

Vulnerability of Senegal's South coast: Perspectives with the climate change's context

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Key words: shoreline, marine hydrodynamic, climate change, coastal vulnerability

SUMMARY

The shoreline is an environment that serves as an interface between continent and sea. The analysis offers a succession of natural ecosystems and socio-economic installations. The space remains under the influence of the urbanization, the development of tourism, the seaports, the fisheries, etc. Thus, it occupies an important aesthetic and economic position like the Senegal's petite côte shoreline¹.

Indeed, the south shoreline saw settling down since the colonization several industrial, tourist and nautical activities. The Port of Dakar participated into the reconfiguration of the landscape by taking a catalyst role on the proliferation of the industrial units. The port makes also the increase of the urban population on the Cap Vert's peninsula. The place is a site of profusion of the economic actors. The evolution of the natural environment is at the origin of several anxieties both on the balance of the shoreline ecosystems and on the durability of the coastal developments.

The major challenges that appear in the management of the harbor's coast, are diverse and the rise of the sea level constitute a fundamental aspect in the future of shoreline. At present, the climate change mean, on a large scale, several modifications in the functioning of the marine environment. The disturbances that are observed into the circulation's mode of the marine waters, and they involve collectively a rise of the marine level with harmful consequences on the coastal areas. The south coast is under the strong variability of the marine level and its impacts.

The effects of climate change place the harbor coast in a vulnerability position to the sea inching. The low zones are exposed to the sea level rise. The floods and the lands' losses are aspects that underline the exposure to the natural phenomena. ...

¹ The petite côte's shoreline begins at Cap Manuel to Casamance. For this study, our choice concerns the shoreline between Cap Manuel to le Saloum. The developpement of socioéconomics activities are more important in this part of the Senegalese's coastal area.

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1. INTRODUCTION

The petite côte's shoreline² shelters many natural habitats and resources: mangroves swamps, strikes rockies, sandy beaches, wet zones and lagoons, bays, coral reefs, etc. The coastal area is a sector of profusion of the marine life. The presence of the coastal and marine ecosystems reveals the importance of this coast's wealth. Several natural elements facilitate its charm and biodiversity. (DIAW A. T. et al. (1993). *Gestion des ressources côtières et littorales du Sénégal : Actes des ateliers de Gorée 27-29 juillet 1992*, UICN, Gland, Suisse, +484p.)

Thus, diverse socioéconomics arrangements and human establishments adjoin or take turns on the south coast. The cohabitation of the aforesaid factors is more important on the harbor domain. Between Cap Manuel and Yenne, the zone constitutes a pole of convergence where the interactions between the diverse harbor, industrial, tourist actors are very marked. The arrangements became diversified and the activities are multiplied in connection with the natural environment. (NDIAYE K. (2003). *La problématique de manutention des produits dangereux au Port Autonome de Dakar*, mémoire maîtrise, UGB, 138p.) **Fejl!**
Henvisningskilde ikke fundet.

Indeed, the harbor coast sets up as a site of interaction between physical, biological and anthropological constituents. The space is subjected to an evolution or a reconfiguration of the coastal environment. (BENGA A. G. F. (2006). *Potentiels et productions Anadara senilis dans la réserve de biosphère du delta du Saloum perspectives d'exploitation rationnelle*, thèse doctorat 3ème cycle, UCAD, 371p.) The confrontations earth / sea raise many problems of vulnerability in the place, especially with the emergence of the climate change.

Then, following the example of shorelines environment, the harbor coast is overstressed by the impacts of climate change and the activities' variety. The strong variations of the climatic effects strain on the environment many changes on the dynamics of the marine midships. (NDIAYE C. O. (2007). *Pollution du littoral par les activités du Port Autonome de Dakar*, mémoire de maîtrise, UGB, 131p. En ligne) The marine hydrodynamics hold an important place from the point of view of harbor water. It's more fundamental in the sectors which the structure is semi closed as bays or wide handles. The harbor environment is a space exposed to the evolution of the natural environment.

² The coast of Senegal is divided between the Grande Côte (North) and the Petite Côte (South). The city of Dakar is like an island what owes the name of peninsula of Cap Vert, it is the most advanced headland of the African West Coast. The north part of Saint Louis's coast up to the headland of Almadies belongs to the Grande Côte; and the south part between the Cap Manuel to Casamance is located on the Petite Côte. In this study, the interest is essentially concerned a part of the Petite Côte of Senegal.

2. PLACE OF STUDY

The shoreline coast is an environment hardly desired for the socioéconomics activities. The industrial units, the urban establishments and the nautical spaces extend gradually along the coast. This evolution remains bound to the presence of the harbor of Dakar that plays, since its creation, a role of attraction of activities. The juxtaposition of the investments around the harbor puts anxieties both on the marine environment and on the future of the arrangements on an unstable and changeable shoreline space.

