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Evolution of Beninese Coastline from 1963 to 2005: Causes and Consequences

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Research Article

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ABSTRACT

The coastal zone of Benin is the interface between the marine environment and the straightforward continental environment. It is constituted of sandy cords, lagoon system, lakes and flood plains. This zone shelters a population of about 3 million inhabitants that is more than 30% of the Beninese population. As all coastal regions of the world, this zone remains very sensitive to climatic changes (global elevation of the sea level, perpetual variations of the weather marines conditions) and to human activities (large inland dams, harbour infrastructures, urbanization) that drive to the rupture of the equilibrium in this coastal environment with enhanced risks of beach erosion as the main consequences. This study monitors the evolution of the Beninese shorelines around Cotonou and underlines the causes mainly human that negatively affect this naturally fragile environment. Natural factors (tempests and erosive processes) and human actions (building of the port of Cotonou (1962) then Lome (1967) and hydroelectric dams on Volta (1966) and on Mono (1987) rivers) aim the coastal evolution of the Benin. They procreate, on the sandy cords at East of ports and rivers mouths, an erosion about 10 m linked to the reduction of provisions in sand and the fragilisation of cords by farms, steps and of anarchic occupations.

Keywords: Coastal zone; beach erosion; remote sensing; Benin.

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1. INTRODUCTION

The Beninese coast is an integral part of the geo-system of the Beninese gulf located between the Cape Three Points in Ghana on the West side and the western facade of the Niger delta in the East. It occupies the central part of this gulf (Fig. 1).

This geo-system is characterized by an intense coastline transit on a beach of average and big size sands where two main streams meet: the river Volta in Ghana and Mono between Togo and Benin. Before the sixties, the quantities of sediments of these two rivers were respectively 1.000.000 m^3/year (EEC, 1989) and of 100.000 m^3/year (CEDA, 1998). Nowadays – because of natural or sometimes anthropological causes - this coastline evolves in a context of erosion and accumulation. Indeed, the global rise of the marine level connected with the global warming which affects the coastlines of the whole world (Houghton and al., 2001) represents a natural cause, on one hand. The major human accomplishments which fundamentally disrupted the coastal balance during these last forty years are on the other hand an anthropological cause. Thus, the Akossombo dams built on the Volta River (1966) and Nangbeto dam on the Mono River (1987) strongly reduced the sedimentary contributions of these two streams. Besides, the harbor works in Lome (Togo) in 1967 and Cotonou (Benin) in 1962 in certain places stopped the littoral transit.

These various human accomplishments split up the coastal domain of the Beninese gulf. Its functioning can then only be unraveled by an elementary approach. We thus resorted to the approach of study using sedimentary cells which is a notion that takes into account the temporal and spatial irregularities of a coastline and allows us to better comprehend the functioning of the natural sandy or anthropogenic beaches (Certain and Barusseau, 2002; Anthony, 2009).

A sedimentary cell or an hydro-sedimentary, morpho-sedimentary - or a drift cell is known as a section of coastline in a state of well-balanced global sedimentary assessment, along which sediments flow (Cohen and al., 2002). It includes four borders (Certain and Barusseau, 2002): [1] the ground border, closed, made up of dunes and aerial beach; [2] the marine, open border; [3] a side border marking the departure of a coastline transit (source area) and [4] a side border marking an accumulation sector of the sand it transported (accumulation area). The last two areas (source and accumulation) are linked by a transition area.

Generally, the source area is featured by an erosion and accumulation area by accretion. However between both areas there is a stabilized transition area (Certain and Barusseau, 2002).

On a coastline where the engine of dynamics is the littoral drift, it is both side borders which matter most. They can be mobile or fixed. The fixed limits can be natural (cape, embouchure) or anthropological (sea wall, harbor bridge), impermeable (if they completely block the littoral transit) or permeable (if the sedimentary material exceeds - even partially - the limit).

The application of this analytical approach brings us to subdivide the coastal domain of the Beninese gulf into five sedimentary cells (Fig. 1):

- Cell I: it extends from the Cape Three Points to the Volta delta;
- Cell II: it is limited by the Volta delta and Lome harbour;

- Cell III: lies between the Lome harbour the Mono river mouth in Avloh;
- Cell IV: it corresponds to the coastal domain extending from the embouchure of Mono to the Cotonou harbour;
- Cell V: it extends from the Cotonou harbour in the western facade to the Niger delta in Nigeria.

Our study area covers partially the last two sedimentary cells (Fig. 1 and 2). The phenomena of erosion that this coastal domain undergoes were studied by numerous authors (Rossi, 1989; Oyede et al., 1998; Dossouhoui, 2001; Kaki et al., 2001; Blivi, 2003; Hounkpe, 2004; Oyede et al., 2005; Adjoussi, 2008; Degbe and al., 2010). These authors denounce the anthropological practices which accelerate the intensification of the erosion. However, their studies didn't track the diachronic evolution of the coastline.

