A MODELLING APPROACH TO THE STUDY OF FAECAL POLLUTION IN THE SANTOS ESTUARY

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1 INTRODUCTION

The need for adequate disposal techniques and sites for urban wastewater has long been recognized. The most convenient place to discharge wastewater, whether treated or untreated, is usually into any nearby body of water. Communities located in estuarine and coastal areas have several alternatives for disposal their wastewater: direct discharge into the sea through submarine outfalls, in the watercourses and tributaries feeding the estuary, and directly in the estuarine waters. The availability of a nearby water body leads many communities to discharge untreated or partially treated wastewater into estuarine and coastal waters. A basic assumption is made that dilution can lessen pollution-related problems. However, mixing in coastal waters is far from complete and in estuaries even less complete, thus leading sometimes to the presence of plumes with high concentration of polluting agents. In more stagnant areas the wastewaters can promote the formation of ”hotspots” in the immediate vicinity of the discharge point, where concentrations rise to significant levels.

Domestic wastewater contains a large number of pathogenic organisms originating from humans who are infected with disease or who are carriers of a particular disease. The most common pathogens found in sewage are those that cause typhoid fever, dysentery, gastroenteritis, diarrhea and cholera. The faecal coliform group of bacteria is usually used as a proxy for pathogenic agents in wastewater. On average, each person discharges from 100 to 400 billion coliform organisms per day, along with many other potential harmful bacteria and virus. The number of viable coliforms in fresh domestic sewage ranges from 10^8 to 10^9 MPN (Most Probable Number) per 100ml (Bishop 1983).

2 FAECAL POLLUTION IN THE SANTOS ESTUARINE SYSTEM

Until recently in Brazil less than 13% of Municipal Wastewater was treated before disposal in a river, lake or ocean (UNEP 2003). As such, the faecal pollution in the Santos area is a common challenge shared with many other Brazilian coastal systems. The main health problems observed in coastal populations in Brazil include the increase and re-emergency of diseases like yellow fever, dengue, malaria, water borne disease (diarrhea, hepatitis, typhoid fever, cholera) and virus diseases (Garreta-Harkot 2003).

This chapter focuses on a model application to assess the health of the marine water bodies along the Santos - São Vicente estuary, with special attention to a specific indicator of faecal contamination, *Escherichia coli*. The need of this analysis was based on the fact that the region - as other coastal metropolitan areas - has densely populated urban areas without a sewage drainage network or sewage treatment and a high number of irregular dwellings. Because of their location close to the mangrove and river banks, a significant part of these housing nuclei drain considerable loads of domestic effluents directly to the estuary. This type of pollution has not been as intensively studied as other research lines developed in the region (which were more frequently associated to the history of chemical pollution of the sediments and the water by industrial activities). However, some works have pointed out the need for these analyses due to the high and increasing rate of faecal coliforms found in the waters of the estuary (Cetesb 2005, 2006). The presence of many slum quarters and quarters without sewage network or treatment, as well as the three sewage treatment plants and the submarine outfall, create a considerable anthropogenic pressure on the aquatic environment, affecting the biota as well as human health in the Santos - São Vicente estuarine system (Braga et al. 2000, Abessa et al. 2005).

The *in-natura* domestic sewage dumping in estuarine channels and rivers has been classified as a potential source of pollution in Santos - São Vicente estuarine system (Braga et al. 2000, Cetesb 2001, Lima 2003, Gianesella 2006). The extent and the degree of contamination as well as the resilience of this environment to the increase of microbiological contamination is still unknown. Numerical models are very useful to estimate contaminant dispersion, particularly faecal coliforms, because they can combine hydrodynamic and water quality processes (Frick et al. 2001). This work presents such an application, based on the MOHID model system (Leitão et al., Mateus and Fernandes, this volume), aiming to validate a faecal decay model for the Santos Estuary so it can be used as a management and predictive tool.

