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BEHAVIOR OF THE PHENOMENON OF COASTAL EROSION AFTER THE COMPLETION OF PROTECTION WORKS IN THE EAST OF SIAFATO IN COTONOU

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ABSTRACT
In order to curb coastal erosion of the east of the SIAFATO spit in Cotonou, seven dykes were constructed. The study aims to analyze the evolution of the coastline after the construction of the seven dykes located in east of the SIAFATO dyke. To achieve this, several topographic survey phases using dual-frequency GPS were performed. The analysis of the 2012 and 2015 ridge lines indicated a sharp decline in the coastline between the SIAFATO dyke and the dye 7. The study conducted in 2017 reports shoreline stabilization in most cells when comparing the 2015 and 2017 ridge lines. The coastlines of 2017 indicate a sea advance on the continent ranging from 6m to 11m compared to those obtained in 2015. Downstream of the dyke 7, the erosion rate calculated is of the order of 26 m / year contrary to 35 m / year obtained during the 2015 studies. It follows that the advancement of the sea is not linear. Nevertheless, these results mark the vertiginous pursuit of erosion in this unprotected coastline. It is urgent to take bold measures to safeguard the property assets in this part of the coast.

KEYWORDS: Cotonou, coastal erosion, coastline, dyke, SIAFATO

1. INTRODUCTION
Coastal erosion marks beaches whose process links coastal oceanographic parameters, sediment volume, shoreline configuration, and anthropogenic factors. The recession impacts are generally quite high, especially12m / yr in the 5km stretch of coast to the east of the Cotonou port infrastructure system in Benin (BLIVI 2001). The socio-economic data, in general, remain to be mastered to define the economic impact caused and to claim an integrated development of consequent coastal development. The various studies of modeling and protection of the coast by seven rock structures in the East of SIAFATO have been very expensive. The sites remain protected and stable. By fully integrating our work in the context of the "Prospective Balance Sheet", we were interested in the study of the dynamics of the littoral after the implantation of the dykes located in the East of the dyke SIAFATO. This study is considered at two temporal and spatial scales. On the one hand, it is based on a synthesis of the work carried out from 2009 to 2015 on this portion of the coastline and, on the other hand, on the current hydrodynamic and sedimentary behavior that takes place between two dykes protection structures and by consequently, over the entire impact zone of the construction project for these structures. The objective is to highlight and measure the erosion and accumulation phenomena that have occurred for several years at both scales.

2. CONTEXT AND RATIONALE OF THE STUDY
Studies conducted in recent years in different parts of the world show that regression of sandy coasts is a global phenomenon (FAYE 2010). More recently, it also pointed out that the evolution of sandy coasts is also dominated by a regressive trend (BEER 1997). The processes of erosion and accumulation characterize the beaches of the Gulf of Guinea (GUILCHER 1954). They are marked by very different rates of evolution depending on the parameters and have been subject to technical monitoring. In recent decades, the coast in the Gulf of Guinea has been subjected to violent erosion due to natural and anthropogenic causes (ANTHONY and

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BLIVI 1999). In the 1960s, a dynamic equilibrium existed when two facts came to modify the parameters: on the one hand the commissioning of the Akossombo dam, about fifty kilometers upstream of the mouth of the Volta, on the other hand the construction of the ports of Lomé and Cotonou, which intercept the sedimentary volume in transit and cause a disruption of the hydro-sedimentary conditions along the coast. It results in a beach in gradation and a beach in erosion (CEE 1989). Decreases of the order of 10m / year are observed over 4 to 5km of coast to the east of the Cotonou maritime system (BLIVI 1993a).

The damage generated in the Gulf of Guinea is very considerable: displacements of populations, very difficult socio-economic changes, destruction of various infrastructures (habitats, roads, hotels). A country like the Gulf of Guinea , Benin is suffering the horrors caused by the phenomenon of coastal erosion (HOUNSOU 2015). Therefore, in order to protect the interests of these local and surrounding populations and to fight against this disaster, the Beninese State has taken certain measures to this effect. Thus the project of realization to the East of the dyke of SIAFATO, of seven (07) works of protection of the coast of the type dyke with a reorientation of the old dyke of SIAFATO was proposed in the year 2003 and whose actual implementation began in October 2009 to be completed in June 2014 (ROCHE-BAIRD 2003). Since the completion of this project, an evaluation study of the results was done in 2015 on the functioning of these dykes (HOUNSOU 2015).

Following this study and with a view to regularly monitoring the hydro-sedimentary evolution of this part of the coast and deducing the conclusions that emanate from the protection results resulting from the operation of the dykes, we decided to study the behavior of the coastal erosion phenomenon after the realization of the protection works at the east of the SIAFATO dykes in Cotonou.

