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INFLUENCE OF THE FLOW REGIME OF THE PEDRA DO CAVALO HYDROELECTRIC PLANT ON THE SPATIAL AND TEMPORAL BEHAVIOR OF THE SALINITY IN THE FLUVIO-ESTUARINE STRETCH OF THE PARAGUAÇU RIVER.

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Abstract

The SisBaHiA model was the tool used in this paper for the analysis of the events involved in the circulation patterns of water and transport and dispersion of salts in the stretch of the lower course of the Paraguaçu river to the Iguape bay. The modeled scenarios showed patterns of hydrodynamic circulation and saline intrusion by identifying the 5‰ isohaline in the environment, related to the magnitude of flows used to operate the Pedra do Cavalo hydroelectric plant.

Keywords: Environmental Modeling, Salinity, Salt Intrusion, Environmental outflow, Paraguaçu river.

Introduction, scope and main objectives

Estuaries are coastal environments that depend on the conditions of fluvial and tidal forcing, which influence the circulation processes and environmental energy exchange, as well as their physical, chemical and biological (MIRANDA et al. 2002; GENZ, 2006; LESSA, *et al*., 2009). Among such characteristics, the salinity is relevant in the determination of the spatial selectivity of the organisms along of the water body, making regions more or less favorable for some species, which can be cultivated and extracted by the coastal communities of the region.

According Alber (2002), changes in the salinity pattern cause effects on the mobility of aquatic biota along the estuary in different stages of the life cycle. Because of these changes, some organisms are found in certain salinity range because they are more sensitive to large variations in the environmental salts concentrations.

The area under study, that is called the lower course of the Paraguaçu river, is classified as a fluvio-estuarine region, because is influenced by the tidal forcing, it has the presence of the Pedra do Cavalo dam upstream and Iguape Bay downstream. Such characteristics are peculiar, especially because the extension of the Todos os Santos Bay (BTS), where is located the Iguape Bay.

The motivation to study the temporal and spatial variation of the salinity in fluvio-estuarine stretch of the Paraguaçu river was the necessity to understand the changes in environmental characterization of the

stretches downstream of dams, due to the regularization of the water supply in estuaries, in the determination of the the environmental conditions and in the biota, that will develop in the region.

The operating regime of the Pedra do Cavalo dam has great importance in reg in the cities Cachoeira and São Félix (VOTORANTIM ENERGIA, 2013). However, it is determining of the quantity and quality of the seeping water from the hydrographic basin of the Paraguaçu river to the estuary, barring the natural sediments, that are transported from the river bedside, reducing the fresh water supply, which consequently makes the environment more saline, because of the tidal forcing domain. Such impacts bring several consequences to the estuarine environment, such as loss of biodiversity of species in general, which is a major feature of the estuaries (GENZ, 2006; LESSA *et al.*, 2009).

The main approach of this work deals of the longitudinal variation of salinity observed through of the 5‰ isohaline in the downstream stretch of the Pedra do Cavalo dam to the Iguape Bay, to contribute in the definition of the released flows by the operation of the hydroelectric plant on the water quality, considering the hydrodynamics circulation patterns and salinity, through in the field measured data and simulated data by the hydrodynamic model and of water quality, SisBaHiA.

Figure 1 shows the overview of the location of the sampling points in the lower course of the Paraguaçu river stretch and the other regions that make up the estuary of the Paraguaçu river.

