Labomar
Arquivos de Ciências do Mar

DEPURATION CAPACITY OF THE TIMONHA - UBATUBA ESTUARINE SYSTEM, IN CEARÁ STATE, BRAZIL

Capacidade de depuração do sistema estuarino Timonha-Ubatuba, no Estado do Ceará, Brasil

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ABSTRACT

The capacity of purification of the Timonha-Ubatuba estuarine system was evaluated through the application of semi-empirical numeric models. Those models were based on hydrological and morphological characteristics of the estuary basin, culminated with the estimative of the time of discharge for the system different points. This area is located on the semiarid coast of the Brazilian northeastern region, where the rivers are intermittent and they flow only during the rainy season. The monitoring was accomplished during 2004 during both rain and dry periods, in a complete spring tide. At the dry period, practically there was no fluvial discharge, which gives rise to the dilution processes to be just controlled by the oscillation of the tide (tidal prism). On the other hand, during the rainy period the fluvial speed and discharges were capable to renew the waters of the system. During this period, the water's residence was only in the first day. In general the Timonha-Ubatuba estuarine system presented a good capacity of renewal of its waters.

Keywords: *depuration capacity, residence time, tropical estuary, Timonha-Ubatuba estuarine system.*

RESUMO

A capacidade de purificação do sistema estuarino Timonha-Ubatuba foi avaliada através da aplicação de modelos numéricos semi-empíricos e dados coletados em campo. Os modelos baseados em características hidrológicas e morfológicas deste estuario resultaram nas estimativas do tempo de descarga ao londo do canal estuarino. O sistema estuarino está localizado no litoral Semi-Árido do Nordeste brasileiro, onde os rios são intermitentes, com fluxo restrito ao período chuvoso. O monitoramento foi realizado em 2004, durante os períodos de chuva e estiagem em um ciclo completo de mare de sizígia. Durante o período de estiagem, praticamente não houve fluxo fluvial, ocasião em que os processos de diluição foram controlado pela oscilação da maré (prisma de maré). Por outro lado durante o período chuvoso as descargas fluviais foram capazes de renovar as águas do sistema com mais rapidez, com tempo de residência de apenas 1 dia. Em geral, o sistema estuarino Timonha-Ubatuba apresentou uma boa capacidade de renovação das suas águas.

Palavras-chaves: *capacidade de depuração, tempo de residência, estuário tropical, sistema estuarino Timonha-Ubatuba.*

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INTRODUCTION

The purification capacity is one of the water qualities main indicators and of the estuary system degree of support. It varies with the fluvial discharge, flood tide, however, morphological characteristics also exerts influence over that important environmental quality parameter. The purification capacity is inversely proportional to the time of residence and could be easily evaluated through the application of semi-empirical numeric models and by the use and occupation of estuary drainage basin.

In this research the concept of time of residence is considered as the necessary time to travel from any point of the estuary to the external limit of the area(Prandle, 1984). It is also known that fresh water derived from the continental drainage presents a great variety of dissolved substances (Balls, 1994; Nixon *et al*., 1996; Kelly, 1997), and could eventually transport pollutant. It is also important to know the time of discharge.

Then, it was assumed that time of discharge is the necessary time for replacing the whole fresh water of the mixture area at an equivalent rate of a fluvial discharge (Bowden, 1967; Dyer, 1973).

In general, the most used methods for determination of the time of residence assume stationary conditions (budget models), however the hydrodynamic models have been demonstrated more satisfactory results. Methodological restrictions related to the distortions generated by the action of the residual currents impede that the hydrodynamic models are more thoroughly used. On the other hand, the application of stationary models makes possible the comparative analysis in different estuaries. Gómez-Gesteira *et al*. (2003) used a stationary model (box model) to evaluate the fluvial discharge and tide flows influence at the time of residence on the Ria Pontevedra (NW Spain). They observed from the subdivision of the estuary channel that time of residence is not the same everywhere. Similar fact was observed by Vant and Williams (1992) in studies carried out in a New Zealand estuary system. A similar fact has been noted by Wang *et al*. (2004) in the Danshuei Rivr estuary. Shen & Haas (2004) used a three-dimensional numeric model to simulate the behavior of pollutant in the York River estuary.