3 MODEL IMPLEMENTATION

The water quality model is coupled with the hydrodynamic model previously described (Leitão et al., this volume) and so the same assumptions for the physical features of the system are valid here. These are: (1) the water-column is not stratified (2D horizontal); (2) the hydrodynamics in the bay are not affected by shelf water circulation. The external conditions include river discharges, forcing functions, like solar radiation and air temperature, and boundary conditions. The simulations were performed with variable T90 decay model for *E. coli* (see Mateus and Fernandes, this volume).

3.1 Atmospheric forcing

Climatological radiation levels were calculated by the model for the domain geographical coordinates. Air temperature, relative humidity and cloud cover (Figure 1) were also used to force the model, with monthly values taken from field observations made at CODESP meteorological station at Alemoa during 1997. For cloud cover the only complete historical series found is from 1999, obtained by observation at the Brazilian Navy's meteorological station located on Moela Island, at a zone adjacent to Santos bay, about 17 km away from the CODESP meteorological station at Alemoa.

3.2 Initial and boundary conditions

The boundary conditions (temperature, salinity, cohesive sediments and *E. coli* concentrations) considered for open Atlantic boundaries and the initial conditions for the model are given in table 1. The model considers six river inputs inside the domain. In two of these rivers (Cubatão + Henry Borden and Moji + Piaçaguera) a monthly mean faecal coliforms concentration was considered (Figure 2) according to a bimonthly value average between 2000 and 2005 obtained from CETESB's monitored points. The pollution point sources used in the model were determined based on current information on the sanitary conditions of the basin, so that the development of a numerical reference scenario for the current situation could therefore be established. The model considers 31 sewage discharge points, three sewage treatment plants (STP) and the submarine outfall in the bay (Figure 3 and table 2). All discharges are characterized by a cohesive sediment concentration of 120 $\mathrm{mg\ l^{-1}}$, a salinity of 0.5, a temperature of 24 °C.

TABLE 1: *Initial conditions and boundary conditions defined for each property in model simulations.*

Properties	Units	Initial conditions	Boundary conditions
Temperature	ºC	20	20
Salinity	psu	20	36
Cohesive sediments	mg l^{-1}	100	25
E. coli	MPN/100ml	0	0

TABLE 2: *Sewage discharge areas, E. coli concentration and the respective effluent flow ($m^3\ s^{-1}$). Discharges include the outfall, sewage treatment plants (STP), slum quarters and quarters out of sewage drainage (Not treated).*

Sewage discharge points	MPN/100ml	Flow $m^3\ s^{-1}$
Not treated	1.00×10^8	0.436
STP Cubatão	3.72×10^5	0.200
STP Humaitá	5.30×10^5	0.040
STP Samaritá	2.30×10^5	0.040
Santos submarine outfall	7.48×10^6	2.500
Total		**3.216**

3.3 Model validation

The model results were validated with *E. coli* field data from two ECOMANAGE campaigns carried out in August 2006 and in April 2007 (Figure 4). These analyses allowed the identification of the degree of microbiological contamination in the water, especially in the interior of the Santos Estuarine System where data of this nature are scarce. The sampling campaigns were carried out by means of a cooperation regime between UNISANTA through ECOMANAGE Project and SABESP - São Paulo State Basic Sanitation Company: the field sampling was carried out by the UNISANTA team and the analyses by the SABESP team.

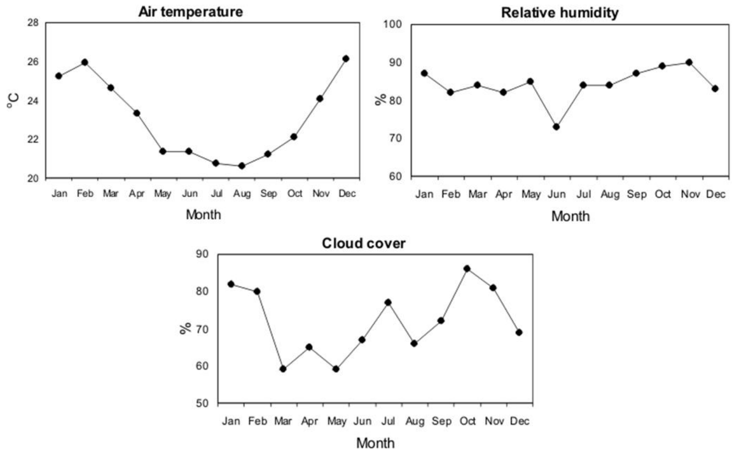

FIGURE 1: *Monthly mean values for air temperature, cloud cover and relative humidity used to force the model.*