The aim of this study is from then on to retrace the evolution of Cotonou Coastline in Benin (Fig. 2) during these past fifty years. The study is based on detailed analysis remote sensing data and completed by various ground missions that make it possible to identify the factors aggravating the phenomena of erosion.

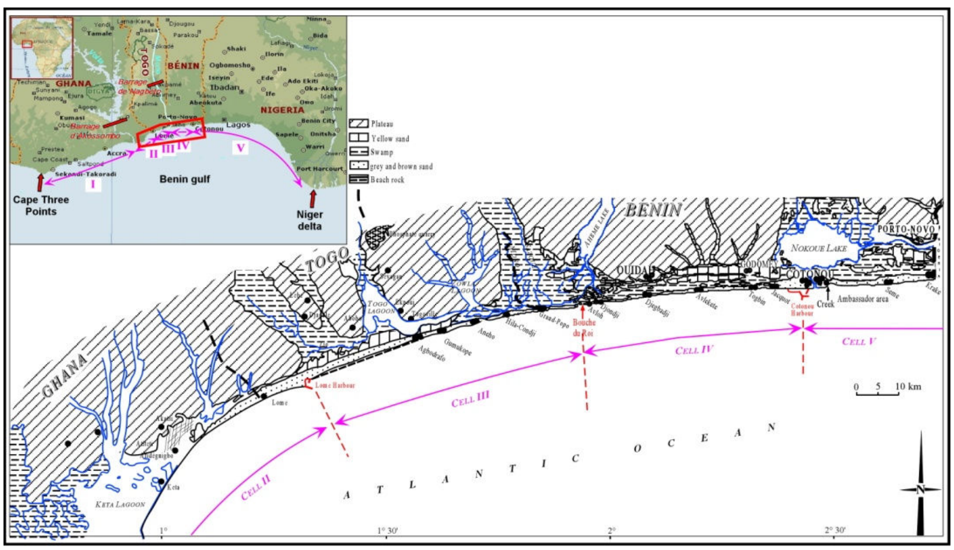


Fig.1: The location of the Beninese gulf in West Africa (upper left corner) and details regarding the sedimentary cells of the central area of this gulf

2. MATERIALS AND METHODS

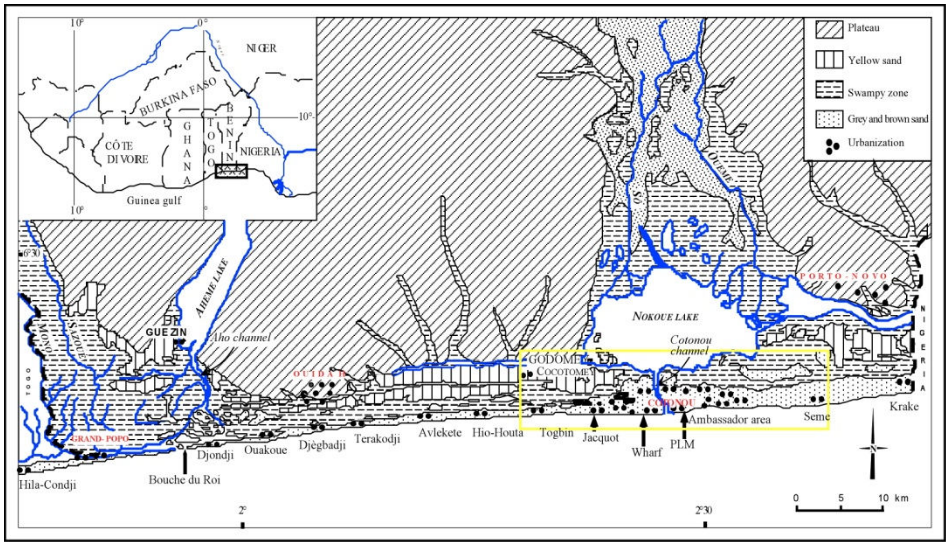
2.1 Data

2.1.1 Aerial photos, maps and satellite images

Various documents were gathered in order to observe the coastal features:

- three topographic cards using the scale 1:50000 (pages Porto Novo 1c, 1d and 2c) published in 1968 by the National Geographical Institute (Paris), realized from the aerial cover of 1956-1957 and pre-completed in 1962-1963;
- aerial photos of1981 using the scale 1:30000;

- aerial photos of 1995 in the scale 1:10000
- satellite images IKONOS of 2000 of 1 meter of resolution



(1 – Plateaux of laterite; 2 – Yellow sand; 3 – Swampy area; 4 – Grey and brown sand; 5 - Urbanization) Yellow box: Domain of study.