The application of this model made possible the evaluation of the system in different time scales, stemmed from the knowledge of the advective and diffusive processes. It is noticed that the numeric modelling of estuary systems have multiple purposes, supplying information undoubtedly useful to the administration of those hydric resources.

The objective of this research was to determine the capacity of purification of the Timonha - Ubatuba estuarine system based on the water time residence. For this purpose a segmented semi-empirical model was applied considering stationary conditions (Ketchum, 1950, 1951; Dyer & Taylor, 1973).

MATERIAL AND METHODS

Study area

The Timonha-Ubatuba estuarine system is located between the latitudes 2º53'S - 3º03'S and longitudes 41º11'W - 41º21'W, State of Ceará (Figure 1). The semiarid rivers in the Brazilian northeastern region, where the studied area is located, are intermittent, flowing only during the rainy season. Rivers get dry during the dry months, which correspond to the period from July to November in Ceará State (Campos *et al*., 2000). The distance of the tidal influence is 25 km from the mouth. The Itaúna dam was constructed in 2002 on the Timonha river and its water volume is 7.75×10^7 m^3. In the dry and it is the only source of continuous freshwater flow for the Itaúna reservoir (1,1 m^3 s^{-1}). When the rains are below the regional average freshwater does not reach the estuary because its shortage in the reservoirs (Morais & Pinheiro, 2011).

This estuarine complex display an exuberance of mangrove ecosystem, being considered the largest of Ceará State with 50 km^2 (Maia *et al*., 2006). There, Shelter mammal species is facing extinction threaten (sea fish-ox). The productive activities of this area are wood and marine salt extraction, agriculture-pastoral, acquaculture, fishing and tourism.

Sampling data

Seven monitoring sections were established along the Ubatuba and Timonha rivers channels and estuaries. In each section there were three sampling stations along the edges and in the middle of the channel (Figure 2). The salinity, depth and density were measured by the CTD-SensorData from the surface to the bottom of the water column. The sampling has been performed at three-hour intervals during ebb, flood, high and low tides and in the estuary channel.

The samples were taken in February (rainy season) and November (dry season) of 2004, during spring tides. The bathymetry has been taken by echo sounder through the fullest extent of the estuarine bed. A tidal ruler was installed to measure the

