Spatial Remote Sensing, a Necessary Tool in the Study of the Evolution of Coastal Erosion: "The Case of the Atlantic Coast of the City of Moanda in the Democratic Republic of Congo"

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Abstract: ***The publications on the theme of spatial remote sensing applied to the study of coastal erosion are relatively recent, since they are predominant and current subject to environmental problems and climate change. On this, the sandy coastline of the city of Moanda presents a characteristic morphology of sandy coasts that following the hydrodynamic phenomena; tend to regress towards the mainland. The coastal area of Moanda is only 40 km long, although small on a global scale, but important for the Democratic Republic of Congo, it abounds in enormous biological, energetic and mineral wealth as well as enormous tourist and socio - economic potential. Moreover, due to its location facing the Atlantic Ocean, it is a major border post ensuring the entry and exit to the Congo River and the rest of the country. Therefore, we can in our case, highlight three major concerns that can appear in this article including (1) The mapping of areas degraded by erosion; (2) The quantification of erosion; (3) Monitoring of erosion. The above - mentioned concerns are the key elements in all the approaches aimed at achieving satisfactory results in this case study. The analyses of the results obtained and the experiments carried out in this field highlight the possibilities offered by spatial remote sensing as well as its limitations. Today, the new sensors and techniques allow us to consider a new approach to degraded environments and to obtain precious complementary information for the planning of these spaces and the monitoring of their evolution. We found an overall average recession of ±45 m only for these four test profiles carried out in this work and an average rate of recession in the order of ± - 1.5 to 2 m/year. It is assumed that by 2050, the coastline will have retreated by about 50 m towards the mainland and this if there had not been any conservation work to protect the coast. This can be seen in the images of the remote sensing evolution part with different trends of the erosion evolution by means of different colored lines. The problem that underlies the study is the spatial and temporal dynamics of the coastline of the city of Moanda. The study aims to show how the coastline has evolved over the period of 1986, 2006 and 2016. This evolution has been mapped and quantified from spatial images exploited with GIS software coupled with data from topographic surveys.***

Keywords: spatial remote sensing; erosion; topographic surveys; multi – temporal

1. Introduction

In most cases, the coastal areas of our planet concentrate a maximum of stakes and risks from the environmental, ecological, economic and societal point of view. Therefore, the coastal zone of the Democratic Republic of Congo, which is only 40km long, and its neighboring countries, is facing this phenomenon which is also one of the main environmental problems facing the coastline of Africa in general and particularly in Central Africa, including the DRC which is our case. It is indeed appropriate for a good strategy of integrated management of these coastal areas, imperatively passed by the improvement of our knowledge of the coastal dynamics which is itself associated with the distribution of sedimentary faces (composition, water content, granulometry, and biomass) and topographic variations.

Moreover, given the desire to preserve the biodiversity of these environments, it is desirable to better understand the variations associated with the types of sedimentary cover. However, at present, the mapping of these areas, which are difficult to access, remains very limited, incomplete and even imprecise and, from now on, it is necessary to provide fine quantitative mapping to better manage these areas.

This situation is likely to evolve to a higher criticality due to environmental pressure related to global change and relative sea level rise. With respect to these major issues, spatial techniques by remote sensing have a determining role to play. The general objective is to know the spatial and temporal dynamics of the coastline of this region. Specifically, it is to analyze the spatial evolution % of the coastline and time of the coastline over the period of 3 different years in 1986, 2006 and 2016, then to map the sensitivity of the coastline of Moanda to coastal erosion.

2. General Presentation of the Area

Our study area is located in the city of Moanda in the Democratic Republic of Congo in the province of Kongo - Central (DRC), between (5°57'31"and 5°53'09") south latitude and (12°19'53" and 12°24'45") east longitude. It is the only province in the country with access to the sea. It extends from the Atlantic Ocean to the capital and the province of Bandundu covering an area of 55, 000 km².