The harbor of Dakar occupies a favorable geographical position because of its natural shelter situated on a wide bay. It is situated on the most advanced headland of the African west coast. It's also leaned in the peninsula of the Cap Manuel, and its water place is able to offer to ships a safe natural site for all their nautical operations. (cf. Figure 1)

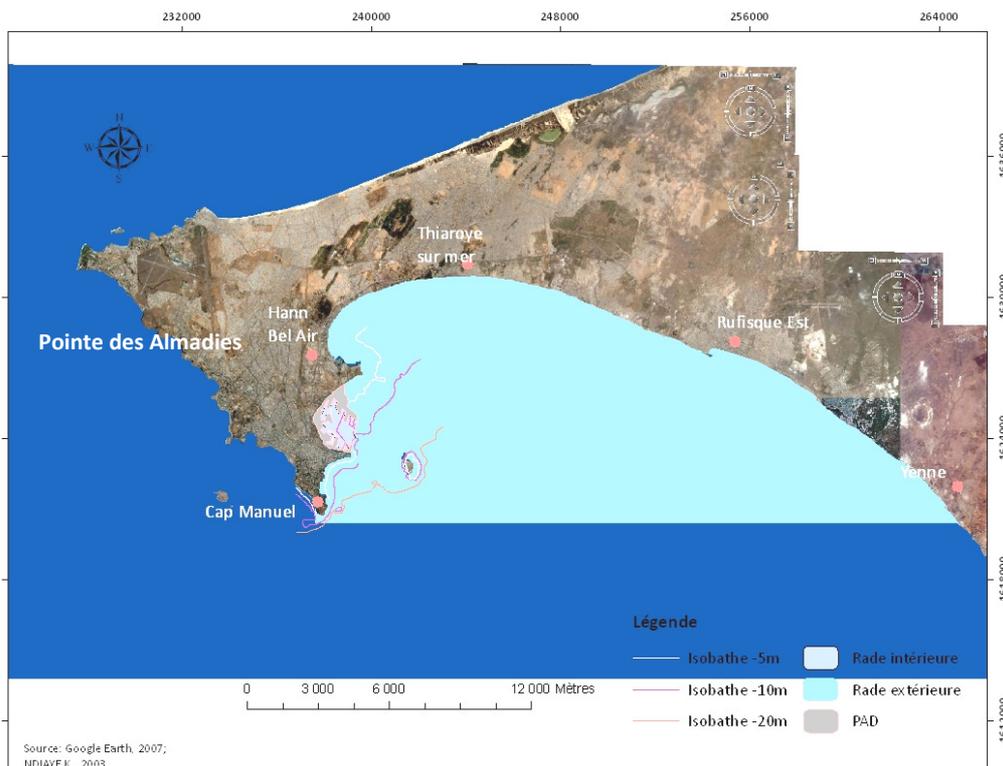


Figure 1 : Peninsula of Cap Vert

Economic investments, industrial arrangements, hotels, dikes, marinas, housing environments and local fisheries set up themselves in a progressive way on the coastal band. The coast was always a dynamic environment of interaction as earth / sea interfaces. The marine phenomena constitute major aspects that cannot be separated from the stability of the coast. The multiple movements of the sea weaken the realizations of the shoreline.

3. MÉTHODOLOGY

It allowed guiding the research during the stages of collection and analysis of data of observation or experiment. It is established by two big phases: the review of the documentation, and the processing of physical data and hydrodynamics.

I. Documentation's Review

During this stage, a review of the documentation produced on the question of research was realized. It allowed us to consult several works to include better the problem of the shoreline zone of the Cap Vert and the marine hydrodynamics.

During its elaboration, several documentation centers were visited. University libraries facilitated the consultation of general works on the shoreline circles. The documentation of training centers allowed entering on knowledge of scientific works (reports, studies, technical reports, etc.) concerning the marine pollution, the dynamics and the evolution of the space of the coast or on the Senegalese Petite Côte.

II. The acquisition and data processing

1. The physicals data

This phase also allowed collecting data on the physical conditions of the Cap Vert (wind, temperature and pluviometer). The previously mentioned factors occupy an important place from the point of view of water midships because they govern the marine state into the harbor domain. Then, it is important to study these factors because they are connected to the marine dynamism of the Petite Côte.

The data on the hydrodynamism of the water stretch were collected at the same time. This information allows us to know the functioning of the marine environment through the conditions hydrodynamics such as the tide, the swell and the sea currents. The data were generally gathered or reconstituted due to the lack of an accessible database.

2. The topography and the bathymetry

The topography is essentially obtained with the data from SRTM 3arcs seconds. The software Global Mapper 9 realized the extraction of contour lines. Therefore, the low zones could be identified for the simulation of the floods in the middle sailor.

The bathymetric data are translated into models three (03) dimensions with the tool to Surfer 8. They are constituted by using a process of three (03) stages: the georeferencing of maps, the research of geographical coordinates of isobathes and data capture in a table Access. The bathymetric information is elaborated to obtain three-dimensional data XYZ (coordinates UTM and depth).

3. The treatment and the analysis

The research required generally the use of cartographic software, statistical treatments, images and the programs of projection in three dimensions (3D). The diverse employed applications are intended to make better the question of the vulnerability of the coastal zone.

On one hand, the mapping was made with the images of the Google software Earth Pro. The downloaded images are georeferenced to complete the data of simulation. On the other hand, the tool Global Mapper 9 allowed the preliminary treatment of the SRTM. The use of this tool

has interest to generate contour lines overall studied zone. The choice of the levels curves is propped up in an interval of 1 m to be able to observe the low zones and the vulnerable sectors in the overhang of the sea.

Then, the Surfer program 8.00 is applied in the bathymetric treatment. The data are elaborated in files DBase IV to be used in the software.

4. RESULTS

I-Slowness of the marine dynamics

The calm of the marine dynamics is approached through the hydrodynamics conditions that govern the water stretch. Swells (directions and periods), the bathymetry and the climatic factors allow a better apprehension of the phenomenon and its behavior on the site.

