Sanitation and microbiological water quality in the watershed of Santos - São Vicente Estuary

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ABSTRACT

This study assessed the evolution in sanitary services and water quality in the watershed of Santos and São Vicente Estuary from 2004 onwards. Results show evolution in services offered to the population after conclusion of the first phase of Onda Limpa Program, when sewage treated at the secondary level evolved from 11% to 14% of population, the pre-conditioning followed by submarine outfall 49% to 53% and population without a sewerage system fell 40% to 33%, being that for the latter 41% are in irregular areas not subjected to coverage. Among the four most populous sub-basins, each has about 90,000 people without a sewerage system, including urbanized and irregular areas. This factor, added to high level of annual rainfall still harms the water quality on the region.

Keywords: *bathing; water quality; Santos Estuary; sanitation*

RESUMO

Este estudo avaliou a evolução do atendimento sanitário e a qualidade da água na bacia hidrográfica do Estuário de Santos e São Vicente a partir de 2004. Resultados mostram evolução no atendimento à população após a conclusão da primeira fase do Programa Onda Limpa, quando o esgoto tratado a nível secundário evoluiu de 11% para 14% da população, os pré-condicionamentos seguidos de emissários submarinos de 49% para 53% e a população sem rede de esgoto caiu de 40% para 33%, sendo que deste último, 41% estão em áreas irregulares não passíveis de cobertura. Dentre as quatro subbacias mais populosas, cada uma possui ainda cerca de 90 mil pessoas sem rede de esgoto, incluindo áreas urbanizadas e irregulares. Este fator, aliado a elevada pluviosidade anual ainda prejudica a qualidade das águas na região.

Palavras-chave: balneabilidade; qualidade da água; Estuário de Santos; saneamento

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INTRODUCTION

Santos and São Vicente Estuarine System (SSVES) is a transition zone between the salt waters of the Atlantic Ocean and the fresh waters found in the watershed of five cities, Cubatão, Santos, São Vicente, Guarujá and Praia Grande (Figure 1). Located in the coastal slope of the state of São Paulo, it is part of Baixada Santista Metropolitan Region (BSMR), made up of nine municipalities covering a 2,402 km^2 area. Despite BSMR having a large area, more than 75% of its fixed population lives in the watershed of SSVES, outnumbering a million inhabitants in 835 km^2.

In the SSVES, the sources of water pollution are industrial and portuary as well as domestic, being the sources of domestic origin and their relation with the water quality in the sub-basins our focus.

Since the Johannesburg Conference in 2002, according to Gianesella & Saldanha-Corrêa (2010), it became evident that the health of coastal environments is directly related to the health of the watersheds, since about 80% of terrestrial pollution reaches the coastal regions through watersheds. In world proportion, these receive almost 90% of *in natura* effluents.

In this sense, an integrated approach between the SSVES watersheds (Figure 1) and the neighboring coastal region turns out to be essential.

According to CETESB (2016), the growth of the towns has caused the urban drainage canals to be the main source of fecal pollution into the beaches, because of numerous sewer connections as well as diffuse pollution. Additionally, areas without a sewerage system and precarious irregular dwellings found in SSVES's watershed, made up of 10 sub-basins, also contribute to the contamination of the region's water bodies.

Precarious dwellings in irregular areas are found in the five cities that make up the SSVES. As reported by Young e Fusco (2006), there are settlements in the region that have been waiting for land regularization for decades, because they require complex solution for being too densified. However, while waiting for solutions, domestic effluents are being dumped in ditches, sewerage systems or directly on the estuarine canals, such as current dwellings as palafittes (SAMPAIO *et al.*, 2008a). Moreover, it is found that the waters of the estuary's interior, too close to places with greater concentration of these dwellings, are used by adults for subsistence fishing and by children and teenagers that live nearby for primary contact leisure, instead of the beaches, more distant from their homes.

In Santos city, issues related to point and diffuse pollution are found to be evident and a couple of measures have been taken, since their beaches and rivers have had frequent oscillations in water quality, harming their use for recreation, despite the city counting on the most widespread coverage of sewerage system, above 93%.

In recent study (RUIZ *et al.*, 2015), the influence of rains in bathing water quality was strongly demonstrated in significant increases in the number of beaches with poor bathing water quality recorded in Santos.

Since 2007, the BSMR has been receiving investments from SABESP through their Onda Limpa Program to achieve the universalization of sewerage system until the year 2025 and improve the indicators of health and water quality.