The Congo River runs the length of the province dividing it in two.

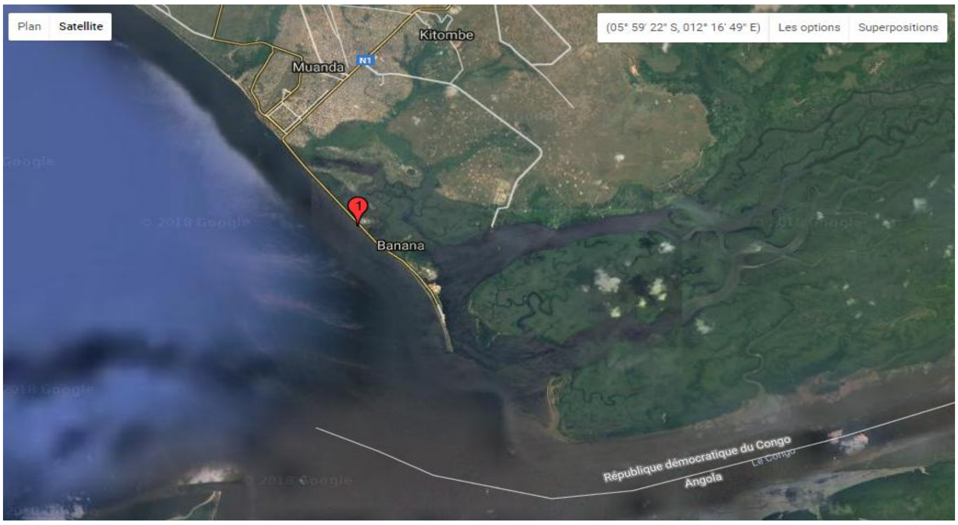

Figure 1: Location of the study area

Apart from this river, the province of Central Kongo is crossed to the northwest by the Shiloango River. The province is bordered by the Republic of Congo to the north; the Atlantic Ocean and Cabinda to the west; the provincial city of Kinshasa and Bandundu to the east; the Republic of Angola to the South. The sandy coastline of the Moanda coast is part of the only side of the country open to the Atlantic Ocean. These sandy beaches are less wide and made of generally fine sediments. This opening of the Atlantic during the Mesozoic led to the collapse of the continental shelf and the formation of a coastal sedimentary basin where detrital deposits of essentially marine origin accumulated. These deposits form cover rocks of Mesozoic to Cenozoic age and are transgresses on the basement formations (Mayumbien) of Mesoproterozoic. They include (from top to bottom) the following major groups (DARTERELLE 1934 and 1936; CAHEN 1954; LEPERSONNE, 1974, in MECN - EF, 2001; MECN - EF, 2006). The topographic profile of the coastal line oriented SSE - NNW includes 3 cliffs interrupted by two estuaries and a barrier beach (AUBREY, 1976, in MECNEF, 2001). The marine currents, of various origins, have a significant influence on the sedimentary processes. Thus, the breaking of waves on the coast leads to the collapse of cliffs and landslides. The directions of these extreme waves vary from 205° N to 230° N and are within 25° of the coastal normal (about 318° N). Thus, for conceptual design purposes, the waves are considered perpendicular to the shoreline (Royal HaskoningDHV 2013).

3. Materials and methods

The studies dealing with the erosion of hillsides by spatial remote sensing are based either on the visual interpretation of satellite images, or on digital processing. The information obtained concerns only the surface of the ground and can also be collected on the basis of two approaches, one based on the analysis of topographic data by direct survey with optical - mechanical instruments (theodolites, telescopic level,. . .) and electronic instruments (total station, electronic theodolite, lidar, differential GPS,. . .) and the other based on the analysis of remote sensing by using data processing software of geographical information such as Arc Gis, mapinfo, Idrisi,. . . of the coastal zone.

