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REFERENCES

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The effect of semi-aridity and damming on sedimentary dynamics in estuaries -Northeastern region of Brazil.

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ABSTRACT

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The estuary Basins in Ceará State are directly impacted by dams located in high and medium river courses inserted in semi-arid terrains. About 95% of the territory of the State of Ceará is dominated by the semiarid climate. Under that condition, the dams are essential, in the short term, to provide water to the population living in the hinterland and coastal zones. Over the past 10 years, dam construction near the coast has significantly increased due to more favorable rainfall (700-1500 mm) and consequently reservoirs are formed. That is te reason why the aim of this study is to evaluate the transport of bottom and suspended sediment in the estuary of the Jaguaribe, Timonha, Acaraú and Malcozinhado Rivers which carry different dimensions, hydrology and hydrodynamics, but all of them under the effect of semi-arid and damming. Due to this fact, the regional and comparative studies on geology, hydrology and freshwater flow in the estuaries have been associated to results that could be useful for the state Integrated Basin Plan. The dams reduced the inflow of freshwater tributaries during the rainy season into the Timonha, Malcozinhado, Jaguaribe and Acaraú estuaries by 83%, 75.45%, 85% and 78% respectively. In the Timonha river there was a reduction in the transport of materials to the coastal zone from 450 t to 100 t. In the Jaguaribe river around 30.000 tons of sediment are annually retained in the small lower course dams. In the estuaries of the Malcozinhado and Acaraú Rivers there was a lateral migration of the waterway causing erosions on the beaches of Águas Belas and Aranaú and damaging services and local communities.

ADDITIONAL INDEX WORDS: ***Tropical Estuaries, Semi-arid, Sedimentation***

INTRODUCTION

The estuary hydrographic basins in the State of Ceará are directly impacted by dams located in high and medium river courses inserted in semi-arid terrains. About 95% of the territory of Ceará is dominated by the semiarid climate. The semiarid region rivers in the Brazilian Northeastern region, where the studied area is located, are intermittent, flowing only during the rainy season. Riverbeds get dry during the drought months, which corresponds to the period from July to November in the State of Ceará (Campos et al.2000).

Seawater penetration in the valleys during high tides hinders these rivers having no communication with the ocean during the dry season (Pinheiro and Morais, 2010). During that season, the flow is practically none, and consequently there is no gradual dilution of the seawater by river waters. The native species in those regions are able to survive, distribute themselves and reproduce under the influence of the large flow seasonal variations (Townsend and Hildrew, 1994).

These estuaries may be considered as temporary, with typically estuarine characteristics of circulation and mix (Dyer, 1997, Miranda et al., 2002), restricted to the rainy period. The input freshwater during that period has important physical, chemical and biological consequences.

Under that condition, the dams are essential, in the short term, to provide water to the population living in the hinterland and coastal zones. In addition to this, they make the valley permanent creating opportunities for expected increased cultivation areas. However, the dams imply an advancement of saline intrusion, increase in the estuaries' residence time, an increase in hypersalinization and a reduction in the load of sediments and nutrients to the coastal zone (Wolanski et al., 1996; Kjerve 1990, Alber, 2002; Marins et al., 2003; Kitheka et al., 2004, Araújo et al., 2006, Molissani et al., 2006, Pinheiro et al., 2006; Genz and Lessa, 2008). Consequently, socio-economic problems in the communities that explore the natural resources existing there will be intensified.

In the Northeastern region's coast, the dams are cited as one of the factors that have caused an expansion of mangroves as the result of saline intrusion and changes in sediment deposition along river margins in the last decades of the 20th Century (Maia et al., 2006). The high insolation results in evaporation rates of 18 $m.year^{-1}$. The rivers dry up in that period and these conditions promote hypersalinity estuaries in the State of Ceará, ranging above 40 ups, and retention of sediments inside the system (Pinheiro et al.2006). Under these conditions since the seventeenth century, the production of salt (sodium chloride) is one of the

main economic activities in the coastal area of northeastern Brazil, mainly the states of River Grande of the Norte and Ceará. In Ceará, from the 90s years, the saline are being replaced by shrimp ponds.

