. It is subdivided into two domains: Kénéma-Man, which is Archean in age, and Baoulé-Mossi, which dates to the Lower Proterozoic. The two domains are separated by the Sassandra fault. They consist of granitoids, mica schists, gneisses, migmatites, dolerites, quartz, gabbro, etc. (Bessoles, 1977). The sediments cover the Precambrian basement and consist of clay, sand, ferruginous sandstones, etc.; they are 170 m thick and belong to the Quaternary and the Mio-Pliocene.

The hydrological regime is influenced by the climatic regime, mostly by the pluviometric regime. The Komoé catchment area falls within three types of climates: transitional and moderate (upper stream), transitional and equatorial (middle stream) and transitional equatorial (lower stream) (Figure 3a). The alternation between wet and dry periods makes the river supply highly variable from one month to another. Precipitation decreases from north to south. The irregular hydrological regime causes the March peak monthly discharge to reach 1.3 m^3/s and the September peak monthly discharge to reach 467 m^3/s. The average monthly discharge for March was 0.2 m^3/s (200 litres), and the peak monthly discharge for September was 1,020 m^3/s. The minimum low tide discharge was 42 m^3/s, while the peak historical discharge is 1,814 m^3/s. The flood wave—which emerges between August and November—comprises 60% of the total water volume of runoff for the year. The low discharges occur between December and May, while the high discharges occur between June and November. The highest average monthly discharges occur in the months of August, September, and October (Fig. 3b). The catchment area is covered with savannah vegetation. The gallery forests develop along the minor riverbed. The water blade that flows down the slopes is 48 mm, which indicates a mediocre runoff considering the high evaporation rate within the climatic regime of the area. The hydrological regime of the Komoé River is influenced by agricultural water requirements. The largest quantity of water is used for irrigation.

The hydrotechnical projects executed at the level of the river mouth include the construction of a connection channel between the Guinea Gulf and the lagoon complex. The marine and river water masses that were set in motion before and after the construction of the Vridi channel (within the Ebrié lagoon) are different. In a natural context, the tidal wave penetrated the lower course of the Komoé River through a 300 m wide and 3.5 m deep opening.

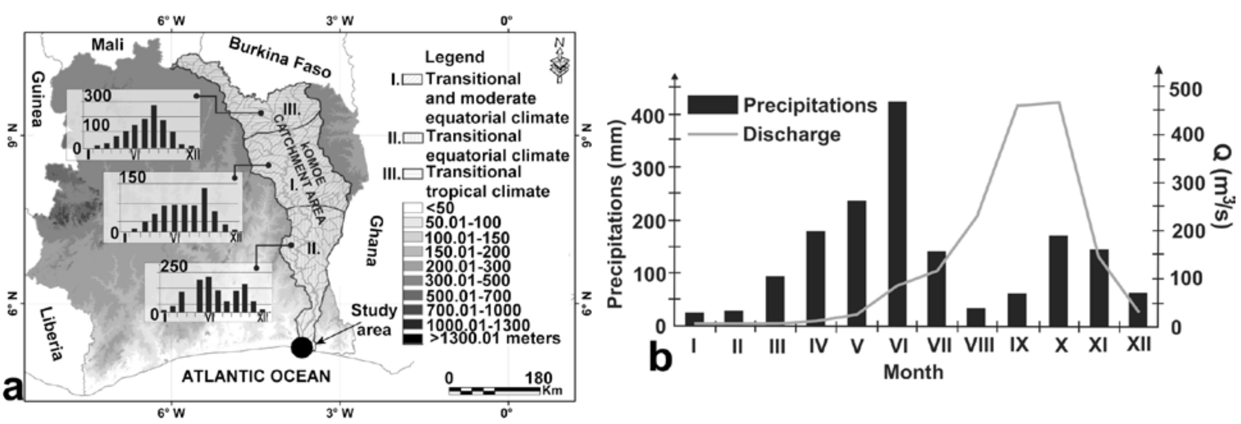

Figure 3. Types of climate in the Komoé hydrographic basin (a); Monthly repartition of precipitations and of average discharge in the Komoé hydrographic basin (b)

The saline cone determines the emergence of sectors with different salinity levels: >30‰ at the confluence with Ouladine; between 10 and 13‰ at the confluence with Adjin and Potou; <10‰ in the central part of the Ebrié lagoon. In this case, the evacuation from upstream was much higher than the inputs from downstream. The construction of the Vridi channel (2.7 km long, 230 m wide, 12 m deep), for facilitating transport in the area of the Abidjan harbour, caused a displacement of the lagoon sector due to significant penetration of the saline cone upstream. In this case, the central zone of the Ebrié lagoon has 20‰ salinity.

The significant penetration of the saline cone indicates an acceleration of sedimentation in the northern and eastern sector of the lagoon, at the confluence with the Komoé River and with the more important tributaries. The main freshwater supplier is the Komoé River (75%); discharge from tributaries that output directly into the lagoon complex is added to the main supply. The volume of the river inputs that penetrate the lagoon complex measure 8.4^9 m^3, while the maritime inputs contribute 38.1^9 m^3. Although it is situated far from the mouth of the Komoé River, the river materials that enter the lagoon complex are eliminated for the most part through the Vridi channel. The oceanic material reaches its maximum during low waters and its minimum during floods.