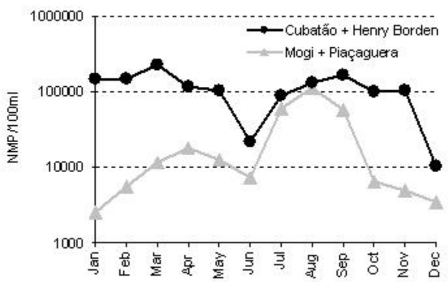

FIGURE 2: *Monthly mean values of E. coli assumed for the major river discharges: the joint discharges of Moji + Piaçaguera and Cubatão + Henry Borden.*

4 MODEL RESULTS

Considering the objective of this work, an analysis of faecal contamination in the Santos Estuarine system, only the model results for faecal coliforms are discussed here. Eight points inside the Santos Estuary (Figure 5) were chosen for the output of model results in order to simplify the analyses. Field data from these stations was used to perform the validation.

The faecal coliform concentration in the water column shows a greater spatial variation (Figure 6 and 7). In the Largo da Pompeba (P6) and Barreiros channel (P7) values above 10^3 MPN/100ml are observed (Figure 6), being the point 6 the most critical in terms of concentration. This higher concentration can be associated with the amount of slum quarters and quarters out without sewage network. Although the Cubatão, Mogi and Piaçaguera rivers discharges contributed with higher concentration of E.coli, the Piaçaguera channel (P5) and Largo do Canéu (P4) areas show concentrations below 100 MPN/100ml.

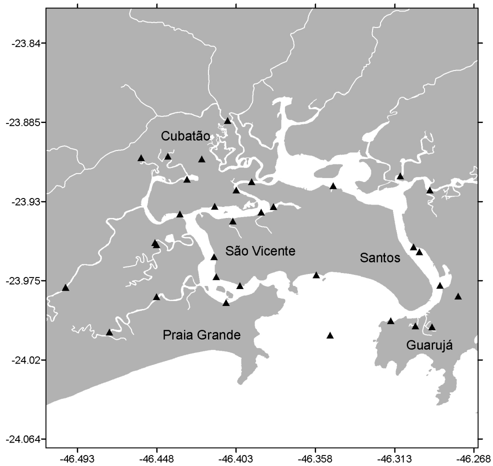

FIGURE 3: *Sewage discharge points defined for the model simulation.*

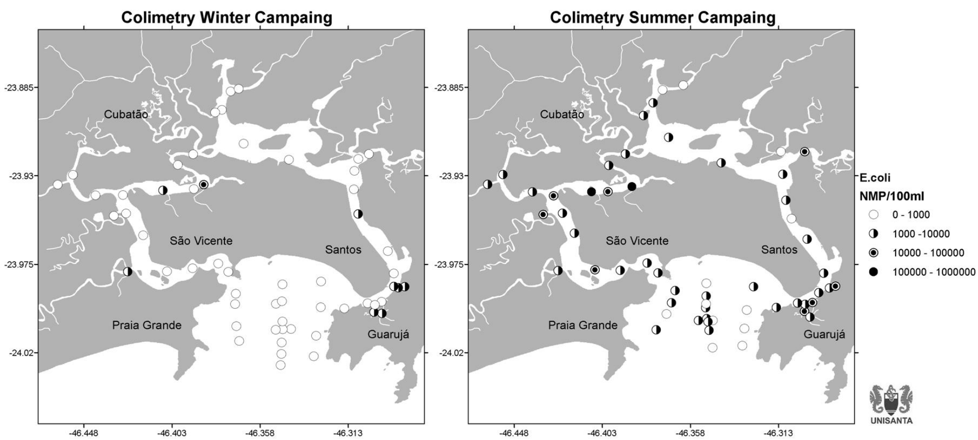

FIGURE 4: *Results from the E. coli data sampling campaign (MPN/100ml) in the summer and winter.*

