Lakes, reservoirs and ponds, vol. 8(1): 28-41, 2014

NATURE AND DYNAMIC OF SEDIMENTS AT THE MOUTH OF KOMOÉ RIVER (IVORY COAST)

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Abstract
Komoé River represents the most important freshwater resource of Ivory Coast. This study aims at identifying the alluvia material and its dynamic at the mouth. The agricultural activity within the upper basin has determined a decrease in liquid discharge and an increase in alluvia transport. Most of the water is used in agriculture. The alluvia material comprises mainly sands and it is included in the middle-coarse category. Mixed sediments are composed of muddy sands and sandy muds. Most quartz grains transported by the river are flattened and glassy (91.66%), while the rest are round and opaque (8.34%). Minerals are angular, subangular, rounded and subrounded. Among heavy minerals, it is worth mentioning as follows: quartz, mica, feldspar, pyroxene, tourmaline, amphibole, gamet, epidote etc. The high degree of alluvia deposit has reduced the depth of the lower river course and it has closed the estuary completely. In this case, the wetland was extended and the vegetation tends to cover the entire surface. Navigation has been made difficult by the alluvial and organic clogging processes.

Keywords: littoral dynamic, granulometry, heavy mineral, fluvial processes, sedimentation

1.INTRODUCTION

The mouth of great rivers that empty into seas and oceans take the shape of deltas or estuaries. The alluvia deposit degree within estuaries is lower than that of deltaic areas. For this reason, navigation is easier and port economy is usually flourishing.

Soil erosion within hydrographic basins has been studied intensely on international level, mostly in the countries based on agricultural economy. Geological substrate and the climate determine an intense process of vegetal layer removal in dry tropical climate. For this reason, most States within the Sahel region use expensive methods to fight against soil erosion and, implicitly, against solid transport within streams.

The importance of Komoé estuary is apparent for the economy of Ivory Coast. However, the climate and geological substrate favour high soil erosion within the hydrographic basin and high degree of alluvia deposit at the mouth. This is why the Komoé River estuary has already closed. Its place is currently occupied partially by the Ebrié lagoon. Studies regarding the sedimentation system and the dynamic of river mouths are extremely rich: Abe et al., 1993, 1996; Adopo et al., 2008a,b; Aka, 1991; Bessoles, 1977; Bodge, 1999; Camil, 1984; Durant & Guiral, 1994; Hauhouot, 2008; Koffi and Abe, 1991; Lawson et al., 2012; Monde et al., 2007, 2011; Romanescu et al., 2012a,b, 2013, 2014; Romanescu, 2010, 2013a,b, 2014; Tastet, 1985.

2. GEOGRAPHICAL LOCATION

Komoé River is the most important hydrographic artery of Ivory Coast. The hydrographic basin is situated between 3°00' 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 (Fig. 1). The littoral barrier openings are currently closed (Adopo & Romanescu, 2013).

3.METHODS AND TECHNIQUES

For morphometric measurement and sedimentary analyses, the following tools 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; Nansen bottle; HANNA turbidity meter (model LP 2000); W.T.W. 82362 multi-parameter sounder and a CRISON OXi 330 portable meter; WHATMAN GF/F glass microfiber filters; Van Veen grab; ECOCELL 111 steriliser; Sartorius BP

610 balance; D407-020 polymeric container, etc. The minerals were analysed with a binocular magnifier and the composition was determined with the help of test minerals.