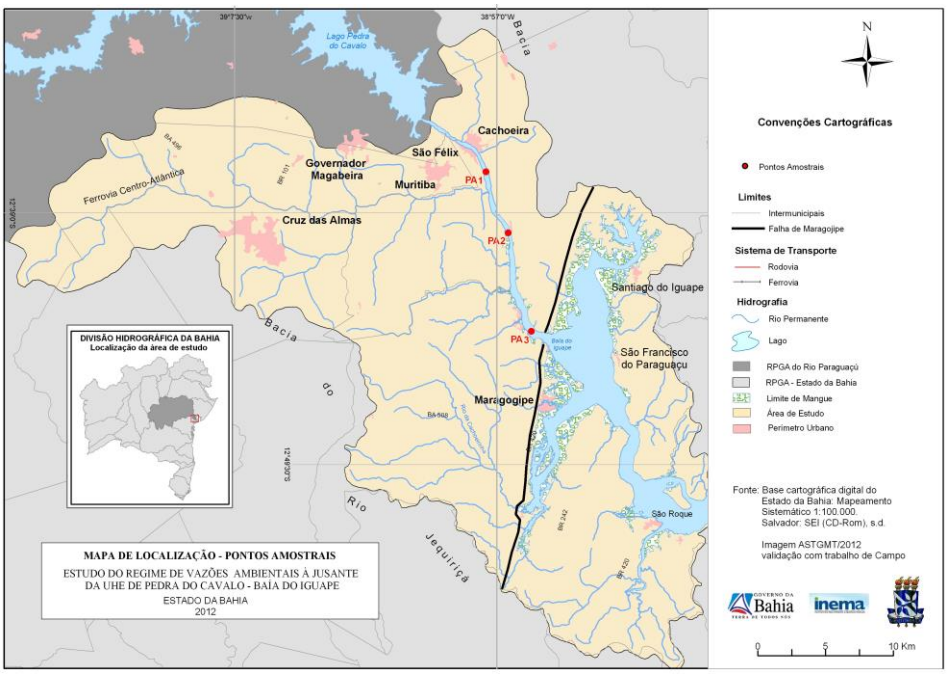

Fig. 1: Sampling points location (APs) in the lower course of the Paraguaçu River and the other regions of the estuary (INEMA/UFBA, 2013b).

Methodology/approach

The methodology consisted in the definition of the adopted procedures for the measurements of the primary data, methods, parameters and used features in the simulation, necessary for the development of the hydrodynamic and water quality model for the transport of salts, in order to represent the patterns of circulation and dispersion of the salinity, which will be used in helping to the analyze of the longitudinal profile variation of the salts in the fluvioestuarino stretch of the lower course of the Paraguaçu river.

With the characteristics that were observed in the study área, for a proper simulation of the environmental phenomena of interest in this work, the SisBaHiA model (Base Environmental Hydrodynamics System) met to the necessary requirements for the modeling of the turbulent flow in free surface of water natural bodies, because it has algorithms that solve baroclinic terms and the

variable flow in opposite directions of the water masses, as well as having the option to engage to the hydrodynamic model the water quality model for salinity (ROSMAN et al., 2013) .

The initial modeling process was the definition of the parameters of the geometric modeling of the terrain, of the hydrodynamic modeling and transport of the salts, to be used in the model. The main parameters that were part of these peculiarities of the environmental phenomena in the area were: the base maps, the mesh modeling, bathymetry, currents measurement, water level and the initial and boundary conditions.

The primary current data, such as speed, distance and depth, were monitored in two field campaigns and under spring tide conditions and quadrature using the Current Profiler Acoustic with Doppler effect (ADCP), attached to a boat, covering with constant speed (about 3 m s^{-1}) the cross section of the river towards the left bank to the right bank and the opposite, in each sampling point (PA1, PA2 and PA3), every 30 minutes over a 13 hours period. To measure the water quality parameters (electrical conductivity, temperature and depth) a hydrographic probe CTD (Conductivity, Temperature and Depth) was used, launched at the deepest point of the each sample point section, synchronized with the same conditions of the current monitoring (INEMA / UFBA, 2013a).

The results of the measurements were used in the calibration and validation process of the model. with The data observed in the field were compared with the simulated data. The results were satisfactory for the representation of the modeled phenomena.

Results

The defined environmental hydrograph took as reference the quantity, quality and seasonality of the defluentes flows in order to ensure the maintenance of estuarine ecosystem processes and the development of the system components. To define the flow that will be applied by the plant were observing the rules and use restrictions, which were determined in the operation plan of the Pedra do Cavalo hydroelectric plant, ensuring all the functions and priorities of the multi-user, including in this context also the estuarine ecosystem (INEMA / UFBA, 2014).

For the generation of environmental scenarios, in order to analyze the hydraulic behavior and the pattern of the longitudinal profile of salinity for the lower course of the Paraguaçu river, were used the hydrological conditions, which are characteristics of the dry year, wet year and year 2011-2012. The latter scenario corresponds to the region hydrological period between 01/10/2011 and 30/09/2012 and to the hydrograph of the defluentes flows of the plant, applied to the operating system. That hydrograph was evidenced through the hydraulic table and power generation for the defined hydrological period. In the hydraulic table, daily hourly flow rates were observed throughout the period, verifying such an operation system of the plant due to the restrictions above mentioned (INEMA / UFBA, 2013b).

Figure 2 shows the defluents environmental hydrographs of the plant for the simulated period, used as inflows to the field of the modeling.

