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The Evolutionary Study of Environmental Conditions of the Guamaré Coast (Northeastern Brazil)

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ABSTRACT

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This work concerns on the environmental coastal evolution of Minhoto beach (Guamaré village, NE Brazil) where a series of pipelines were installed since the 80´s. The primordial purpose was to diagnose the changes verified in the temporary space of five decades (1950 to 2001), relating them to the action of the coastal processes (currents, waves, tides and winds), in order to understand the causes of erosion/deposition on this area. The methodology used included a succession of stages, involving bibliographical and cartographic studies, and aerial photographs interpretation, digital processing of images, field work (sample collection, beaches profiles, characterization of the beach environment and morphodynamics), and laboratory analyses (grain size analyses). The morphologic evolution indicated significant variations in the studied period, mainly, in the dunes, sea terraces, shoreline and tidal flat, evidencing the largest transformations in the temporary space between 1988 and 2001. The analyses of the Minhoto coastline showed a trend to intense erosion, although deposition was observes in other areas. The results of the grain size analyses indicate a predominance of mean to coarse sand in the backshore and intertidal area, while in the shoreface, the analyses indicated medium to fine sand. The morphodynamic studies showed that Minhoto beach is at intermediate state, with interchange to reflective. The areas of larger vulnerability and sensibility are the tidal flat, shoreline, barrier island and mobile dunes, that actually is under great environmental impact with expansion of the shrimp farms, urbanization and natural impacts (erosion of the shoreline).

ADDITIONAL INDEX WORDS: *Coastal monitoring, coastal erosion, hydrodynamic.*

INTRODUCTION

Throughout the world, coasts are zones of transition between the land and the ocean, where waves, currents, and tides act to mold the landforms. The coastal zone constitutes a high energy zone with very active and complex dynamics, in which the Quaternary record shows clearly a history of considerable instability.

Also on the coastal zone lives about two-thirds of the world´s population (KOMAR, 1998). As more and more of us live and vacation along the coast, this fragile portion of the earth is becoming threatened both by overuse and by misuse (DAVIS JR, 1996).

The study region is situated along the northeast coast of Brazil as indicated in Figure 1. On the region around Guamaré Village some long established activities, like salt exploitation and artisanal fisheries, are now being displaced by new ones, like oil industry and shrimp farms. Guamaré comes nowadays consolidating as a petroliferous pole, where a series of oil and gas pipelines were installed since the 80´s on the Minhoto beach. Moreover it is inserted inside of a big project named Pólo Gás Sal (Salt Gas Pole), that foresees exploration of the local resources to the natural gas, diesel oil, liquefied gas - GLP, automotive gasoline, aviation kerosene oil, ethane, among others. Despite of this, Guamaré region is poorly investigated. Only recently some studies were carried on this coastal zone, most of them based on remote sensing data (SILVEIRA, 2002; GRIGIO *et al*., 2002 ab; GRIGIO, 2003; SILVEIRA *et al*., 2003ab).

Conflicts between the various users of the coastal zone make it difficult for planners and ecologists to make the right decisions. Further conflicts arises in trying to reconcile development and the environment. Rational management of the coastal zone requires, at the outset, a detailed study of the marine topography and the compilation of surface geological and geomorphological maps. Knowledge of the sediments, and of sedimentary processes is needed (CHARLIER and MEYER, 1998).

This way our purpose was to diagnose the changes verified in the temporary space of five decades (1950 to 2001), relating them to the action of the coastal processes (currents, waves, tides and winds), in order to understand the causes of erosion/deposition on this area.

A better understanding of the evolution of coasts and their dynamics will enable us all to make informed decisions about their future.

METHODS

Bibliographical studies were performed during the whole research. The icongraphic basic information used were: Topographic map of SUDENE/1970 in the Baixa do Meio Map-MI 899-1 and Topographic map of the Ministério do Exército/1990, Maps Guamaré SB 24-X-D-III-1, MI-899-1 in the scale 1:50.000. To monitoring the area evolution were used air photographs of 1954 (scale 1:40.000); 1970 (scale 1:70.000); 1988 (scale 1:60.000); and satellite digital image of Landsat 7-ETM+ of 2001 in RGB 4-3-NDWI.

A geomorphological comparative analysis of the photographic mosaics and satellite images was carried out after the digital processing (years 1967, 1988 and 2001). The same comparative analises were carried regarding the geology, soils, landuse and coastline changes (years 1954, 1967, 1988 and 2001). The quantification was made using the AutoCAD Map-2000 software. This procedure was complemented by field works (sample collection, beaches profiles, characterization of the beach environment and morphodynamics), and laboratory analyses (grain size analyses).