4.1. Circulation of the swell

The variations of the swell come along with a change of the sea's state. When the height of the swell is important, the sea becomes agitated. The Senegalese coast is subjected to two types of swell:

- a swell of direction NW,
- a swell of direction SW.

The plan of the swell NW knows a progressive diffraction³ of the energy along the coast of the Cap Vert. The first diffraction is produced at the level of the headland of Almadies and in the forefront of Fann (cf. Figure 1). This change of waves' rhythm is going to provoke the second diffraction in the passage of the Cap Manuel. Then a refraction⁴ of the swell occurs. It is due to the decrease of the marine depths on the Cap Manuel's zone. The swell loses a big part of its energy upon his arrival in the bay of Gorée. It takes rather a direction quite perpendicular to coast.

On the other hand, the swell of direction SW tends to shake the sea of the bay of Gorée. This disturbance is also felt at the internal harbor through the movement of reeling of boats. This strong swell is explained by the direction change of the swell into NW. The swell SW changes direction once at the edge of the Cap Manuel for a direction S to SE. It appears generally between June and November.

³ Diffraction is defined, in physic, as an undulatory phenomenon in which the wave scatters in passing at the edge of a solid or by crossing a narrow crack.

⁴ Refraction is a change of the direction of the waves resulting from a change of environment.

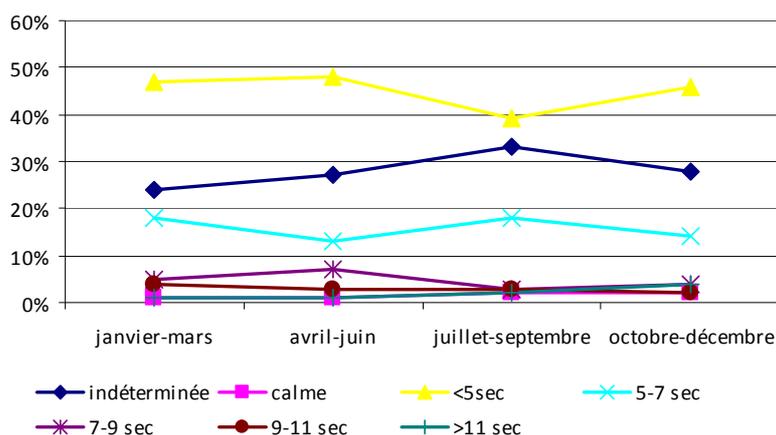


Figure 2 : Swell's periods in thr south part of Cap Vert

Source : According to TURMINE V. (2000). *Dynamique littorale entre Mbour et Joal (Petite côte Sénégal)*, mémoire de maîtrise, université Paris VII, 249p.

Indeed, in the South of the Cap Vert, swells have periods often lower than 5 seconds do. They do not involve a disturbance of the water stretch. The only excitement on the marine environment results from swells than periods are superior to 11 seconds. On the scale of year, these swells have a 4% frequency, so they are weakly distinguished. The months when these strong swells circulate from the point of view of water extend between October and December. The tranquillity of the water stretch in the internal harbor is affected by swells in strong period. (cf. Figure 2Figure 2 : Swell's periods in thr south part of Cap Vert)

It is important to note also that the swells, which come in the internal harbor of the port, are often low. This explains by the north and south piers that protect the stretch of water of the excitements due to the conditions hydrodynamics.

4.2. Bathymetry

The depth, the architecture of the coast and the extent of the water stretch play an essential role on the strength of the hydrodynamics conditions. They participate to increase the consequences of the swell and the currents. The depths of the water stretch in the internal harbor contain isobaths contours -8 to -12 m. In 1997, they are essentially characterized by isobaths contours -5 m and -10 m.

The bathymetry of the internal harbor evolved during the works of extension and dredgings of the harbor of Dakar. The realized operations of dredgings are characterized by absences of information on extracted sediments. Between 1988 and 1990, a total volume of sediments of 541 161 m³ was taken in this environment. They represent a rhythm of 270 580 m³/year approximately. (BCEOM (2007). *Etude de faisabilité pour l'aménagement d'un chenal d'accès au 3ème poste à quai dragué à -13,00 m pour navires porte-conteneurs*, Etude d'impacts environnementaux, version provisoire.)

The water stretch of the outside harbor is marked by the isobaths ontours -10 and -20 m. Between the headland of Bel Air and the bay of Hann, the isobath -10 m is situated in 1 500 m of the shore. Between the sector of Thiaroye sur mer sea and the city of Rufisque, it is 2 000 m of the shore. The isobathe -20 m passes in suburb of the Gorée Island towards the

south part. It is respectively situated at a distance of 6 000 m and 4 000 m of the shore of the bay of Hann and the city of Rufisque. (BCEOM (2007). *Etude de faisabilité pour l'aménagement d'un chenal d'accès au 3ème poste à quai dragué à -13,00 m pour navires porte-conteneurs*, Etude d'impacts environnementaux, version provisoire.)