Over the past 10 years, dam construction near the coast has significantly increased due to more favorable rainfall (700-1500 mm) and consequently reservoirs are formed. For example, Jaguaribe River Basin alone accounts for over 25 of them, including large and small (Morais et al., 2008, Paula et al. 2009). This reflects in various types of impacts arising from the interruption of sediment transport into the estuary, beaches and adjacent inner shelf (Pinheiro et al., 2006, Morais et al., 2008, Paula et al., 2009).

In the estuaries of the Timonha and Malcozinhado Rivers, dams with volumes superior to 1 billion cubic meters were built less than 15 km from the coast. Part of this downstream water from the dams is used by the population for diffuse supply and irrigation and some is lost through evapotranspiration in the mangrove estuary. If it occurs dry period and El Nino at the same time, there is absolutely no flow from all of the dams. This reflects the retention of marine sediments inside the estuary since the rivers mouth is obstructed (Genz and Lessa, 2008, Pinheiro, et al, 2006).

Because of this the aim of this study was to evaluate the transport of bottom and suspended sediment in the estuary of the Jaguaribe, Timonha, Acaraú and Malcozinhado Rivers which carry different dimensions, hydrology and hydrodynamics, but all of them under the effect of semi-arid and damming, thereby contributing together with useful information to management of watersheds (Figure 1). Due to this fact, the regional and comparative studies of geology, hydrology and freshwater flow in the estuaries have been associated to produce results that could be useful for the state Integrated Basin Plan.

STUDY AREA

The motivation to select these estuaries was the construction of dams in 2002 for water accumulation close to the estuaries, considering herein a maximum distance of 35 km (Itaiçaba Dam). In the case of the Malcozinhado and Timonha rivers' estuaries, the distance is of approximately 15 km. These hydrographic basins are inserted in crystalline basement bearing groundwater low potential where the semi-arid climate favors the physical weathering such as igneous and metamorphic rocks disaggregation. The Barreiras formation, geological outline of the coastal plain, is one of the main sources of sedimentary supplies for the alluvia, being constituted predominantly by loamy sandstones, conglomerate and lateritic nodules subject to the leaching (CPRM, 2003). The river displays low competence and intermittent drainage. In the pre-coastal plain, the interaction between climatic and geological agents produces a geosystem characterized by presenting and poor organic matter muddy sand, reasonable ground water potential, medium port scattered vegetation (tree and brush savannahs) with ciliary forest spots and planned relief with unfitted fluvial valleys.

The atmospheric system that exercises a larger control under the climatic conditions is dominated by the Intertropical Convergence Zone (ICZ). The area climate is hot and humid, (Köppen classification), concentrating rains from January to June. Based on a series of historical data (1979/2004), supplied by Fundação Cearense de Meteorologia e Recursos Hídricos (Ceará State Foundation for Meteorology and Water Resources/FUNCEME), the system receives 917 mm of rain, of which 97% occur during the first semester, annually. The thermal regime is around 27ºC without great variations all over the year. The evaporation rate was 202 mm per month with low values in April (91 mm) and higher in October (291 mm). The air relative humidity stays high during the whole year, around 76%.

The insolation is very intense in the coastal area, reaching an annual average of 3000 m, with peaks in September and October with daily sunlight around 8 $h.day^{-1}$. Winds have annual medium speed of 5.2 $m.s^{-1}$ varying seasonally in intensity and direction. It forms a framework that involves moderate speeds during the first semester blowing preferentially from SE quadrant, averaging 4.1 $m.s^{-1}$. Starting from June it becomes stronger, medium speed of 6.3 m s^{-1}, coming from the NE quadrant (www.funceme.br). This is a mesotidal area dominated by semidiurnal waves with medium period of 12.4 h (Morais et al., 2008). It ranges 3.4 m, during syzygy, and less than 1 m during neap tides.