Table 1: General measurements in situ. . (Ibrahim Birame Ndébane FAYE, 2010)

Methods	Studied environments	Data	Accuracy	Advantages	Disadvantages
Acoustic measurements	• Seabed	• Bathymetry • Nature of the sediments • Seabed architecture	• Decimetry	• Precise mapping of the seabed • Measurement of material transport	• Requires large equipment • Does not differentiate silt from sand and gravel, therefore requires sampling (side - scan sonar)
Tacheometer / theodolite	• Foreshore, beach, dunes	• Topography	• Centimetric to millimetric (laser tacheometer)	• Precision of data • Relatively long measurement time	• Insufficient precision for fine studies (microforms) in dynamic mode
Electro - optical sensors (O. B. S)	• Before the coastline	• Moderate disturbance of coastal areas	• Moderate	• Short term studies	• Modification of sediment flows (limits the studies of transport by scavenging or saltation)
Sediment traps	• - Before shore and beach	• Sediment dynamics	• Moderate	• Point and instantaneous data	• Difficulty of field experiments
Tracers	• Bottom sediment transport	• Moderate sediment dynamics	• Moderate		• Is based on treatment assumptions that need to be refined

Differential GPS	• Beach, foreshore, dunes, cliffs	• Topography	• Centimetric	• Precision of data in static mode • Density of measurements in dynamic mode	• Insufficient precision for fine studies (microforms) in dynamic mode.

As for aerial and satellite images, they are also affected by some quality problems related to radiometry and geometric distortions due to the conditions of shooting, materials, films and relief. The main sources of information on the historical position of the coastline are field surveys and most often iconographic documents, in particular maps, aerial photographs, optical and radar satellite images and video recordings. It should be noted in passing that historical maps (topographic, cadastral, marine or bathymetric) are second - hand sources because the coastline shown on them has already been surveyed by topographers or hydrographers and drawn by the cartographer.

Table 2: Table for calculating the margin of error or uncertainty

Periods	Reference line	Average of the deviations (m)	Standard deviations (m)	Average +2 Standard deviations (m)	Margins of error (Average +2 Standard deviations+ pixel size) (m)
1986 - 2006	Shoreline beach teen	0, 05	0, 22	0, 49	1, 49
2006 - 2016	Shoreline beach teen	0, 11	0, 33	0, 77	1, 77

They include sources of uncertainty related to the accuracy of the survey, the design and the support of the map. They always need to be corrected by techniques and methods in the restitution of the data. The data provided by the field surveys are extremely accurate for the quantification of the mobility of the coastline but their acquisition requires a lot of time. For this reason, they are limited in most cases to a few specific sites for short - term studies.