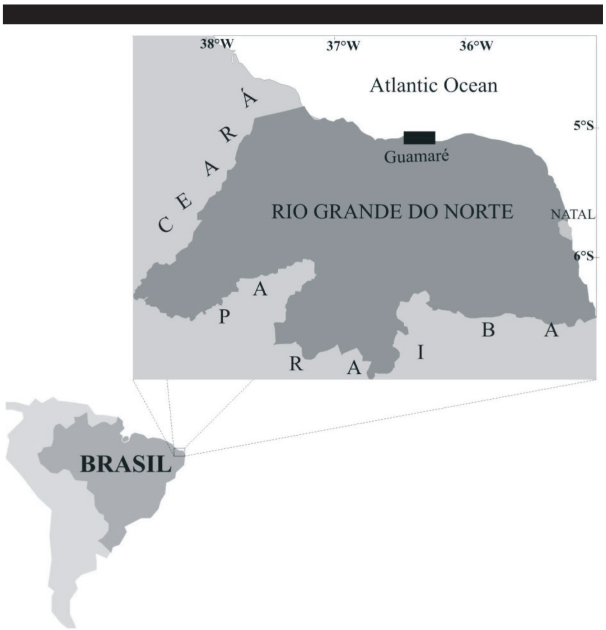

Figure 1. Location of the study area.

EVOLUTION OF GUAMARÉ COAST: SHORT AND MEDIUM SCALES

The evolution of the geomorphologic features was analyzed in a temporary space of three different periods (qualitative and quantitative), as well as the changes occurred in the Minhoto beach coastline for a better understanding of the interaction processes arising from deposition and erosion (Table 1).

Relief Units

The relief units present in the area, in the three periods analyzed, shows the changes occurred in response to the active processes. Several units were identified: planation surface, tidal plain, marine/estuarine terrace, fluvial-estuarine terrace, fixed dunes, mobile dunes, interdunar depression, deflation plain, island barrier, sandy bars, sandy bar emerged in the low tide and foreshore area (Figure 2). These were quantified evidencing the changes during the analyzed period (Table 1). According to SILVA, (1991), these features were molded during the Quaternary period by the sedimentary coastal processes (waves and tides), variation of the sea level and neotectonic activities.

These features are present on the Brazilian northeast coast, being observed from Rio Grande do Norte to Alagoas states; the Guamaré region is characterized by a plane to slightly wavy relief, between 58 and 17 meters decreasing towards the ocean.

Its origin is related to the Cenozoic sedimentary sequences, which are evidenced by erosive unconformities and locally, by paleosoils (VILAÇA *et al*., 1985). These sequences are correlated to deposits of the Barreiras Formation and to the covering sandy beach sediments.

The planation surface locates in the south portion of the area, soon after the dune fields. The comparative study shows that this feature practically was not altered during the studied period, probably because of its stability and the re-mobilization of the fixed dunes; with reference to the mobile dunes there was a migration in its southwest portion in the periods of 1967 to 1988 and 1988 to 2001. These features correspond to 32.1% of the total mapped area. The changes take place as a consequence of the dunes migration towards these compartments.

Tidal Flats

Most of the estuaries margins are rimmed by tidal flats - areas of mud and sand that are exposed at low tide and flooded at high tide. Their extent is determined by the shape of the estuary and by the tidal range. It is topographically defined by a plane

Table 1. *Quantification of the geomorphologic units changes in the years of 1967, 1988 and 2001.*

LAYER	ÁREA km² 1967	ÁREA km² 1988	ÁREA km² 2001	(%) 1967	(%) 1988	(%) 2001
Sand bar exposed in the low tide	0.55	0.52	6.25	0.38	0.39	4.37
Sand Bar	0.23	1.93	0.09	0.01	1.44	0.06
Barrier Islands	0.99	0	1.16	0.68	0.00	0.81
Foreshore	-	-	0.61	0.00	0.00	0.43
Deflation Flat	10.46	7.24	4.67	7.15	5.39	3.26
Interdune Depression	1.25	1.83	0.96	0.85	1.36	0.67
Mobile Dunes	17.56	18.00	20.01	12.00	13.39	13.98
Fixed dunes	30.31	25.46	29.76	20.71	18.94	20.80
Fluvial estuarine Terraces	0.4	0.45	0.18	0.27	0.33	0.13
Marine Terraces	3.73	5.19	4.00	2.55	3.86	2.80
Tidal Flats – Intertidal	14.87	2.64	7.62	10.16	1.96	5.33
Tidal Flats – Mangrove	9.69	11.82	8.54	6.62	8.79	5.97
Tidal Flats – Supratidal	5.16	2.34	1.06	3.53	1.74	0.74
Planation surface	47.02	46.05	42.91	32.12	31.92	32.18
Salt Exploration	1.17	8.73	10.14	0.80	6.49	7.09
Lagoons and rivers	0.46	2.37	1.99	0.31	1.76	1.39
Rivers	2.52	2.98	2.98	1.72	2.22	2.22
TOTAL	146.3	134.4	143.9	100.0	100.0	100.0