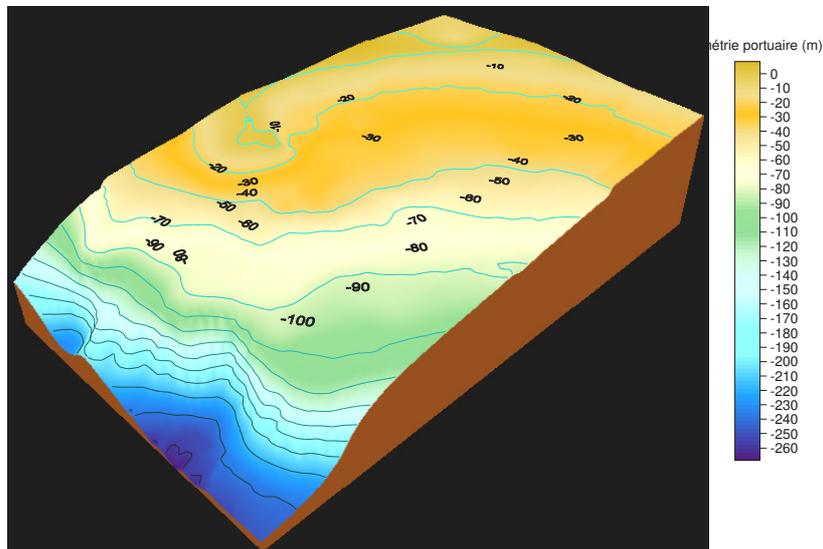


Figure 3 : Bathymetry of harbor domain

Source: According to data of Canadian Hydrographic Service, bathymetry of Senegal (january – april 1976)

The Figure 3 allows us to observe the bathymetry of the harbor domain. The continental shelf widens more by leaving from the Cap Manuel towards Yenne. Isobaths contours goes away from the shore when we progress to the south of the harbor domain. This fact justifies the width of the continental shelf that extends gradually by leaving to the south of the Petite Côte.

The bathymetry of the harbor water stretch is little deep because of the width of the continental shelf (isobaths contour -20 m about 6 000 m of the shore and going away from the shore in the South of the Cap Vert). The depth of seabed also intervenes on the strength of swells registered in the harbor water stretch. When it is important, the heights of the recorded swells are rather strong.

Slopes also participate into the hydrodynamism of the harbor domain. In the outside roadstead, they are more important near of the headland than on bays. The slopes of the headland of Dakar and Bel Air are respectively 0,009 and 0,007. The bay of Dakar presents slopes situated between 0,004 and 0,006 (BCEOM (2007). *Etude de faisabilité pour l'aménagement d'un chenal d'accès au 3ème poste à quai dragué à -13,00 m pour navires porte-conteneurs*, Etude d'impacts environnementaux, version provisoire.). Their weakness is bound to the surface of the continental shelf on the harbor domain. Isobaths contours are spaced out and they make the implementation of low slopes on this middle.

4.3. Temperature marinades and circulation of the wind

The temperature of the harbor's water stretch varies between 20°C and 28°C. The salinity of the seawater is situated approximately in 35‰. Often these factors (temperature and salinity) vary through the months and according to the seasonal contrasts on the coast of the Cap Vert. There are two main seasons on the oceanic masses waters into the harbor's water stretch. We distinguish a warm season and a cold season marked by phases of transition.

The cold season stretches on November to May. It is characterized by marine temperatures around 20°C and salinity 35‰ into the harbor's water stretch. The coastal upwelling settles down gradually in January to April. It is subjected to the influences of trade winds. Marine waters are salted and cold and they replace surfaces waters. (cf. Figure 4)

The warm season is included between June to August. The temperature of the seawater is situated around 27°C with salinity 36‰. Waters are warm and less salted. The current of Guinea pushes away the waters masses from the current of the Canarian Islands to northward. These warm sea currents explain the increase of the marine temperatures inside the harbor's water stretch. (cf. Figure 4)

Subsequently, temperatures of 28°C and salinity of 35‰ mark the rest of the season. (NDIAYE K. (2004). *La pollution du littoral : la qualité de l'eau du Port Autonome de Dakar*, mémoire DEA, UCAD, 77p.)

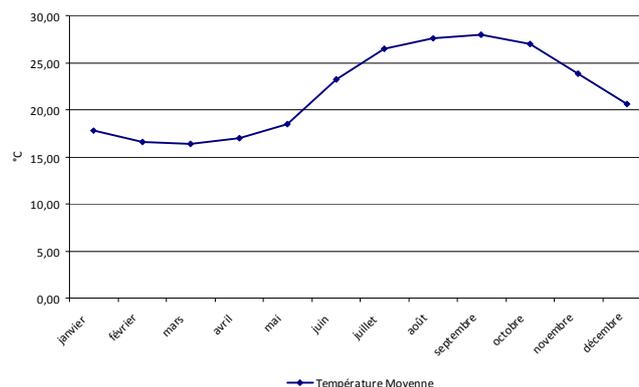


Figure 4 : Variation of surface water temperature at the costal station of Thiaroye (1965-1983)

Source: According to FREON, (1986)

Finally, the hydrodynamics conditions of the water stretch are dominated by the winds. The winds involve vertical movements to the water surface. They make side movements of pollutants thrown back in the sea. Therefore, the wind counts among the main factors leading the manuring of pollution. The variations of the dominant directions influence partially the horizontal movement of the water and then the pollutants at the sea surface.

The Figure 5 puts in relation factors such as the speed of prevailing wind and the temperatures of the sea and the air observed on the harbor domain.