Fig. 2: Geomorphologic map of the coastal area of Benin (Kaki et al., 2001) and situation of the study area

2.1.2 Ground missions

A regular follow-up of the studied coastline was realized over a period of 18 months, starting in February, 2002 till October, 2003. Thus, on 4 observation stations (Seme, El Dorado, Jacquot and Djegbadji) which were chosen along the coastline (Fig. 2), we proceeded with:

- the elaboration of the beach profiles and with the analysis of their morphology;
- the measure of the ebb and flow of the sea by means of a meter ribbon.

2.2 Methods

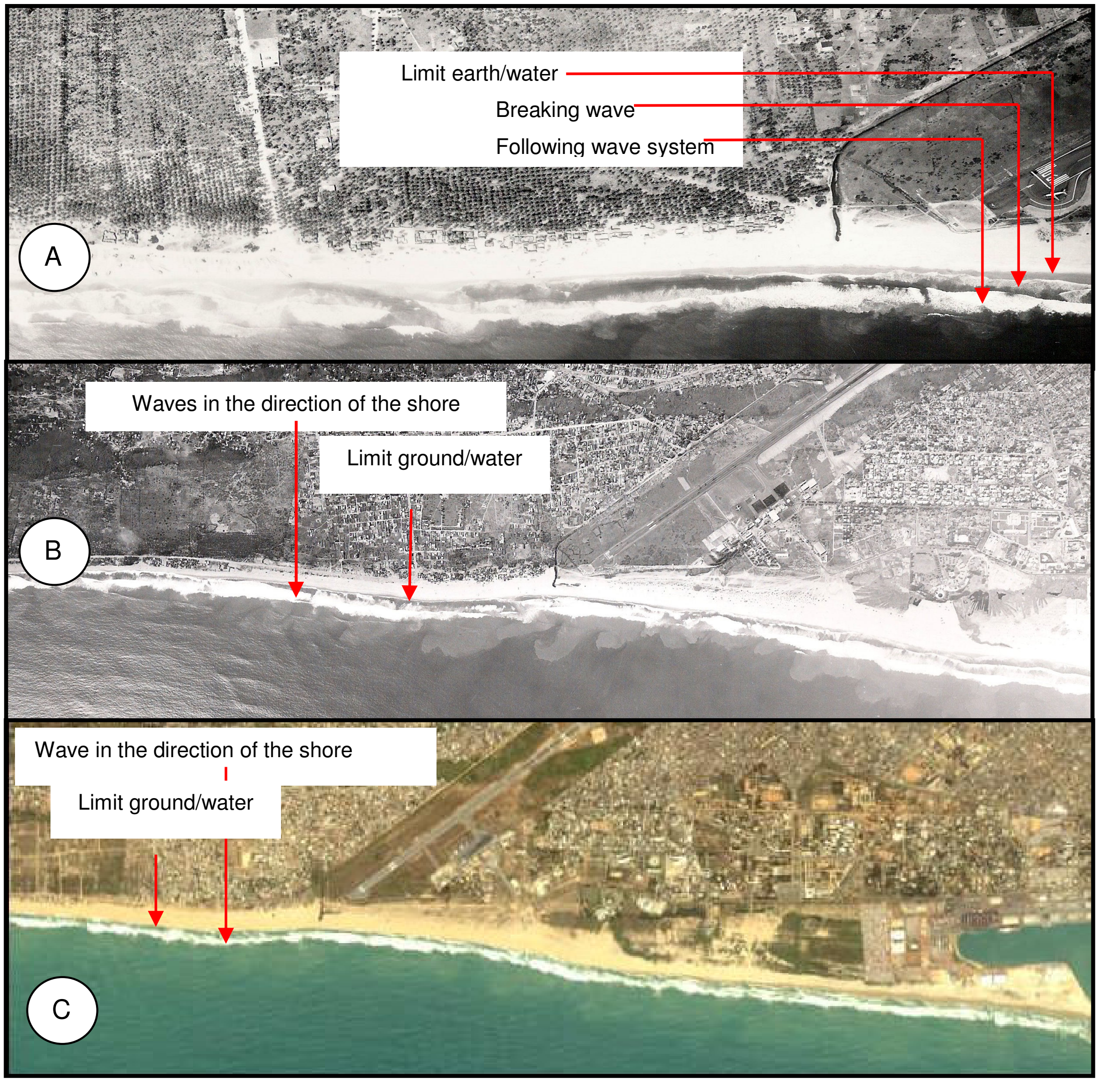
2.2.1 Treatment of aerial photos, maps and satellite images

The various cartographic, aerial and satellite data were analyzed by using three software: Adobe Photoshop, Erdas Imagine 8.7 and Canvas 6.