A reason for this result can be related to the fact that these areas, being shallower, have higher solar radiation levels in the water column, the main agent that controls the survival of enteric bacteria in the water (Sarikaya and Saatci 1995, Serrano et al. 1998). Besides, these points are far from the sources of dumping, so dilution also contributes to the low concentration. At Santos channel (P2) the model shows concentrations below 10^3 MPN/100ml, slightly lower than the measured data. This discrepancy can be related to the discharges of untreated sewage of Vicente de Carvalho besides the slum quarters. Spring and neap tide cycles cause great variation on *E. coli* concentrations, as seen in the model results (Figure 7). A greater variability is seen in the monitored points located in the Santos (P1) and São Vicente (P8) channels, São Vicente having higher concentrations. The concentrations in these areas are regulated by hydrodynamic conditions. During a spring ebb tide the model shows that these channels contribute to increase the faecal contamination at Santos bay (Figure 7), mainly close to the São Vicente channel.

The influence of the submarine outfall at the Santos Bay is clearly noted, but the high concentration of *E. coli* from this source does not seem to reach Santos and São Vicente beaches, as seen in Figure 4. However, it is worth pointing out that the simulated conditions refer to a 2D model integrated in vertical, representing patterns of circulation in Santos forced only by astronomical tide and without the influence of wind.

5 MODEL VALIDATION

Validation was performed by matching simulated values with field data, as illustrated in Figure 8. The model performed very well for the winter, producing realistic estimates for *E. coli* concentrations in most of eight points. Only the results for points 3 and 5 were not so well reproduced. The model estimates for summer did not match results as well as for winter. In the summer only point 2 matched the campaign result. This difference between model results for summer and winter conditions can be attributed to the fact that an elevation in the discharges by urban drainage was not considered for the summer in the model, except for the river flow. Historical data on total and faecal coliform samplings carried out at Santos bay shows a significant elevation in microbiological contamination rates in the rain season coincident with the summer in the region (Sartor 2000, Lima 2003). Besides, one has to consider an increase in sewage generation incurred by the population growth in this season too. The measure campaign performed within the project corroborates this scenario, considering that the number of samples that exceeded the 10^3 MPN/100ml in summer was 5 times higher than winter samples (from a total 57 samples). This variation was observed all over the estuary. Another point that must be considered is that the data used to validate the model has been from surface samples and the model presents the water column average results.

6 FINAL CONSIDERATION AND FUTURE WORK

E. coli concentrations were used in this study as indicators of aquatic pollution and anthropic interference in Santos - São Vicente estuarine system originated from urban residual water dumping on the superficial water bodies. Two microbiological data sampling campaigns performed during the project showed a marked faecal coliform fluctuation between the summer and the winter when compared to each other - where the summer analyses showed a number of points (45) over 10^3 MPN/100ml. The results clearly reveal a seasonal variability within the estuary. The results corroborate the existing literature related to the contribution of urban pluvial drainage to microbiological contamination (Sartor 2000, Lima 2003). Still, in this estuary these simulations tend to become even more complex owing to the need of considering an increase in tourist population, as well as a greater contribution of diffuse loads from pluviometric precipitations, both being a typical summer phenomena in the region.