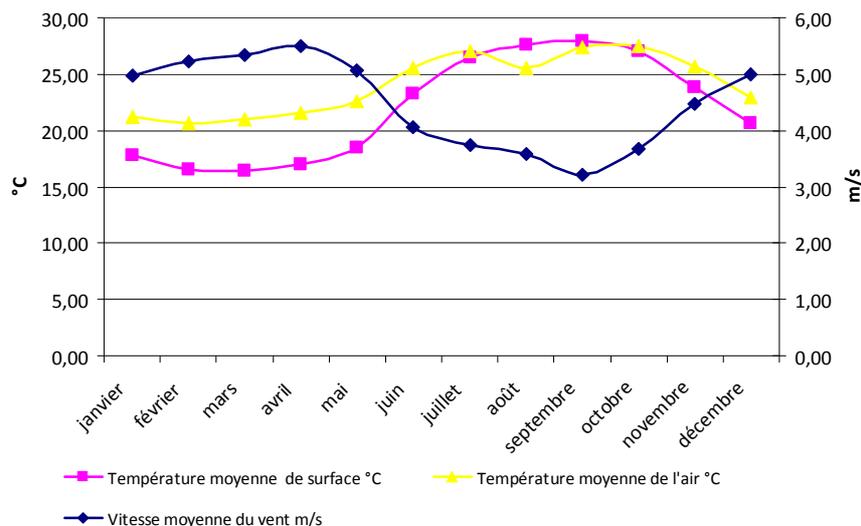


Figure 5 : relation between wind speed and the temperatures of sea and air (1965-1983)

Source: According to FREON, 1986

The temperatures of sea surface and the air evolve both except during the month of August. Two cold and warm marine seasons can distinguish themselves. They result essentially from movements of the oceanic masses on the coast. The cold season stretches from November until May. The warm season extends between June and October over the harbor domain.

When the temperatures (sea and air) increase, the wind speed becomes low in the place. The winds importance comes along with a decrease of the surface temperatures and with the air. The wind circulation influences the direction of sea currents. They perturb the state of the water stretch during the end of the cold season (in April-May).

II-Rise of the sea level

Tides show the evolution tendency of the marine level, we set as the references observation from 1907 until 2008. The water heights increased through maxima observed on the last decade. The level of marine waters began to rise from 1998 on the harbor. The peaks of high waters are important at 1998 but they are especially perceptible in 2007. (cf. Figure 6)

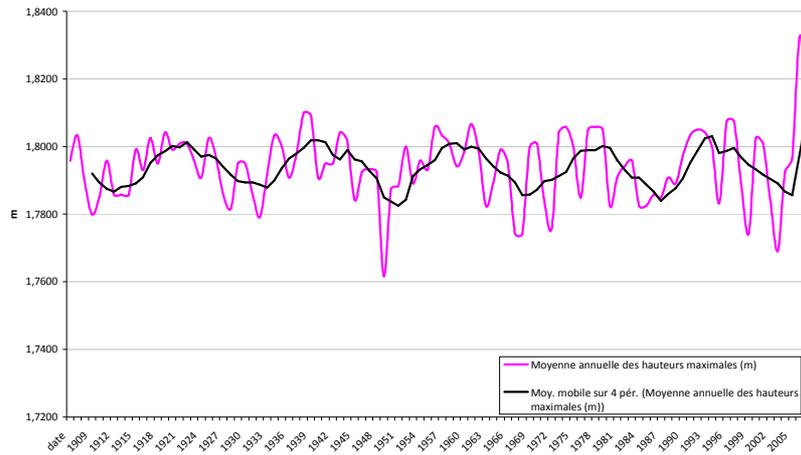


Figure 6 : Les moyennes annuelles des hauteurs maximales entre 1907 et 2008
 Source: D'après données du SHOM, 2008

Between 1907 and 2008, the average level of the middle-tide from in Dakar is 1,003 m (according to the data of SHOM). The data predicted over 101 years allowed to establish annual averages, and then they have had a treatment looking for an overall average of the tide on the chosen scale.

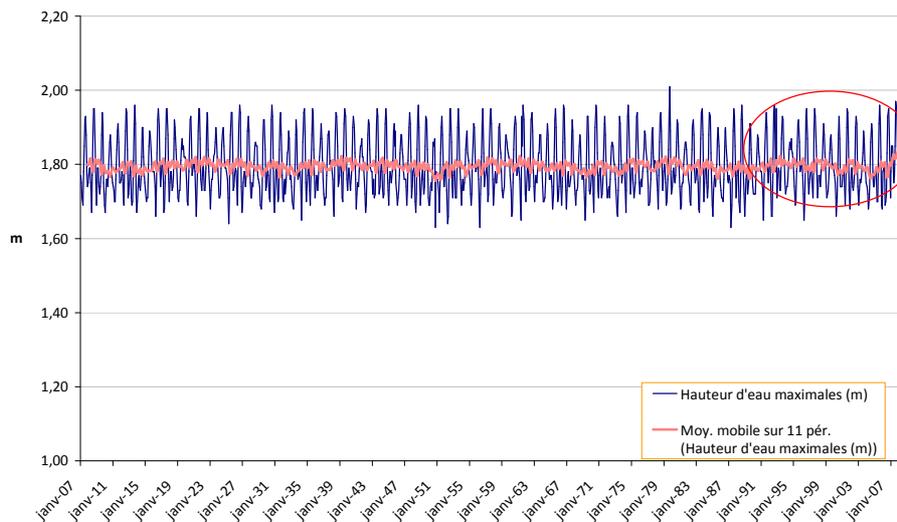


Figure 7 : Evolution of maximal water heights (1907-2008)
 Source: According to data of SHOM, 2008

The Figure 7 presents the maximal water heights registered on the harbor. She allows noting the appearance of high tides between 1998 and 2008. The maximal rises of marine waters became more marked during this previously mentioned period. Year 2007 allowed to observe peaks in the observations on the maximal water heights.