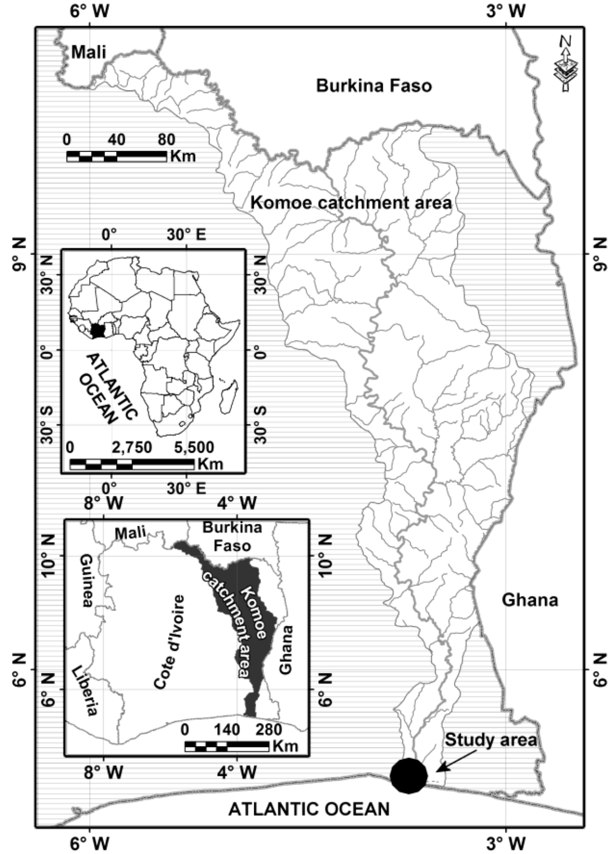

Figure 1 Geographical location of the Komoé hydrographic basin and of the coastal zone near the river mouth

Topographic profiles were raised on the seacoast and on the lower river course (Figs. 2, 3). The measurement points were chosen from among the immovable objects found in the environment. The measurements were conducted in the period 2007-2011 and they concerned the morphographic and morprhometric features of the coastal barrier and the lower course of Komoé River.

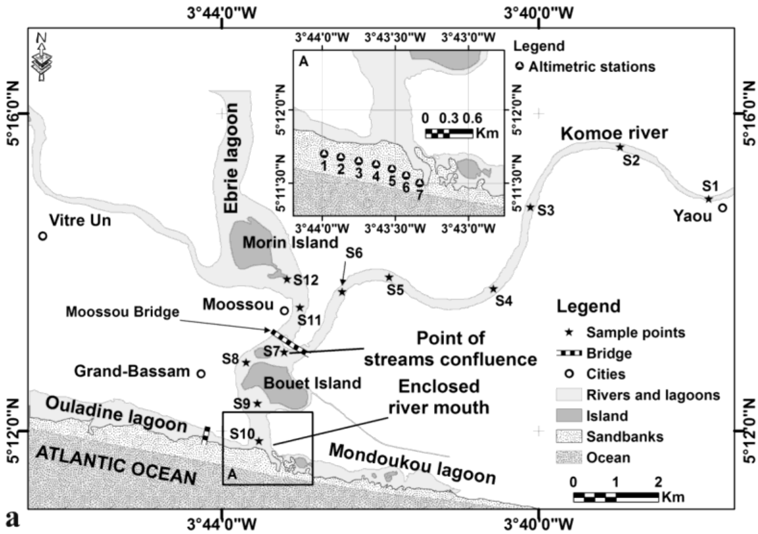

Figure 2 Repartition of measurement stations and sampling on the littoral barrier and distribution of the sampling points for water samples in the lagoon complex of the Komoé River

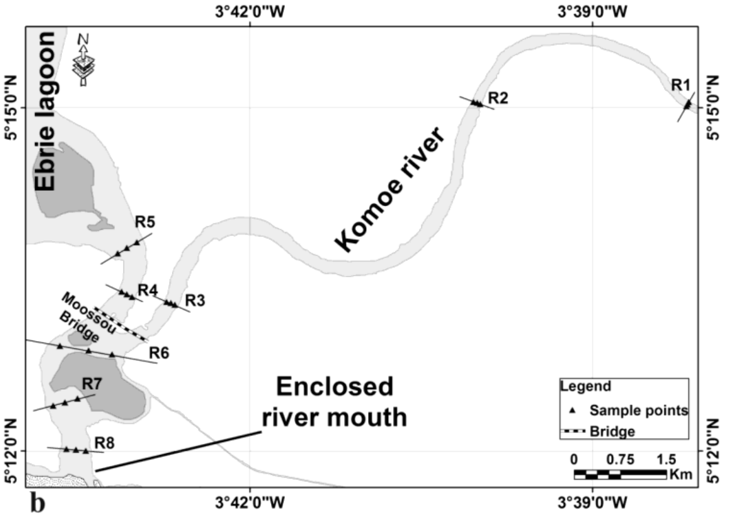

Figure 3 Repartition of measurement stations and sampling on the littoral barrier and distribution of the sampling points for water samples in the lagoon complex of the Komoé River

4. RESULTS AND DISCUSSIONS

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). The crystalline basement rocks of the hydrographic basin belong to the West African craton, specifically to the Man shield (Bessoles, 1977). 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 (Fig. 4). The hydrological regime is influenced by the climatic regime, mostly by the pluviometric regime. The Komoé hydrographic basin falls within three types of climates: transitional and moderate (upper stream), transitional and equatorial (middle stream) and transitional equatorial (lower stream).