METHODS

The first stage of the study consisted in a historic data

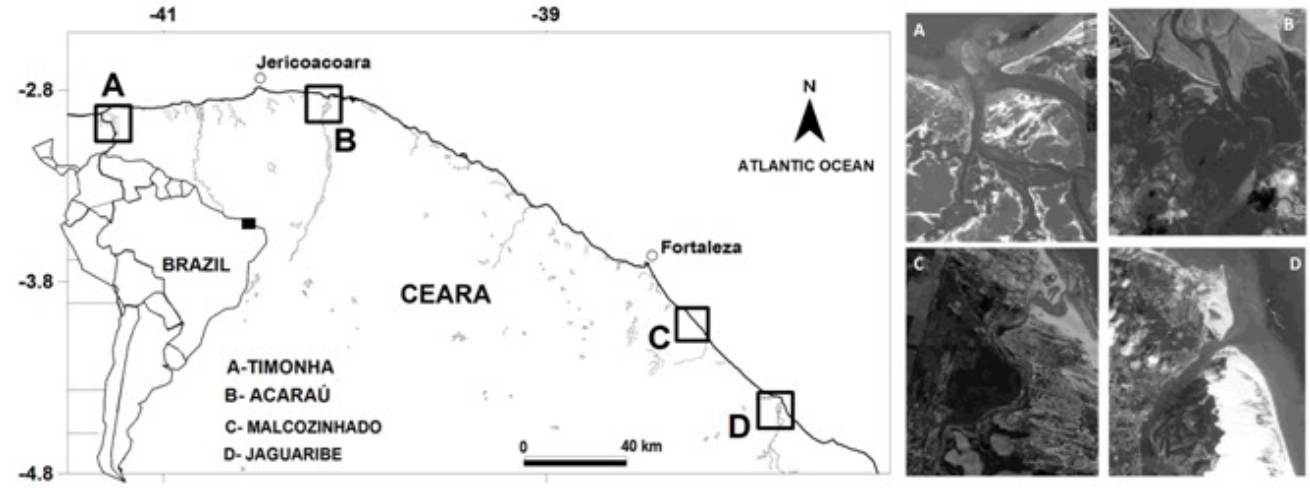

Figure 1. Study area

survey on the climatology, hydrology and transport of sediments in the hydrographic basins by regional research institutes and in the database held by HidroWEB-Hydrological Information Systems of the National Water Agency-ANA. Considering the absence and the reduced number of real-time monitoring stations, through the use of the empirical equations proposed in the works of Kjerve (1990) and satisfactorily applied by Medeiros and Kjerfve (1993), Kjerfve et al. (1996), Molisani et al. (2007) and Pinheiro and Morais (2010) in tropical estuaries, the affluent flow was simulated before and after the dams. The simulations after the dams were validated with the data on the flow of dams and the data available in the literature on the concentration of sediments in estuaries and in springs. The main emerged and submerged features together with sedimentation in the estuary were obtained through remote sensing and bathymetric data. The first collections were undertaken in 2003, before of the functioning and construction of the reservoirs, during the rainy and drought periods and during the syzygy and neap tides. The remaining samplings were undertaken from 2004 to 2008 under the same tide and seasonality conditions. The current measurement intensity and directions and flow water of the vertical profiles were conducted in the middle of the estuarine channel, at the stations in their longitudinal axis. The current intensity and directions were recorded with a Sensordata-SD 6000, ADP made by Sonteck and STD made by Saiv with an O.B.S. sensor.

The material samplings in suspension were only performed in the ebb and flood tide cycles, as there is a strong relationship among current speeds, transport and concentrations of total suspended solids in these cycles (Dyer & New, 1986). It has been determined by gravimetry. The cross-section area was obtained and rectified with an echo-sounding and water level data. The water flow (Q) has been worked out in each section, as the product of the section of the area by the mean current velocity of the water column perpendicular to the cross-section (u) (Schettini et al., 1998, 2002; Miranda et al., 2002).

If it is considered that the estuaries are laterally homogenous and to obtain the suspended sediment transport (C = T.dia^{-1}) the values should be correspondent to the product of the water flow by sediment concentration (c) in mg.l^{-1} (Dyer, 1995). In addition to reaching the calculation of the sedimentation estuary – ocean, there has been taken the imported and exported segmented balance which is very important to sectors and processes that favor the sediment greater retention rate in the inner system.