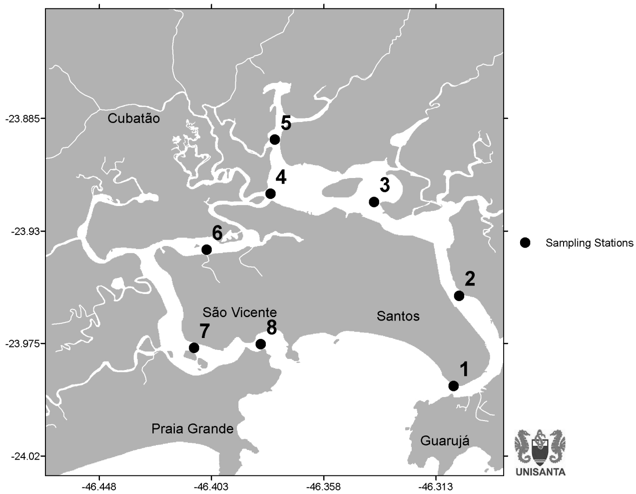

FIGURE 5: *Sampling stations for the data survey campaigns.*

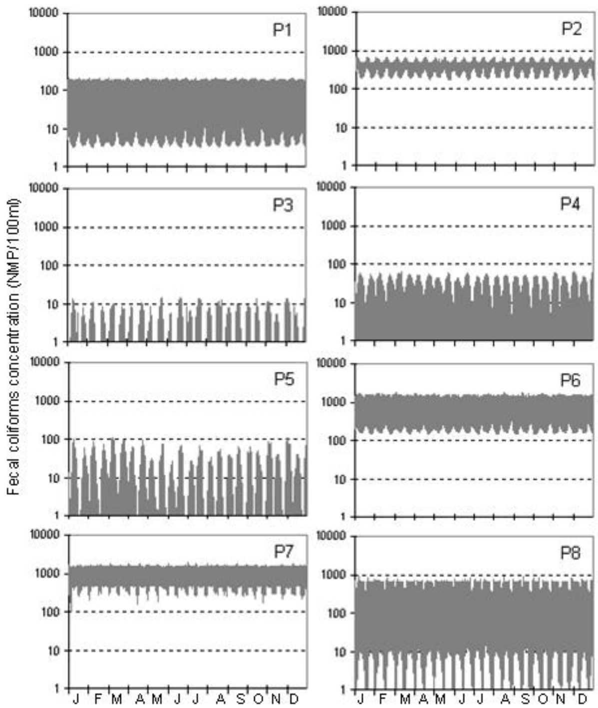

FIGURE 6: *Model output results for E. coli concentration (MPN/100ml) at the eight monitored points.*