The main stages undertaken are the following ones:

2.2.1.1 Mosaic and geometrical correction

Having scanned the topographic maps and the aerial photos, we proceeded with doing their mosaic as well as observing the images IKONOS obtained with the help of the Erdas Imagine 8.7 software. We then based ourselves on the topographic map in order to realize their geo-referencing, with the help of the same software. This stage has managed to be successful with a Root Mean Square Error (RMSE or root-mean-square error) ranging between 0.35 and 0.5 for three series of images acquired (two assemblies of aerial photos of the missions in 1981 and 1995, and an assembly of IKONOS satellite images of 2000).



A: Aerial photograph during 1981 mission 1981; B: Aerial photograph of the 1995 mission; C: Image Ikonos 2000

Fig. 3: Digitalized reference line

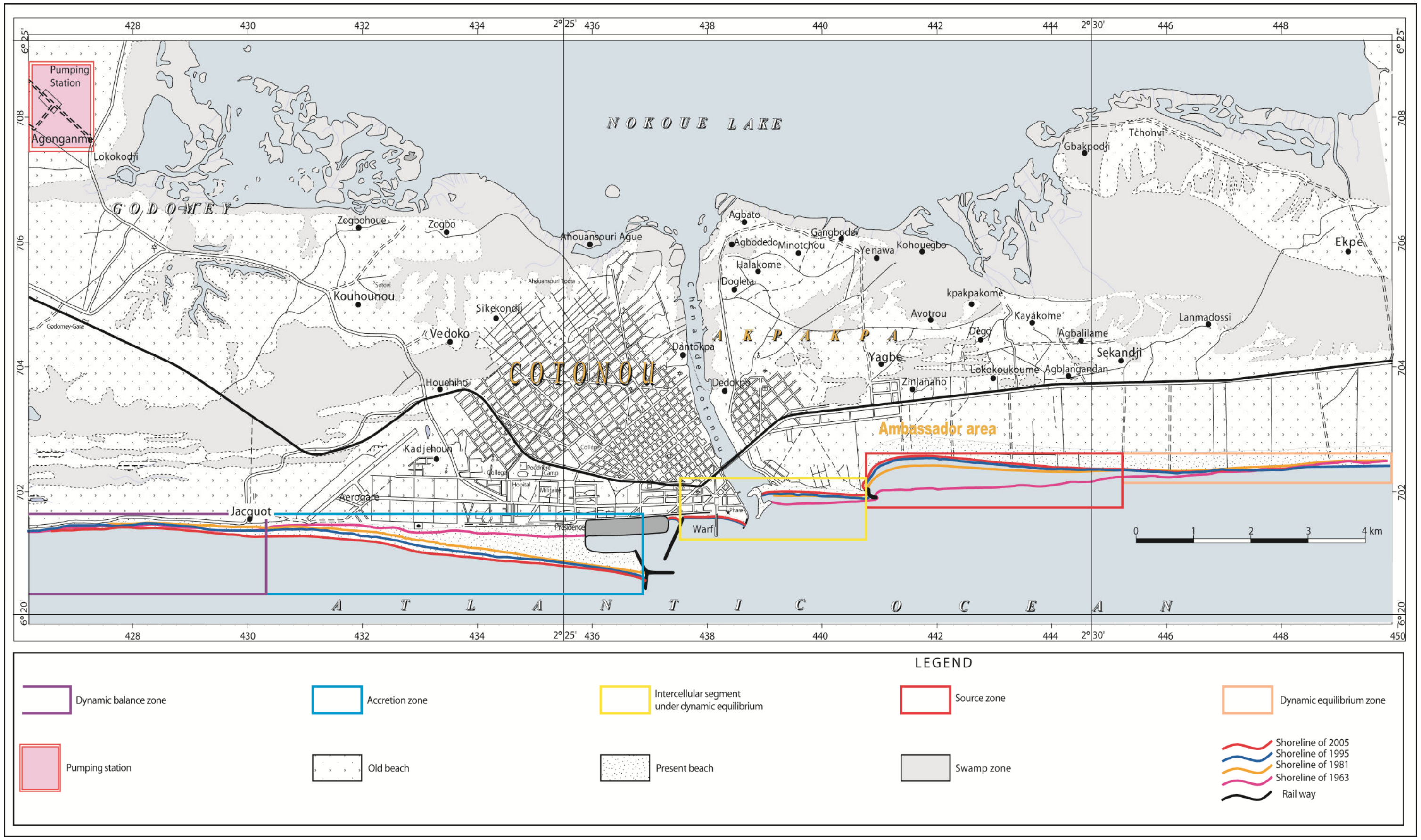


Fig. 4: diachronic study of Cotonou littoral with the help of remote sensing

2.2.1.2 Selection, digitalization and superposition of the coastal features (reference line) corresponding to the various periods

The selection of the reference line remains visual, but it is necessarily based on a certain logic which depends on the context in which the analyst finds himself and on the information which he has. Actually, there are several reference factors used in observing a coastline (Robin, 2002) such as the riverbank line, the level of tide, the type of vegetation, the level of high tides, crest of cliff, dunes, the foreshore beach and the earth / water limit. We chose the last reference line, that of the earth / water limit. Indeed, this limit appears very sharply on all our aerial photos and on the IKONOS images (Fig. 3).

