Erosive Processes Monitoring Linked to the Estuarine Evolution Systems Nearby Águas Belas, Cascavel-CE, Brazil

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ABSTRACT


The Malcozinhado estuarine-lagoon system, at NE-Brazil, is located at the County of Cascavel, 75 km to southeast of the city of Fortaleza-CE. Its drainage basin occupies an area of 380 km² that due to its high aesthetic value, was included in the PRODETURIS Rota do Sol Nascente (Sun Rise Route) a Touristic Project. The urban expansion that took place during the last two decades resulted in a series of impact upon the Malcozinhado estuary and upon adjacent beaches, such as beach erosion, hypsarsalinization and outlet migration over urban areas. This problem is expected get worse as a 3,800,000 m³ reservoir for water supply is being built, 7.5 km upstream and will further reduce the Malcozinhado river flow, thus its capacity to maintain its original channel and impair saltwater intrusion.

We aimed to assess and monitor the evolution of estuarine and beach morphodynamic and hydrodynamic behavior nearby the Águas Belas village in the search for information that can contribute to solve and/or mitigate present environmental conflicts. Available aerial photographs, images and maps for the area were analyzed, CTD profiles and current measurements taken at ten stations along the Malcozinhado estuary, for a full tidal cycle, during dry and rainy seasons, in addition the evolution of bathymetric survey of the estuariusy cross-section. The system dynamic is highly dependent of the freshwater discharge that together with the sediment reworking processes, longshore drift, eolian deflation and tides composes a cyclical framework well marked by wet and dry semi-arid conditions typical of tropical regions.

ADDITIONAL INDEX WORDS: Estuarine morphodynamic, coastal erosion, coastal management.

INTRODUCTION

Estuaries are unic environments that play a major ecological role as source of nutrients, organic matter and sediments to coastal waters, besides to generate goodness and services for local communities. The silting up of fluvial channels, development of extractive activities, construction of dams, unordenated occupation and turistic exploration can endanger its well functioning and thus jeopardize its biodiversidade, productivity and water quality and coastal dynamics, with strong reflex to the local community.

STUDY AREA

The study area (Figure 1) corresponded to the Malcozinhado estuarine-lagoon system, at Cascavel County, located 75 km to southeast of the city of Fortaleza-CE. The system drains an area of 380 km² of high aesthetic value, and as so, included in the Rota do Sol Nascente (Sun Rise Route) of the Touristic Project PRODETURIS. During the last two decades the area has experienced beach erosion, lost of urban areas due to the migration of the estuarine channel and hypsarsalinization, due to the accelerated urban expansion. Intensification of the problems can be expected as a 3,800,000 m³ reservoir for water supply is being built, 7.5 km upstream. The reduction of the river flow will also reduce the capacity of the Malcozinhado in maintain its channel and impair saltwater intrusion. The goal of this study was to assess and monitor the evolution of estuarine and beach morphodynamic and the hydrodynamic behavior near the village of Águas Belas in the search for information that can contribute to solve and/or mitigate present environmental conflicts.

METHODS

The first stage of the work consisted in the analyses of aerial photograph and TM-LANDSAT-Band 4 images, available for the 1959-2002 period. For these analyses, we used the Catholic church of Nossa Senhora at Águas Belas, at the 5m level, as the reference point, to trace the evolutive behavior of the mouth of the Malcozinhado. The image classification was based on the reflectance of the terrain moisture in the gray scale, making possible to infer the evolution of the supralittoral, mesolittoral and infralittoral zones for each time period.

The construction of a digital model of the evolution of the estuarine channel was not possible due the lack of preterit bathymetric information for the area.

The bathymetric survey of the estuarine was conducted at 11 cross-sections along the system, from a motorboat, using a Furuno ecobathgraph associated to a DGPS for the navigable portion of the estuary, and by means of topographic survey at the shallow areas. A series of limnograph were installed along the system, in order to permit correct bathymetric data for tidal oscillation.