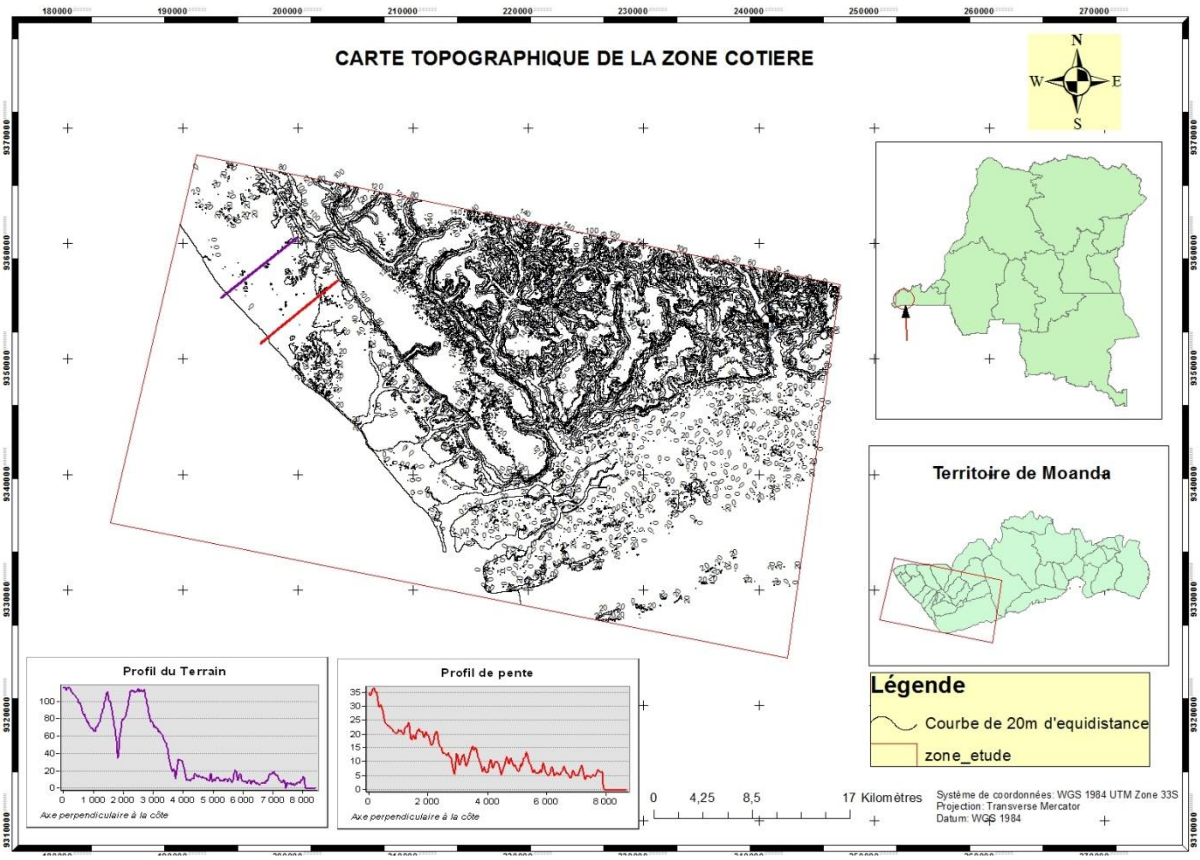

Figure 2: Representation of slope profiles and the study area

The quantification of coastal erosion is estimated using a mathematical model based on rainfall data, topography, morphology, crop succession etc. It can also be done by making cross - sections (transects) at well - defined and specific locations on the established coupled support (topographic map and satellite image), as is the case in our article.