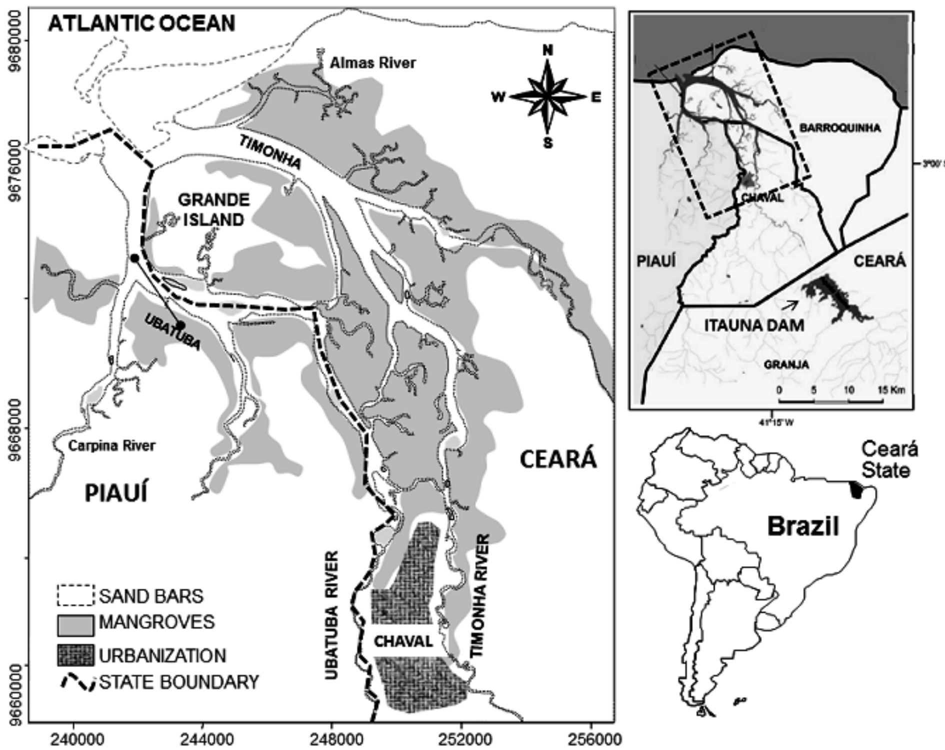

Figure 1 - Study area.

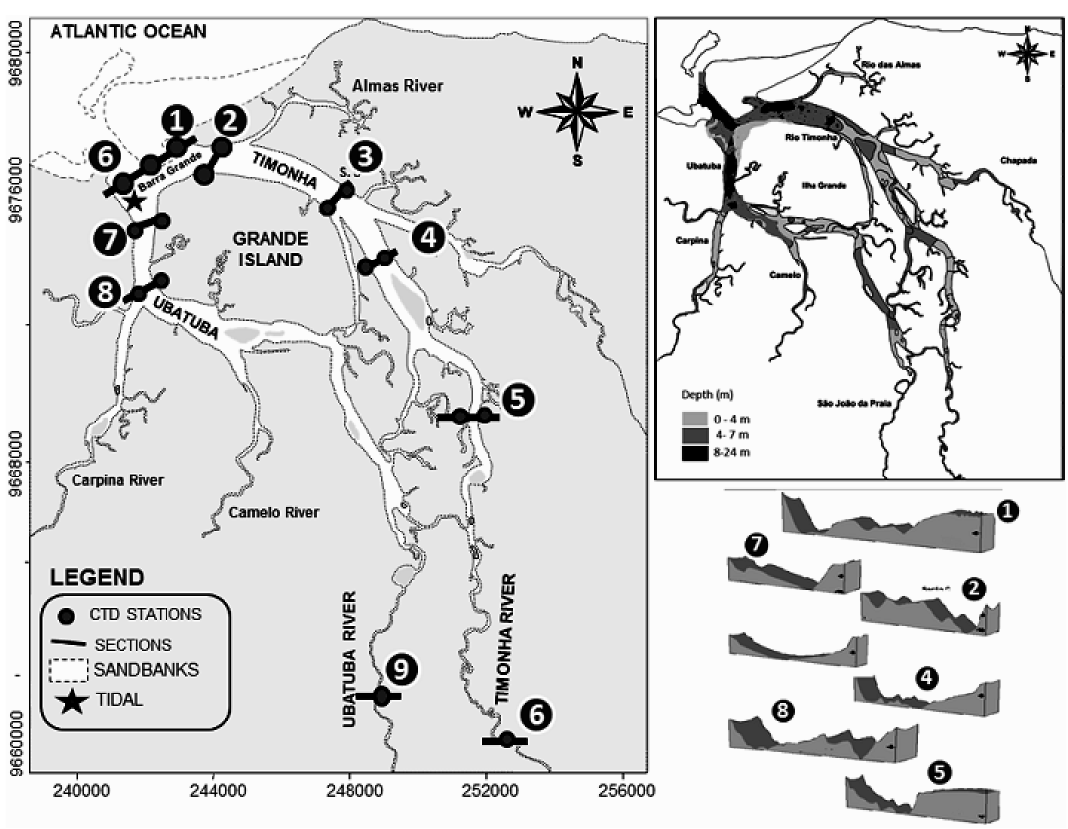

Figure 2 - Map of the Timonha-Ubatuba estuarine system, and position of sampling stations. Solid lines represent transects.

diurnal variation of the water level. The topographic level of the ruler was referring to the datum of DHN (Diretoria de Hidrografia e Navegação). The data were integrated and calculated the volume of the estuary and the residence time of the water with the semi-empirical equations detailed in the next section.