The digitalization and the superposition of the coastline features were made with the 6-Canvas software.

2.2.1.3 Representation of the kinematic quantity: estimation of the recession speed from the reference line and the kinematic surface

These operations were finalized with the 6-Canvas software. The maximal speed of recession of the coastal line between two periods was calculated taking into account the maximal distance between banks corresponding to two periods considered following the perpendicular between both banks (Robin, 2002).

The surface erosion was also calculated starting from the polygons encircling the eroded surface, according to the method of kinematic polygon by Robin (2002).

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Kinematic study

The diachronic study of the littoral evolution by remote sensing (Figure 4) shows two littoral landscapes on both sides of autonomous harbour of Cotonou

3.1.1.1 Cell IV

An area of continual accumulation was observed in the west of sea harbour of Cotonou (Fig. 4). This is the shaft area of cell IV (Fig. 1). It is more extended in the west by an area of dynamic equilibrium or transition area (Fig. 4). The source area of this cell IV consists of Mono river embouchure (Fig. 1). This river drained about 100,000 m^3 / year before the dam Nagbeto as opposed to 44,000 m^3 /year at present (Blivi 2000). Though poor, the supply from Couffo was added to that of Mono (Fig. 1). The western border of the cell can also be considered permeable as the supply of littoral drift from cell III (Fig. 1).

- Between 1963 and 1981 (Fig. 5), the shore shows two different characteristics:
    - In the transition area, a strip of sand with a maximum width of 75 meters was eroded during 18 years, which means an erosion of a maximum speed of 4 m / year, sinking 13.3 hectares.

- The shaft area, on the other hand, shows an advancement of the shore. A strip of sand with a maximum width of 460 meters was built during 18 years, at a maximum rate of 25.5 m / year, erecting a beach strip of 130.5 hectares.

- Between 1981 and 1995, there was an accumulation both in the transition and shaft areas. An advancement of the beach with a maximum width of 100 meters in 14 years was observed, at a speed of 7 m / year. Position was therefore the fattening of 9.8 hectares in the transition zone and 37.0 hectares in shaft area.

- From 1995 to 2000, it is the same pattern as in the previous period. A strip of sand with a maximum width of 115 meters was built in five years, at an increasing speed of 23 m / year. Kinematic surface was 18.5 ha in the transition area and respectively 23.8 ha in the shaft area.

3.1.1.2 Cell V

The area right next to the East of the sea port shows intense erosion (Fig. 4). It is the source area of cell V (Fig. 3). It is called "Eldorado Creek." Sediments that were pulled out were redistributed after crossing a stability area that was only a few kilometers away (Fig. 4). The shaft area covers an important coastal line from Seme beach (Fig. 4) to the west side of the Niger Delta in Nigeria (Fig. 3).

- Between 1963 and 1981 (Fig. 6):
  - The distance between the two lines of the shore, in the source area, was 380 meters in 18 years, at an erosion speed of 21 m /year. Kinematic Surface was 145 ha.
  - In the zone of accretion, a strip of sand with a width of 80 meters was accumulated in the area covered by air photographs, at a settling speed of 4.5 m / year.

- Between 1981 and 1995 (Fig. 6):
  - In the source area, a strip of beach with a maximum width of 135 meters was sunk by the sea in 14 years, at an erosion speed of 10 m / year. The kinematic surface was 32.75 hectares.
  - In the accumulation area, from 1981 to 1995 the gap between the shore was of 165 meters, showing an accumulation speed of 12m/year.

- Between 1995 and 2000 (Fig. 6):
  - In the source area, a strip of land with 55 meters was sunk in five years, which means the erosion speed is of 11 m / year. The kinematic surface was 17.75 ha.
  - In the of accretion area, an erosion was paradoxically observed sinking a strip of sand with a maximum width of 100 meters in the area covered by aerial photographs, at an erosion speed of 20 m / year.

We defined the transition area linking the two neutral points particularized between the shores of 1963 and 1981 on one hand and between 1981 and 1995 on the other hand. These neutral points indicate the limits beyond which the redistribution of material removed in the source area begins. The two neutral points lie on the Pier East, 9.3 km away from the first one (neutral point between the shores of 1963 and 1981) and 4.3 km away from the second neutral point (neutral point between the shores of 1981 and 1995). Contrary to the previous characteristic of the shores, the shore of 2000 did not identify the neutral point, but rather a neutral area of about six kilometers comprised between the 4th and 10^{th} km east from Pier East.