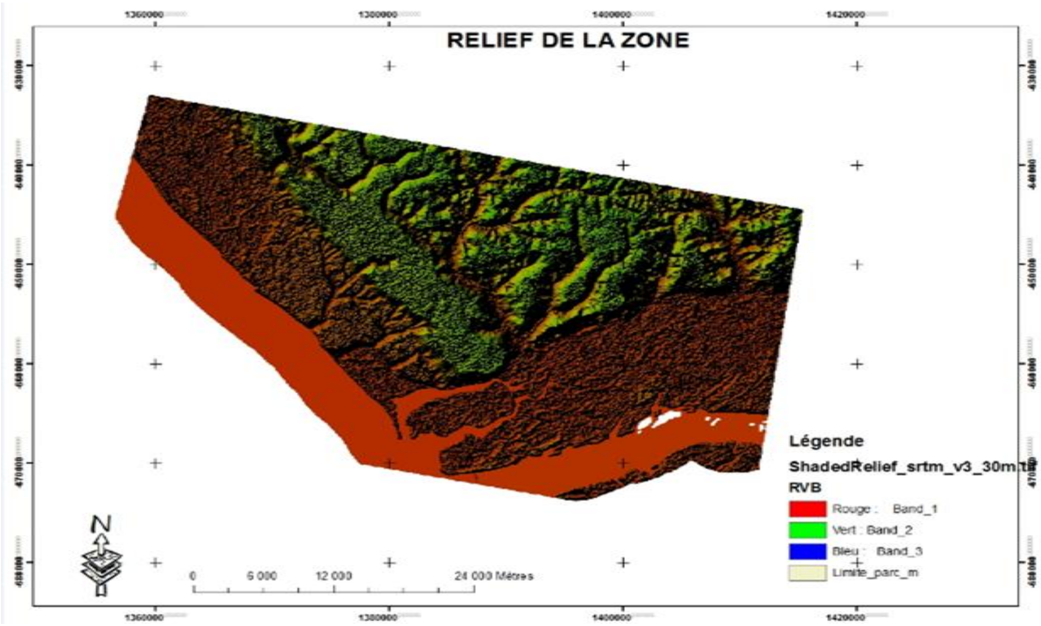

Figure 3: RGB representation of the study area

We represent a synthesis of a general table of in situ measurements of their methods, study environments, data collected, accuracy, advantages and disadvantages of each in Table 1 below.

In terms of prevention and damage estimation, satellite images can be useful, especially since they are repetitive. Finally, to evaluate erosion, satellite data are integrated either in a soil erosion study model or in a hydrological model (USLE).

The evolutionary monitoring of coastal erosion is done by multi spectral and multi temporal analysis of satellite data on a map, useful for the knowledge of coastal erosion processes.

Table 3: Representation of the evolution of erosion in the study area

Periods	Distances (m)	Speeds (m/year)
1986 - 2006	- 30	1, 5 - 2
2006 - 2016	- 15	1, 5 - 2

4. Discussions and Results

Our study which was interested in the coast of Moanda, served with the topographic data in situ and associated with the analyses of the satellite images to different years (1986, 2006, 2016) to follow the spatio - temporal evolution of the coastline and that of the limit of vegetation.

On those, we have resorted ultimately to the tools of the geomantic by the fact that they offer interfaces that are adaptable and can in some cases to overcome possible limitations in the exercise of the different software for the treatment of the received data. On the basis of the topographic plan realized and coupling it with the image plan on the basis of the fixed and known landmarks, we have established cross - sections at places presenting great degradations on dimension.

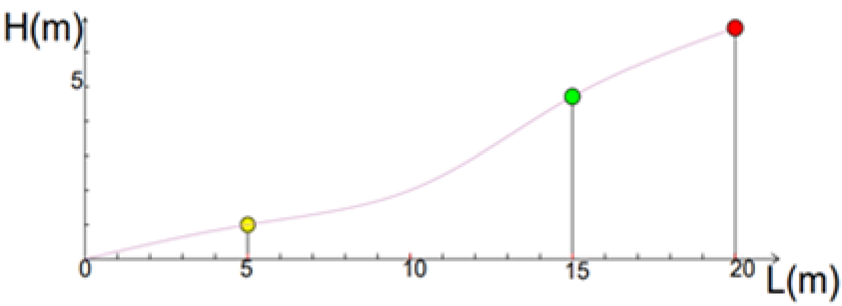

Figure 4: L9. Representation of the evolution of erosion in the study area

On these sections, indicated the position of each evolution of erosion at different periods by colors (yellow, red andhe same will be true for the representation of coastal features in satellite images. Starting from the topographic plan coupled with the plan of satellite images representing the limits of erosion in different years, we have highlighted the gaps and have positioned the limits of the features with distinct colors assigned to each evolution of the limit of erosion as follows: (1) Position of the coastline in 1986; (2) Position of the coastline in 2006; (3) Position of the coastline in 2016.