However, results from coastal water quality monitoring point out that, despite investments, great variation in statistics of bathing water quality has been found in recent years, showing how complex is the ecosystem (CETESB 2016).

GOALS

This work aims to assessing the evolution of SSVES sewerage system coverage between 2004-2014, assessing its influence as well as pollution we will simply call "diffuse" on the microbiological water quality in the sub-basins regions, thus contributing with information to its improvement.

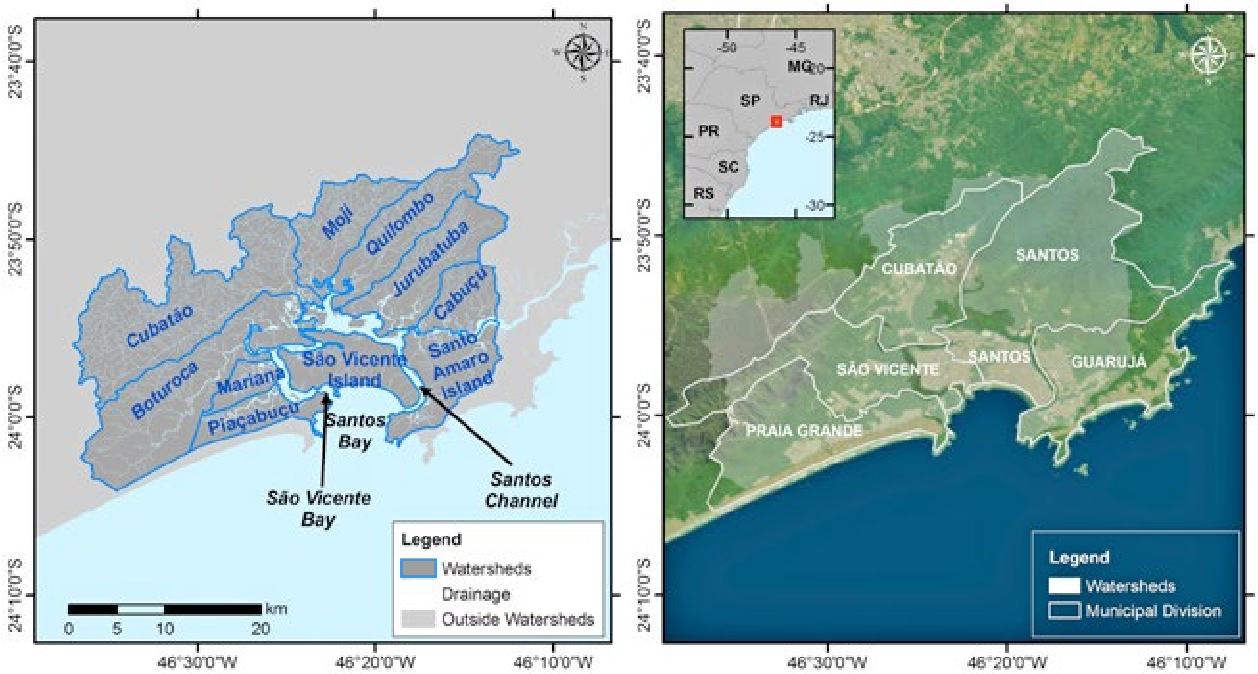

Figure 1: Location of SSVES. On the left watershed (dark grey) and sub-basins division, and right municipal division.

METHODS

To assess the evolution of sewerage system coverage and the population attended at SSVES sub-basins, the sewerage system coverage plants provided by SABESP for the five cities in the region were all georeferenced. These plants have had two distinct years of reference: a) the first, obtained during the ECOMANAGE Project (NEVES *et al.*, 2008), related to the amplitude of the sewerage system coverage for the year 2004, before the works for Onda Limpa Program were started (MACEDO *et al.*, 2007); b) and the second, related to the year 2014, with the first phase for the works of Onda Limpa Program concluded, with its complementary works remaining before its second phase can start.

To assess the number of people attended by the sewerage system, the information of the coverage área of the system in 2004 and in 2014 were merged with the populational data of census sectors of demographic censuses carried out in 2000 and 2010 (IBGE, 2000; 2010) using a GIS tool. In the scale of census sectors, greater detail in the population attended was obtained, different from that found in previous studies at the scale of neighborhoods (SAMPAIO *et al.*, 2008b) or in conventional approaches at municipal scale (BRASIL, 2016).

