

## RESEARCH ARTICLE

## Relationships between Grain Size and the Slopes of the Ivorian Coast

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### Abstract

The Ivorian coastal line of 526 km was followed by a topographic survey of the beach profile between 2007 and 2012. The observed morphologies have determined the overall mean slope of the coastlines of the seafront communities. The classification of beach slopes was based on traditional methods. Slopes ranged from low (3.13%) to very high (21.42%). Knowledge of the size of the average grain is not addressed in a sectoral manner, but encompasses the entire coastline. The size of the grains of sand encountered on the Ivorian coast varies according to the beach areas. Fine to very coarse grains are found. The most coarse sediments are found on the beach of Port-Bouët and the finest in the area of Assinie. A relationship is established between grain size and slope and shows that slope and grain size change proportionately.

**Keywords:** Slope; Beach; Particle Size; Sand; Map; Coastline

### Introduction

The slope of a coastline varies greatly from one foreshore to another. The slope is an important physical parameter because it is considered in the search for the vulnerability of beaches to the risks of marine submergence [1]. Low or dissipative slopes increase the risk of marine submergence [2]. In France, the marine submergence (xynthia) of 28 February 2010 was particularly deadly and destructive on the low coasts. The slope is also linked to the morpho-dynamic index of a beach. It is used to quantify the phenomenon of sea level rise to the coast due to marine agitation. Its increase over time over a given coastal area is a sign of vertical erosion [3]. When the slope study is sequentially approached, the different slope variations inform the most dynamic part of the foreshore [4]. In Côte d'Ivoire, the issue of beach slopes has been addressed in some works because of the extent of erosion. A slope classification is developed with the work of [5]. Four slope classes, including: low ( $P \leq 5\%$ ), medium ( $5\% < P \leq 10\%$ ), high ( $10\% < P \leq 20\%$ ) and very high ( $P > 20\%$ ) were adopted. The work of [3] shows that the coast of Port-Bouët has strong to very strong slopes. The survey looked at the Morphodynamic index of the slopes of the profiles of the Ivorian coastline [6]. All these ancient works concern portions of the beach of the Ivorian coast. The particle size is extensively discussed in the work of [3,6-13]. The themes used in these studies are average grain size, sorting method, classification type, deposition, transport, source conditions.

This study focuses on the classification of slopes and the size of the entire Ivorian coastline. It also establishes a relationship between particle size and beach slope.

### Materials and Methods

Surveys of beach, monthly to bimonthly, were carried out between 2008 and 2012, according to a network of 52 stations located along the coast of Tabou in Assinie. The frequency of surveys and the number of stations are related to the sensitivity of the coast to erosion. The profiles are correlated with topographic nails placed on stable areas (pillars...) [2]. The measurement accuracy is in the order of the centimeter with a maximum vertical error of 2.2 cm [2]. Between 12 and 24 profile states were obtained during this period by sector. Beach slope classification was based on the commonly used method [2,14,15]. Sampling of sediment was carried out during some topographic profile surveys. These sediments have undergone the standard treatment of washing, drying and sifting according to the Saaidi method [16]. This operation was carried out on 100g of dry sediment mounted on a column of 13 series AFNOR (Association Française de Normalization) screens with meshes ranging from 2 mm to 63  $\mu\text{m}$ . The fractiles were obtained with the easysieve software and the average grain size was calculated on the Excel spreadsheet. We then showed the relationship between average grain size and profile slope from Excel software.

## Results

### The Tabou-Fresco Coastal Area

This coastal area is characterized by medium to strong slopes (6.24 to 18.41%) (Figures 1 and 2, Table 2). You rarely encounter low slopes. This area includes the beaches of Tabou, San-pedro, Sassandra. The beaches in this coastal area are mostly steep slopes (53.85%) followed by medium sloping beaches (38.46%) and low sloping beaches (7.69%) (Figure 1b). Sands in this coastal area are coarse to medium (Figure 3 and Table 2).

### The Fresco-Abidjan coastal sector

This coastal area also has a medium to steep slope (Figure 1c). The average slopes were encountered in Jacquville and Fresco and the strong slopes in Grand-Lahou (Figure 2). In this coastal area, the grain size changes from the coarse in Grand Lahou by means of Jacquville (Figure 3 and Table 2).

### The coastal sector of Abidjan-Assinie

This coastal area dominated by the steep slopes (Figure 1d) is representative of the Ivorian coastline, as it is the only one with all sorts of slopes. Slopes are declining in this area from west to east (Figure 2). Thus, very steep slopes are encountered in Abidjan on the edge of the bidet (pierced by the former opening of the canal). These slopes will then gradually decline to a low slope in Assinie (Figure 2). The Bassam area has medium slopes.