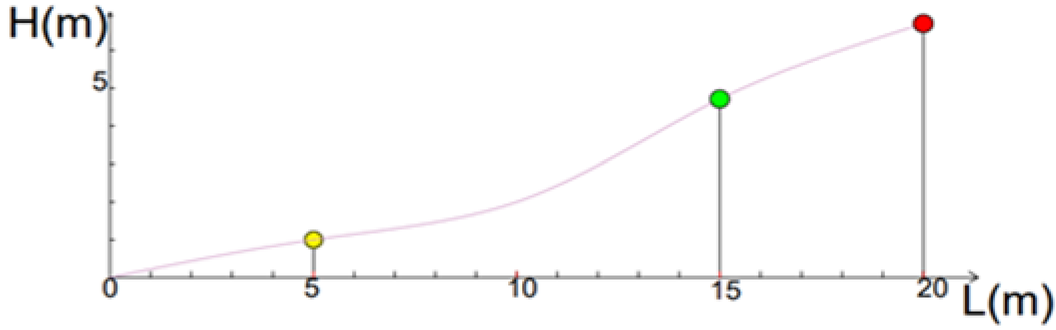

Figure 5: L10. Representation of the evolution of erosion in the study area

These sampled gaps were used to determine the magnitudes of the erosion advancement during a study period and to be able to make a projection of its progression in the future years.

The different heights are determined by interpolating the position of the point representing the limit of each erosion evolution with the contour lines from the topographic plan.

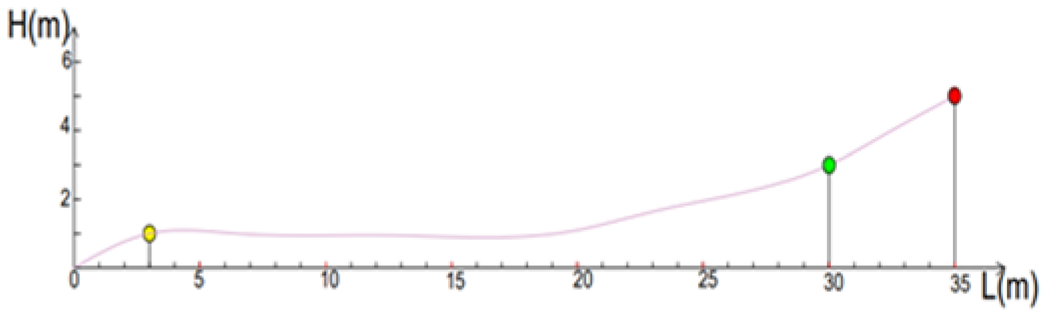

Figure 6: L11. Representation of the evolution of erosion in the study area

We had to make four cross - sections and the results are these after 30 years:

- Section L6 shows a recession of more than minus 50 m towards the mainland and a difference in height of more than minus 6m.
- Cut L9 shows a retreat of more than minus 80m towards the mainland and a difference in height of more than minus 23m.
- Cut L10 has a setback of more than minus 15m towards the mainland and a height difference of more than minus 19m.
- The cut L11 presents a recession of more than minus 30m towards the mainland and a difference in height of more than minus 11m.

The statistics of these results give us an arithmetic mean of 43.75 m and a standard deviation of 40.98 m.