Surface, with maximum elevation of three meters, being cut by tidal channels, which flow forward in the land direction. Three distinct and important environments comprise this unit: supratidal flats, intertidal flats, and mangrove.

The tidal channels dissect the tidal flat system. These networks carry both the tidal flux and sediments which are transported as bedload and suspended load. The same currents that distribute sediments throughout the estuary and along the shoreline also deposit them onto the tidal flats.

Tidal flat sediment is composed mostly of mud and fine-grained sand and the shells of the small animals that have lived there (bivalves, crabs, gastropods, among others). Sediments are generally bioturbated due to the abundance of burrowing organisms and the rooting of the mangrove trees. Peat layers may be developed. The sedimentary structures more common are thin, regular layers called tidal bedding, and tidally produced stratification, the tidal bundling.

Mangrove trees colonize various parts of the intertidal to supratidal zone. It is worth to point out, that the suppression of these areas with potential for mangrove development, are restricting the available zones to this important ecosystem (Table 1); these areas has been substituted mainly by the shrimp culture.

Supratidal Flats

The unvegetated supratidal flat is quite featureless and without relief, being washed by the spring tides (up to 2.6 m). This region may in some locations be vegetated with upland vegetation, and at least partially covered with algal mats. The largest alteration occurs from 1988 to 2001 (Table 1), because of the substitution of this feature by shrimp farms (Figure 2).

Intertidal Flats

Parts of the tidal flats lying between high and low tide range (respectively 2.6 and 0.6 m during neap tides), the intertidal flat, make up the major areal extent of the tidal flat.

It was observed that this feature is retreating during the studied periods (Table 1). The decrease is related to the salt exploration activities (1967/1988) and to the expansion of shrimp farms (2001).

Marine/Estuarine Terrace

The studied area presents two levels of baselines with horizontal or slightly sloping surface, occurring between the mobile dunes and deflation flats units, constituting topographical surfaces modeled by hydric erosion.

The origin of these terraces is probably associated to the hydric erosion (fluvial, estuarine and/or marine) in period of higher oceanic waters levels during the Quaternary. The influence of the continental movement is evident; in other words, a structural control for origin of these terraces. The geometry of this unit changes during the three studied periods, probably related to the re-working of the eolian sands.

Fluvial-Estuarine Terrace

This unit constitute horizontal surfaces, or slightly sloping, existent inside the estuary, elevated in relation to the waters level from zero (0) to two (2) meters, according to visualization in field.

These terraces are usually called island, and are vestiges of higher old estuarine plain, being characterized mainly by the presence of alluvial deposits of supratidal and intertidal origin and covered by vegetation. In the evaluation done in the studied periods, there was little variation in its geometry.

Fixed Dunes

These dunes are fixed by vegetation. Morphologically they present wavy relief, with dominated SE/NW orientations, coincident to the general direction of the prevailing winds. They occur more or less parallel, and in contact to the planation surface, with height ranging from 5 to 30 meters. The origin of these dune fields is related to the climatic conditions and the sea level oscillations.

The dunes fixed by vegetation, probably, developed during low sea levels with periods of arid to semi-arid climate. These dunes were re-worked morphologically according to the climatic changes. More humid conditions, favored the development of vegetation and consequently stabilization of the dune sands.

This feature now represents about 28.3% of the total area. Observation for the analyzed periods showed that part of this shape was covered again by the mobile dunes in NE/NW direction, mainly from 1988 to 2001 (Table 1).

It is clearly observed, in the area, the migration of the mobile dunes over the fixed ones.

Mobile Dunes

The mobile dunes are migrating inland. They are the crescent-shaped dune ("barchans"), found in groups or as solitary dune, with heights superior to 10 meters. They are the products of limited sand supply and unidirectional winds coming from east and northeast. In the southeast portion of the studied area, ponds may be covered by the migrating dunes; deflation basin, corridors and dune crests are the aeolian macroforms found.