The particle size changes according to the slope of the beaches. Sediment size decreases from the west (Abidjan) to the east (Assinie). The immediate east of the current opening of the vridi canal (Port-Bouët Cakpo) presents the coarse grains of the coast. These are very coarse sand grains found on this coastal perimeter. The rest of the Abidjan coastline has coarse grains.

The coastal area of Bassam has medium grains that are rarely coarse. Assinie's grain is fine (Figure 3). The Ivorian coastline has all sorts of slopes (Figure 4). This coastline is heavily dominated by steep and medium slopes. These slopes are spread over the entire coastline. Low slopes occupy a small area in the east. The particle size range is varied from fine sand to very coarse sand (Figure 5).

### Correlation between slope and particle size

The color of the legend is taken in the same way on Figures 1 and 2. Thus, a given coastal area is generally marked by the same color as shown in Figure 1, which is the map of the slope, or in Figure 3, which is the map of the size scale. This result is even better appreciated in Figure 4, where the distribution of points is predominantly around the correlation-line. The average grain size changes in proportion to the slope (Figure 6). Coarse grains are found on high slopes and fine grains on low slopes.

Sometimes, in Abidjan, Grand-Lahou and Tabou, there are slopes too strong for the type of particle size. The main reason for the steep slope beaches in Abidjan (PP3, PA2, PK) could be the proximity of the bottomless pit canyon. Alternatively, as in the case of Port Bouët Cakpo and Gbamblé (Abidjan-Bassam), the slopes are too small for the beach size.

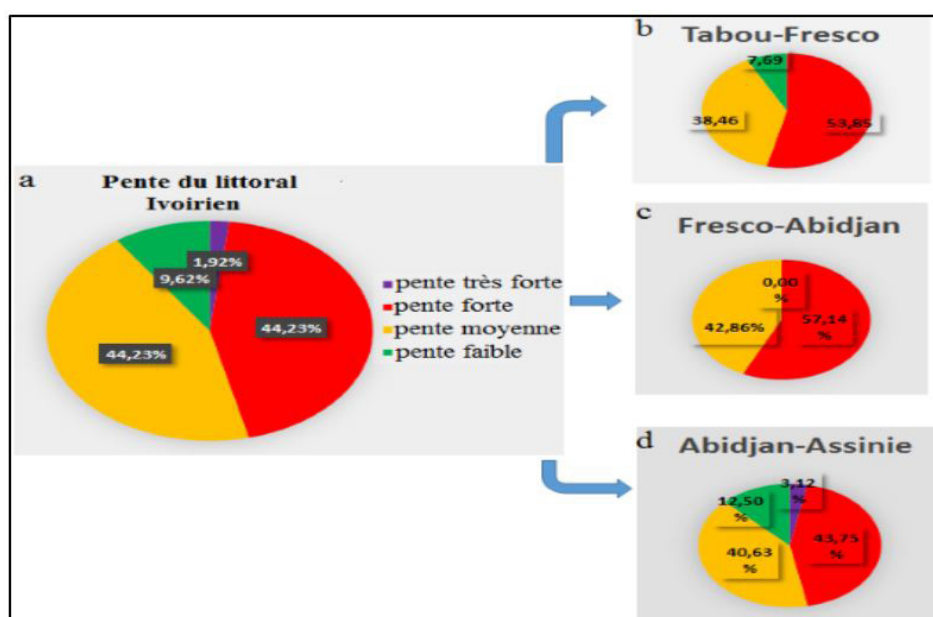
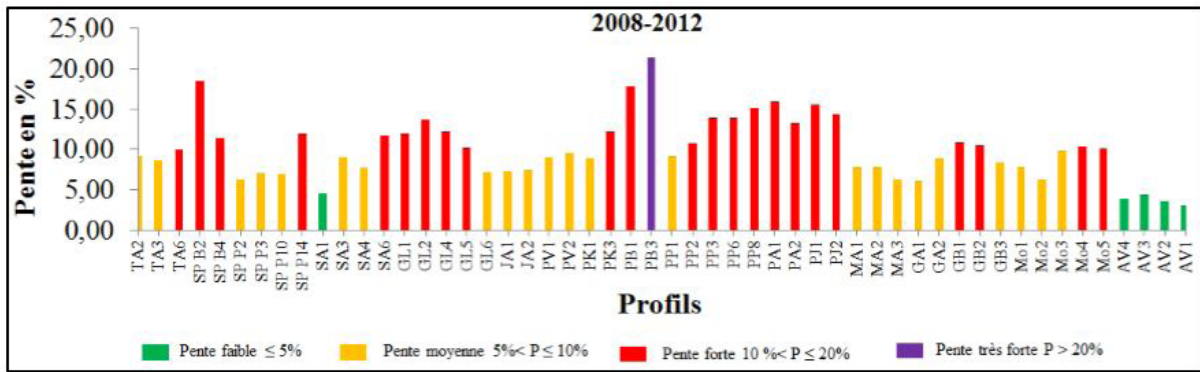