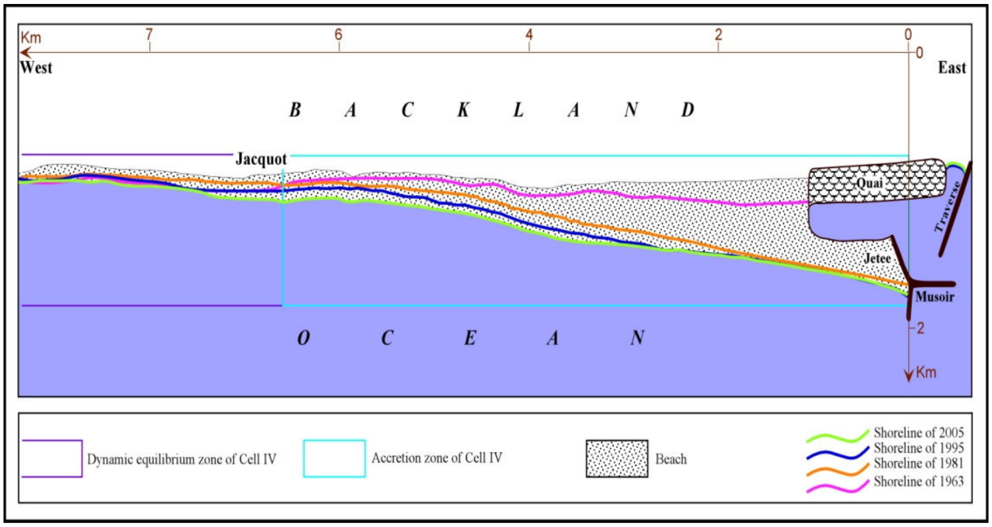


Fig. 5: Kinematic evolution of cell IV from 1963 to 2005

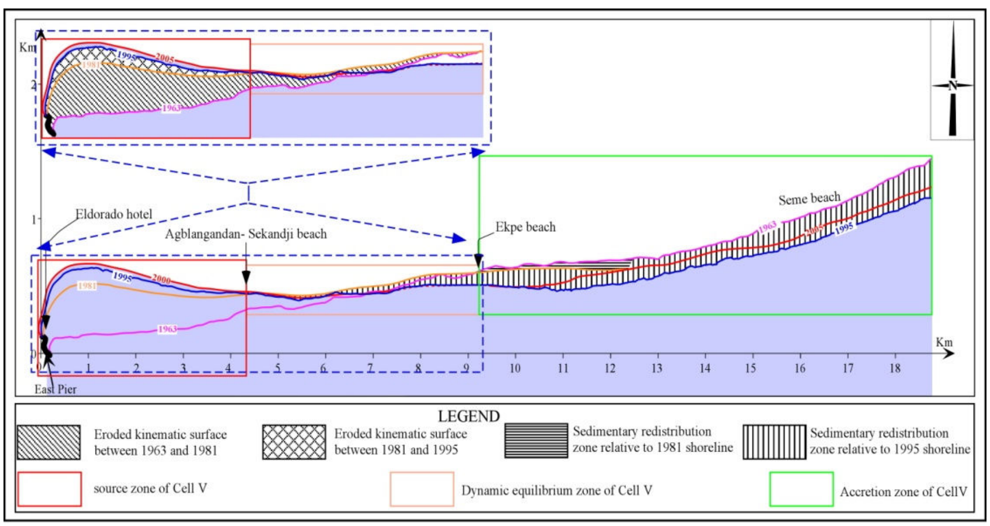


Fig. 6: Kinematic Evolution of cell V from 1963 to 2005

3.1.2 Study of sedimentary morphodynamic

From February 2002 to October 2003, the profiles of beach along the coastline of Benin from Djondji to Seme were thoroughly and regularly monitored. We showed here the beach profiles of four stations (Fig. 7) where rapid morphodynamic changes were observed. The first two correspond to cell IV and the last two to cell V.