Under this method, the quantitative data of the population attended or not by the sewerage system could be re-grouped in the division into sub-basins. The spatial outline of the sub-basins and the municipal information related to the macrodrainage system were obtained through the cartographic base of the Baixada Santista Committee for Watersheds (CBH-BS, 2013).

To assess the effect of the diffuse pollution with the contribution of drainage from the sub-basins, a monitoring campaign for quantifying the concentration of *Escherichia coli* and *Enterococcus* was carried out in nine points distributed at the mouth of the sub-basins, as well as two points at São Vicente Bay that counts on no floodgate system for its drainage, as well as most of tributary drainage system of the Santos Bay, totalling 11 microbiological data collection stations (Figure 2). This campaign took place during a quadrature tide in the summer of 2016 for four days in a row, being the first day with a dry weather collection, no rainfall at all, and the three following days happened during and after rainfall. For comparison, in seven out of the 11 points monitored, concentration of *E. coli* monitoring station carried out in quadrature tide in the summer of 2007 were brought together during the ECOMANAGE Project, prior to the works of Onda Limpa Program.

Samples of water from 2007 and 2016 were collected on the surface, kept in ice, taken to the Baixada Santista Environmental and Sanitary Laboratory from SABESP where microbiological analyses of E. coli were carried out by means of the method *Colilert®*. In addition, in the 2016 campaign, samples were analyzed by the method *Enterolert®*.

Data from the meteorological stations of DAEE and CEMADEN were obtainded to assess the rainfall volume in the sampling periods (Figure 2).

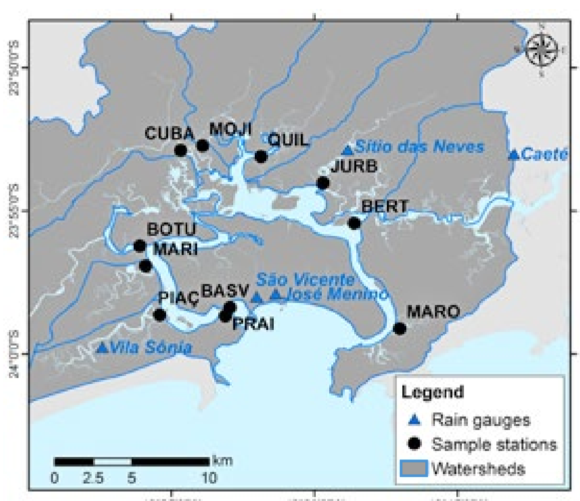

Figure 2: Location of the water sampling stations (black circles) and the rain gauges (blue triangles).

RESULTS AND DISCUSSION

Considering the total population distributed in sub-basins (1,240,249 inhab.), the most populous one, housing more than half of the total resident population of SSVES is that of the São Vicente Island (52%), followed by Santo Amaro Island (17%), Boturoca (12%), Piaçabuçu (10%), Mariana (6%) and Cubatão (2%) whereas Cabuçu, Jurubatuba, Moji and Quilombo hold together less than 0,1% of the total population.

According to the results obtained (Table 1), there was an increase in about 100.000 inhabitants (8%) between 2000 and 2010 and it happened in a heterogenous way in the basin. The sub-basins that showed populational growth among the highest in this period were Piaçabuçu (32,754 inhab.; 35%), Boturoca (24,740 inhab.; 20%) and Mariana (14.695 inhab.; 26%), followed by Santo Amaro Island (13,321 inhab.; 7%) and São Vicente Island (8,377 inhab.; 1.3%), whereas in Cubatão and Moji, population decreased 1,014 inhabitants (-3%) and 920 inhabitants (-67%) respectively; in Cabuçu and Jurubatuba a small populational nucleus was recorded only in 2010.

Predominantly located in the sub-basin of São Vicente Island, Santos is still the most populous city (419,400 inhab.) and the one that shows a near zero growth rate within the sub-basin in the period. On the other hand, Praia Grande, despite having only a small portion of its territory placed in SSVES's watershed (sub-basins Piaçabuçu and Boturoca), concentrated 59% (155,207 inhab.) of total population of the town (262,051 inhab.) in this area and had the highest rate of populational growth in the period assessed (33%). São Vicente, the second largest city in population (332,445 inhab.), with its territory divided into two portions, one of them being in conurbation with Santos on São Vicente Island and the other distributed in four sub-basins in the continent (Piaçabuçu, Boturoca, Mariana and Cubatão) showed a populational growth of 9%. However, previous studies carried out by Sampaio *et al.* (2008b), point out that the populational growth vector of the town has been occuring in the continental part of the city (sub-basins Piaçabuçu and Mariana). This trend may be confirmed when observing the populational increase in 26% between 2000 and 2010 in Mariana's sub-basin.