From a morphologic perspective, the Ivorian coast is characterised by the existence of low cliffs and low beach zones. The low coast has ante-Holocene and Holocene sedimentary formations. The littoral barrier that encompasses the mouth of the Komoé River has a width of 5 km and the sedimentation contributes to its increase in width by an average of 1 m/year. Coastal modelling is influenced by maritime (waves, aquatic currents, tide, levels, etc.) and fluvial (solid discharge, liquid discharge, fluvial current speed, etc.) factors. The effect of tides can be felt as far as 70 km away along the river stream (as far as Alépé).

3. MATERIALS AND METHODS

For the geographical positioning of the elements and for the terrestrial and aquatic measurements, the following devices were used: a portable GARMIN GPS 40, positioned as a constellation of 24 satellites, of which 21 are main satellites and 3 are secondary satellites; a GPS Leica 1200 System to measure the beach profiles; a Lowrance LMS-160 echo-sounder for the bathymetric elevations of the lagoon complex at the mouth of the Komoé River.

The topographic elevations targeted seven profiles that are distributed over the entire littoral barrier (Fig. 4a): three profiles east of the ship channel that connects the lagoon to the ocean; three profiles to the west; one profile on the main river stream, near the mouth. The measurement distance between two consecutive stations was 200 m. The measurement points were chosen from among the immovable objects found in the environment: coconut trees, houses, etc. The beach profiles were determined before assessing the evolution trend. The superposition of the beach profiles at the same measurement point and the calculation of erosion or deposition rate and volume were determined based on the trapezium and triangle geometric calculation methods.

For the bathymetric measurements, the echo-sounder was placed according to the RGIR001-CCT geodesic point of Abidjan. The soundings had a frequency of 160 kHz to prevent the penetration of the muddy layer. In this case, the sounding measures the distance between the echo-sounder and the water–sediment interface. The sounding corrections were performed after determining the actual depths of each point. The corrections are relevant to the diving value of the echo-sounder and the dynamic tide: for the real sounding, one must also add the diving value of the echo-sounder and the value of the tidal range during the measurement. The bathymetric map was created using the Golden software “Surfer.”

The water samples were collected using a Nansen bottle. The turbidity was determined in the laboratory using a HANNA turbidity meter (model LP 2000). The physical-chemical properties of the water (temperature, pH, salinity, redox potential, conductivity, dissolved oxygen) were measured using a W.T.W. 82362 multi-parameter sounder and a CRISON OXi 330 portable meter. Water samples were collected each week during all four hydrological seasons: the long dry season (from December to May), the long wet season (from May to July), the short dry season (from July to October) and the short wet season (from October to November). A total of 1,344 water samples were collected at 13 measurement stations (Fig. 4a). For a maximum water depth of 14 m, water samples were taken at 0.5 m, 2 m, 5 m and 10 m to conserve homogeneity. For filtering of the solid material in suspension, WHATMAN GF/F glass microfiber filters (47 mm in diameter and 0.45 μm porosity, weighed beforehand) were used. The filters were dried out for two hours at a temperature of 105ºC. The solid annual load of the estuary of the Komoé River obtained is dependent on the seasonal concentration of the samples.

The sediment samples from the bottom of the river mouth were collected using the Van Veen grab. The drying out process took place in an ECOCELL 111 steriliser; a Sartorius BP 610 balance with 0.1 mg precision was used for weighing the samples. A D407-020 polymeric container was used for sieving. Samples were collected in every season at eight measurement stations; three points were collected for each transect (two on the shorelines and one in the channel) (Fig. 4b). The granulometric analyses were conducted on dry samples. The organic matter contained in the sediments was eliminated with oxygenated water, and the shell detritus was dissolved with hydrochloric acid. The sieved samples weighed 100 g. The cartographic material used consisted of topographic maps with 1:50,000 and 1:200,000 scales prepared by the Centre de Cartographie et de Télédétection de Cote d'Ivoire, geological maps, satellite imagery, etc.