The general objective is to study the evolution of the coastline after the construction of protection works located east of SIAFATO. More specifically, it has the following objectives:

- Analyze ridge lines from topographic surveys between two periods 2012 and 2015;
- Study the position of the crest line between each cell after the completion of protective works in the years 2015 and 2017;
- Estimate coastal dynamics in the east of the dyke 7.

3. PRESENTATION OF THE STUDY AREA

3.1. Commune of cotonou

Located in the northern hemisphere, between the parallels 6 ° 21'30 " and 6 ° 25'37 " north latitude and the meridians 2 ° 20'04 " and 2 ° 29'4 " east longitude, the municipality Cotonou is in the southeast of the Republic of Benin on the Atlantic coast. It covers an area of 79 Km², or about 0.07% of the surface area of the Republic of Benin. The commune of Cotonou is limited to the North by Lake Nokoué and the commune of Sô-Ava, to the South by the ocean

Atlantic, to the East by the commune of Sèmè-Podji, and to the west by the municipality of Abomey-Calavi.
Administratively, the commune of Cotonou is assimilated to the department of Littoral which testifies to its importance. The commune of Cotonou has thirteen (13) arrondissements (see figure1) subdivided into city districts.

3.2. Municipality of sèmè-podji

Located between the parallels 6 ° 22 'and 6 ° 28' of latitude North and the meridians 2 ° 28 'and 2 ° 43' of east longitude, the commune of Sèmè-Podji is contained in the department of Ouémé, which is located in the south-east of the Republic of Benin and bordered on the south to the Atlantic coast. It covers an area of 218 km² or about 0.19% of the area of the Republic of Benin (Communal Development Plan in 2005). The commune of Sèmè-Podji is limited to the North by the commune of Porto-Novo, Aguégués and that of Adjarra, to the South by the Atlantic Ocean, to the East by the Federal Republic of Nigeria and to the West by the city of Cotonou.
Administratively, the municipality has six (06) districts (Agblangandan, Ekpe, Aholouyeme, Djèrègbé, Tohouè, Sèmè-Podji) subdivided into 38 villages and city districts.

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The present study is circumscribed in the 1st and 4th districts of Cotonou commune and those of Agblangandan and Ekpè of Sèmè-Podji commune (figure 1).