Figure 1: Distribution of slopes of the Ivorian coast



Tabou (TA), San-Pedro (SP), Sassandra (SA), Grand-Lahou (GL), Jacqueville (JA), Port Bouët Vridi canal est (PV), Port Bouët Kackpo (PK), Port Bouët Bidet (PB), Port Bouët Phare (PP), Port Bouët Aéroport (PA), Mafiblé (MA) (intervalle Abidjan-Bassam), Gbambélé (GA) (intervalle Abidjan-Bassam), Grand-Bassam (GB), Mondoukou (Mo), Assouindé Valtur (AV)

Figure 2: Variability of beach profile slopes on the Ivorian coast

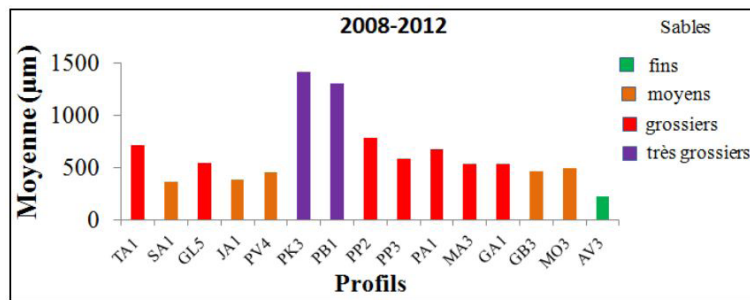


Figure 3: Granula variability of the Ivorian coast



Figure 4: Slopes of the Ivorian coast

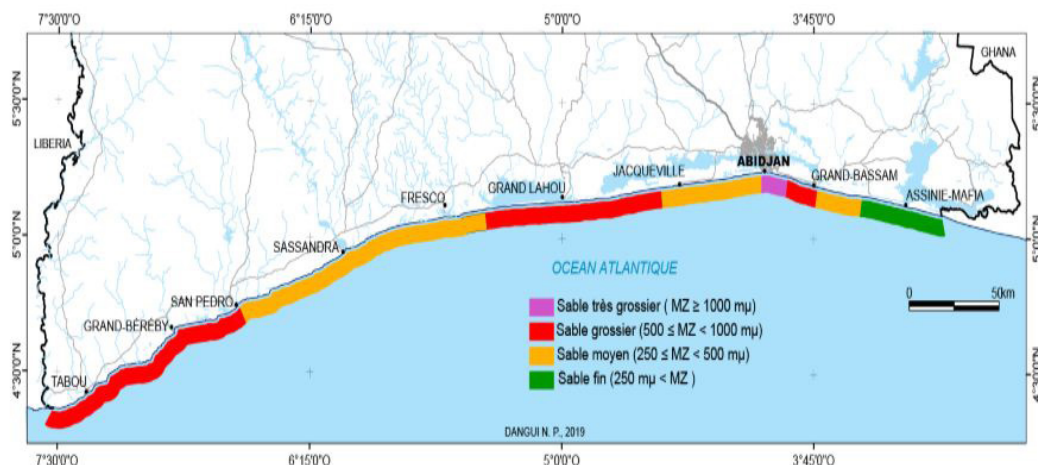


Figure 5: Size of the average sand grain of the Ivorian coast

Localites	Profils	Pente (%)	Localites	Profils	Pente (%)
Tabou	TA2	9,23	Abidjan (Port-Bouet)	PP1	9,13
	TA3	8,61		PP2	10,73
	TA6	10		PP3	14
	SP B2	18,41		PP6	13,94
	SP B4	11,49		PP8	15,18
	SP P2	6,24		PA1	15,92
	SP P3	7,04		PA2	13,35
	SP P10	6,94		PJ1	15,56
San-Pedro	SP P14	11,9		PJ2	14,41
	SA1	4,58		MA1	7,8
	SA3	9,02		MA2	7,9
	SA4	7,7		MA3	6,22
Sassandra	SA6	11,69		GA1	6,19
	GL1	11,92		GA2	8,96
	GL2	13,62		GB1	10,86
	GL4	12,21		GB2	10,49
	GL5	10,21	GB3	8,37	
	GL6	7,15	M O1	7,89	
	JA1	7,4	M O2	6,25	
Jacquerville	JA2	7,43	M O3	9,84	
	PV1	9,11	M O4	10,33	
	PV2	9,64	M O5	10,17	
	PK1	9,64	AV4	3,87	
Abidjan (Port-Bouet)	PIO	1221	AV3	4,43	
	PB1	17r73	AV2	3,6	
	PB3	21r42	AV1	3,13	