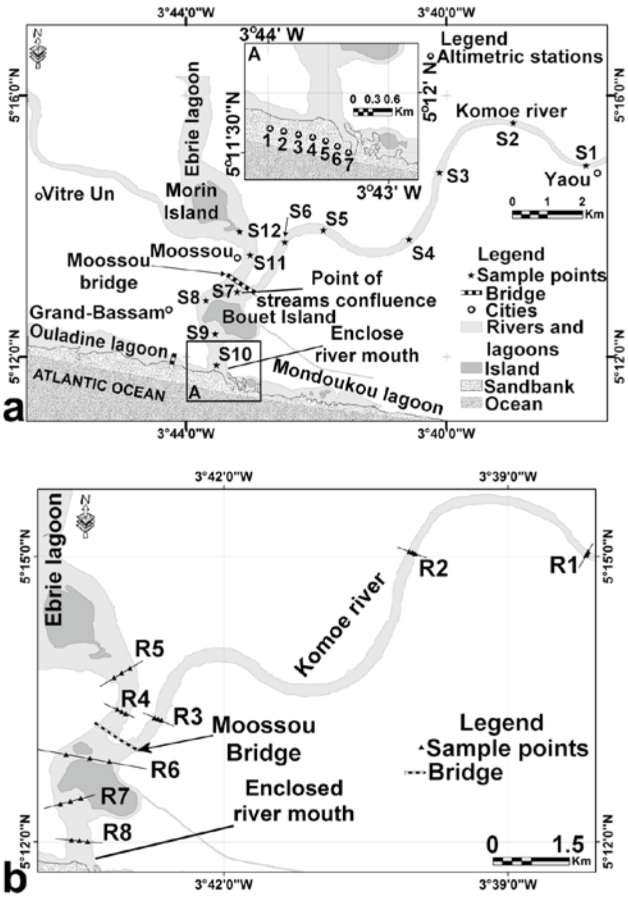

Figure 4. Repartition of measurement stations and sampling on the littoral barrier and distribution of the sampling points for water samples in the lagoon complex of the Komoé River (a); Repartition of measurement stations and sampling on the littoral barrier and distribution of the sampling points for water samples in the lagoon complex of the Komoé River (b)

4. RESULTS

The battle of the two forces—fluvial and maritime—means that the alluvia deposited in the lagoon complex is continuously in motion. The largest amount of solid fluvial discharge is rolled along on the bottom of the riverbed (Milliman & Meade, 1983; Morton et al., 2000; Phillips, 1991). For the rivers in the temperate climate zone, the bed load discharge represents only 2-4% of the total solid discharge. For the Komoé River, the bed load discharge, which is usually coarse, makes up 70-80% of the total discharge (Bodge, 1999).

The disposal of solid material occurs in two ways: in calm waters, when the fluvial liquid discharge is reduced, and in agitated waters, when the fluvial liquid discharge is high. Due to this, there is an alternation of vertical and horizontal sedimentation. The phenomenon is also intensified by the penetration of the saline cone (dynamic tide).

The depths in front of the mouth of the Komoé River reach a maximum value of 12 m at low water level and 14 m during high waters. The morphology of the Komoé estuary and of the water stream is complex (Fig. 5). The orientation of bathymetric curves underlines the existence of a channel with a NE–SW direction. The bottom of the estuary rises in the downstream-upstream direction.

The maximum depth of the estuary is 14 m around the locality of Moossou. The slopes of the lagoon cuvette are weak, varying between 0.4 and 0.6%. The depth downstream from the confluence of the Komoé River with the Ebrié lagoon increases rapidly from 1.5 m to 5 m, over a distance ranging between 50 and 200 m.

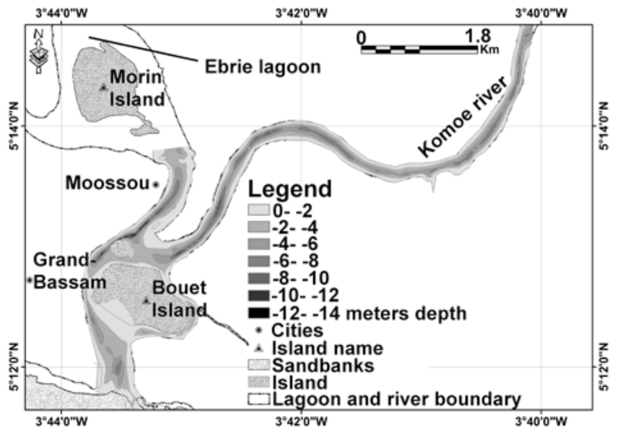

Figure 5. Bathymetric map of the lower stream of the Komoé River

The depths at the confluence of the Komoé River with the Ebrié lagoon do not usually exceed 1 m. The sediment loads favour the development of aquatic vegetation. The main channel of the Komoé River is deeper on the east shoreline within the lagoon complex. The relatively flat morphology is maintained along most of the channel, in a "U" or "V" (saw-like) shape (Figs 6a,b).

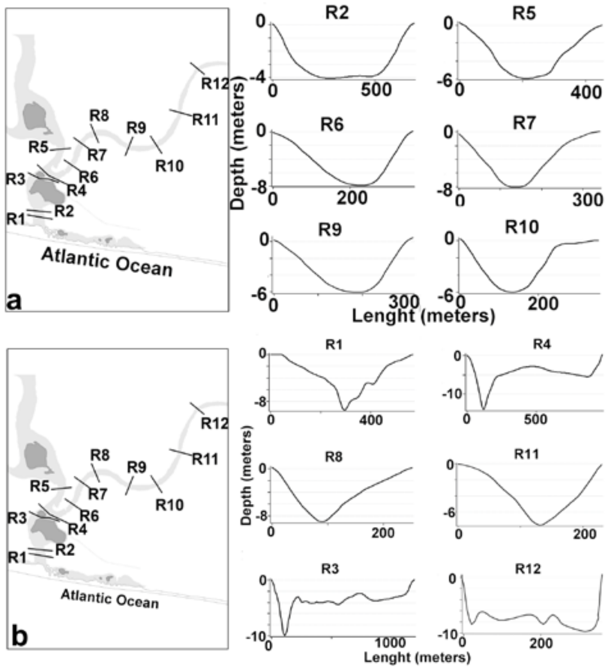

Figure 6. “U”-shaped bathymetric profiles (a); “V”-shaped (saw-like) bathymetric profiles (b)

The “V”-shaped profile shows the existence of significant erosion. The transverse “U”-shaped profile shows a balance between the deposition and erosion agents. However, the action is cyclic and erosion or deposition may change in intensity.