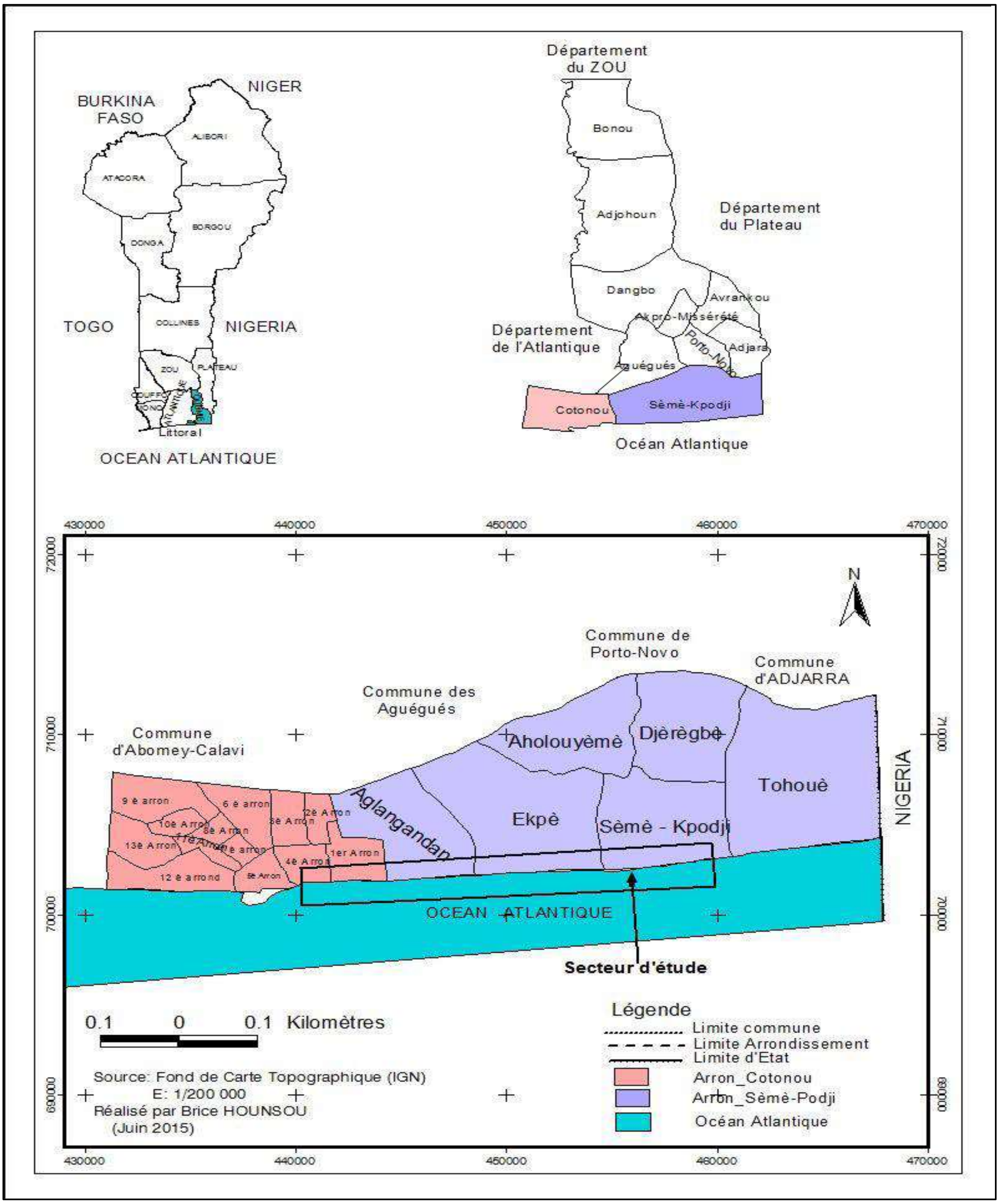

Figure 1: Location of the communes of Cotonou and Sèmè-Podji

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4. MATERIALS AND METHODS

For the present study the fundamental materials used are:

- ✓ Stonex's real-time, static-mode, dual-frequency GPS with a ten (10) kilometer space coverage and accessories;
- ✓ A Samsung-branded digital camera for taking pictures;
- ✓ Software for data processing (AUTOCAD 2008 associated with COVADIS 10.1, ArcGIS, ERDAS IMAGINE 2014).

In the context of such a study, we chose to use: the method called "direct method based on topographic surveys carried out using GPS because of the precision sought (precision less than 2 centimeters)" for the determination of the coastline thanks to the rising of the crest line. To this end, in addition to the data collected during the years 2009, 2012 and 2015, the present topographic mission was organized in three phases: the first took place at the beginning of February 2017, the second at the beginning of the month of April 2017 and the third at the end of May 2017.The necessary data collected were processed. The pretreatment consisted of an inventory of the existing data used to establish the dykes of the selected study area (East side of the SIAFATO dkye). These are: graphic documents drawn up in 2009 and 2012 which present the state of the crest line prior to the completion of the dyke, associated literal documents on the one hand and those drawn up in 2015 after the completion of the dykes on the other hand. In addition to these graphic and literal documents, the research carried out as part of this study at IGN-Benin has made it possible to find other digital data (satellite images, etc.).

The necessary data contributing to the knowledge of the spatial behavior of the coastline and its geometric shape after the treatment made it possible to adopt a model of analysis of results.

- ➢ Analysis of the results

The first study completed in 2015 was supplemented by the field surveys and analyzes 2017. From these GPS surveys, the coastline plans were made. They are surveyed regularly to follow the evolution of the coastline. These features of coast were then superimposed on the same plane by considering two different years (2012 and 2015 then 2015 and 2017) then the features of coast obtained in the same year during the last three topographical missions of 2017 were superimposed.

However, the crest lines of the years 2013 and 2014 have not been the subject of a consistent analysis because it is during these years that the groynes were built.

In addition, the position of the ridge lines at the east of the dyke 7 was the subject of a special study because of the notorious changes observed on this part of the coast.

5. RESULTS AND DISCUSSION

5.1. Variation of the coastline before the realization of the dykes

The results of the various studies carried out by two organizations on this part of the Beninese coast provide information on the rate of annual evolution of the coastline before the implantation of the dykes. It is of the order of 11,86m / year according to the restitution of the satellite imagery of the IPD report, where as the results obtained in 2005, by the DEFT laboratory of Grenoble (France) indicate a rate of more than 8m / year (OTD 2005; CAPO 2008). In order to best adopt a value from which the analyzes will be made, a new estimate of the annual erosion rate of the coast has been made. The rate of erosion regression in the area was then evaluated. These are the crest lines of the years 2009 and 2012 (effective start date of the construction work of the dykes) which were used. To achieve this, it has been associated with this displacement, the theorem of accidental errors of indirect measures developed in the theory of probabilities by Michel (BRABANT 2000). It is this method that made this estimate possible. Then a confidence rate of the result obtained was determined. The results from these measurements (ranging from the protective coating of the Beach Hotel ELDORADO to the east of the dyke 7) are shown in Table I.