About sanitary infrastructure, the SSVES's watershed is provided with five wastewater treatment plants (WWTP) distributed in the Cubatão, Boturoca, Mariana and Santo Amaro Island sub-basins, two of them deployed in the period assessed. Besides, the region is provided with a marine outfall (Santos) that serves the sub-basin of São Vicente Island and other four marine outfalls (three at Praia Grande city and one in Guarujá city) located out of the SSVES's watershed, that serve a small part of the population in Boturoca, Piaçabuçu and Santo Amaro Island (Figure 3).

Table 1: Inhabitants per sub-basins. In parentheses the names of the sampling stations related to sub-basins are given.

SUB-BASINS	Population (2000)	Population (2010)	Growth%
Ilha São Vicente (BASV / PRAI) *	636,250	644,627	1%
Sto Amaro (MARO)	203,164	216,485	7%
Boturoca (BOTU)	125,235	149,975	20%
Piaçabuçu (PIAÇ)	93,247	126,001	35%
Mariana (MARI)	56,326	71,021	26%
Cubatão (CUBA)	31,538	30,524	-3%
Cabuçu (BERT)	-	654	-
Moji (MOJI)	1,377	457	-67%
Jurubatuba (JURB)	-	262	-
Quilombo (QUIL)	-	243	-
TOTAL	1,147,047	1,240,249	8%

*Stations in São Vicente bay

It is possible to see that the sanitary conditions are very different in the sub-basins of the region (Figure 4). This comes as evident by analyzing the four most populous sub-basins (São Vicente and Santo Amaro Islands, Boturoca and Piaçabuçu), that hold over 92% (1,137,088 inhab.) of the resident population of SSVES.

Analyzing the coverage of sewerage system implemented in these most populous sub-basins until 2014 (Table 2), 68% (771,296 inhab.) of the resident population are being served by a sewerage system, an evolution of 21% as related to 2004. In the most populous, São Vicente Island, 86% (551,395 inhab.) of the population had a sewerage system linked to the preconditioning plant and to the Santos submarine outfall, whereas 6% of the population (39,472 inhab.) remains in irregular areas, despite the decrease in 28% in the period (Table 3). In the sub-basin of Santo Amaro Island, there was an increase of 52% in servicing, evolving to 62% (133,395 inhab.) of population served by sewerage systems (36,4% connected to a new WWTP and 25,2% connected to the preconditioning plant and to the Guarujá submarine outfall), while 19% (40,926 inhab.) of the population is in irregular areas and 19% (42,164 inhab.) in an urbanized area without a sewerage system. In Boturoca, there was also an evolution of wastewater services in 63%, the second largest in the region in percentage; however, 60% (90,537 inhab.) of population has no sewerage system (36% in urbanized area, 20% in irregular areas and 4% in non-urbanized areas); in this sub-basin the number of people in irregular dwellings increased to 84% in ten years. Although the population served by the sewerage system has increased in 1,213%, in the sub-basin of Piaçabuçu, the high rate of populational growth in the period kept unchanged in 79% (98,933 inhab.) the percentage of population without a sewerage system (63% in urbanized area and 16% in irregular areas) and the number of inhabitants in irregular areas increased in 62%.

It is worthy noting that the number of people living in irregular areas in the region need more comprehensive and detailed investigation. Surveys provided by municipal administrations published by Sampaio e Harari (2012) in periods that were very close to the census carried out in 2000 showed a populational difference of up to 69% higher as related to the IBGE Census for 2000, showing that the numbers of the census in the region are underestimated. According to Maricato (2000), there are no general trustworthy statistics about the occurence of slums or irregular lotting throughout Brazil. On account of methodology failures or even of an obvious difficulty in learning about land possession documents of the land slums are currently settled on, IBGE shows data that is rather undersized. The search for more accurate statistics leads us to some diagnostics elaborated by municipal administrations, academic theses or state organisms that, however, provide restrict and local-limited data. Thus, the total number of people living in irregular areas, as presented in this work, 130,682 inhabitants, may be even greater.