Description of the models

The application of numeric models in the evaluation of the capacity of water renewal in tropical estuary systems is still a methodological procedure little used. In Brazil. They stand out Miranda & Castro (1993) in Channel of Bertioga (SP) and Kjerfve *et al*. (1996) in the pond of Araruama (RJ), both using stationary models. In this research, this formulation type was used for determination of the time of discharge (Ketchum, 1950).

$$T = \frac{V_f}{Q_f + Q_T} \qquad \text{Equation 1}$$

where, Vf represents the volume of fresh water kept in the mixture area and Qf the fluvial discharge and QT is an oscillating water flux on a tidal time scale. The values of Vf and Qf were calculated by Dias (2005). The historic data of the rainfall and evaporation were provided by FUNCEME (Ceara Foundation for Meteorology and Water Resources). For the freshwater flow data of the hydrographic basins the database of the HidroWEB-Hydrological Information Systems of the National Water Agency-ANA was used. During the rainy period, the volume of fresh water (V_f) kept in the mixture area, at the end of a complete tidal cycle was 8.7 x 10^6 m^3 in the river Timonha and 5.2 x 10^6 m^3 in the river Ubatuba. The Qf was 8,5 x 10^8 m^3 for the river Timonha and 5,5 x10^8 m^3 for Ubatuba river.

A segment of the estuary system was singled out for the fluvial discharge (Qf) in each station to determine the time of discharge in different points along the estuary. The climatic model, elaborated by Kjerfve (1990) was used to estimate the fluvial discharge in function of the superficial drainage basin and of the diffuse drainage. The volume corresponding to the tidal prism was calculated in agreement with Kjerfve *et al*. (1996). QT was expressed as the prism entering the estuarine system per tidal cycle, although in reality, this transport only occurs during half a tidal cycle.

$$Q_T = \frac{A_{E} \times \Delta h}{44714} \qquad \text{Equation 2}$$

where, A_E (m) is the estuarine surface area e and Δh (m) is the mean tidal range the variation of the tide inside the system. The product of these two variables divided by 44714 (seconds), corresponding value the duration of a half tidal cycle of tides.

RESULTS AND DISCUSSION

Geomorphology

The geometric volume of the Timonha and Ubatuba estuarine system is approximately 7.2 x 10^7 m^3. The average depth of Ubatuba and Timonha Rivers are 4.5 m and 5.5 m, respectively. The estuarine area is the 2,6 x 10^4 km^2. The maximum depth was 13 m at the mouth of Timonha Rivers and 14 m in Ubatuba. The maximum channel width reached 650 m in Ubatuba and 800 m in Timonha Rivers. The channel formed by the confluence of estuaries has a width of 2.7 km. The banks of the estuarine system have gentle topography being covered by a dense mangrove vegetation. The main channels have the longitudinal axis oriented N and NW. It is observed that the mouth of the system tends to migrate westward, under the influence of longshore currents that contribute to the development of a spit from the Pontal das Almas sandy beaches.

Salinity characteristics

The average salinity in the Timonha River estuary at rainy season was 24.5 with a standard deviation of 7.6. The estuary of Ubatuba average salinity was 28, with a standard deviation of 4.0 In dry seasons this average rise is 40.2 with a standard deviation of 1.6 in Timonha River, and 39 with an SD of 0.9 in Ubatuba estuary. The water salinity in Ceará continental shelf varies between 35.0 and 37.0 in the wet season and 37.0 to 38.0 during the period of summer (Freire, 1989). During rainy season, the estuary is vertically homogeneous with longitunidal stratification (Figure 3).

During the dry season, those estuaries are filled with water of marine origin, which explains the high homogeneity of salinity and water mass of the system at all stages of the tide. The estuarine system with a small river discharge forced by mesotide or macrotides, the bottom current shear tends to produce turbulence causing the estuary upstream to be able to completely erode the halocline. In this case, the vertical transport of salt is negligible and the mixing process occurs primarily in the longitudinal direction (Miranda *et al*., 2002).