During the period of 1982–2006, radical changes occurred in the liquid discharge of the Komoé River. The monthly discharge did not exceed 200 m^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).

The largest amount of solid fluvial discharge is rolled along on the bottom of the riverbed. For the Komoé River, the bed load discharge, which is usually coarse, makes up 70-80% of the total discharge (Table 1). 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. 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 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.

Table 1 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

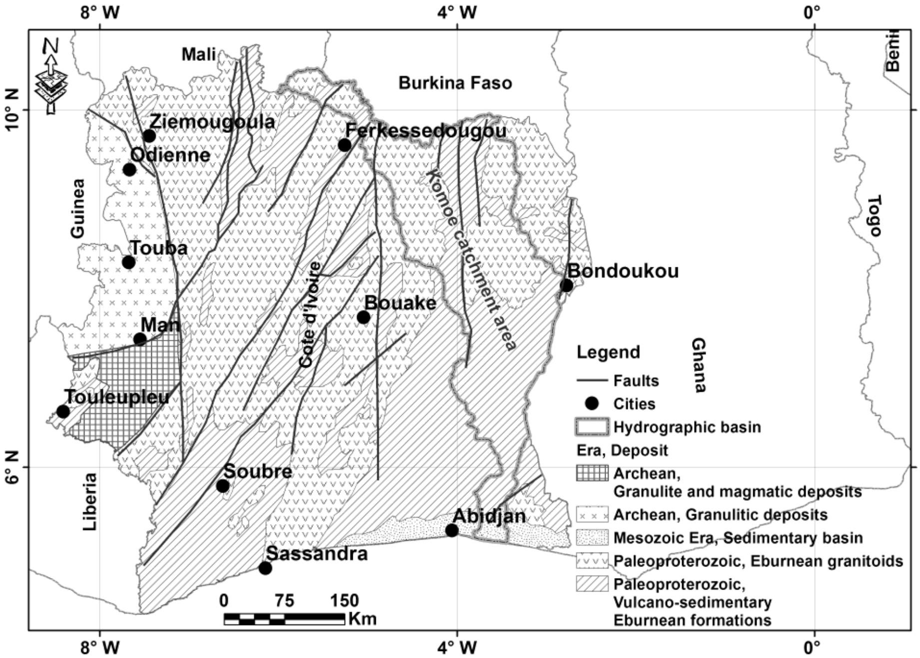

Figure 4 Geological map of the Komoé hydrographic basin

Within the estuary, water and sediment from the Komoé River come from upstream, while water and sediment from the Atlantic Ocean come from downstream. Sandy and muddy particles are deposited within the cuvette. The brown-yellowish sand ranges between fine and coarse (in granulometric terms) in the upstream-downstream direction. The mud has variable facies—from greenish to black—and is rich in organic matter; it is mainly deposited near the shorelines and islands, where the aquatic currents are weaker. Mixed sediments are composed of muddy sands and sandy muds (Table 2).

Table 2 Lithologic description of the sediments deposited in the estuary of the Komoé River

Sampling point	Coordinates	Description of sediments	Mz	Sk	So	Md	σ	A
1*	429324/581026	Blackish fluid mud, rich in organic matter	< 63	(-)	(-)	(-)	(-)	(-)
2	429324/580827	Red coarse sand, with moderate clasticity	765	0.66	0.95	124	0.48	0.19
3	429324/580477	Grey coarse sand, with moderate to low clasticity	515	0.82	0.23	355	0.75	0.33
4*	425629/580028	Blackish fluid mud rich in organic matter	< 63	(-)	(-)	(-)	(-)	(-)
5	425629/579728	Red coarse sand, with	625	0.75	0,55	420	0.29	0.44