Analyzing results of *Enterococcus* concentration, a marked influence of contribution of drainages from the sub-basins and consequently of diffuse pollution was clear to observe. At the first day of sampling (without rainfall in the last 24 hours - Table 4), the quartile of 75% was 65 MPN/100ml. On the two following days, with rainfall (ranging from 8.1 to 78.6 mm/day), the quartile of 75% was 1,202 and 905 MPN/100ml, respectively, thus representing an increase in up to about two orders of magnitude. On the last day, with the cumulate of rainfall ranging from 0.0 to 7.5 mm/day, the *Enterococcus* concentrations decreased, the quartile of 75% coming to 79 MPN/100ml (Figure 5).

This pattern, influenced by rainfall was also observed in *E. coli* concentrations (Figure 6). Overall, the concentrations were higher on the second and third sampling days, decreasing on the fourth. At the sampling points located at the São Vicente Bay region (BASV and PRAI), the concentration of *E.coli* was similar, when were compared the second and third sampling days. However, it's worth noting that the sampling stations located in sub-basin more to the west (PIAC to MOJI) showed greater contamination on February the 17th, whereas at the stations at sub-basins more to the east (QUIL, JURB, BERT and MARO) the greatest concentrations were on February the 16th. Rainfall along the sub-basins also showed similar variation: on the pluviometer located more to the west the cumulation of rain in 24 hours was higher on February the 17th, while the opposite was recorded in the pluviometers located to the east.

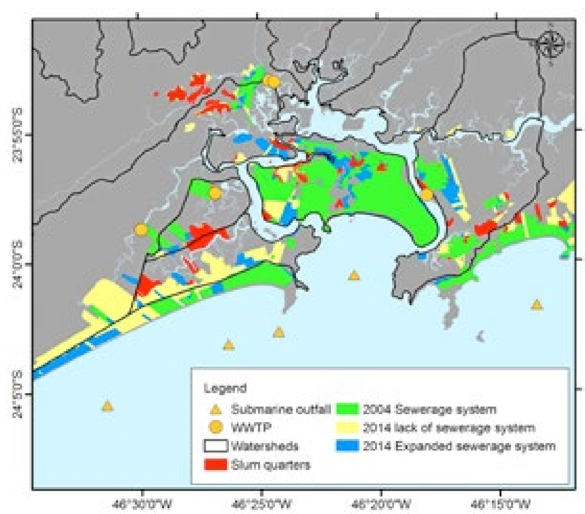

Figure 3: Sewerage system coverage. Areas with sewerage system (green), without one (yellow), area with irregular dwellings (red) and expanded sewerage system area between 2004 and 2014 (blue). Based on SABESP (2014) and IBGE (2010).

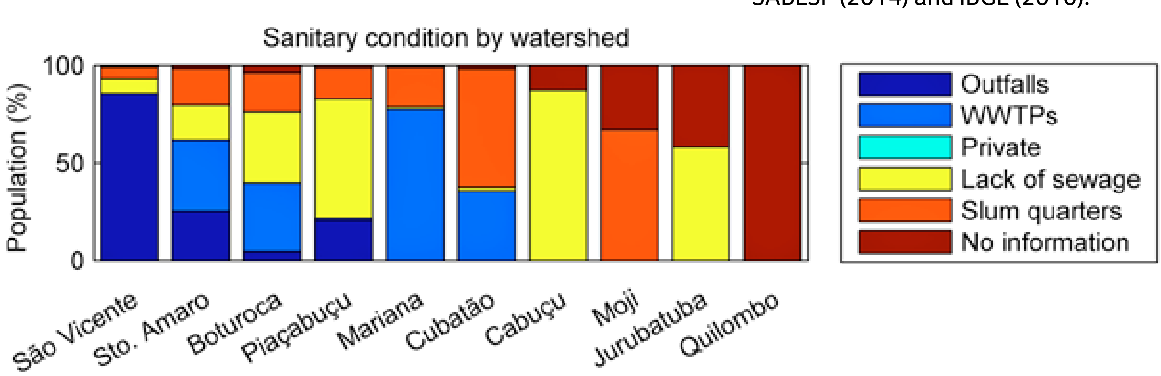

Figure 4: Sanitary conditions in 10 sub-basins of SSVES (in descending order of population from left to right). Based on 2014 sewerage system coverage and total inhabitants from IBGE 2010 census.