For the evolutionary characterisation of the bottom of the lagoon cuvette at the river mouth, the 1.14 m reference level for the aquatic surface was considered. During the period of 2005-2007, the bottom of the Komoé lagoon cuvette suffered extensive erosion or deposition alterations. In this case, mean variations of −5 cm were recorded for erosive surfaces, and 15-20 cm for deposition surfaces (Fig. 7a). The sediment assessment for this period shows the dominance of sediment loading (580,500 m^3) and an erosion volume of 285,000 m^3 (Figs 7b,c,d).

The littoral barrier beach that encompasses the mouth of the Komoé River is permanently modelled by maritime and continental factors. In this case, sand loads are reshuffled. The transport has a two-way pattern, dependent upon the force of the factors that act on the littoral level. The profile measurements were collected during all four seasons: June–July 2006, August–September 2006, October–November 2006 and March–April 2007 (Table 2–7; Fig. 8).

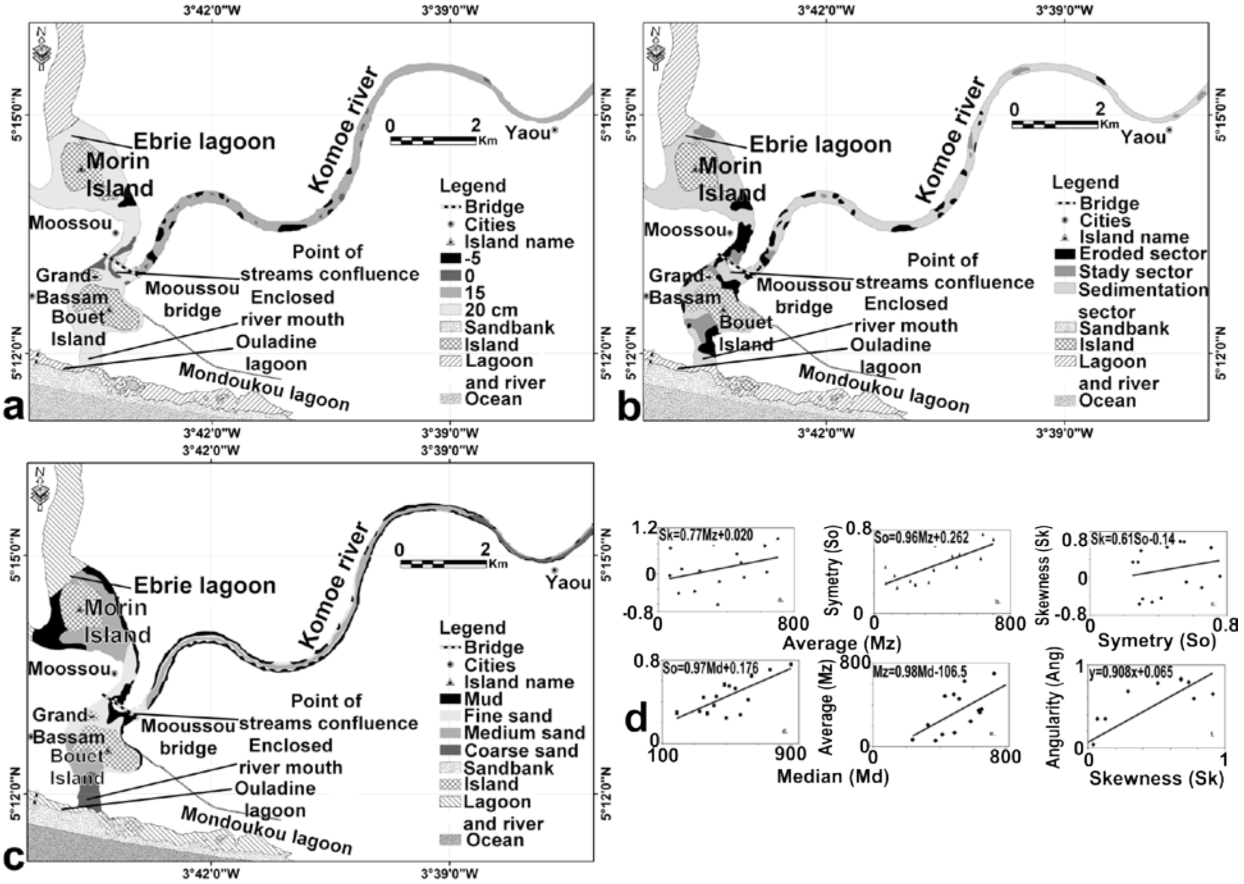

Figure 7. Distribution of unconsolidated bottom deposits in the lagoon complex at the mouth of the Komoé River (a); Map of interpolation between erosion and deposition areas in the lagoon complex of the Komoé River (b); Repartition of surface sediment facies at the mouth of the Komoé River (c); Diagrams of granulometric dispersion at the mouth of the Komoé River (d)

Table 2. Evolutionary trend of the beach at the mouth of the Komoé River between June and July 2006

Station	Eroded surface m^2/l	Volume of eroded sand m^3	Prograding surface m^2/l	Volume of deposited sand m^3	Difference m^2	Evolutionary trend
1	9.70	1,940	4.70	940	-5	Erosion
2	8.41	1,682	5.20	1,040	-3.21	Erosion
3	6.75	1,350	13.0	2,600	+6.25	Progradation
4	5.50	1,100	15.0	3,000	+10.5	Progradation
5	6.50	1,310	25.0	5,000	+19.5	Progradation
6	11.72	1,354	6.68	1,336	-5.04	Erosion
7	10.70	2,140	5.58	1,116	-5.12	Erosion

l = linear metre.