The circle placed on the figure underlines the increase of the water heights on the harbor marine environment. The levels of water stretch variation are marked by a rise of the sea, which asserts itself since 2005.

Besides, the seasonal evolutions of the tide are more raised in comparison to the last decade of the recorded tides. The waters heights are characterized by seasons of very important high waters between June and October. Between January and March, tides are also high, but they do not overtake almost 1,85 m.

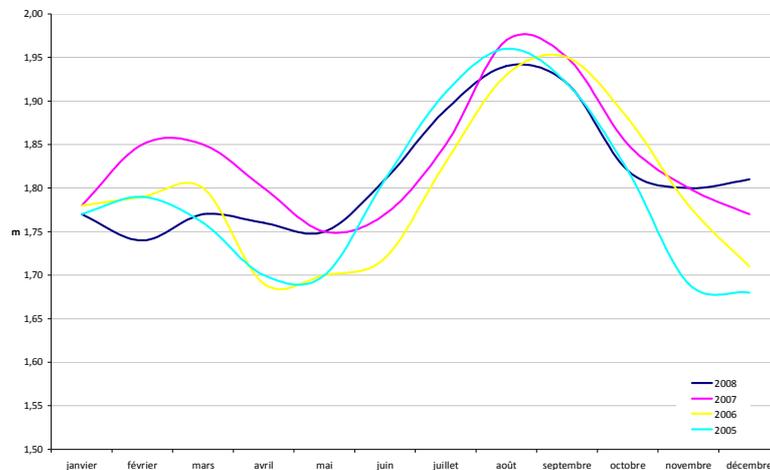


Figure 8 : Evolution of maximal heights (2005-2008)

Source: According to data of Shom, 2008

The Figure 8 presents the seasonal evolution of the tides' maxima on the harbor of Dakar. The distances between maxima can vary 15 even 20 cms over one year of observation (as year 2008).

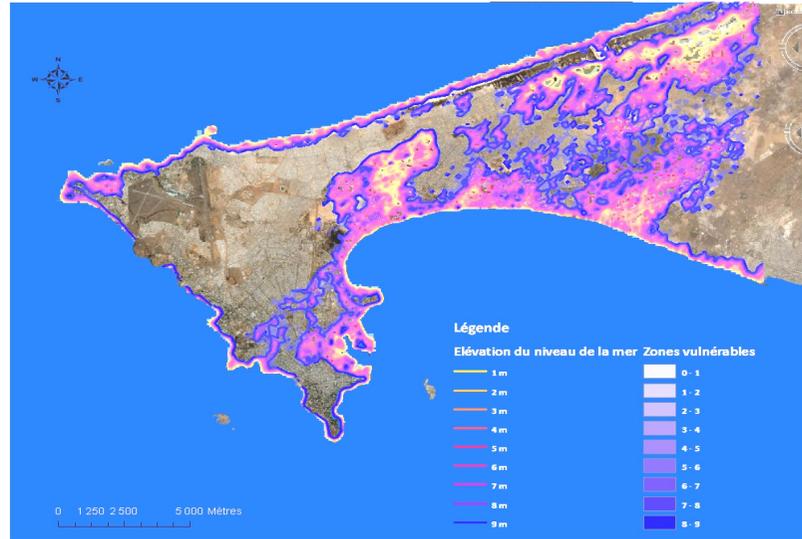
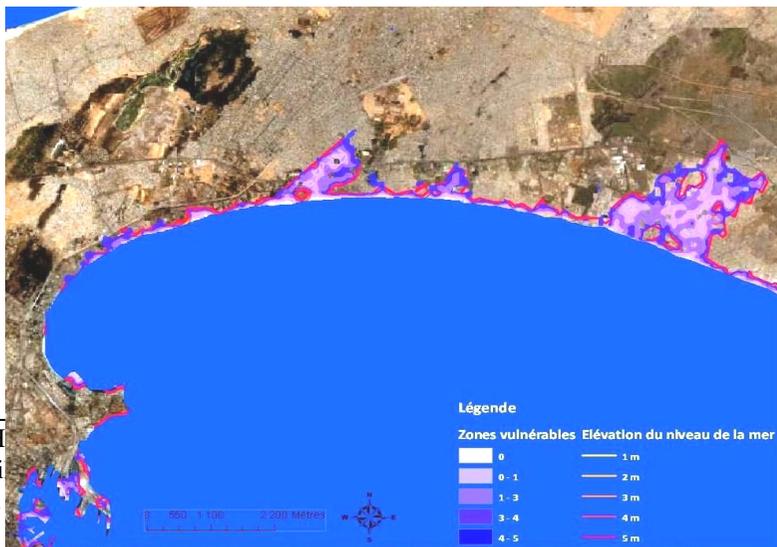
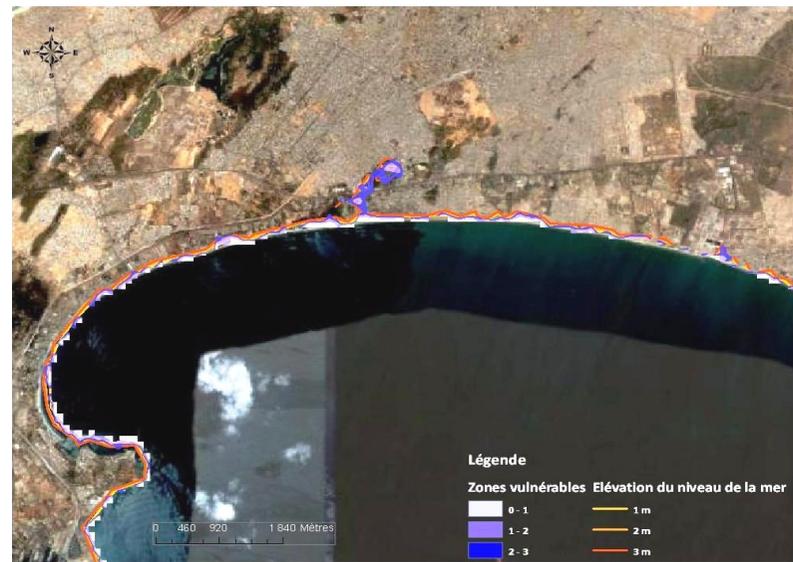
Indeed, during 2007 the maximal tides got closer to 2 m. The distances between the seasonal heights can vary from 9 cms to 10 cms. The seasonal heights of water evolved a lot, and they became very important.