RESULTS AND DISCUSSIONS

Water flux

The dams reduced the inflow of freshwater tributaries during the rainy season to Timonha, Malcozinhado, Jaguaribe Acaraú estuaries by 83%, 75.45%, 85% and 78% respectively. However, during the dry period (July to November), in years of rainfall within the regional average, the contribution of freshwater to the downstream of the reservoir ranged 1.65 x 10^5 to 7.7 x 10^6 m^3 in rivers. At Timonha the contribution of the sub-basins flowing to the Itaúna dam represents 44.8% of the total freshwater that it would be available for the estuarine sub-basin. Nowadays, as a result of the Itaúna Dam construction, the system receives 5.6 x 10^8 m^3 per year, being 87% coming from the sub-basins of the Ubatuba River.

The total contribution of the Malcozinhado River and its affluents were of 24.73 $m^3.s^{-1}$, being responsible for 75.45% of the entire freshwater entering the estuary. The second largest contribution come from the Tijuca Creek (3.6 m^3/s) and the coastal sub-basin (2.42 $m^3.s^{-1}$), while this later one is predominantly due to diffuse flow (overland flow), considering the characteristics of topography and ground vegetation. After the construction of the public dam of Malcozinhado there was a reduction in the annual freshwater contribution from 32.55 $m^3.s^{-1}$ to approximately 7.95 $m^3.s^{-1}$ in the estuaries of the Jaguaribe and Acaraú Rivers.

Sedimentary Dynamics

The concentrations of sediments in suspension in the studied estuaries is low if compared to those obtained in the springs, such as the ones found by Wiegand (2009) in the Jaguaribe River, which varied from 600 mg.L^{-1} in the most rainy months to 26 mg.L^{-1} in the drought months. During the rainy period, the medium concentration of SSC in the Timonha estuarine system was of 23.4 mg.l^{-1}. In general, the highest values occurred during the ebb tide (average = 47.7 mg.l^{-1}) and the lowest ones during the low tide (average = 10.2 mg.l-1). In the river Timonha, the medium concentration of SSC was of 28.3 mg.l^{-1}. During the ebb tide, the maximum concentration of SSC (132.4 mg.l^{-1}) happened in the area on direct influence of the Chapada River.

The highest volume of sediments in suspension in the Ubatuba River (62.0 mg.l^{-1}) was verified close to the mouth (to 1.3 km of distance of the sea), also during the ebb tide. In that same point, during the high tide, the concentration of SSC was of 8.0 mg. l^{-1}. The average for the Ubatuba River, regarding the rainy period, was 15.0 mg.l^{-1}, in other words, 47% smaller than the one of the Timonha River.

In the drought period the largest concentrations of SSC were observed during the tide flood (average = 39.1 mg.l^{-1}) and the smallest ones during the low tide (average = 18.2 mg.l^{-1}). The medium concentration of SSC of the estuarine system was of 28.5 mg.l^{-1}, approximately 18% above observed during the rainy period. The Ubatuba River presented medium concentration of SSC 30% more than that for the Timonha River.

The results indicated that, during the rainy season the Timonha and Ubatuba Rivers together exported 250 t.day^{-1} of SSC while, in the drought period, they imported 150 t. This means 58% of the volume exported during the first semester of the year. That demonstrates that the discharge of SSC of the estuarine system for the adjacent coastal area, at the end of one year, corresponded to approximately 100.000 t. Before the annual contribution of sediments in suspension was of approximately 420.000 t.

As observed in the studies undertaken in worldwide semiarid areas, Achite and Ouillon (2007), present a study on the transport of sediments into the Wadi Abd basin (2.480km²), in a semiarid area of Algeria, where the precipitations amount to around 250-350 mm. That study provides data for a period of 22 years, whose load of transported sediments was of 339 x 10³ ton/year.