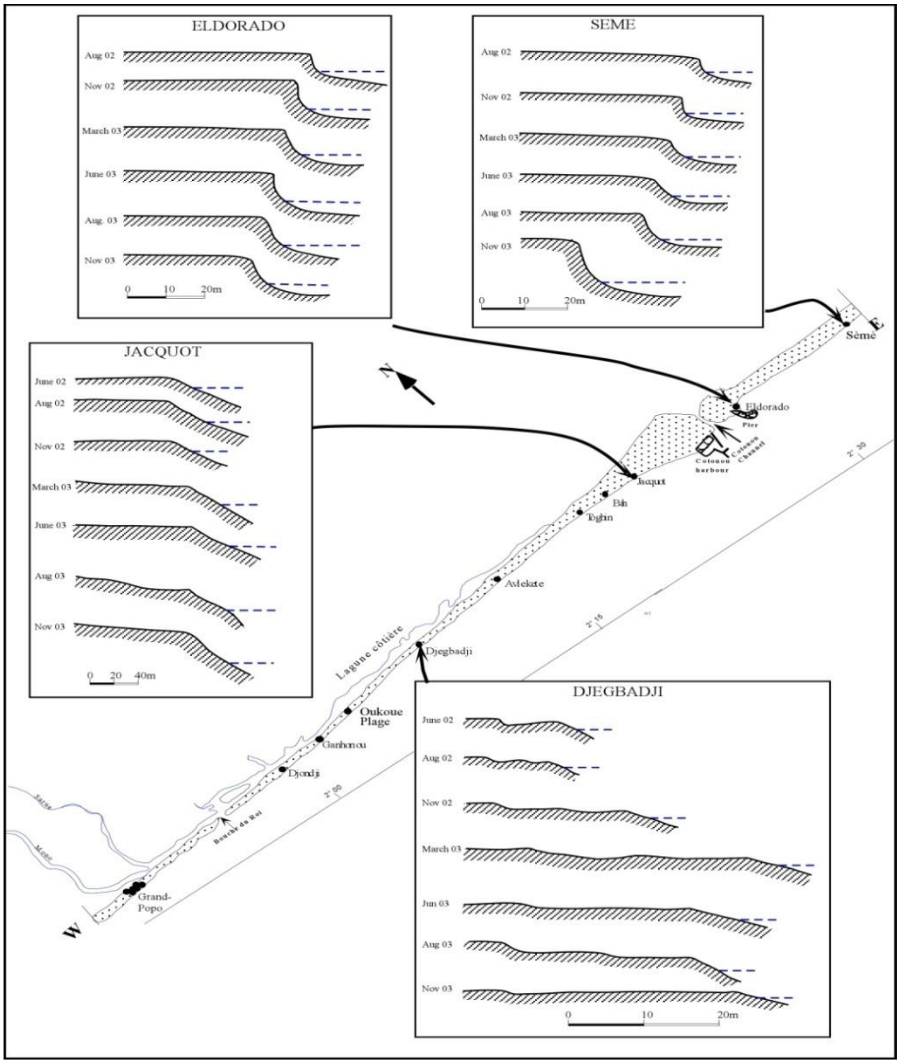


Fig. 7: Evolution of certain coastline profiles in Benin from 2002 to 2005

3.1.2.1 Cell IV

- _Djegbadji station_ (Fig. 7): from April to August 2002, the beach of Djegbadji was eroded and about 5 meters of shoestring sand were carried away over a period of four months. From November 2002 to November 2003, a progressive advancement of the beach was observed.
- _Jacquot station_ (Fig. 7): the beach of Jacquot showed wasteful profiles. Within 14 months, from June 2002 to August 2003, 18 meters of beach were covered by the sea. Overall, this beach shows signs of advancement. However, it is sometimes sporadic erosions that make reflective profile and are probably in connection with episodes of storms (Maspataud, 2011).

Photo 1: Source area of Cell V showing the anarchic occupation of the coastline (March 2005)

Photo 2: Certain damages caused by coastline erosion in Benin (March 2005)

Photo 3: Source area of Cell V showing the erosion parabola within the continent (March 2005)

3.1.2.2 Cell V

- *Station of Eldorado Hotel* (Fig. 7): the point of observation in this area was located right next to the East of Eldorado Hotel bordered by the Pier East. It is the source area of cell V which, paradoxically, was still heavily occupied by fishermen settled in slum settlements (Photo 1). It shows a reflexive profile (photo1). Within 15 months, 11.5 meters of offshore bar were submerged by the sea, destroying the slums or shanty towns. As a matter of fact, immediately after the hotel, the sea made an incursion upon the continent, eroding the downstream cord of the pier and isolating the hotel in a space that could nearly be compared to an island. It caused the destruction of buildings, roads and other coastal works (Fig. 2), forming an erosion parabola in the continental area (Photo 3) with a crest located at about the vertical of Yagbe (Fig. 5).

- *Seme station* (Fig. 7): Seme beach shows a very reflective profile revealing erosion of sea cliffs of very abrupt consistency. Within twelve months, there was an erosion of the beach of thirty meters destroying coconut trees and threatening the reserved forest of casuarinas.

3.2 Discussion

As we mentioned beforehand, the diverse regional anthropological factors (harbours, dams) that have disrupted the equilibrium of beaches dated the beginning of the sixties and led to a cellular segmentation of the coastline of Benin gulf (Laibi and Oyede, 2011). The evolution of the coasts between these anthropological dams (harbour bridges, ears) - which could moreover be as natural (cape, headlands) - was thus regrettably predictable. However, the recent kinematics of the last ten years raise an issue suggesting the appearance of a new dominating factor that causes the recession of beaches.