		moderate clasticity							
6	425629/579479	Grey fine sand, with moderate to low clasticity	135	0.85	0.25	612	0.38	0.45
7	421485/578181	Olive grey to olive black sandy mud, with moderate clasticity	73	0.81	0.29	615	0.45	0.17
8	421485/577981	Red to grey middle sand, with moderate clasticity	482	0.68	0.45	587	0.66	0.42
9	421485/577731	Grey fine sand, with moderate to low clasticity	240	0.85	0.26	590	0.58	0.54
10*	419885/577132	Creamy greenish mud, with vegetal and shell detritus	< 63	(-)	(-)	(-)	(-)	(-)
11*	420085/577132	Greenish fluid mud, rich in organic matter	< 63	(-)	(-)	(-)	(-)	(-)
12	420387/577132	Olive grey to olive black sandy mud, with moderate clasticity	68	0.83	0.27	325	0.68	0.75
13*	419638/577931	Blackish fluid mud, rich in organic matter	< 63	(-)	(-)	(-)	(-)	(-)
14	420636/577931	Red to grey middle sand, with moderate clasticity	412	0.76	0.50	258	0.66	0.80
15	420037/577931	Olive grey to olive black sandy mud, with moderate clasticity	67	0.84	0.29	210	0.50	069
16	419438/576384	Red and grey middle sand, with moderate to low clasticity	358	0.66	0.52	200	0.54	0.65
17	420087/576384	Yellow-red to grey middle sand, with moderate clasticity	459	0.78	0.55	463	0.78	0.56
18	420489/576384	Red to grey middle sand, with moderate clasticity	476	0.77	0.48	198	0.81	0.55
19*	419138/575584	Grey creamy mud, rich in organic matter	< 63	(-)	(-)	(-)	(-)	(-)
20*	419488/575584	Grey creamy mud, with vegetal and shell detritus	< 63	(-)	(-)	(-)	(-)	(-)
21*	419788/575584	Blackish fluid mud, rich in organic matter	< 63	(-)	(-)	(-)	(-)	(-)
22	419388/574836	Grey fine sand, with moderate to low clasticity	158	0.86	0.30	410	0.46	0.68
23	419588/574836	Grey fine sand, with moderate to low clasticity	213	0.80	0.31	521	0.39	0.52
24	419887/574836	Grey fine sand, with moderate to low clasticity	120	0.82	0.28	498	0.37	0.37

*Sampling point near the shorelines; (-) unidentified parameters; Mz-mean; Sk- Skewness index; So-clasticity index; Md-median; σ-sorting index; K-peakedness.

The granulometric mean size of the sand within the Komoé estuary ranges between 240 and 765 μm (this sand has a general mean of 425 μm). The clasticity index ranges between 0.58 and 1.12 (with a general mean of 0.85). The sand displays moderate to weak clasticity. The skewness index ranges between 0.06 and 0.25, which indicates a significant decreasing trend in the case of sediments. The sediments at the mouth of the Komoé River have a heterogeneous spatial distribution. 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. The Ebrié lagoon is dominated by muddy sand with good clasticity. This indicates that the sand deposition occurred within calm areas.

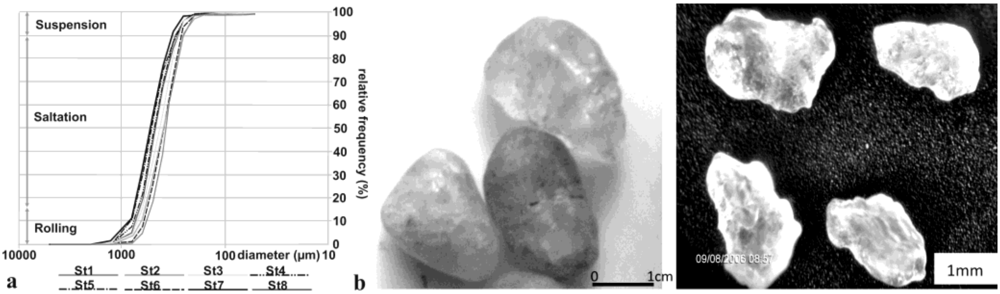

Figure 5 Granulometric curves and sand transport ways in the lagoon complex of the Komoé River (a); Quartz grains analysed in the lagoon complex of the Komoé River: rounded and opaque (left); flattened and glassy (right) (b)

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; the median varies between 250 and 900 μm. Three granulometric populations of sands are present within the lagoon complex of the Komoé River (Fig. 5a): fine sands (Mz <200 μm) transported by suspension, middle-sized sands (Mz between 200-500 μm) transported by saltation, as well as a few cases of transport in suspension, and coarse sands (Mz >500 μm) transported by sliding or rolling. The middle-sized and fine sediments are mainly transported by sliding or rolling (75%). Only 15% of the sediments are transported by saltation. This explains the granulometric differentiation from middle-sized (in the river) to fine (towards the lagoon outlet).