Table 2: Inhabitants in the four most populous sub-basins with (wSS) and without (nSS) sewerage system from 2004 and 2014, and its evolution. Data and percentage are based on total inhabitants from IBGE 2000 and 2010 census.

SUB-BASIN	2000/2004		2010/2014		Evolution	
	wSS	nSS	wSS	nSS	wSS	nSS
SÃO VICE	510,357 (80%)	125,893 (20%)	551,395 (86%)	93,232 (14%)	8%	-26%
MARO	87,986 (43%)	115,178 (57%)	133,395 (62%)	83,090 (38%)	52%	-28%
BOTU	36,574 (29%)	88,661 (71%)	59,438 (40%)	90,537 (60%)	63%	2%
PIAÇ	2,061 (2%)	91,186 (98%)	27,068 (21%)	98,933 (79%)	1,213%	8%
TOTAL	636,978 (60%)	420,918 (40%)	771,296 (68%)	366,152 (32%)	21%	-13%

Table 3: Inhabitants in irregular dwellings in the four most populous sub-basins and its evolution. Data and percentage are based on total inhabitants from IBGE 2000 and 2010 census.

SUB-BASIN	2000	2010	Evol.
SÃO VICE	55,075 (9%)	39,472 (6%)	-28%
MARO	62,702 (31%)	40,926 (19%)	-35%
BOTU	16,425 (13%)	30,269 (20%)	84%
PIAÇ	12,349 (13%)	20,015 (16%)	62%
TOTAL	146,551 (14%)	130,682 (11%)	-11%

Regarding the variation of *Enterococcus* concentration along the sampling stations, the station found in the sub-basin of Cubatão River (CUBA) showed a smaller median concentration (25 MPN/100ml), followed by BERT (25,5 MPN/100ml). On the other extreme, the stations MARO and PIAÇ showed the greatest medians (1,817 e 984 MPN/100ml), being that in the sub-basins of both stations there is a significant number of people not served by sewerage system (Piaçabuçu about 100,000 inhab., Santo Amaro Island about 83,000 inhab.). However, is worth mentioning that the monitoring station MARO despite located in this sub-basin, receives only part of the drainage of this number of dwellings without a sewerage system. On the other hand, even in the two sampling stations of São Vicente Bay that receive effluents from the urban drainage from areas already served by a sewerage system showed median concentrations of 200 MPN/100ml.

Moreover, the samples located in not very populated sub-basins (QUIL: 243 inhab. and JURB: 262 inhab.) also showed elevated concentrations for both fecal contamination indicators in samplings collected after the periods of intense rainfall. This can be related to both the natural contribution of the sub-basin from hot-blooded animals; it might be not necessarily related to the presence of pathogenic organisms (SOLLER *et al.*, 2010), but it might also be related to sources unidentified in this work, for instance, the presence of industries and a landfill, thus pointing out to the need of more investigation.

Concerning the evolution of the water quality on the horizon of time between the samplings carried out by ECOMANAGE Project and those of the current work, there is a high variability in the concentration of these indicators, chiefly related to diffuse pollution, rainfall, among other factors (BOEHM *et al.*, 2002). In 2007, on the days prior to the sampling, significant rainfalls occured; this way conditions were similar to the samplings carried out on the 16th and 17th of February 2016, and by means of comparison of *E.coli* concentration results, it is noted that the values are in the same order of magnitude. Therefore, despite de significant difference found between the samples collected in 2007 and the first sampling of 2016 carried out in this study, one cannot affirm there was a positive evolution in the bathing water quality in the inner region of SSVES.

In this sense, the results of fecal indicator bacteria at the mouth of SSVES and São Vicente Bay sub-basins, using *Enterococcus* and *E.coli* show that there is still compromising of the bathing water quality and it is worsening through diffuse pollution after heavy rainfall events.

However, overall, there was an evolution of the services to the population between 2004 and 2014 in both, drainage and treatment of wastewater. In this period, the treatment by secondary-level WWTPs increased from 11 to 14% of total SSVES population, the outfalls increased from 49% to 53% and unserved population fell from 40 to 33%. From these 33%, at least 164,026 people (41%) are in irregular areas that demand complex solutions to ensure for them access to these services in the future. Among the four most populous basins, each one holds about 90,000 people without a sewerage system among urbanized areas without a sewerage system and irregular areas, being that two of them showed the greatest populational growth in one decade.