At each of the 10 cross-section along the estuary, current speed and direction were determined with a Sensordata SD30 current meter, near surface and near the bottom, and vertical temperature, salinity and OBS signal profiles obtained from surface to bottom with a SeaBird CTD, during, high, ebb, low and flood tidal stages, for the dry and rainy seasons.

Additionally, water and sediment samples were also gathered respectively for total suspended solids determination and characterization of bottom deposits. The collected data was then used to infer the distribution of monitored variables, the pattern of water circulation, the material fluxes within and from the system and their spatial and temporal variability as well as to identify and quantify the evolution trends and the processes governing the system dynamics.

RESULTS AND DISCUSSION

Evolution of the Malcozinhado System

The coast of the State of Ceará is characterize by a large number of drainage basins dammed by dune fields and/or sand
bars that isolate partially or completely the estuaries from the sea, forming extensive flood plains that often evolve towards lacustrine and/or lagoon systems. In some cases, these lagoons become areas of groundwater discharge of mobile or edaphic dunes as function of the climatic seasonality. The evidence and the temporal scale of these processes are highly variable occurring in the last 18,000 years or in shorter time scale, as by the Malcozhinho estuarine mouth.

Since the coastal regions are hydrographically downstream zones, they are under strong dependence from the continental drainage. Nowadays, coastal erosion is a widely spread process along sand beaches. The major causes of erosion are related to (i) variation in sea level and in wave, tides, and currents' energy; (ii) reduction of the sediment supply and (iii) modification of the effectiveness of the hydraulic jetty effect at the river mouth due to anthropic intervention in the drainage basins (Van Der Wal et al., 2002). Data for the coastal plains of the Paraíba do Sul and São Francisco rivers indicated that the evolution and dynamics of those system mouths are mainly controlled by the interaction of the river discharge with the longshore currents due to wave action. At the State of Ceará, similar behavior was verified, at the mouth of the Jaguaribe, Pirangi, Choró and Malcozinho estuaries governed by the hydraulic jetty effect and the seasonal inlet migration due to the mobilization of dunes and sand bars.

The estuarine system at Águas Belas hangs above all, to the seasonal rainfall regime together with the sediment reworking processes and longshore drift, aeolian deflation and tidal forcing. These compose a cyclical framework well marked by wet and dry semi-arid conditions characteristic of the tropical regions. That system, as many others stretched along the Ceará State littoral, presents a great deal of siltation and as result, outlets migrates towards the urban areas.

The presence of submerged sand bars and sand banks witness this evolution and accumulations of sediments at the river right margin explaining the consequences of the sediment behavior. This means a shifting in the estuarine major channel of approximately 111 m over the last nine years. It must be said that for the last 43 years (1959-2003) the channel has progressed 180 m in the Águas Belas in a rate of 4.18 m.y. This rate has been compared to other special ones in order to attain an overall picture of the area sedimentary behavior. From 1993 to 1997 a channel displacement of 60.97 m at a rate of 15.24 m.y was found. In 4 years the erosion rate corresponded to 89.66% of that verified in the previous 43 year-interval (Figure 2). It is worth to point out that rainfall for the period from 1990 to 1994 well below (only 45%) that of historic records for the area. This low rainfall most likely contributed for the intensification of the aeolian transport enhancing the migration of the estuarine channel. Although the period from 1995 to 1997 can be considered typical in term of rainfall, the river flow was not able flush and reshape the sand bank formed in the previous 4 years. From 1997 to 2001, the channel migration was of 45 m at a rate
From September 2001 to April 2002, the channel retreated 6 m intensified by the lingering drought period. The urban expansion in that period was held according to the 0.61 km² area accretion, in other words, the urban area that in 1959 was 0.23 km² increased to 0.85 km² in 1993. This has been derived from the summerhouses edification and incipient hotels in Aguas Belas district. Even with progress channel migration trend registered in 1993 there was a permanent expansion of urbanization at the areas adjacent to the estuary, and along the beach strip with 0.29 km² of land accretion in this same year. The urban growth observed for the 9 years interval (1993-2002) was similar to that verified in the pass over a 43-year period (1959-1993).