The wet year hydrograph presents greater variability in the magnitude of the flows during the periods of flood and drought, promoting environmental seasonality, that is necessary for the maintenance of estuarine processes. The dry year hydrograph showed more moderate variation in the magnitude of flows. However, kept the variable and seasonal stream observing the characteristic periods of flood and drought of the region, unlike the 2011-2012 year scenario. This presented uniform flow without seasonality during the whole hydrological period, serving restrictions of low average daily flows, also being observed zero flow in some day periods.

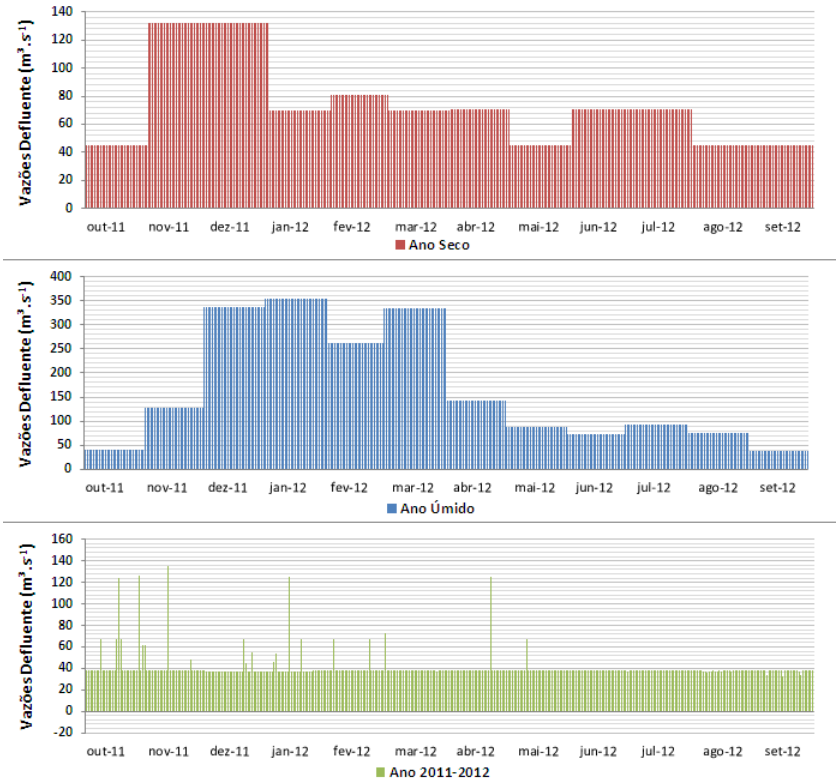

Fig. 2: Defluents environmental hydrographs of the plant for the characteristic hydrological periods to dry year, wet year and year 2011 - 2012.

The results of the salinity simulation for dry year scenario showed that in spring tide conditions, period of floods and high tide, the isohaline of 5 ‰ penetrates approximately 14 km ranging up to 10 km in the stretch, changing its location depending on the tidal cycle. During the dry season, under the same conditions, the isohaline of 5 ‰ moves to the estuary influence limit, about 18 km ranging up to 16 km, increasing the salinity variation range (5-35 ‰) in all fluvio-estuarine stretch of the Paraguaçu river. In neap tidal conditions for the periods of full, the saline intrusion penetrates up to 11 km, ranging up to 7 km. During the dry season, the saline intrusion reaches 15 km ranging up to 12 km, both due to the tidal cycle.

The Figures 3 and 4 exemplify with dry year scenario the representation of the results obtained for the longitudinal profile of salinity for the different simulated scenarios.

For the wet year, the simulation results of salinity, on spring and neap tide conditions, in the characteristic period of floods and during the tidal cycle, showed that the isohaline of 5 ‰ does not penetrate in the lower course of the Paraguaçu river; it is located in the stretch downstream, while in spring tide, in the dry season penetrates about 13 km, ranging up to 7 km, due to the tidal cycle; under neap tide conditions in the dry period the saline intrusion penetrates up to 10 km, ranging up to 7 km, because the tidal cycle.