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Table 1. Table of calculation of the three-year erosion rate east of the dyke SIAFATO

Order N°	Distance between lines (xi)	Vi=(Xi-25.5762651)	Vi²	Order N°	Distance between lines(xi)	Vi=(Xi-25.5762651)	Vi²	Order N°	Distance between lines(xi)	Vi= (Xi-25.5762651)	Vi²
1	16.14	-9.43626506	89.0430983	18	22.94	-2.63626506	6.94989347	35	30.01	4.43373494	19.6580055
2	19.90	-5.67626506	32.219985	19	21.67	-3.90626506	15.2589067	36	24.46	-1.11626506	1.24604768
3	26.95	1.37373494	1.88714768	20	23.09	-2.48626506	6.18151395	37	28.38	2.80373494	7.86092961
4	31.36	5.78373494	33.4515899	21	11.40	-14.1762651	200.966491	38	27.24	1.66373494	2.76801395
5	32.72	7.14373494	51.0329489	22	13.61	-11.9662651	143.191499	39	25.26	-0.31626506	0.10002359
6	31.40	5.82373494	33.9158886	23	21.75	-3.82626506	14.6403043	40	26.36	0.78373494	0.61424046
7	38.30	12.7237349	161.893431	24	16.54	-9.03626506	81.6540862	41	19.48	-6.09626506	37.1644477
8	38.25	12.6737349	160.623557	25	17.56	-8.01626506	64.2605055	42	22.49	-3.08626506	9.52503202
9	40.29	14.7137349	216.493996	26	23.65	-1.92626506	3.71049708	43	20.70	-4.87626506	23.7779609
10	34.59	9.01373494	81.2474176	27	22.14	-3.43626506	11.8079176	44	19.34	-6.23626506	38.8910019
11	35.38	9.80373494	96.1132188	28	24.13	-1.44626506	2.09168262	45	17.79	-7.78626506	60.6259236
12	40.84	15.2637349	232.981604	29	23.79	-1.78626506	3.19074287	46	16.35	-9.22626506	85.123967
13	40.10	14.5237349	210.938877	30	25.61	0.03373494	0.00113805	47	17.95	-7.62626506	58.1599188
14	34.24	8.66373494	75.0603031	31	25.64	0.06373494	0.00406214	48	16.00	-9.57626506	91.7048525
15	29.93	4.35373494	18.9550079	32	25.06	-0.51626506	0.26652961	49	8.95	-16.6262651	276.43269
16	22.15	-3.42626506	11.7392923	33	23.09	-2.48626506	6.18151395	50	11.82	-13.7562651	189.234828
17	23.26	-2.31626506	5.36508383	34	25.33	-0.24626506	0.06064648	51	20.04	-5.53626506	30.6502308

Table 1. (cont. 1): calculation table for the three-year erosion rate east of the SIAFATO Spur

Order N°	Distance between lines (xi)	Vi=(Xi-25.5762651)	Vi²	Order N°	Distance between lines(	Vi=(Xi-25.5762651)	Vi²	Order N°	Distance between lines(	Vi=(Xi-25.5762651)	Vi²
52	16.02	-9.55626506	91.3222019	74	21.21	-4.36626506	19.0642706	96	28.89	3.31373494	10.9808393
53	17.57	-8.00626506	64.1002802	75	25.38	-0.19626506	0.03851997	97	28.34	2.76373494	7.63823082
54	22.47	-3.10626506	9.64888262	76	25.40	-0.17626506	0.03106937	98	29.36	3.78373494	14.3166501
55	18.29	-7.28626506	53.0896585	77	24.68	-0.89626506	0.80329106	99	27.62	2.04373494	4.1768525