Correlation between erosion rate and rainfall during the study period was highly significant (r² = 0.99). An even when the river didn't carry out enough competence to open the channel and to cast the sandy material into the alongshore drift, the remaining flow delayed the migration process towards Aguas Belas. Aside of the intermittent flow of the Malcozinhado river, the irrational terrain use and occupation along its margin contributed significantly to modify the system hydrodynamic behavior. In example, the deforestation of the margin of the Camurim and Mataquiri.

The largest contributions to the production of sandy sediments are from farms settled over the cliffs of the Barreiras' Formation, bordering 7 km of the estuarine plain.

The estuary bottom deposits is mainly formed by quartz sands, silty mud with predominance of clay minerals, sandy mud and silt-clay slime. The major clay minerals in the estuary and at the Ceará’s coast are esmectita, illita and caolinite. There is a greatly significant concentration of illite and esmectite between the sea and the tributaries, indicating a good mixing of riverine and marine sediments within the estuary, with a domain of marine sediments (quartz).

The distribution of the total suspended solids (TSS) revealed a similar pattern of that found for the bottom deposits. The average TSS concentration during the dry season was 53.23 mg/l. Higher mean values were observed during low tides, during both dry and rainy season (61.58 mg/l and 63.96 mg/l respectively). During the rainy season higher registered values were 76.4 mg/l and lower 36.45 mg/l, respectively during high and low water stages. The mean rate of sediment transported from the sea into the estuary during the dry season was 1.30 g/s. The exportation rate was 1.14 g/s, 12.30% smaller then the volume entering the estuary. During rainy season ebb tide, an incremental contribution from the Macozinhado river to the beach area occurs at a transport rate of 3.34 g/s. The upstreamwards sediment transport rate was 0.30 g/s, 77% lower than the rate verified during the dry season, indicating the barrier that the river exerted in the transport of marine sediments into the system.

The Estuarine Geomorphology

The answer of those processes is a shallow estuary with an average depth of 1.3 m. The deepest area (3.5 m) corresponds to the area near the estuary mouth. Prevailing currents during flood and ebb tides attack frontally the urban structures causing erosion by sapping. The lodgings and hotels owner frequently piles sand bags, swap iron, stake, etc. by the beach shore attempting to contain erosion. Also, during the weekend and
hollydays, the flux of bathers to the area is high. Not rare, they try swimming across the river during ebb tide. Since currents are 30% stronger during spring tides, the area present some risk to drowning mainly to unwarned, elderly, children and to persons under the effect of alcohol. In spite of the wave energy being higher that of the riverine flow, the river runoff contributes to the maintenance of the main axis of the estuary mouth.

The total contribution by the Malcozinhado river and its tributaries to the estuarine system is of 24.73 m$^3$.s$^{-1}$, accounting for 75.97% of the freshwater entering the system. The controlled discharge of the dam of 0.426 m$^3$.s$^{-1}$ will result in a 75.45% reduction of the water contribution to the estuarine system, thus to the overlapping induced by the tides, to the rise of mean water salinity and to the reduction of dissolved oxygen levels in the estuarine water with negative reflexes to the biological productivity of this system. During the equinocial spring tides at Sep/2001 0.3 tons of sediment were transported into the estuary during flood tidal stages. The shallow depths are observed in the central and southern most portion of the estuary, with a mean depth of 0.50 m.

The velocity of the silting up is enhanced by the wave action, tides and aeolian deflation of the sand banks in the backshore, during the dry season. From Sep/2001 to Oct/2002 the sand banks migrated 6m towards Aguas Belas reducing the area of profile 1 by 24% in 13 months. The same behavior was observed at profile 2, were the material derived from the dunes reduced the area of the profile by 11%. In those areas, at spring low tides, extensive areas became exposed, impairing navigation in the dry season. Along the fluvial channel the average depth registered in Apr/2003, was 1.0 m.