Table 3. Evolutionary trend of the beach at the mouth of the Komoé River between August and September 2006

Station	Eroded surface m^2/l	Volume of eroded sand m^3	Prograding surface m^2/l	Volume of deposited sand m^3	Difference m^2	Evolutionary trend
1	11.8	2,360	7.10	1,420	-4.70	Erosion
2	5.30	1,060	42.0	8,400	+36.70	Progradation
3	9.40	1,880	30.0	6,000	+20.60	Progradation
4	10.61	2,122	6.80	1,360	-3.19	Erosion
5	7.20	1,440	35.0	7,000	+27.80	Progradation
6	9.30	1,860	60.0	12,000	+11.75	Progradation
7	7.30	1,460	51.0	10,200	+43.70	Progradation

l = linear metre.

Table 4. Evolutionary trend of the beach at the mouth of the Komoé River between October and November 2006

Station	Eroded surface m^2/l	Volume of eroded sand m^3	Prograding surface m^2/l	Volume of deposited sand m^3	Difference m^2	Evolutionary trend
1	5.03	1,100	9.60	1,920	+4.57	Progradation
2	11.19	2,238	7.26	1,452	-3.93	Erosion
3	20.57	4,094	10.57	2,114	-10.0	Erosion
4	19.90	3,920	12.90	2,580	-7.0	Erosion
5	16.91	3,382	9.50	1,900	-7.41	Erosion
6	16.82	3,364	6.50	1,300	-10.32	Erosion
7	12.51	2,502	7.45	1,550	-5.06	Erosion

l = linear metre.

Table 5. Evolutionary trend of the beach at the mouth of the Komoé River between March and April 2007

Station	Eroded surfaces m^2/l	Volume of eroded sands m^3	Prograding surfaces m^2/l	Volume of deposited sands m^3	Difference m^2	Evolutionary trend
1	22.5	4,500	8.40	1,680	-14.1	Erosion
2	7.97	1,594	25.0	5,000	+17.03	Progradation
3	8.98	1,796	35.0	7,000	+26.02	Progradation
4	9.07	1,814	42.0	8,400	+32.93	Progradation
5	9.50	1,900	50.0	10,000	+40.50	Progradation
6	10.02	2,004	21.0	4,200	+10.98	Progradation
7	9.15	1,830	7.50	1,500	-2.45	Erosion

l = linear metre.

Table 6. Estimate of the volume total of sand set in motion in the interval June 2006–April 2007

Volume/Period	June–July	August–September	October–November	March–April	Total
Volume of eroded sand m^3	41,856	32,182	30,586	45,438	-120,062
Volume of prograded sand m^3	114,812	228,680	128,776	445,260	+880,520
Difference m^3	+72,956	+196,498	-98,190	+389,822	+760,458
Evolutionary trend	Progradation	Progradation	Erosion	Progradation	Progradation

Table 7. Morpho–sedimentary and granulometric synthesis on the sand barrier of the estuary of the Komoé River

Station	Erosion	Progradation	Granulometry
1	-		Middle–Coarse
2	-		Middle–Coarse
3		+	Middle–Coarse
4		+	Middle–Coarse
5		+	Middle–Coarse
6	-		Middle–Coarse
7	-		Middle–Coarse

The sediments at the mouth of the Komoé River have a heterogeneous spatial distribution (Fig. 7c). The middle- to coarse-sized sand is in the main riverbed. Between the confluence area and Bouet island, middle-sized sand is present (500–250 μm). The relative proportions of these granulometric divisions demonstrate that middle-sized sand comprises 65% of the sediments. Near the islands of Bouet and Morin, as well as at the confluence with the Ouladine lagoon, fine sand is visible (70–120 μm) and represents 75% of the entire deposit. After communication with the sea was closed, a huge amount of mud rich in organic detritus was loaded on the shorelines full of aquatic vegetation. Near the river mouth, the proportion of the olive black sand is 80%. The Ebrié lagoon is dominated by muddy sand with good clasticity. This indicates that the sand deposition occurred within calm areas.