Table 1: Profile Average Slopes of the Ivorian coast 2008-2012

Localites	Profils	Grain moyen (µm)
Tabou	TA1	717,67
Sassandra	SA1	368,5
Grand-Lahou	GL5	550
	JA1	384,95
	PV4	454
	PK3	1415,14
	PB1	1305,52
	PP2	784,46
Abidjan (Port bouet)	PP3	583,62
	PA1	675,54
	MA3	537,94
	GA1	535,97
	GB3	464,31
Grand-Bassam	MO3	493,56
Assinie	AV3	231,96

Table 2: Medium grain of Ivorian beaches sediments

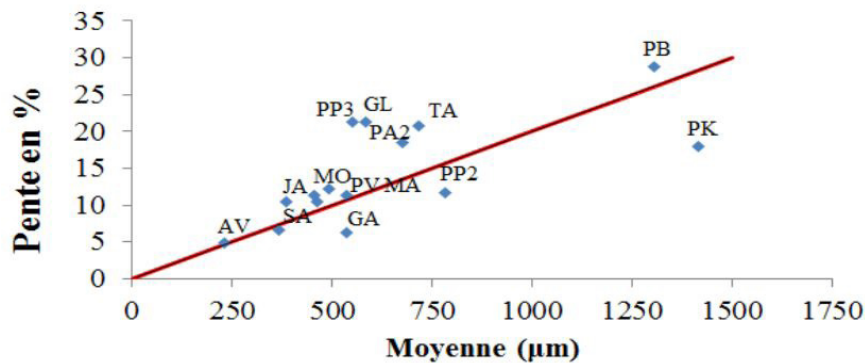


Figure 6: Evolving slope with average grain

## Discussion

Overall, our results show a decrease in grain size from west to east, notably between Abidjan and Assinie in accordance with the work of [3,7,9,10,17]. It was attributed to the west east coast drift. The direction of longitudinal sediment displacement on the Ivorian beach is mainly from west to east. Sediments removed as a result of rock alteration are transported and deposited. The coarser sediments first lay down and the finer ones continue their path further. This process results in declining longitudinal growth from west to east. This grading is very well done east of the Ivorian coast. In the western part of the coastline (between San Pedro and Abidjan), due to the scale layout of the coast, the decline in sediment size is not steady [7,8,10].

The average range gradient values change in proportion to the grain size had already found that the slope of a beach is even higher because of its large size [18]. They were able to establish an abacus where for a given particle size a slope type is associated. Thus very fine sand grains from 0.06 mm to 0.250 correspond to low slopes of 1 to 3°. Mean sand grains from 0.250 to 0.500 mm in diameter correspond to a slope of 5° and sand grains from 1 to 2 mm in diameter correspond to slopes of 9°. These results are qualitatively similar to ours. The average range gradient values, although low for a given range type; vary in proportion to the size. Experimental studies by [19] on sedimentary dynamics in a river context show that the slope of a system decreases with the percentage of fine sand grains and increases with the percentage of coarse sand grains. The risk of marine submergence is even higher as the coasts are low and sandy and trap at times under normal hydrodynamic conditions of water remnants [20]. In Côte d'Ivoire, only a small portion of the beach in the far south is characterized by low slope sandy beaches and thus may pose risks of marine submergence.

## Conclusion

The south-west coast of Côte d'Ivoire has mainly steep beach profiles. This type of slope is encountered in Tabou, San-Pédro, Sassandra and Grand-Lahou. Between these steep slopes are intercalated by average slopes in these coastal areas. The coastal area of Jacqueville has average slopes. The southern coast, on the other hand, has strong to very strong slopes in the Abidjan area. These slopes are declining eastward. Thus, in Bassam and Mondoukou, there are medium and low slopes in Assinie. The size of the southwest coast is almost coarse on the entire coast. Mean grain intercalations may be encountered. The southeast coast has grains that decrease in grain size eastward. The coarse grains on the coast are found on Port Bouët beach. The coastal area of Bassam and Mondoukou has average grains. The one in Assinie has fine grains. In general, the grains are distributed proportionally to the slope, so that the coarser grains are found on high slopes and the finer on low slopes.

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