During the analyzed periods those features migrated about 1.155 meters to SW and W directions, corresponding around 55 meters/year.

Deflation Flats

This relief unit comprises, the space between the narrow foreshore and the dune fields (mobile or fixed) and, locally, for levels of terraces.

The relief is plane or slightly wavy, with dominant steepness for the ocean, and elevation between 2 and 6 meters.

The origin of the deflation flat is related to the fluvial-estuarine and/or marine terraces, most of the covered by aeolian sands.

The comparative analysis between 1967 and 1988 maps, show a reduction of this unit of 30%. It suggests that on this interval of time occurred a decrease of sediment supply towards the continent. However, take in account the period between 1988 and 2001, an increase in the sediment supply about 20.2% could be deduced (Figures 2B and C).

Interdunar Lagoons

Placed inside the corridors of the mobile dunes, this unit present several forms, perpendicular to the coastline. The lagoons water level depends on the dry and rainy seasons, and most of the lagoons exist only in the rainy season.

Such features, probably, are originating from valley that were totally closed by coastal dunes, being fed mainly by the dune aquifer, forming true oasis between the dunes. Changes were observed during the studied period as showed in Table 1.

Barriers Islands

This unit is constituted by a narrow and prolonged sandy body, parallel to the coast, limited to east by the Guamaré channel and to west by the Amaro Island.

In the aerial photos analysis, between 1954 and 1967, it was observed the existence of a second sand bar, linked to the barrier island, prograding towards W (in 1954), with about 1,000 meters. In the 1967 photo this sand bar was totally eroded, staying the Amaro spit with 910 meters. In the period from 1967 to 1988, it was observed that the Amaro spit, incorporated a sandy bar adjacent to the west margin of the tidal channel. In 1967, the bar adjacent to the channel had 1,47 kilometers and the channel opening 210 meters, indicating an increase about 770 meters. This accretion of sediments could be attributed to the dredging of the Port of Guamaré occurred in 1983.

In 2001, this feature is similar to 1954, with the formation of two spits, with the first coupled to the Amaro spit, with about 1,67 kilometers and the second one to the Guamaré channel.

Sand Bar

It corresponds to a finite unit of sand accumulated linear and shore-parallel, in response to beach processes. In 1967, this bar had about 1 kilometer in E-W direction. It is also observed that the channel between the bar and the barrier island was of 350 meters. In 1988 this bar linked to the Amaro Barrier Island, constituting a sandy body of 2,500 meters of distance and a width of 310 meters. In 2001, that feature separates again, and is still observed the formation of two others bars; one bordering the tide channel present in its internal portion and other in west direction evidencing an intense erosive process.

Sand Bar Exposed in the Low Tide

These features also denominated of spits, since they are linked to the land, exposed in the low tide and covered in the high tide. Its origin is related to the marine and estuarine contribution of sediments.

In the area in study these features were visualized in all of the analyzed periods, intensifying more in 2000 to 2001. Probably, the sediment supply to these features is originated from the re-working of marine sediments and of the dredging of the Guamaré channel (1983 and 1992), once the fluvial contribution is inexpressive.

Foreshore

This feature was only possible to be mapped in the satellite image of 2001. It comprises the lower shore zone that lies between the normal high and low-water marks. It is characterized by a plane slope dipping seawards at a low angle (6.3º), and with medium width of 116 meters.

It can be divided in two parts, an inferior with low tide domain and other superior with dominant dynamics of high tide. However, in the studied area, it is noticed practically, a continuous surface from the inferior part to the superior. Exception done to the period of exceptional tide, as it was observed in October/2000 and October/2001, where the backshore was washed and connected with the Amaro channel.