3.2.1 Kinematics of the shores and sedimentary morph-dynamics of the cell IV

The behavior of the transition area which is expressed by erosion from 1963 till 1981 and an increase in dimensions since 1981 can be ascribed to the definition of this area which actually represents a reserve of sand which the sea can remove during storms and gradually restore during periods of good weather.

The profile of Jacquot beach is compatible with the context of the station of measure, the accumulation areas of the cell IV.

The station of Djegbadji can be also considered as belonging to transition area which is in dynamic equilibrium, thus with alternations of erosion and increase in dimensions in time. But the truth is that this beach was the siege of sand deposits. Actually, during the period between May and August, 2002, the population of Ouidah was still exploiting the quarry of Djegbadji situated approximately one kilometer east of the point of measure. Since September, 2002, the quarry was abandoned by the population following an order from the Mayor. The dissipating profile of this beach since November 2002 can be thus interpreted as a restoring of the sedimentary equilibrium following the abandonment of quarries.

3.2.2 Kinematics of the shores and sedimentary morph-dynamics of the cell V

If the transformation of the neutral point in a neutral area noticed in the transition area can be connected to the dynamic nature of the sedimentary equilibrium of this area, the appearance of erosion in the accretion area is worrying and triggers the consideration of a new dominating factor provoking the recession of beaches.

The analysis of the beach profiles shows that the morphology of El Dorado beach is in agreement with the context of the station of measure: the source area of the cell V. Let us nevertheless note here the anarchical occupation and the stamping that causes the weakening of the sandy cords in the grip of erosion (photo 1).

On the other hand, the profiles of the Seme station are not in adequacy with the context of the following station: the accretion area of the cell V.

Actually, since the closure of the sand quarry of Jacquot (Fig. 3), the population of Cotonou resorted to Seme beach since 1994 (Fig. 4 and 6) which is nothing else but accumulation area of the sand from the El Dorado creek. According to the labour union of the transporters in Benin (UNACOB), 1000 000 m^3 of sand are taken in this area yearly. Indeed, uncountable quarries are wildly opened and exploited there by truck drivers who work on it daily, transforming the Seme beach into a real construction site (photo 4).

This disturbance of the coastline dynamics is thus at the base of the behavior of shore of 2000 which was constantly eroded on 18 km east of the Siafato Pier with regard to the state of the shores of 1995, contrary to the trend observed at the level of the coastline characteristics during the previous years (1981 and 1995). The profile of beach which was supposed to be dissipating (characteristic of the accretion area) thus becomes reflexive with "cliffs" of sand on a very steep slope (photo 5).

Photo 4: Synthesis of certain images taken at Seme quarry (Photo: August 2005)

Photo 5: State of an accumulation area after anthropological perturbations: reflexive profile of Seme beach (August 2005)

4. CONCLUSION

The remote sensing allowed us to have a synoptic view about the evolution of our coastline. Thus it proves to be an indispensable tool with an affordable cost and a simple and reproducible methodology. Monitoring and ground measures which are time consuming and requiring large human resources are only necessary during the validation of the results.

Out of the two natural and anthropological factors influencing the coastline evolution, the second one is much involved in the erosive process of the Beninese coastal environment. Indeed, for nearly half a century, the Beninese coastline has successively suffered the pernicious effects of the harbour works of Cotonou (1962) and then of Lome (1967). Furthermore, the construction of the hydroelectric dams on Volta (1966) and on Mono (1987) reduced the sedimentary contributions on a long-term basis. These first two regional causes coupled recently with daily destabilizing practices (extraction of aggregates, weakening of sandy cords by stamping and anarchic installations) are the direct consequence of the demographic explosion of the coastal cities. The quantity of sands annually extracted from beaches situated at the east of Cotonou is alarming and equivalent to the contributions of the river Volta before even the construction of the Akomsombo dam.

Thus the perpetuity of Beninese beaches is under threat if no intervention of integrated rehabilitation and protection is envisaged in the short term. Indeed, with this speed of current erosion of about 10 m/year, the district of the Embassies area will disappear under water before 2030 if nothing is done (Fig. 4). It is thus urgent – using the available means - to start envisaging from now on some actions to limit these inconveniences, looking forward to a functioning integrated management of the whole coastal area of the Benin gulf.

At first, the anarchic extractions of sands from beach and the randomly built houses must be banished with rigor. During the studies several other deposits of sand "outside the coastline" were identified as possibilities for replacing the beach sands. Their importance is not insignificant and moreover, they are more indicated for constructions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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