The prevailing wind direction at the Malcozinhado river mouth during the dry season followed the pattern of historic series for Fortaleza and Aquiraz. Winds blow mainly from E-S (65%), followed by winds from NE (21%) and from NNE and ENE. These later two corresponding to the sea breeze. Stronger winds occurred in November when humidity level reached a minimum value of 74%. Average winds blows at 7 m.s$^{-1}$, with minimum of 2 m.s$^{-1}$ and maximum of 9 m.s$^{-1}$. Gusts of wind are frequent during this time of the year reaching speed of up to 10 m.s$^{-1}$. During the rainy season wind speed varied from 0 to 5 m.s$^{-1}$, with gusts up to 9 m.s$^{-1}$. Average wind speed during days of no rain is 4 m.s$^{-1}$ while during days when rainfall lasted for more than 8 hours it was average wind speed was 1.3 m.s$^{-1}$ prevailing winds from the SE (68%) during the day and from SSE at night.

During the dry season current were stronger at high water (0.30 m.s$^{-1}$) and ebb (0.31 m.s$^{-1}$) tidal stages. Velocity profiles were near homogeneous from surface to bottom with an overall standard deviation of 0.019 m.s$^{-1}$. At the surface the prevailing current direction was E-W under the local winds influence while near the bottom the major currents followed the channel contour (ENE-WSW).

During the rainy season current speed ranged from 0 to 0.852 m.s$^{-1}$ and prevailing direction was that of the channel major axis. During this season, current reversal was observed near the bottom indicating a dominant gravitational transport within some sections. Stronger currents being registered in front the urban area of Aguas Belas. The volume transported over a tidal cycle was 1.12 tons pointing out to the effect of evaporation and stagnation of the lagoon waters.

During the rainy season the salt volume transported upstream was of 0.403 tons and the volume transported seawards of 0.426 tons, with a standard deviation of only 0.01 ton. The net differences between the up and downstream transported volume has only been 0.06 tons while exported volume was 0.343 tons. This indicates the action of the river discharge in reducing the vulnerability of the process of hypersalinization and oxygenation of the water, and required element to the development of the biota.

The tides at the estuary are semiidiurnal, with a spring amplitude of 1.50 m near the mouth and of 0.58m at the limit of the estuarine zone with a 45% amplitude damp relative to the tides at the Mucuripe Harbor (3.3 m). During the rainy season, despite the precipitation has been remained with the mean values, the tidal range was 1.26 m wich means 16% less, wich was due to the sand banks migration silting up the estuarine main canal in front of Aguas Belas.

Near the system mouth low water lags tides at Mucuripe by 20 minutes during dry season, while during the rainy season the measured lag was of 2h and 35 min. Further south, the time-lag of low waters in Set/2001 was of 4h and 35 min. Relative to tides at the system mouth. This indicates a much longer residence time for the system during dry season favoring evaporation and reducing the system capacity to receive sewage and wastewaters. The case becomes worse as we visualize the proximity of the reservoir construction and the ephemeral downward drainage predominantly placed in sandy lands carrying out a projected urban expansion increasing 40% of the current state.

**CONCLUSIONS**

Turbulent diffusion is the major mechanism for mixing and salt transport along the Malcozinhado river system. The salt volume transported during the dry and rainy seasons was respectively 1.12 and 0.426 tons, indicating the importance of the river flow to minimize hypersalinization.

The beach area under the direct influence of the Malcozinhado river is a highly unstable environment with a backshore completely occupied by shore protection structures. Erosion will most likely continue to take place, independently of the changes in sediment supply by the Malcozinhado river and other associated process.

The sediment deposition observed along the right river shore cause the river channel to migrate 111m in the last 9 years, resulting in beach erosion at Águas Belas.

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**LITERATURE CITED**