Before the Malcozinhado Reservoir's operation, which was built in 2004, the annual exported sediments rates were of 100 t. in the rainy period. The rates of imported and exported material were of + 84 kg.day^{-1} and -19 kg.day^{-1} after the first year of operation of the reservoir. The loads in the drought period were of +64 kg.day^{-1} and -3kg.day^{-1}.

The sediment plume migrates preferentially upstream due to the tide current actions rations were 7.5 less than was before the dam foundation. Comparing with the values taken in 2001 and 2002, there was a flow reduction 56 t. In spite of the area has passed by a short rainy period showing values above the average,

the river had reduced competence with the progressive siltation of the mouth and deposition of restricted fine sediments the south portion of the system. In Malcozinhado, reducing the flow promoted by dam between the years 2001 and 2010 a reduction of 65% of the area at the mouth of the channel, with lateral migration and erosion of the village of Águas Belas (Figure 2).

In the Acaraú River, the concentrations of SSC varied from 40 to 70 mg.L^{-1}. After the dams there was a reduction in the contribution from 620.000 t to 280.000 t per year. Part of that material is retained in the form of banks recently colonized by mangroves inside the system. The same process was observed in the estuary of the Malcozinhado and Pacoti rivers by Pinheiro et al., 2006 and Lacerda et al.2007.

In the lower course of the Jaguaribe river, already inside the estuarine area, Paula et al (2009) found values of around 60mg.L-1 during the rainy period and 10mg.L^{-1} during the dry season. Such values would be, then, associated to greater proximity with the river mouth and the influences of the Barreiras Formation, which limits the canal to west along that stretch. In the Jaguaribe estuary the rate of export during the rainiest months (February and March) is on average 3200 kg.day^{-1}. Quartz associated to illite, smectite, kaolinite and other forms the main transported set of minerals in suspension (Morais et al.,2006). Clay minerals and diatomite together with organic matter content increases during rainfall periods.

In the Jaguaribe River during the rainy season from 2009 to 2010 were left to be transported to the estuary, and consequently to the coastal area, around 1972 tons of sand with a particle size ranging from fine to medium. Considering the volume taken as the unit for 12 small dams between the Castanhão Dam (capacity of 6.5 billion cubic meters) and Itaiçaba dam, physical limit of the estuary, could be estimated that over 30.000 tons of sediment would be retained in the river valley

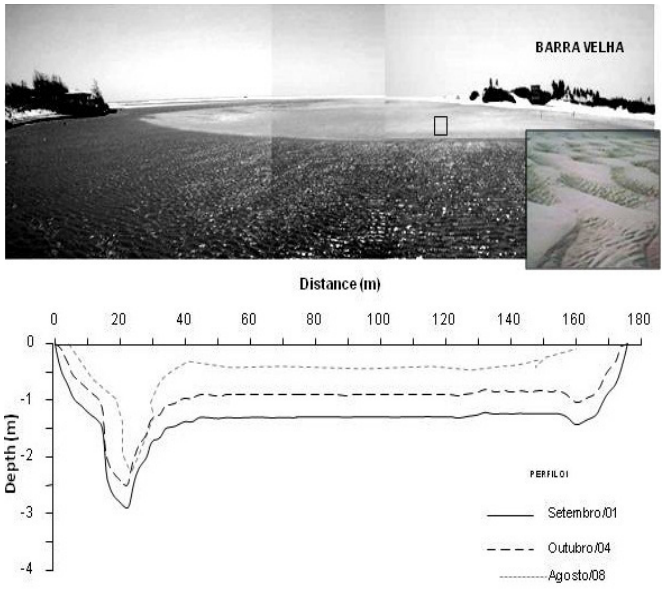

Figure 2. Assoreamento by sediments of origem marinha of the foz of the estuary of the River Malcozinhado no period entre 2001 and 2008.

This resulted in erosion of the Pontal beach in the city of Maceió, in the loss of the ability to accumulate water and increased flooding adjacent to these damming (Figure 3). The contribution of sedimentary material produced Itaiçaba amount to the nearby coastal area is restricted to the events of La Nina.