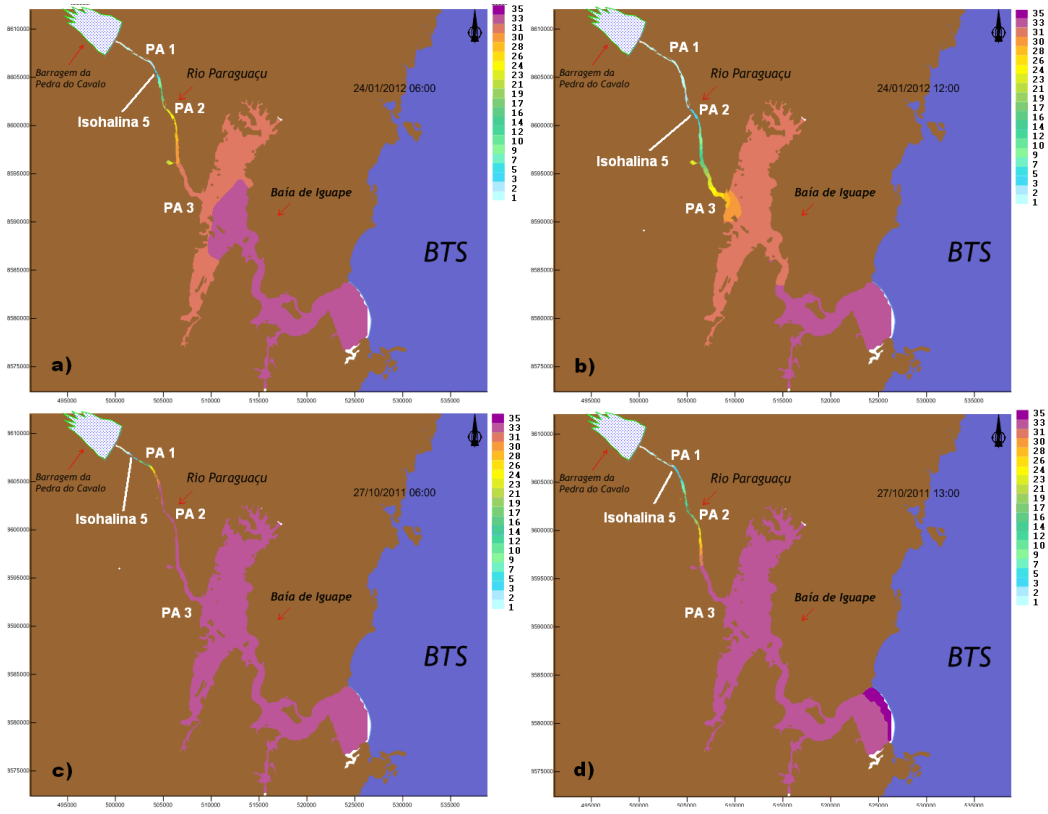

Fig. 3: Longitudinal profile of Salinity (‰) a) spring tide - during floods - high tidal; b) spring tide - during floods – at low tidal; c) spring tide - dry season - high tidal. d) spring tide- dry season – at low tidal