During this period greater salinities were observed inside the estuaries. This indicates a tendency

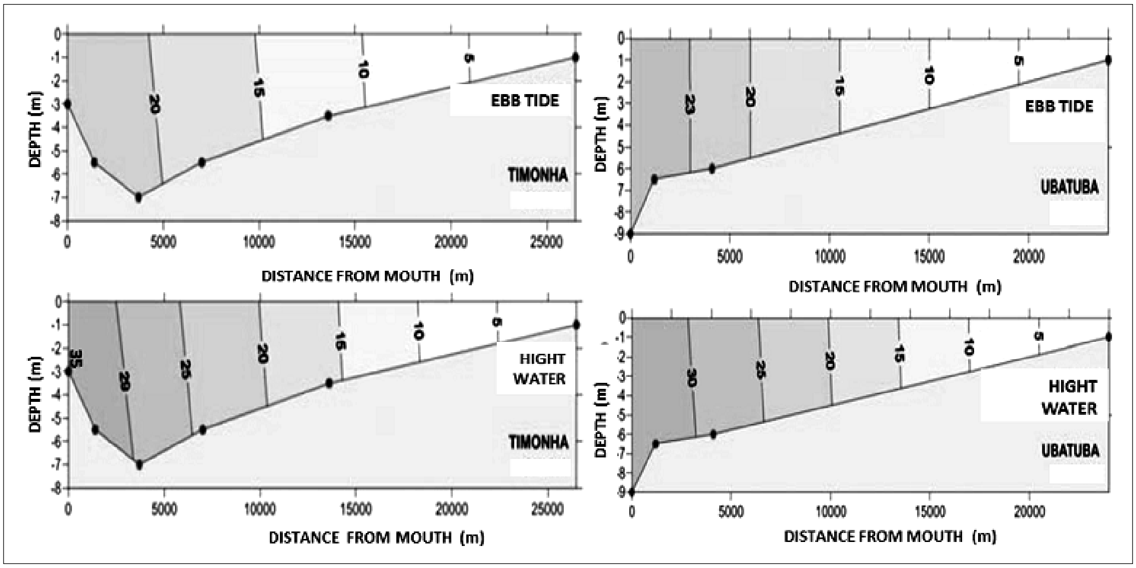

Figure 3 - Vertical and longitudinal distribution of salinity in the Ubatuba-Timonha estuarine system during rainy periods (February, 2004).

to hypersalinitation (Figure 4). The salt concentration is associated with the evaporation of water. This process is enhanced by morphological characteristics of the longitudinal profile. The mouth is shallower than the inner region, which hinders water exchange with the ocean, especially during the dry season. On the average bathymetric profile of the Timonha River, it is clear that the system acts as a reservoir.

Diurnal tidal oscillations

The tides are important mechanisms for the estuary hydrodynamics in regions of low river inflow and it is primarily responsible for the vertical oscillation of the surface of estuaries. The tide in the estuary system is semidiurnal. The tidal ranges during the rainy and dry seasons were 2.8 m and 3.0 m, respectively. There was a lag of only 50