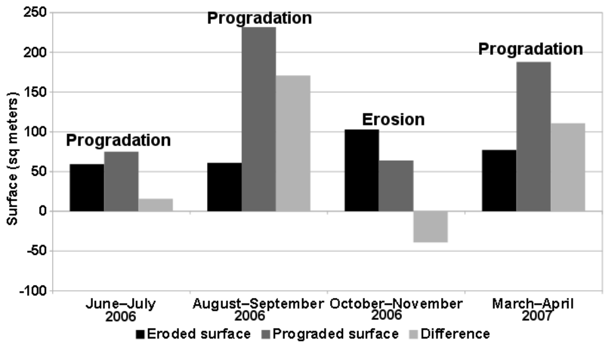

Figure 8. Estimate of the eroded or prograding littoral sand surface in the interval June 2006–April 2007

The dispersion diagrams of the sandy fraction within the lagoon complex of the Komoé River demonstrate that the middle-sized particles range between 100 and 800 μm (Fig. 7d); the median varies between 250 and 900 μm. The clasticity index varies between 0.25 and 0.75. Asymmetry has a minimum value of -0.75 and a maximum value of +0.90. The clasticity and asymmetry indices are less than 1. The cloud points in the SO-Mz and So-Md representations are near the regression line, which proves a good correlation. The Sk-Mz and Sk-So representations are dispersed and extended along the regression line, which shows a weak correlation. The curves of the trends shown by granulometric parameters are ascending lines. The slope of the regression lines is close to 1, which indicates good correlation between the characteristic parameters.

5. DISCUSSIONS

During the period of 1982–2006, radical changes occurred in the liquid discharge of the Komoé River. The monthly discharge did not exceed 200m^3/s between 1982 and 1996, while it reached 2,300 m^3/s in the period between 1997 and 2006. The largest amounts of solid material are transported during the wet season, of which over a half are transported during the short wet season (43,395 t between 2005 and 2006, out of a total of 72,134 t, and 44,371 t between 2006 and 2007, out of a total of 71,396 t) (Table 8).

Table 8. Distribution of the seasonal mean of liquid and solid discharge at the mouth of the Komoé River

Period	Season	Short wet season	Long dry season	Long wet season	Short dry season	Total
2005–2006	Liquid discharge (m^3/s)	274	17	41	349	681
	Solid discharge (t/year)	43,395	1,789	8,540	18,410	72,134
2006–2007	Liquid discharge (m^3/s)	281	17	41	355	694
	Solid discharge (t/year)	44,371	1,427	6,874	18,724	701,396

The turbidity and solid load in suspension within the Komoé River is twice as high than that of the Bandama River. The low amount of sediments within the Bandama River, which is situated within the same climatic conditions, is due to the two dams situated upstream that prevent a part of the alluvia from penetrating. The vegetation within the catchment area is not able to stop the high erosion rate (Fig. 9a). At the same time, it is worth noting a slight increase in agricultural surfaces, which leads to the elimination of the initial, soil-stabilising vegetation. The opening of the Vridi channel causes a dynamic lack of balance between the sedimentary and the intertidal movement, and between the fluvial current and the flood dredging.