Most quartz grains transported by the river are flattened and glassy (91.66%), while the rest are round and opaque (8.34%) (Table 3, Fig. 5b). The river and the sea model the flattened and glassy fractions, while the round and opaque fractions are transported by the river. The mean of the rounding degree in the case of the quartz grains is 0.39; the median is 0.40 and the standard deviation is 0.03. The grain sphericity has a mean of 0.75, a median of 0.7, and a standard deviation of 0.06 (Table 4). The rounding mean varies between 0.33 and 0.45, while the sphericity varies between 0.64 and 0.82. The percentage of flattened glassy grains is 30%, which demonstrates the marine modelling.

Table 3 Relative proportion of the various morphoscopic types of quartz

Morphoscopic aspects	Number of grains	Proportion %
Flattened and glassy	550	91.66
Round and opaque	50	8.34

Table 4 Mean rounding and sphericity coefficients of the quartz minerals in the lagoon complex of the Komoé River

Sample	Nature of sediments	Rounding	Sphericity
1	Sandy mud	0.45	0.71
2	Coarse sand	0.40	0.65
3	Coarse sand	0.38	0.80
4	Muddy sand	0.33	0.81
5	Coarse sand	0.42	0.78
6	Fine sand	0.43	0.68
7	Muddy sand	0.34	0.69
8	Middle sand	0.40	0.82
9	Fine sand	0.45	0.81
10	Sandy mud	0.36	0.79
11	Sandy mud	0.39	0.64
12	Sandy mud	0.35	0.66
13	Sandy mud	0.34	0.64
14	Muddy sand	0.40	0.78
15	Muddy sand	0.37	0.71
16	Middle sand	0.44	0.82
17	Middle sand	0.42	0.81
18	Middle sand	0.41	0.80
19	Muddy sand	0.36	0.70
20	Muddy sand	0.34	0.71
21	Muddy sand	0.35	0.81
22	Fine sand	0.40	0.79
23	Fine sand	0.41	0.78
24	Fine sand	0.44	0.80
Mean	-	0.39	0.75
Maximum	-	0.45	0.82
Minimum	-	0.33	0.64
Median	-	0.40	0.78
Standard deviation	-	0.03	0.06

The mean values of rounding and sphericity demonstrate that the rounding index is more important for the sand (0.59) (Table 5). Low values are present in the case of the muddy sand (0.33) and of the sandy mud (0.30). Sphericity is important for the sandy mud (0.82). Low values are present in the case of the muddy sand (0.68) and of the sand (0.58). Minerals are angular, subangular, rounded and subrounded.

Table 5 Rounding and sphericity coefficients by the sedimentary facies

Sedimentary facies	Mean rounding	Mean sphericity
Sand	0.59	0.58
Muddy sand	0.33	0.68
Sandy mud	0.30	0.82

The mean dissymmetry indices of the sandy quartz grains within the lagoon complex of the Komoé River range between 0.35 and 0.89, with a mean of 0.68; the standard deviation is 0.14, while the median is 0.26. The flattening indices range between 0.05 and 2.30; the general mean is 1.39, the standard deviation is 0.43, and the median is 1.38. It is worth noting that the flattening index is close to 1, which is higher than the dissymmetry index (Table 6).

Table 6 Mean dissymmetry and flattening index of the sandy quartz minerals in the lagoon complex of the Komoé River

Sample	Nature of sediments	Flattening	Dissymmetry
1	Sandy mud	0.58	0.71
2	Coarse sand	1.10	0.65
3	Coarse sand	1.11	0.45
4	Muddy sand	1.10	0.56
5	Coarse sand	2.30	0.89
6	Fine sand	1.98	0.55
7	Muddy sand	1.15	0.55
8	Middle sand	1.15	0.35
9	Fine sand	1.45	0.81
10	Sandy mud	1.36	0.79
11	Sandy mud	1.39	0.64
12	Sandy mud	2.25	0.66
13	Sandy mud	1.34	0.64
14	Muddy sand	1.40	0.78
15	Muddy sand	1.37	0.79

16	Middle sand	1.44	0.84
17	Middle sand	1.42	0.83
18	Middle sand	1.41	0.77
19	Muddy sand	2.26	0.70
20	Muddy sand	0.98	0.71
21	Muddy sand	0.99	0.84
22	Fine sand	1.40	0.72
23	Fine sand	1.41	0.68
24	Fine sand	0.94	0.50
Mean	-	1.39	0.68
Maximum	-	0.89	0.89
Minimum	-	0.35	0.35
Median	-	1.38	0.26
Standard deviation	-	0.43	0.14

The flattening index is very weak for sand, weak for muddy sand and high for sandy mud (Fig. 6a); it is proportional to the amount of mud present in the sediments. The values range between 1 and 1.85. The evolution of the index can be illustrated as an ellipsoidal shape toward middle flattening.