The estuaries bed formed predominantly by quartz sands, mud clay, predominating clay minerals, sandy muds and silty cay oozes. Smectite, illite and kaolinite are the most spread clay mineral in this estuary. There are significant differences of illite smectite concentrations in the sea and the tributaries, revealing that the fresh water and marine sediments are very well mixed in

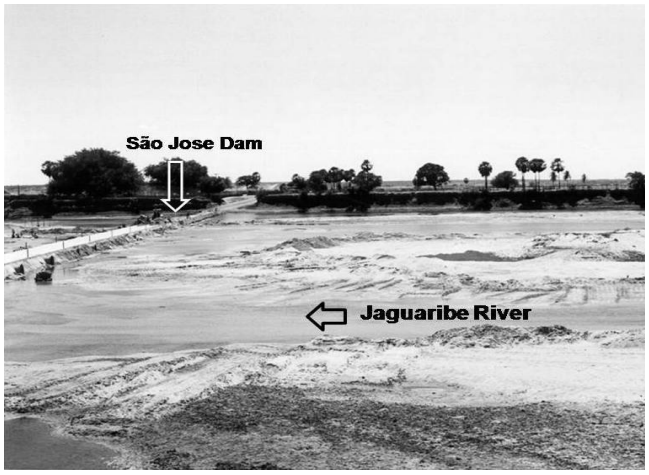

Figure 3. Silting of little dams in Jaguaribe River.

the estuary with some domain of the marine sediments (quartz). The distribution of the sediments in suspension showed the same pattern of the sediments of the bottom. The main minerals found in the membranes were the quartz, ilite, esmectite and kaolinite. In the winter the clay minerals concentrations of clay minerals, mainly diatomite, increased together with the percentile of organic matter.

CONCLUSIONS

-The dams reduced the inflow of freshwater tributaries during the rainy season to Timonha, Malcozinhado, Jaguaribe Acaraú estuaries by 83%, 75.45%, 85% and 78% respectively.

. In the river Timonha there was a reduction in the annual transport of materials to the coastal zone from 450 tons to 100 tons. In the Acaraú River it has been estimated that that reduction was from 620.000 tons to 28.000 tons.

-In the Jaguaribe River around 30.000 tons of sediment are annually retained in the small lower course dams, contributing to the coastal erosion process on the Pontal Beach in the city of Maceió.

- In the estuaries of the Malcozinhado and Acaraú Rivers there was a lateral migration of the waterway causing erosions in the beaches of Águas Belas and Aranaú with damages to services and local communities.

- River sediments are deposited inside the estuaries and along the entire canal the sediments of sea origin are predominant. A part of that material is retained in the form of sandy banks and/or are colonized by mangroves.

CITATED LITERATURE

Achite M. and Ouillon S., 2007. Suspended sediment transport in a semiarid watershed, Wadi Abd, Algeria (1973-1995). *Journal of Hydrology*, 343 (3-4), 187-202.

Araújo, J. C. de; Güntner, A. and Bronstert,A. 2006. Loss of reservoir volume by sediment deposition and its impact on water availability in semiarid Brazil. Hydrological *Sciences–Journal–des Sciences Hydrologiques*,51(1),256-267.

Campos, JNB., Studart, TMC., Luna, R. and Franco, S. 2004. Hydrological Transformations in Jaguaribe River Basin during 20 th Century. *Proceedings of the 20th Annual American Geophysical Union*. Fort Collins: Hydrology Days Publications, 2000. p**P**. 221-227.

Dyer*, K. R. 1997. Estuaries: a physical introduction.* 2.ed. New York, John Wiley & Sons, 165 p..

Dyer, K.R. 1995.*Sediment transport processes in estuaries*, p. 423-449, *in* Perillo, G.M.E. (ed.), Geomorphology and sedimentology of estuaries. Elsevier, 495 p.

Dyer,K.R. and New, A.L. 1986.Intermittency in estuarinemixing, in Wolfe, D. (ed.), Estuarine variability.Academic Press, 508 p.