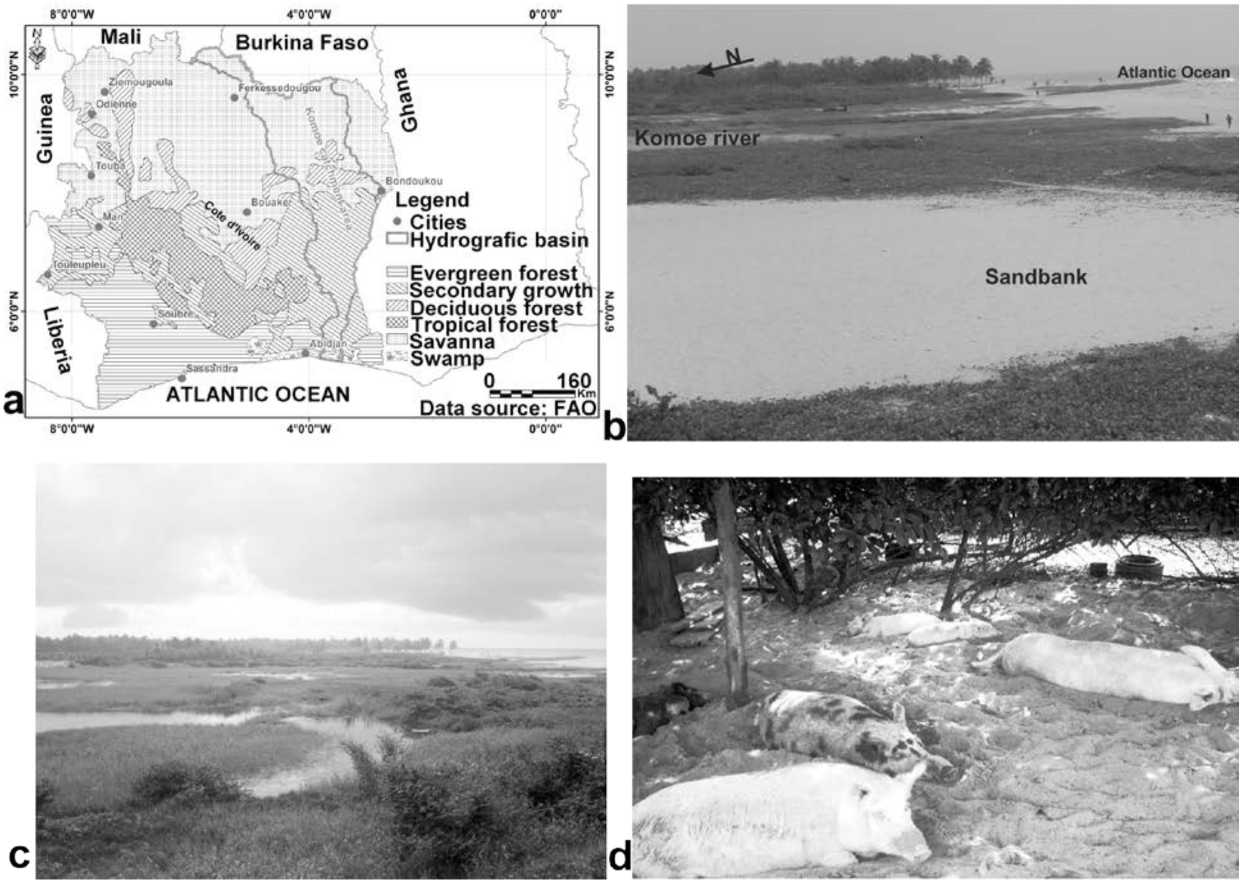

Figure 9. Distribution of the vegetal layer within the Komoé hydrographic basin (a); Sandbank at the mouth of the Komoé River (b); Luxuriant development of aquatic vegetation at the mouth of the Komoé River (c); Semi-wild pig breeding on the littoral barrier of the Komoé River (d)

After the inauguration of the Vridi channel in 1951, a water deficit emerged in the lagoon complex at the mouth of the Komoé River. The natural opening eliminated only 66% of the discharge, with the rest being removed by the Vridi channel-after a course of several kilometres through the Ebrié lagoon—or by other small-sized openings in the littoral barrier. The reduction in the water volume corresponds to a decrease in the speed of the current within the estuary and its rapid flow into the sea. The long residence within the cuvette of the estuary increases evaporation and infiltration through the sand of the littoral barrier. The further elimination of water causes the natural opening in the littoral barrier to be influenced by the maritime littoral drift and by intertidal sediments. This is the reason for significant clogging in the sea-lagoon complex direction at the river entrance, where an ebb tidal delta emerged (Fig. 9b). The reduction in the speed of the currents diverts the water towards the Vridi channel and favours the definitive clogging of the opening. In this case, the floodwaters, loaded with high amounts of alluvia, are forced to deposit their entire load into the lagoon.

A direct consequence of the rapid elimination of lagoon waters is the reduction in the degree of salinity, which dropped to 3‰. The eutrophisation process emerges, which favours the development of new, invading vegetation. Together with eutrophisation, the fact that the water is less saline leads to an invasion of aquatic vegetation in the cuvette, which contributes to the deposition of sediments and to the formation of organic mud. The extension of lacustrine vegetation also makes it more difficult to navigate the main channels and reduces the open water surfaces for fishing. It is worth mentioning that fishing is the main occupation of the inhabitants of the region (Fig. 9c).

The rapid development of vegetation is also favoured by uncontrolled pig breeding, which produces high amounts of faeces that is eventually turned into fertiliser (Fig. 9d). Additionally, the amounts of household waste have recently increased rapidly. Both of these inputs of waste influence the eutrophisation process. The transformation of faeces into humus leads to the emergence of incipient arenosols and to the development of pioneer vegetation. The decomposition of organic matter leads to the production of methane, which has a pernicious effect on organisms and water quality. Furthermore, the pestilent odour and the emergence of harmful insects inevitably lead to a decrease in the number of tourists (mosquitoes –

Anopheles gambiae; sand flies – *Phlebotomus sergenti*, *Ph. papatasi*; black flies – *Simulium damnosum*).

Through the development of floating leaves, floating aquatic vegetation prevents the light from penetrating the water and, thus, hinders the normal development of organisms (especially of the fauna). The luxuriant development of vegetation alters the repartition of fish and crustaceans. If there is an opening in the littoral barrier, species tolerant to certain salinities can enter (e.g., herring, white carp, etc.). When the lagoon is closed, there is a reduction in the amount of fish and crustaceans (e.g., Grand-Bassam, Bonoua, Alépé). The luxuriant development of vegetation on navigable channels forces the local population to detour 15–0 km over land to reach the private plantations.

Bathymetry and the assessment of sediment thickness deposited in the lagoon complex of the Komoé River allow the identification and quantification of sedimentary deposits, as well as areas affected by erosion or deposition. The assessment of the sediments in the period 2005–2007 indicates a deposited volume of 580,500 m^3 and an eroded volume of 285,000 m^3. The deposition segments are seasonal and are localised in the main channel and in the confluence points. There is permanent deposition of sedimentary material in the secondary channels, through which the water flows into the sea. During low waters (December–July), temporary sandbanks emerge that load the channels and make navigation difficult. In this case, the maximum depth does not exceed 12 m. During floods (September–October), all of the sandbanks are covered by water and sand deposits are set in motion again. Hence, the high bottom is in emersion in the period of low waters and in submersion in the period of floods.

The maximum depth reaches 14 m and is recorded during regular floods at the confluence between the river and the Ebrié lagoon, near Moossou. This is due to the dredging works that facilitated the construction of the two Moossou bridges. In 1979, the maximum depth was 18 m. Since the closure of the opening to the ocean, the lagoon complex of the Komoé River acts only as a sediment receptacle.