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56	19.83	-5.74626506	33.0195621	78	24.47	-1.10626506	1.22382238	100	28.63	3.05373494	9.32529708
57	19.17	-6.40626506	41.040232	79	26.70	1.12373494	1.26278021	101	27.59	2.01373494	4.05512841
58	17.24	-8.33626506	69.4933152	80	28.34	2.76373494	7.63823082	102	28.69	3.11373494	9.69534528
59	14.92	-10.6562651	113.555985	81	25.05	-0.52626506	0.27695491	103	30.42	4.84373494	23.4617682
60	12.20	-13.3762651	178.924467	82	25.57	-0.00626506	3.9251E-05	104	33.00	7.42373494	55.1118405
61	29.11	3.53373494	12.4872826	83	24.94	-0.63626506	0.40483323	105	33.22	7.64373494	58.4266838
62	24.92	-0.65626506	0.43068383	84	26.68	1.10373494	1.21823082	106	31.51	5.93373494	35.2092103
63	24.76	-0.81626506	0.66628865	85	25.00	-0.57626506	0.33208142	107	35.45	9.87373494	97.4906417
64	26.73	1.15373494	1.33110431	86	25.64	0.06373494	0.00406214	108	35.42	9.84373494	96.8991176
65	25.10	-0.47626506	0.22682841	87	26.07	0.49373494	0.24377419	109	37.53	11.9537349	142.891779
66	25.03	-0.54626506	0.29840552	88	28.08	2.50373494	6.26868865	110	32.72	7.14373494	51.0329489
67	23.62	-1.95626506	3.82697299	89	22.65	-2.92626506	8.5630272	111	34.71	9.13373494	83.4251139
68	23.66	-1.91626506	3.67207178	90	26.86	1.28373494	1.6479754	112	32.55	6.97373494	48.632979
69	21.04	-4.53626506	20.5777007	91	27.00	1.42373494	2.02702118	113	31.11	5.53373494	30.6222224
70	23.07	-2.50626506	6.28136455	92	27.35	1.77373494	3.14613564	114	30.36	4.78373494	22.88412
71	23.67	-1.90626506	3.63384648	93	27.57	1.99373494	3.97497901	115	29.28	3.70373494	13.7176525
72	23.55	-2.02626506	4.10575009	94	26.82	1.24373494	1.5468766	116	21.00	-4.57626506	20.9422019
73	24.06	-1.51626506	2.29905973	95	26.72	1.14373494	1.30812961	117	19.62	-5.95626506	35.4770935

Table 1. (Continuation 2 and end): Table of calculation of the three-year erosion rate for the east of the SIAFATO spike

N° of order	Distance between lines (xi)	Vi= (Xi-25.5762651)	Vi²	N° of order	Distance between lines (xi)	Vi= (Xi-25.5762651)	Vi²	N° of order	Distance between lines (xi)	Vi= (Xi-25.5762651)	Vi²
118	22.28	-3.29626506	10.8653633	132	28.01	2.43373494	5.92306576	146	27.41	1.83373494	3.36258383
119	23.03	-2.54626506	6.48346576	133	26.56	0.98373494	0.96773443	147	27.9	2.32373494	5.39974407
120	24.23	-1.34626506	1.81242961	134	24.96	-0.61626506	0.37978262	148	27.66	2.08373494	4.3419513
121	25.07	-0.50626506	0.25630431	135	25.41	-0.16626506	0.02764407	149	27.26	1.68373494	2.83496335
122	26.1	0.52373494	0.27429829	136	24.53	-1.04626506	1.09467058	150	27.22	1.64373494	2.70186455
123	28.23	2.65373494	7.04230913	137	25	-0.57626506	0.33208142	151	28.48	2.90373494	8.4316766

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124	27.05	1.47373494	2.17189467	138	26.34	0.76373494	0.58329106	152	30.22	4.64373494	21.5642742
125	25.38	-0.19626506	0.03851997	139	27.48	1.90373494	3.62420672	153	31.46	5.88373494	34.6183368
126	25.61	0.03373494	0.00113805	140	26.87	1.29373494	1.67375009	154	34.95	9.37373494	87.8669067
127	26.4	0.82373494	0.67853925	141	26.5	0.92373494	0.85328624	155	28.79	3.21373494	10.3280923
128	25.6	0.02373494	0.00056335	142	26.34	0.76373494	0.58329106	156	18.92	-6.65626506	44.3058646
129	27.81	2.23373494	4.98957178	143	28.16	2.58373494	6.67568624	157	14.4	-11.1762651	124.908901
130	27.9	2.32373494	5.39974407	144	28.36	2.78373494	7.74918021	158	7.27	-18.3062651	335.11934
131	29.31	3.73373494	13.9407766	145	28.25	2.67373494	7.14885853	159	12.93	-12.6462651	159.92802
Total	4245.66	-3.908E-14	6086.66568								
									XAvg= 25.5762651		σ= 6.05530022

In view of the results obtained, erosion evolved on average by a distance X = 25.576m from 2009 to 2012. We deduce that for a year, the average rate of erosion is: (25.576m) / 3 = 8.525m about 8.50m / year (HOUNSOU 2015). This result only confirms that of the DEFT laboratory in Grenoble (France) in 2005. The same research bureau has published an alarmist study according to which "sirienn" is done before 2025, the coast must retreat of 950m compared to 1963, resulting in almost all the districts of Cotonou as well as the portion of the RNIE N° 1 located east of SIAFATO (CAPO 2008).