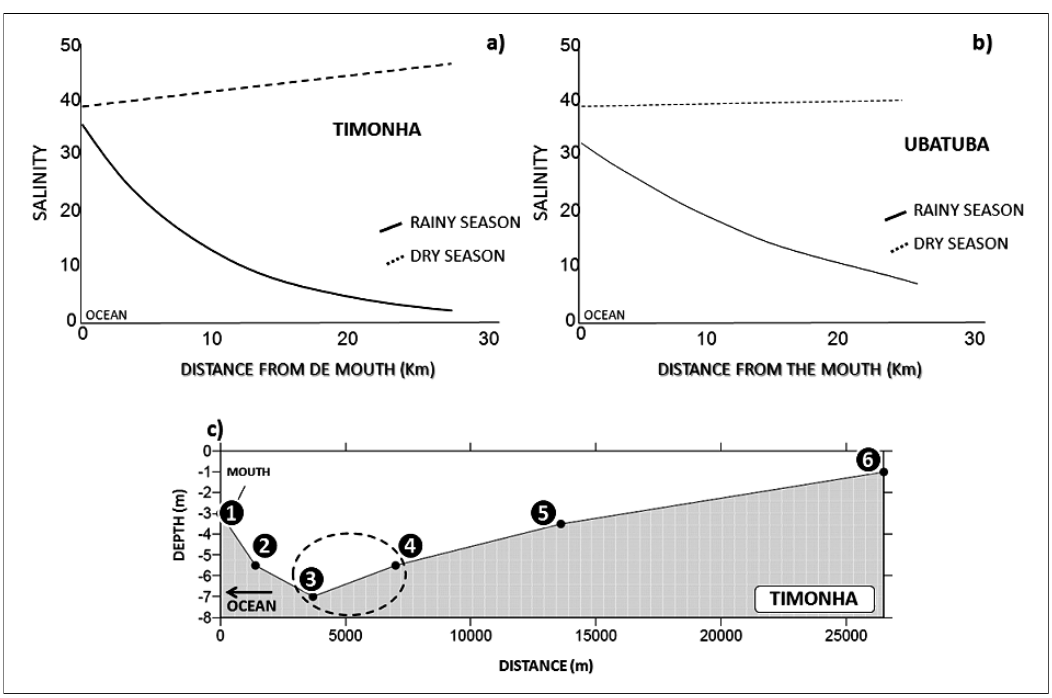

Figure 4 – Average salinity in the water column during rainy and dry seasons in the Timonha (a) and Ubatuba (b). (C) Longitudinal profile of channel Timonha estuary.

minutes in relation to high tide recorded in Luis Correia harbor (Figure 5). In the Timonha, the volume of the tide prism was of approximately 3.6 x 10^7 m^3 while, in the river Ubatuba was 4.3 x 10^7 m^3. These results demonstrated that the effects of the tide oscilation was stronger on the estuarine channel of Ubatuba estuary, because its mouth's morphology is shown to be free of sand bars obstructions, as it happens in the Timonha river.

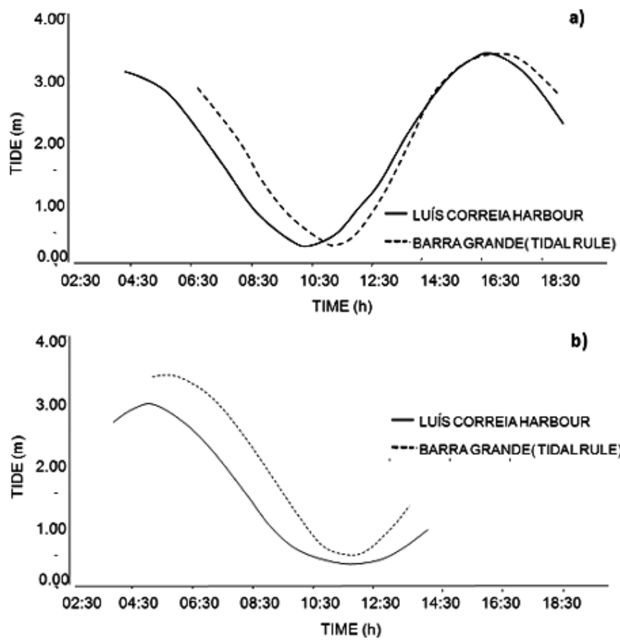

Figure 5 – Variatiion trends in water level during spring tide in Luis Correia harbor and Barra Grande (mouth of the estuary system), during (a) the dry season and (b) the rainy season.

Flushing time

In the rainy season the water's renewal capacity of the estuary is twice as much in the Ubatuba as in the Timonha. Then, if it is considered that the residence time decreases uniformly towards the sea, the period required to restore the Timonha water would be approximately one day while in Ubatuba estuary would be only 0.5 day.

During the dry period, the residence time of the estuarine system was 3.5 days. In Timonha River, freshwater launched early in the estuarine area during the dry season, and it takes approximately 5 days to reach the adjacent coastal zone, while in Ubatuba river, this time is only 2 days. It is observed that the effect of river discharge plays an outstanding role, whether the residence estuarine system is considered.