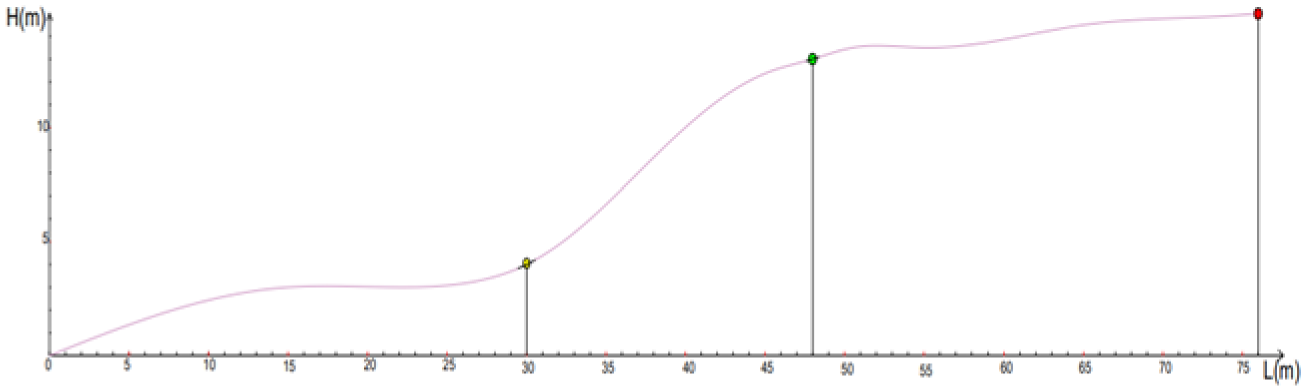

Figure 7: L6. Representation of the evolution of erosion in the study area.

We have shown that the coastline has experienced widespread erosion in the observation period. This observation is globally in agreement with the work done by Baert, G., (1991), the MECN - EF of the DRC coastal zone profile (2006 and 2007), Kitenge (2014) and Kitsia, B. J. S., (2015). These studies concluded that the coastline recession oscillates between 1.5 and 2 m /year.

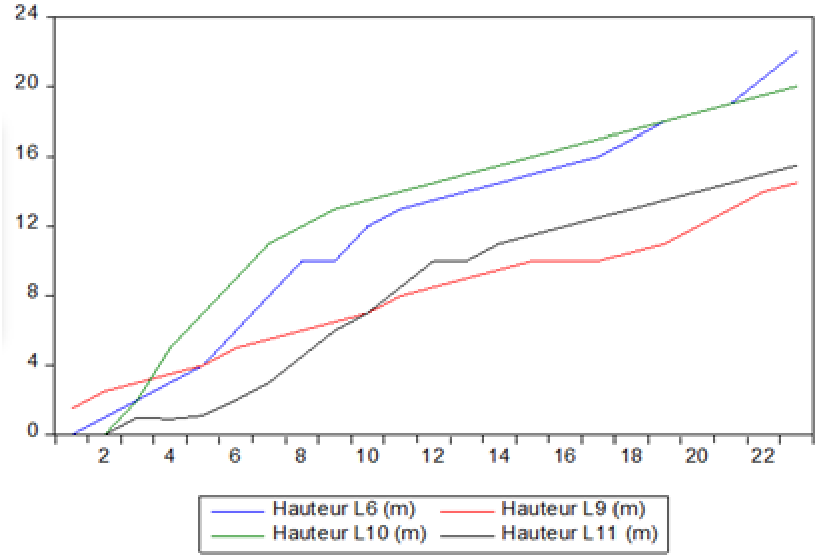

Figure 8: Representation of the overall evolution of erosion in the study area

5. Conclusion

This study shows us that the coastal zone of Moanda is really threatened by coastal erosion which tends to a total degradation of the city. This is explained by our results carried out in each different point mentioned above to support by the graphs resulting from the data collected on the ground.

This approach has allowed us to have an idea on the trends of the coastal erosion advancement and that we could make a projection of the preventive measures on the state of the coast in the future if there were no works having traits has its protection.

We have observed a general average recession of more than minus 50 m in the test profile and a recession of more than minus 1.67 m/year. It is assumed that by 2050, the coastline will have retreated by about 60 m towards the mainland, if there had been no conservation works to protect the coastline.

Spatial remote sensing appears to be the means of inventories and systematic monitoring over large areas; these inventories consist of drawing up a precise description of a certain number of environmental parameters at each point.

It opens the access to the collection of multidisciplinary information in a region and can intervene as a complementary means to the traditional systems, allowing facilitating and even improving the data collection.

In almost all cases, it will be necessary to combine satellite imagery and aerial photographs with field surveys. Observations made on a small scale make it possible to identify problems and guide the use of ground resources.

In short, spatial remote sensing does not compete with traditional methods of data acquisition, but complements them, and is a tool that can help in the spatial planning of sustainable urban development.

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