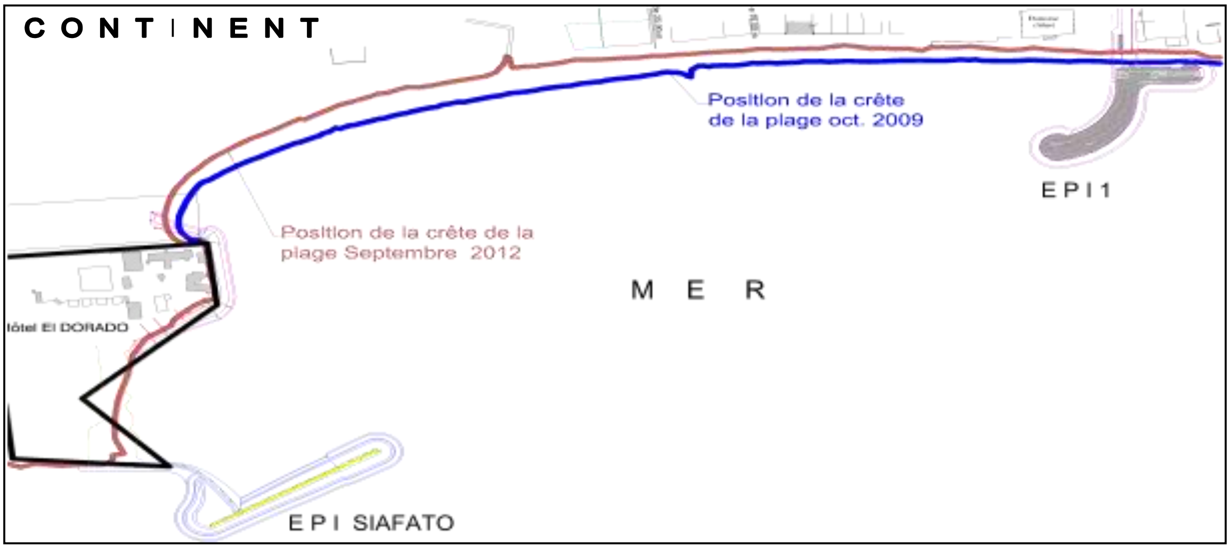

Figure 2: Position of the coastline during the years 2009 and 2012 between SIAFATO's dyke and the dyke 1

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5.2. Variation of the coastline obtained after implantation of the dykes in 2012 and 2015

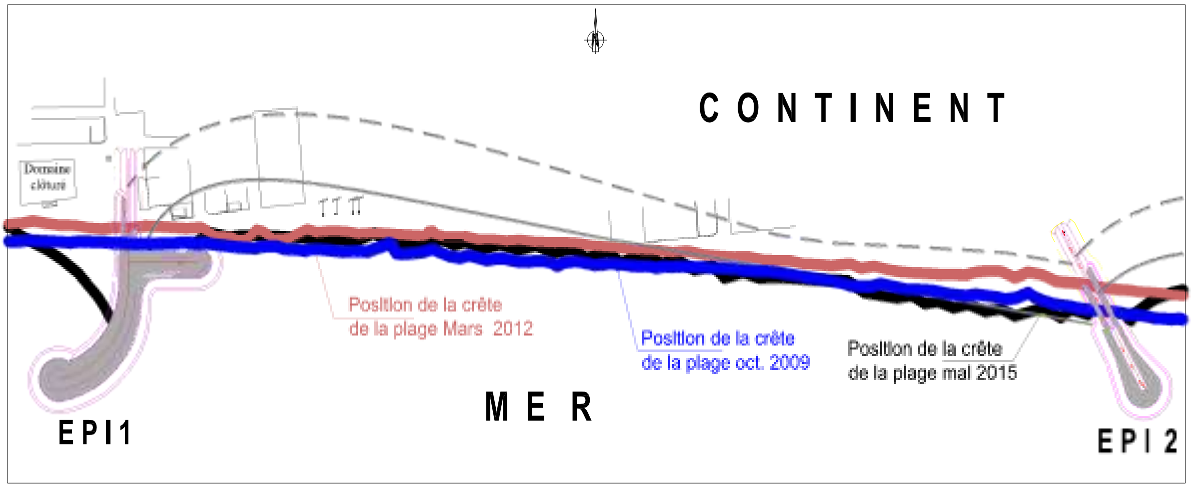

Figure 3: Coastline position in October 2009 September 2012 and May 2015 between dyke 1 and dyke 2