In the Ubatuba and Timonha Rivers, the differences related to the retention time of the mass freshwater are also determined by the channel morphology. In this case, the configuration of the Ubatuba river channel favors the input of sea water, contributing to the increase of the capacity of purification of that estuary.

The longitudinal variation in residence times demonstrates that the standard discharge along the estuarine river channel in Timonha river is not linear. It was estimated that, at 26.5 km away from its mouth, the mass of freshwater would take 3.5 days to renew. However, in the area between 3.7 km and 7.0 km away from the sea the river has taken a strong tendency to retain water coming to a time equivalent to almost a week residence. In this sense, it is noteworthy that the morphology of Timonha River's channel contributes to the accumulation of water in the inner estuary and hence it increase the residence time (Figure 6).

In the Ubatuba River, in contrast to what occurs in the Timonha River, time residence decreases from the mouth. During the rainy season, the average time required to restore waters of this estuary was 1.5 days with a maximum occurring in the area at 4.0 km far from its mouth.

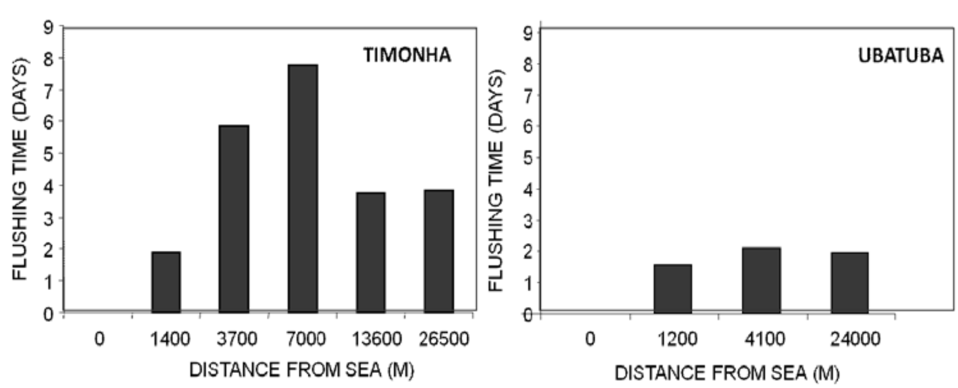

Figure 6 - Flushing time calculated for segments of the Timonha-Ubatuba estuarine system during the rainy season.

The Timonha-Ubatuba estuarine system has shown a good capacity for their water renewal. However, during the dry season, the residence time undergoes an increase, possibly associated with the absence of river discharge. Further, tidal fluctuations account for the main water body entering the system, a mechanism which favors the advective transport and diffusive barotropic nature. However, the discharge in the rainy season minimizes the effects generated by tidal pumping through the maintenance of a drain connected to the freshwater forces to generate motion towards the low parts of the estuary.

The segmented model was more appropriate to the analyze the carrying capacity of the system than the lineal model. However, given the insignificance of the fluvial discharges during the dry period, the application of that method and handling of the estimates obtained for that period became unfeasible..

CONCLUSIONS

In general, the Timonha/Ubatuba estuarine system presented a good capacity of renewal of its waters, and the fact is that it turns out to be more evident during the rainy period, before great fluvial discharges and from the Itaúna reservoir. During the dry season practically there is no fluvial discharge, being the tidal prism the main component of dilution of the inner waters.

In the Timonha River, the volume of the tide prism was of approximately 3.6×10^7 m^3 while, in the Ubatuba River it was about 4.3×10^7 m^3. These results demonstrated that the effects of the oscillation the tide was stronger on the estuarine channel of the river Ubatuba.

During this period greater salinities were observed inside the estuaries and at the rivers' mouth, indicating hypersalines conditions. The salt concentration is associated with water evaporation.

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REFERENCES

Balls, P.W. Nutrient inputs to estuaries from nine Scottish east coast rivers: influence of estuarine processes on inputs to the North Sea. *Est. Coast. Shelf Sci*., v.39, p.329-352, 1994.