The channel, which is influenced by fluvial runoff, features three morphological types of riverbed: “U”, “V” and intermediary. The “U”-shaped channels are in balance with depositional and erosive agents. The “V”-shaped channel is specific to erosive sectors. Intermediary morphology marks the change from erosion to deposition and features attenuated shorelines. The sectors with erosive dominance are situated at confluence points and downstream from the main sandbanks, where the tourbillion currents are very intense.

The sediments of the littoral barrier that encompasses the mouth are distributed by modelling factors. In this case, these factors are fluvial (from upstream) and maritime (from downstream). The constituting sandy material falls, in granulometric terms, between middle-sized in the east and coarse in the west. They are classified as moderate to weak and they feature reduced asymmetry. The red colour is due to the presence of iron oxides. The quartz grains are rounded and subrounded, and they indicate the existence of long-term modelling (Romanescu et al., 2012b). The maritime contribution of sandy sediments was 361,466 t during the period of 2006–2007. The shoreline of the littoral barrier at the mouth of the Komoé River is mainly prograding. In some seasons erosion may dominate, while in others deposition may be primary. Finally, it is worth noting a surface increase of 258.53 m^2 over a year; the total volume of deposited sand is 760,458 m^3 over the same period.

The existence of erosive and prograding sectors indicates a different mechanism and the existence of specific local factors; the causes may be natural (e.g., constant rise of sea level, sedimentary deficit, natural slope instability, absence of a natural structure able to attenuate the effects of swell on the beach, existence of low sandy littoral, joint effect of coastline orientation and swell direction, etc). Because of coastal erosion, several villages and poorly placed tourist attractions were abandoned.

The sedimentary distribution within the estuary of the Komoé River is heterogeneous. The middle-sized and coarse sand is specific to the fluvial riverbed. The granulometry is directly related to the shape of the particles and decreases upstream to downstream, from 765 μm to 240 μm, respectively. The clasticity index ranges between moderate and week, while the skewness (asymmetry) index ranges between high and low. The strong current in the channel transports coarse particles, while the currents near the shorelines transport the finer particles, such as mud. The highest speed in the channel is also determined by the existence of a higher general slope. Furthermore, mud and fine sands are deposited near the islands, where depths are reduced and the aquatic vegetation extends onto large surfaces. The deposition of fine alluvia in these locations is favoured by the reduction in the water runoff speed (caused by friction with the shorelines and with the bottom of the estuary, the trapping of alluvia due to the existence of aquatic vegetation, etc).

The geologic substrate within the catchment area is intensely eroded and the materials that are shed eventually manage to arrive at the mouth. Hence, the transported sediments have different degrees of rolling and the shape or degree of erosion indicates the distance they have travelled. The clasticity and asymmetry index does not exceed 1, which indicates that the transported sediments are derived from a fluviatile paleoenvironment. The existence of flat and glassy grains shows a long-distance fluvial transport. Nonetheless, the increase in dissymmetry indicates the sudden change from sands to sandy muds. The increase in the proportion of mud consolidates the sedimentary deposits, which makes them more resistant to motion. Muds are rich in organic matter derived from the catchment area or from the decomposition of aquatic organisms. In the case of sand particles, shock hits are more common. In this case, the quartz minerals are highly degraded, which reduces their dissymmetry index. The existence of sands in the mud deposits increases the degree of asymmetry.

The closure of the communication between the lagoon and the sea is due to the opening of the Vridi channel, which has diverted much of the liquid and solid discharge. Because of this, the freshwaters of the Komoé River are deviated towards the Ebrié lagoon. However, the existence of islands, sandbanks and vegetation does reduce the influence of the river.

6. CONCLUSIONS

The mouth of the Komoé River has a particular hydro-sedimentary dynamic. The natural closing of the estuary determines the integral deposition of the alluvia transported by the river. The mud deposits, which are rich in organic matter, and the agricultural economic activities lead to the formation of a mud rich in organic matter. The excess of freshwater leads to a decrease in the salinity of the entire water mass within the lagoon complex; thus, the aquatic vegetation becomes luxuriant.

The opening of the Vridi channel within the Ebrié lagoon directs most of the water towards the Atlantic Ocean, through the western sector of the lagoon complex. It is worth noting that there is a strong clogging process in front of the mouth of the Komoé River. The erosion within the catchment area is high because the geologic substrate and the climatic conditions allow for chemical and physical alteration of the crust. The uneven hydrologic regime favours the long-distance displacement of solid particles. Many of the solid particles are transported over a long distance. This fact is shown by the results provided by the granulometry.

The littoral barrier that encompasses the mouth of the Komoé River is currently expanding, as the deposition is stronger than the erosion. To this deposition, one must add the alluvia transported by the river, as well as the sediments set in motion by maritime factors. Whilst the western and eastern sectors of the littoral barrier are currently being eroded, the sector in front of the river mouth has been experiencing accentuated advancement. The amount of alluvia transported by the river is deposited, for the most part, at the mouth, with only a small portion directed towards the Ebrié lagoon. The amount of alluvia directed towards the Ebrié lagoon is determined by the luxuriant aquatic vegetation and by large sandbanks.

To reduce the clogging in front of the mouth of the Komoé River, the old communication with the sea within the littoral barrier should be re-opened and the economic activities (i.e., semi-wild animal rearing) that lead to water eutrophisation and to the invasion of aquatic vegetation should be eliminated. The secondary inlets that are already clogged should be channelled.

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