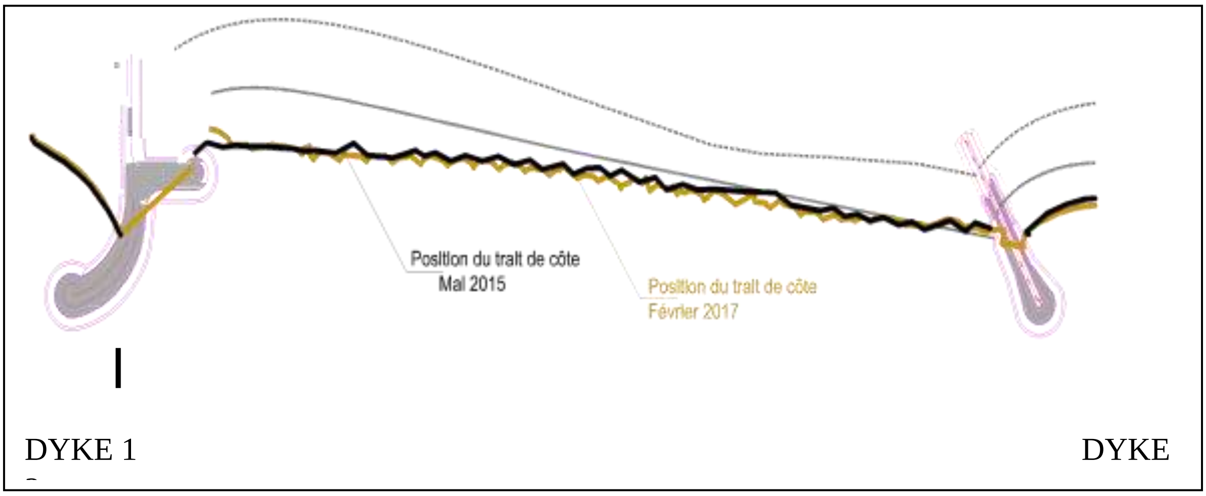

Figure 4: Peak line of May 2015 and February 2017 between dyke 1 and dyke 2

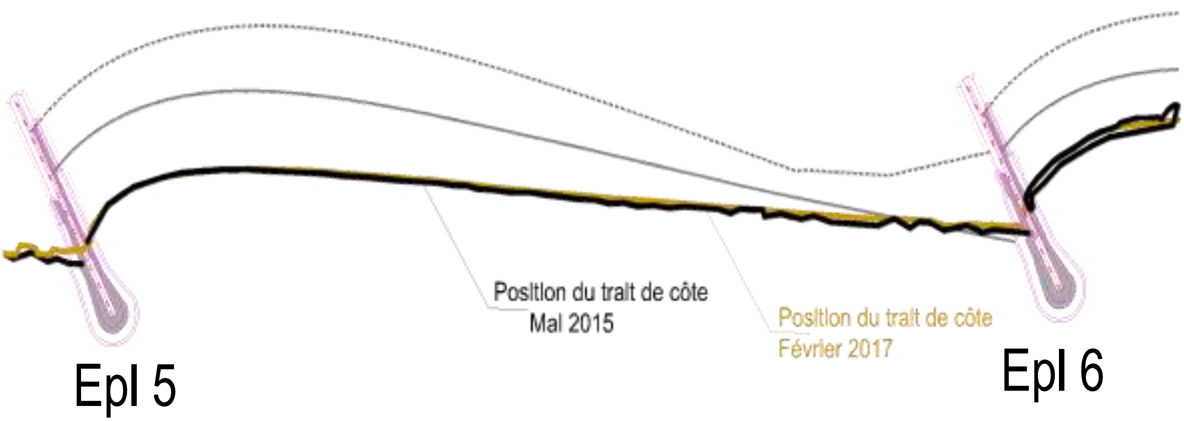

Figure 5: Peak line of May 2015 and February 2017 between dyke 5 and dyke 6

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In general, erosion has been a hindrance in most cells defined by the dykes. If the results of the 2015 studies between SIAFATO and dyke 7 seem to be in agreement, what about the results obtained in the East of the dyke 7?

5.3. Evolution of the east coastline of the dyke 7

The lack of protection works on the east coast of the dyke 7 generates increased mobility waves that in their wave movements do not encounter any obstacle during their journey. Thus, after the discharge of sediments to the west of this dyke, we are witnessing in the East a continual and vertiginous erosion in this zone. It has already been shown that the annual erosion rate before building a dyke between 2009 and 2012 is about 8.50m / year. In addition, in the absence of a protective structure in the east of the dyke 7, the erosion is very pronounced causing a disturbing advance of the sea. Hence the calculation of the annual erosion rate between 35m and 51m according to the date of the considered ridge lines (HOUNSOU, 2015). With the aim of confirming or invalidating these values, a new estimate of the erosion rate downstream of DYKE 7 was determined by considering the crest lines of May 2015 and may 2017 and then the crest lines of February 2017 and May 2017. The results obtained are given in Table 2.