Bowden, K.F. Circulation and diffusion, p. 15-36, *in* Lauff, G.H. (ed.), *Estuaries*. American Association for the Advancement of Science, Washington, D.C, 1967.

Campos, J.N.B.; Studart, T.M.C.; Luna, R. & Franco, S. Hydrological transformations in Jaguaribe River basin during 20th Century, p. 221-227, in.*Proceedings of the 20th Annual American Geophysical Union*. Hydrology Days Publications, Fort Collins, 2004.

Dias, C.B. *Dinâmica do sistema estuarino Timonha/Ubatuba: Considerações ambientais*. Dissertação de Mestrado, Programa de Pós-Graduação em Ciências Marinhas Tropicais, Universidade Federal do Ceará, 130 p., Fortaleza, 2005.

Dyer, K.R.. *Estuaries: a physical introduction*. John Wiley and Sons, 140 p., New York, 1973.

Dyer, K.R. & Taylor, P.A. A simple, segmented prism model of tidal mixing in well-mixed estuaries. *Est. Coast. Mar. Sci*., v.1, p.411-418,1973.

Gómez-Gesteira, M.; Castro, M. & Prego, R. Dependence of the water residence time in Ria of Pontevedra (NW Spain) on the seawater inflow and the river discharge. *Est. Coast. Shelf Sci*., v.58, p.567-573, 2003.

Kelly, J.R. Nitrogen flow and the interaction of Boston harbor with Massachusetts Bay. *Estuaries*, v.20, n.2, p.365-380,1997.

Ketchum, B.H. Hydrographic factors involved in the dispersion of pollutants introduced into tidal waters. *J. Boston Soc.Civil Eng*., v.37, p.296-314, 1950.

Ketchum, B.H. The exchange of fresh and salt waters in tidal estuaries. J. Mar. Res., v.10, n.1, p.18-38,1951.

Kjerfve, B. Manual for investigation of hydrological processes in mangrove ecosystems. UNESCO / UNDP, 79 p., New Delhi, 1990.

Kjerfve, B.; Schettini, C.A.F.; Knoppers, B.; Lessa, G.C. & Ferreira, H.O. Hydrology and salt balance in a large, hypersaline coastal lagoon: Lagoa de Araruama, Brazil. *Est. Coast. Shelf Sci*., v.42, p 701-725,1996.

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

Miranda, L.B.; Castro, B. M.. Condições oceanográficas no canal de Bertioga. Relatório Técnico. Fundação de Estudos e Pesquisas Aquáticas, São Paulo, p.1-97, 1993.

Miranda, L.B.; Castro, B.M. & Kjerfve, B. *Princípios de Oceanografia Física de estuários*. EDUSP. 417 p., São Paulo, 2002.

Morais, J.O. & Pinheiro, L.S. The effect of semi-aridity and damming on sedimentary dynamics in estuaries- Northeastern region of Brazil. *J. Coast. Res*., v.64, p.1540-1544, 2011.

Nixon, S.W.; Ammerman, J.W.; Atkinson, L.P.; BerouunskY, V.M.; Billen, G.; Boicourt, W.C.; Boynton, W.R.; Church, T.M.; Ditoro, D.M.; Elmgren, R.; Garber, J.H.; Giblin, A.E.; Jahnke, R.A. & Owens, N.J.P. The fate of nitrogen and phosphorus at the land-sea margin of the North Atlantic Ocean. *Biogeochemistry*, v.35, p.141-180,1996.

Shen, J. & Haas, L. Calculating age and residence time in the tidal York River using three-dimensional model experiments. *Est. Coast. Shelf Sci*.,v.61, p.449-461,2004.

Vant, W.N. & Williams, B.L. Residence times of Manukau Harbour, New Zealand. *New Zeal. J. Mar. Freshw. Res*., v. 26. p.393-404,1992.

Wang, C.-F.; Hsu, M.-H & Kuo, A.Y. Residence time of the Danshuei River estuary, Taiwan. *Est. Coast. Shelf Sci*, v.60, p.381-393,2004.