Genz, F.,and Lessa, G. 2008. Vazão mínima para estuários: um estudo de caso no rio Paraguaçu (BA). *Revista Brasileira de Recursos Hídricos*, 13, 73-82.

Kitheka, J. U.; Obiero, M.; Nthenge, P.2005.River discharge, sediment transport and Exchange in the Tana Estuary, Kenya. *Estuarine, Coastal and Shelf Science*, 63, 455-468.

Kjerfve, B. 1990. Estuarine characteristics, circulation and physical processes. In: DAY JR, J.W. et al (ed.). *Estuarine Ecology*. Jonh Wiley and Sons Inc, New York, NY, pp.47-78.

Kjerfve, B., Schettini, CAF., Knoppers, B., Lessa, G. and Ferreira, H.O.1996.Hydrology and salt balance in a large, hypersaline coastal lagoon: Lagoa de Araruama, Brazil. *Estuarine Coast and Shelf Science,* 42(6), 701-725.

Lacerda, L. D. Menezes, M.O.T. and Molisani, M. M. 2007. Changes in mangrove extension at the Pacoti River estuary, CE, NE Brazil due to regional environmental changes between 1958 and 2004. *Biota Neotropica* (Ed. Portuguesa),7, bn00807032007-6.

Maia, L. P. ; Monteiro, L.H.U. and Lacerda, L.D.2006. Changes in mangrove extension along the Northeastern Brazilian coast (1978-2003). ISME. *Glomis Electronic Journal*, 5, 1-5.

Marins, R. V.; Lacerda, L. D.; Abreu, I. M. and Dias, F. J. S. 2003.Efeitos da açudagem no rio Jaguaribe.Ciência Hoje, Rio de Janeiro, 33(197), p. 66-70.

Medeiros, C. and Kjerfve, B. 1993. Hydrology of a Tropical Estuarine System: Itamaracá, Brazil. *Estuarine, Coastal and Shelf Science*, 36(1), 436-515.

Miranda, L. B, Castro, B. M.and Kjerfve,B. *Princípios de Oceanografia Física de Estuários.*EDUSP: Universidade de São Paulo, 356 p.

Molisani, M. M., Cruz, A. L. V. and Maia, L. P. 2006.Estimativas das descargas fluviais para os estuários do Estado do Ceará. *Arquivos de Ciências do Mar*, .39, 53-60.

Morais, J.O. ; Pinheiro, L. S. ; Cavalcante, A. A. ; Paula, D.P. and Silva, R. L.2008. Erosão Costeira em Praias Adjacentes às Desembocaduras Fluviais: O caso de Pontal de Maceió, Ceará, Brasil. *Gestão Costeira Integrada*, 8,61-76.

Paula, D.P., Morais, J.O., and Pinheiro, L.S. 2009. Longitudinal suspended sediments transport in the Jaguaribe river estuary, Brazil. *Arquivos de Ciências do Mar*, 42,15-38.

Pinheiro, L. S., Medeiros, C. and Morais, J. 2006. Erosive processes monitoring linked to the estuarine evolution systems nearby Aguas Belas, Cascavel, Ceará, Brazil. *Journal of Coastal Research*, Itajaí, SI 39(1), 1403-1406.

Pinheiro, L.S. and MORAIS, J.O. 2010. Interferências de Barramentos no Regime Hidrológico do Estuário do Rio Catú-Ceará-Nordeste do Brasil. *Sociedade & natureza (UFU. Online)*, 22, 237-250.

Schettini, C.A.F. and Carvalho, J.L.B.1998.Suspend sediment balance in the estuary of Itajaí-Açu River during a low discharge period, *Anais da Academia Brasileira de Ciências*, 420,430.

Townsend, C. R. E and Hildrew A.G. 1994. Species traits in relation to a habitat templet for river Systems. *Freshwater Biology*,31, 265 - 275.

Wolanski, E., Huan, N. N.., Dao, L. T., Nhan,N. H. Thuy, N. N.1996. Fine-sediment dynamics in the Mekong River Estuary, Vietnam. *Estuarine, Coastal and Shelf Science*, 43, 565-582.

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