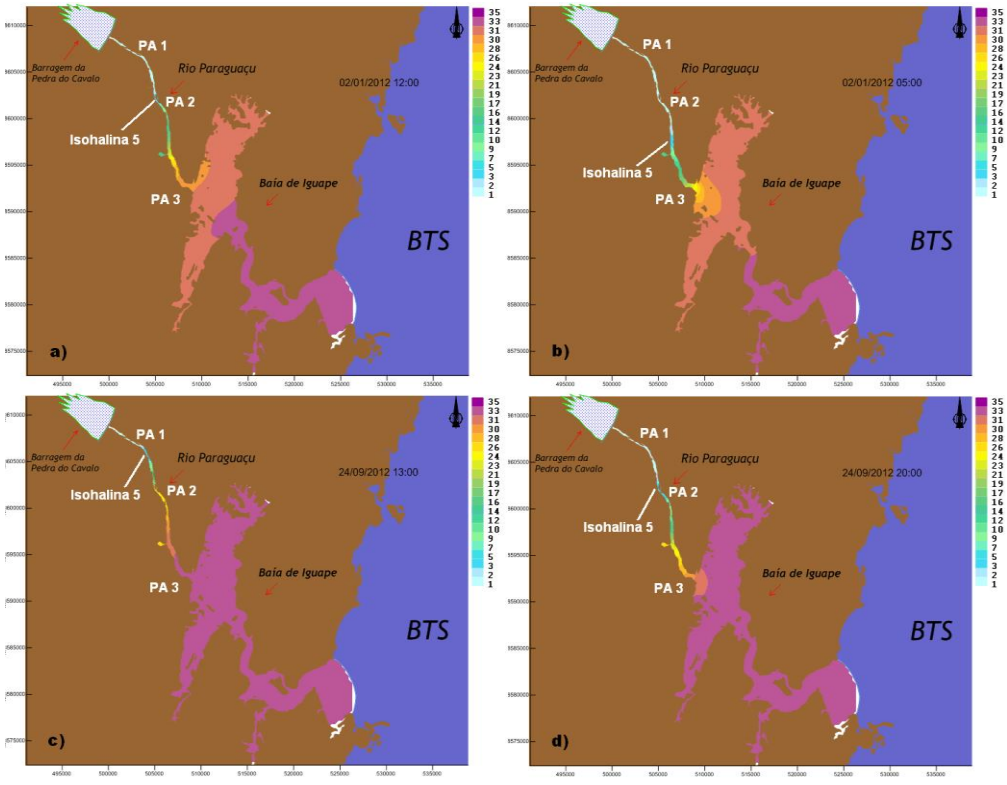

Fig. 4: Longitudinal Profile Salinity (‰) a) neap tide - during floods - high tidal; b) neap tide - during floods - low tidal; c) neap tide - dry season - high tidal d) neap tide - dry season - low tidal

The simulation of salinity for the scenario year 2011-2012 showed in spring tide conditions, characteristic period of floods and drought, the 5‰ isohaline penetrates the lower course of the river Paraguaçu reaching up to 16 km above the estuary, ranging up to 11 km, due to the tidal cycle. In neap tide conditions for the period of floods the 5‰ isohaline penetrates a little in the lower course of the Paraguaçu river about 7 km, near the PA3, ranging up to 2.5 km; in the dry season the saline intrusion penetrates up to the PA1 about 16 km ranging up to 13 km, because of the tidal cycle.

Discussion

The SisBaHiA model presented good representation of the hydraulic behavior, transport and longitudinal dispersion of salts in fluvioestuarino stretch compared to the scenarios by the environmental hydrograph, as proved in the calibration and validation modeling process.

In the dry year scenario the highest values of salinity were observed in spring tide condition, in the dry season and high tide (5-35 ‰), where the saline intrusion reached the estuary influence limit (18 km) upstream the PA1, being related to low defluentes flows. Lower values were observed during neap tide, during floods and at low tide (5-26 ‰), where the saline intrusion regressed to 10 km, due to larger magnitudes of defluentes flows. Presented simulated results allowed to characterize the environment as mixoaline (Ferreira et al., 2006) with wide range of salinity variation and favorable development of euryhaline biota.

In the wet year scenario in the characteristic period of floods independent of the cycle and tidal condition, the stretch fluvio-estuarine remains in freshwater environments conditions (Ferreira et al., 2006), without the penetration of the saline intrusion. However, in the dry period, related to low defluentes flows, there is a marked increase of the salinity range in the neap tidal and in high tidal condition, penetrating between 13 and 10 km near the PA2 due to the tidal cycle. These results allow the characterization of oligoalino environment (Ferreira et al., 2006) in large part of the period, being favorable to maintain the biota estenoalino more sensitive to large saline variations in the environment.

The year 2011-2012 scenario has shown that both during the period of flooding as in the dry season, in the spring tide condition occurs saline intrusion locating at 16 km in high tidal and 11 km at low tidal in the fluvio-estuarine stretch, between the PA1 and PA2. In neap tide conditions during floods, the saline intrusion penetrates maximum 7 km (5 to 21 ‰), ranging up to 2.5 km (5 to 7 ‰), near the PA3. In the dry season, the saline intrusion reaches 16 km being located near the PA1. These simulated results make possible to characterize the environment as mixoalino varying to polialino (Ferreira et al., 2006) in large part of the period, being favorable to the maintaining of the euryhaline biota, that is tailored to the high variability of salinity conditions.

Conclusions/outlook

In general it can be concluded that the environmental variability was maintained with the Dry and Wet Year Scenarios; It did not occur in Year 2011-2012 due to the low magnitude of flows uniformly applied taking into account the rules and operational constraints of the Pedra do Cavalo plant, in serving to the multiple users.

The studies have shown the change of the hydrodynamic behavior in the low course of the Paraguaçu river depending on the magnitude of the released flows by the plant, evidenced by the reduction of flood time relative to the time of ebb of the local tidal cycle.

The simulated scenarios presented changes in the environmental quality in relation to salinity. Regions near the PA1 and PA2 were more favorable to the development of the estenoalino biota due to the small salinity variation, while regions close to PA3 were more favorable to the development of the euryhaline

biota characteristic of brackish water, due to the wide range of salinity variation in the fluvio-estuarine stretch.

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