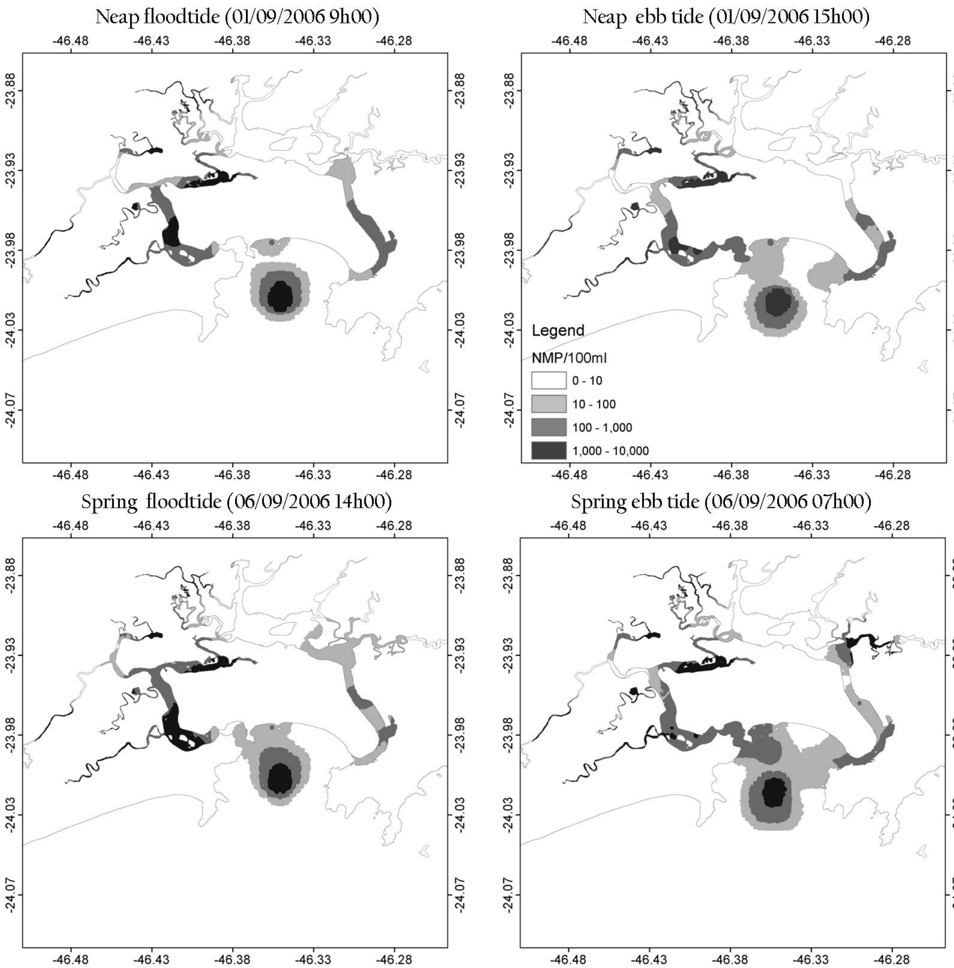

FIGURE 7: *Model output results for E. coli concentration (MPN/100ml) in different tide conditions.*

The model captures the spatial-temporal patterns of *E. coli* dynamics in the system. However, the summer results showed the importance of considering the affluent discharges of pluvial origin typical of this season in future works for a better reproduction of the coliform behavior in this period. Therefore, it is recommended that more research be done to achieve an effective assessment of the role of this contribution in modelling simulations. Even though the solution of the model is integrated for the water column, the comparisons between measures and model results were satisfactory, especially in Santos and São Vicente channels, both characterized by a stronger natural hydrodynamic regime when compared to other areas.

The validation outcome for the dispersion of microbiological plumes has been positive, but the need for a more advanced validation process, based on a broader and systematic field monitoring is evident. Although this sort of ongoing monitoring is an expensive effort, the results are fundamental for a proper understanding of the system's functioning, therefore fundamental for a correct calibration and validation of the numerical models. Together, more field data and modelling simulations will increase the knowledge of the seasonal microbiological behavior in the interior of the estuary. This is of paramount importance to determine spatial-temporal variation in faecal concentrations with more precision and, consequently, perfecting the forecast capability of the modelling system. Such a system is required for a proper management of the Santos bay water quality, given that the source of much of its contamination is located inside the estuary, as suggested by field data and supported by model results.

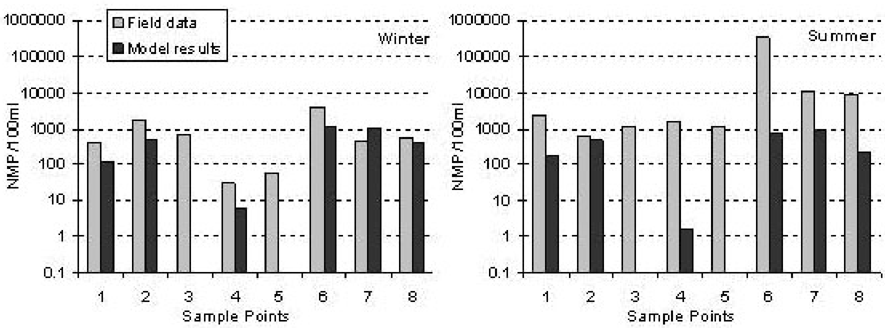

FIGURE 8: *Comparison between model output (black bar) and data field (gray bar) at the monitored sample points.*

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