III. Hydrodynamic and vulnerability of shoreline harbor

The vulnerability of the coast due to climate change depends on phenomena of the sea's overhang. The low coast is sensitive middle to the marine rise.

The urban zones are generally localized along the coast. Considerable lands losses and important floods according to the topography of the middle can affect them. However, the overhang of the sea leads problems of floods or vulnerability for several cities and installations situated along the harbor coast.

Indeed, the industrial units and the housing environments located on Hann Bel Air, Thiaroye sur mer and Mbao are subjected to the impacts of the sea level increase. The consequences on the environment are multiple, and we can hold floods and strong coastal erosions without quoting the damages of the coastal arrangements and the controls improvements.



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Figure 9 : Vulnérables zones to the sea level rise

The harbor coast is marked by coastal spaces with low topography such as the bay(berry) of Hann (cf. Figure 9). The effects of 1 m rise besides the current marine level lead important socioeconomic impacts on the coastal harbor domain. Housing environments and industrial units situated on the middle will be exposed to the influence of marine waters.

Indeed, the bay of Hann constitutes a sector where the topography is not high enough. The waters limits in high tides are close to houses situated near of Hann Plage. The se level rise will induce inevitably a strong vulnerability of the zone. The Figure 10 allows to note the potential impacts of the sea overhang on the harbor coast. In high tide, marine waters get closer to houses situated in front of the bay. The risks of erosion are important, they concern generally the bay of Hann, the sector of Thiaroye and the zone of Rufisque to Bargny.



Figure 10 : Vulnerables places to the sea overhang

The sea rise of 5 m involves a sea overhang that can cut the Boulevard du Centenaire of the municipality of Dakar. Marine waters will occupy the industries in the bay of Hann, and houses are threatened or flooded by the sea.

In 9 m sea rising, the major part of the peninsula of the Cap Vert will be under waters. The tombolo of Dakar maybe invaded by the sea and the peninsula risks to be besides cut by the continent. Nevertheless, the places where the topography is rather high like Yoff and the Plateau are certainly sheltered from the seawaters rise.

Analysis and discussion

The peninsula of the Cap Vert registers the emergence of several arrangements to modernize the middle. The city of Dakar develops inward absorbing peripheral zones until Rufisque (cf. Figure 11). The arrangements line the coast and they put challenges of management effective of the urban space.

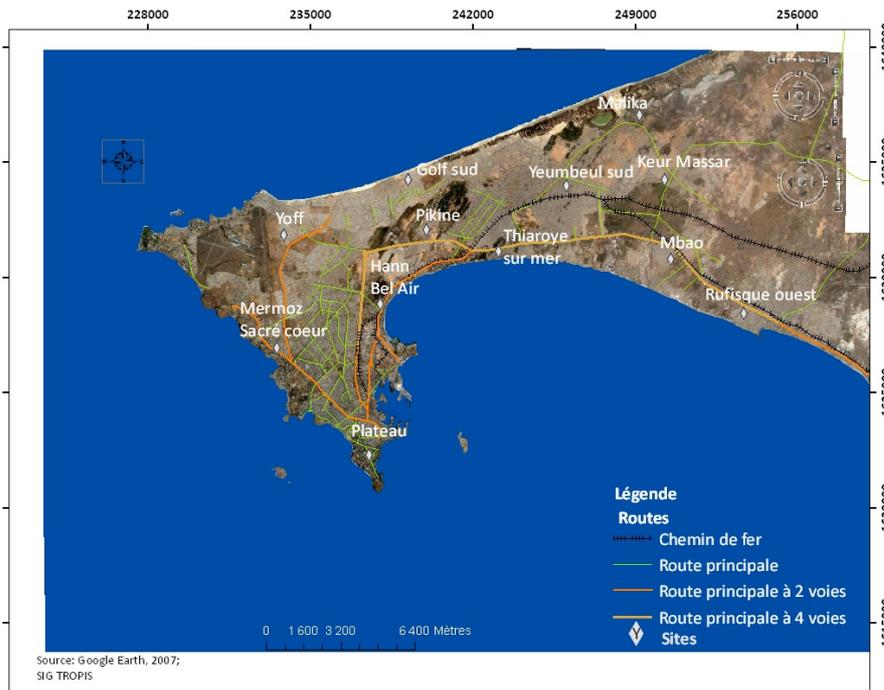


Figure 11 : les villes portuaires vulnérables à l'avancée de la mer

The activities have for point of departure the Plateau, and then they became diversify around the harbor and along the coast. The topography of this place is low, the effects of the sea level rise can have direct incidents on the stability of the infrastructures. The middle is confronted to the problems of erosion and the sea remains threatening. Through scenarios, the evolution of the coast can be perceived, but it remains limited because of the prediction.