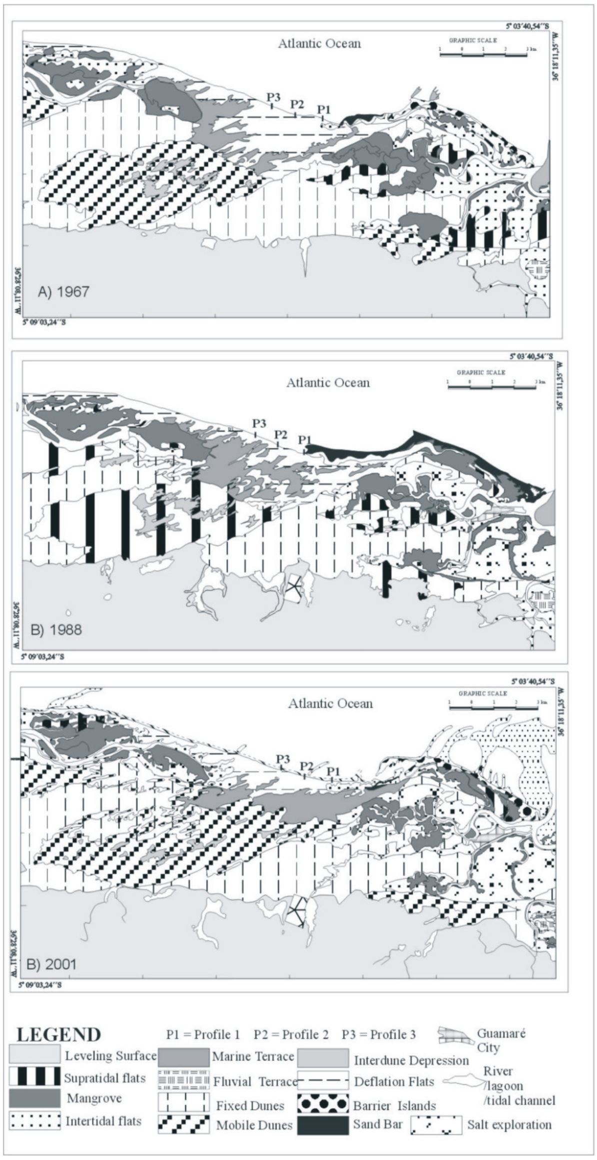

Figure 2. Location of the study area.

SOURCE: Air photographs (years 1967, 1988) and satellite image (year 2001).

Evolution of the Coastline

The coastline constitutes one of the most dynamic features of the planet. Its position changes constantly in different time scales. Many are the factors that modify this landscape. Some are of natural origin, as coastal processes, and others of anthropic origin, as the case of the constructions.

The studied coastline has a main direction E-W, and 31,5 kilometers of extension. It is characterized by flat sandy beaches, with a medium slope of 1/36. Grain size analyses indicate a predominance of mean to coarse sand in the backshore and intertidal area, while in the shoreface medium to fine sand is present. The area is subject to waves coming from NE and wind blowing from NE to SE. The currents present speeds of up to 0.5 m/s, with resultant to West; currents are also influenced by the tide, which is semi-diurnal and has amplitude varying from 1.0 to 3.1 meters. The morphodynamic studies showed that Minhoto beach is at intermediate state, with interchange to reflective.

Sedimentation and erosion were quantified regarding the location of three profiles on the Minhoto beach, where oil and gas pipelines are currently exposed on the beach. Profile 1 and Profile 3 are situated respectively eastern and western of the pipelines, while Profile 2 is in the middle, between them.

In the period between 1954 and 1967 the largest retreat (erosion in the order of 265 meters) occurred in the profile 3; the others profile P1 and P2 showed an retreat respectively of 63 and 162 meters. Between 1967 and 1988, the largest erosion occurred in the Profile 1 (189 meters); while the smallest one (93 meters), occurred in the Profile 3.

In the period of 1988 to 2001 a retreat shoreline of 46 and 91 meters were observed respectively to Profile 1 and 2; while the profile 3 erodes 221 m, the largest retreat in this period.

As a result of this study we can infer that the area suffers a very intense dynamic process, with a trend to erosion.

CONCLUSIONS

An overview of the Guamaré geoenvironmental conditions was initiated with the results of this study; a pioneer one for this area. It collected different data concerning geology, soil, landuse and evolution of the relief units, as well as the monitoring of the hydrodynamic, morphodynamic, sedimentology and variation of the coastline; the integration of this database allow a vulnerability and environmental sensibility indication for the area.

The superposition of the photographic mosaics (1954, 1967 and 1988) and satellite image (2001), demonstrated the temporary changes of the Guamaré coastline in five decades; The results indicate the fragility of the area, where the erosive processes are dominant.

The Minhoto beach, area where oil and gas pipelines from PETROBRAS are exposed, was identified environmentally as the most vulnerable point of the coastline, because of the erosion in the analyzed periods. Other areas of larger vulnerability and sensibility are the mobile and fixed dunes, the coastline, the barriers islands and the tidal plains. The tidal plain is under significant environmental impacts due to the evidenced expansion of the shrimp farms in the area.

These results point out therefore, the need of a constant monitoring program, at least on the area where the pipelines are exposed on the beach; such programs are important to a better understanding of the hydrodynamic and coastal processes, acting in the area.

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