The dissymmetry index is important for sandy muds, somewhat important for muddy sands and weak for sands. Dissymmetry evolves proportionally with the amount of mud within the sediment (Fig. 6b). The mineralogical spectrum is characterised by a set of light and heavy minerals. The heavy minerals of the sandy fraction are neosilicates, represented by garnet. There are also inosilicates such as amphibole and pyroxene, cyclosilicates such as tourmaline, and sorosilicates such as epidote. Among the light minerals, it is worth mentioning that the tectosilicates are represented by quartz and feldspar and the phyllosilicates are represented by mica (Fig. 6c).

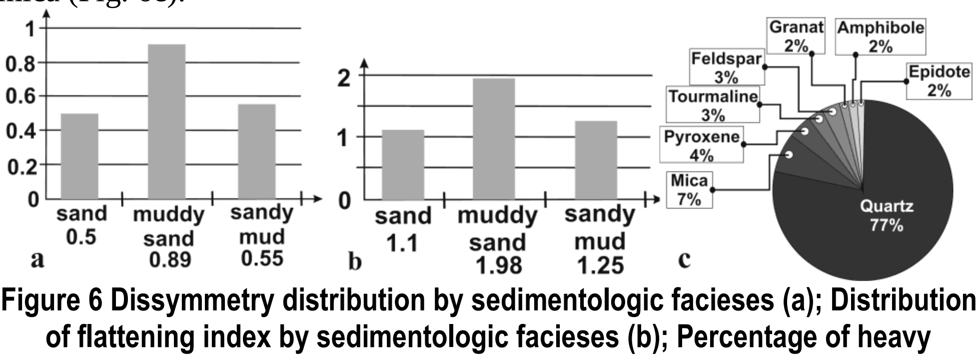

Figure 6 Dissymmetry distribution by sedimentologic facieses (a); Distribution of flattening index by sedimentologic facieses (b); Percentage of heavy minerals identified in the lagoon complex of the Komoé River (c)

Quartz is the constitutive mineral of the sandy phase, with a mean of 77% and a maximum of 85% upstream from the mouth. The sandy set of minerals is completed by biotite (7%), feldspar (3%), pyroxene (4%), tourmaline (3%), amphibole (2%), garnet (2%) and epidote (2%) (Table 7).

Table 7 Percentage of heavy minerals in the estuary of the Komoé River

Mineral/Qualifier	Quartz	Mica	Feldspar	Pyroxene	Tourmaline	Amphibole	Garnet	Epidote
Mean %	77	7	3	4	3	2	2	2
Standard deviation	15.5	2.10	1.5	1.6	1.5	1.15	1.15	1.15
Minimum	45	5	4	3	0	0	0	0
Maximum	85	12	10	15	5	7	5	5

5.CONCLUSIONS

The alluvia material transported by Komoé River comes from the upper basin, where strong soil erosion has been noticed. Agriculture has taken over most of the liquid discharge and it has contributed to superficial erosion. Most of the transported sand is coarse and middle. The finest materials are deposited within the Ebrié lagoon.

The seacoast of the littoral barrier has been eroded by winds and currents. The inner part of Komoé estuary is highly clogged. The alluvia deposits on the bottom of the lower course are overwhelming, because the runoff speed is very low. The vegetation has a very important role in retaining the alluvia.

The freshwater or saltwater vegetation is luxuriant and it tends to occupy the entire area of the mouth. Dredging is recommended in order to avoid further clogging. Animal breeding and other unauthorized activities have led to a high degree of pollution in the area.

ACKNOWLEDGMENTS

Our thanks go to the Cocody University of Abidjan (Ivory Coast) and to the Geo-archaeology Laboratory within the Faculty of Geography and Geology, “Alexandru Ioan Cuza” University of Iasi, which provided the tools and carried out the processing of the data.

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