Table 2. Summary table of erosion rate

	Year	Annual erosion rate (inferior limit)	Annual erosion rate (Superior limit)	Interval
Results	2015	35m	53m	[35m–53m]
	2017	26m	51m	[26m–51m]

It arises from the results obtained during the years 2015 and 2017 and from those obtained only in the year 2017 that follows: the increase of the erosion rate in the East of the dyke 7 is not uniform over the years.

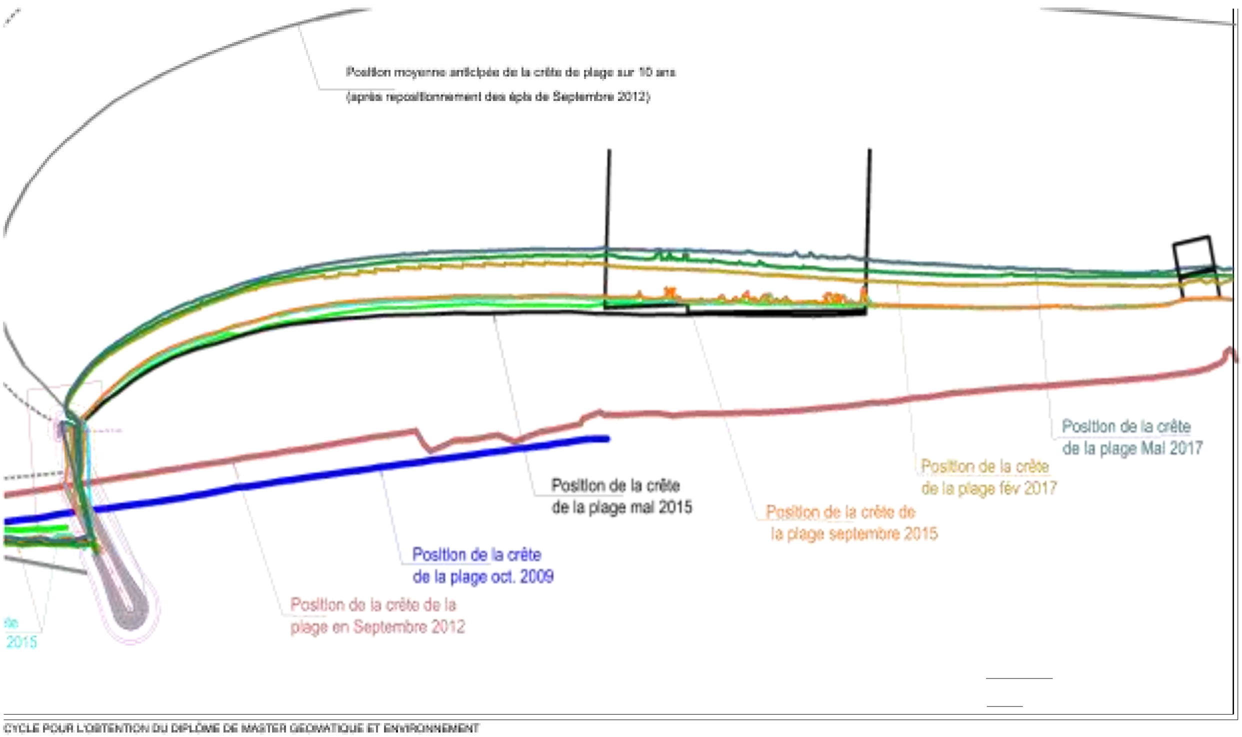

Figure 6: Peak line of the months of October 2009, September 2012, May 2015, February 2017 and May 2017 East of the dyke 7

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6. CONCLUSION

This study, which focuses on the dynamics of the coastline east of the SIAFATO dyke, was aimed mainly at following the evolution of the coastline in this part of the Beninese coastline. Among other things, it was necessary to identify the position of the coastline in each cell constituted by two dykes on the one hand and to evaluate the rate of advance of the ridge line downstream of the dykes 7 in order to compare the results obtained in 2015 to those provided by the coastline of 2017. Overall over the 12 km of coast explored, eight kilometers were stabilized. This testifies to the efficiency of the functioning of the works put in place but the phenomenon of erosion is postponed downstream of the dyke 7 where the sea is making great strides on the continent. This advance, which was estimated at 35m per year in 2015, is currently estimated at 26m per year.

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