Scenarios⁵ were established to follow the evolution of the water stretch subjected to the effects of the climate change. They rest on certain hypotheses which allow to feign the heights of water by taking coast of rise which will be added a year until approximately 2050. Therefore, the absence of an accessible database on the hydrodynamics conditions does not allow making precise simulations of the rise of the marine level.

The research carried in the south part of the Dakar's region showed a increase rate of the relative sea level by 1,4 mm/year between 1943 and 1965 (NIANG DIOP I. (1995). *L'érosion côtière sur la petite côte du Sénégal à partir de l'exemple de Rufisque*, thèse 3ème cycle, Université d'Angers, 477p.). The study did not make corrections on the tidals data due to the lack of exhaustive information. It bases itself on scenarios that concern several hypotheses of increase of marine level.

The scenarios of sea level rise are made on the data of the middle-tide of the harbor's water stretch of. The average of the middle-tide between 1907 and 2008 is used to make the

⁵ A scenario constitutes an approach integrating a series of hypotheses which allows to describe the future state of the marine environment.

scenarios of increase of the heights of water until 2050. Three scenarios of rises of the marine level taken are: 0,01 m, 0,1 m and 0,2 m.

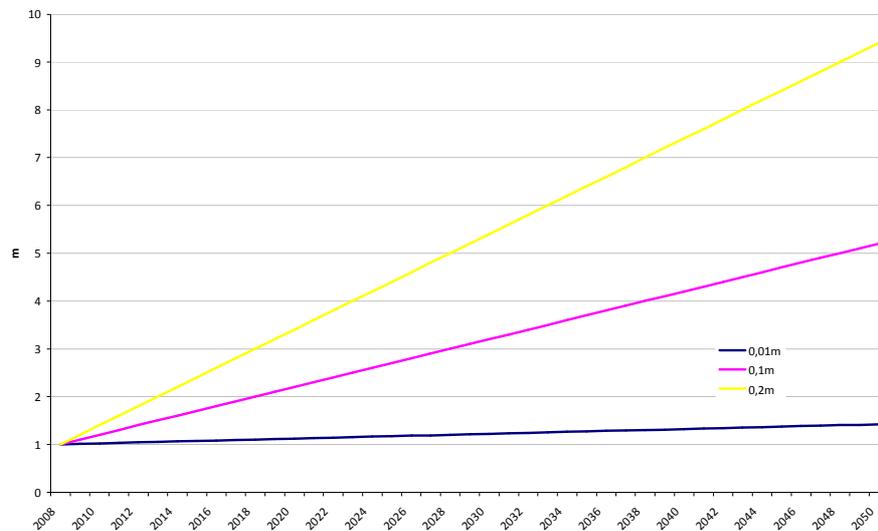


Figure 12 : Scenarios of sea level rise

The sea level rise is doubtless a slow process. It is often in the order of some millimeters per year. The scenarios are modes of forecasts, but they cannot be real on the studied environment because based on hypotheses.

The Figure 12 presents three (03) scenarios of sea level rise for the harbor domain. The average data of the middle-tide accompany the projected treatment. The height of 1,00261175 m is obtained by making the average of the annual heights into the definite period (since 1907 to 2008) .Une rise of 0,01 m / year gives a waters height than gets closer to 2 m. When a rise of 0,2 m / year occurs, the waters heights will go to 9 m. They induice a vulnerability of the peninsula of the Cap Vert.

Besides, the evaluation of the potential risks can be perceptible only by the basis of modelling application for the functioning of marine waters. It is also relevant within the framework of the increase of the current marine level to make projected models of the functioning of the marine environment.

5. CONCLUSION

The climate changes induice several disturbances on the marine environment. They are perceptible into the functioning or on the rise of the long-term marine level. Even if the rise is slow, in order of some millimeters per year, the shoreline spaces are vulnerable to the climate changes having direct effects on the marine environment.

The sea level rise places the low zones such as the bay of Hann as a vulnerable sector. It leads a big fragility of the harbor coast. The sea advances gradually on the continent, and marine waters threaten the industrial, harbor installations and the housing environments. The losses

of lands due to an activity of the sea risk affecting the coast within the framework of the increase of the marine level.

A good knowledge of the phenomena participates into the implementation of projected models for the coast. It asserts himself like bases of information on the shoreline spaces in connection with the variability of the marine environment. These aspects remain fundamental even if they are limited because based on theories. However, they supply appreciations on the evolution of the middle and the choice on the coastal infrastructures.

The zones that have fewer resources have the most low capacity of adaptation, and they are the most vulnerable in the effects of the climate change. The climatic impacts on the harbor coast are multiple, but the only option of the sea level rise causes several marigolds on the future of the coastal cities.

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