Table 4: Accumulated rainfall (mm) in the 24 and 48 hours prior to the sampling dates in different rain gauges located in the study area.

DATE	RAIN GAUGE	CUM.	
		mm/24h	mm/48h
10/04/2007	Caete	34.7	41.6
	São Vicente	10.9	10.9
15/02/2016	S. das Neves	0.0	0.0
	José Menino	0.0	0.0
	Vila Sônia	0.0	0.0
16/02/2016	S. das Neves	78.6	78.6
	José Menino	21.1	21.1
	Vila Sônia	26.6	26.6
17/02/2016	S. das Neves	22.0	100.6
	José Menino	8.1	29.2
	Vila Sônia	36.8	63.4
18/02/2016	S. das Neves	7.5	29.5
	José Menino	0.0	8.1
	Vila Sônia	0.6	37.4

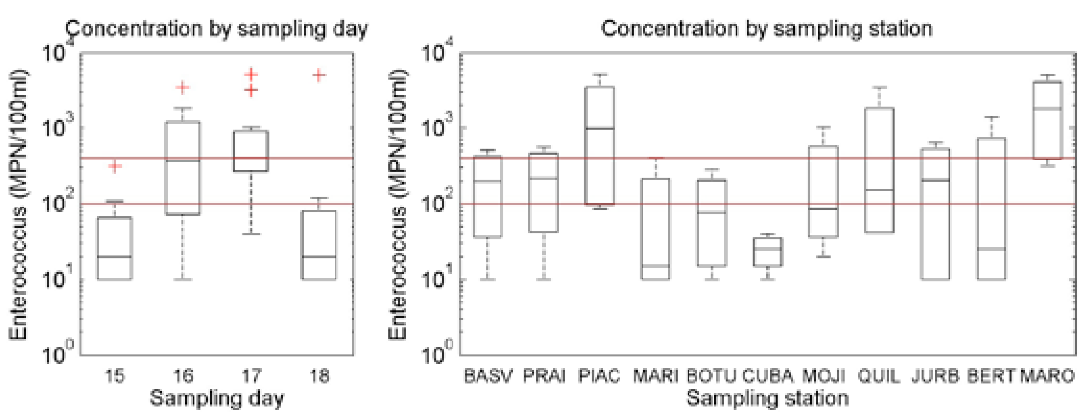

Figure 5: Box plot for Enterococcus concentration (MPN/100ml) considering all of the stations in each sampling day (to the left), and considering all the days sampled in each sampling station (to the right). Red lines represent the thresohlds of 100 and 400 MPN/100ml (Box-plot presenting the values of maximum, minimum, 25% and 75% quartiles with their respective median. The symbols + on the figure to the left stand for extreme values that were removed from the box plot).

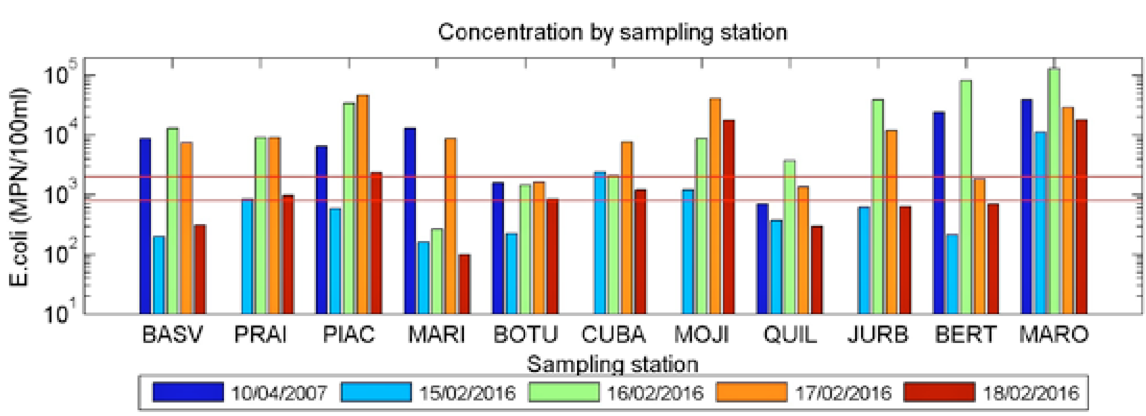

Figure 6: *E. coli* concentration at stations sampled between 15 and 18 feb 2016, and also sampled 10apr2007 (dark blue). Red lines represent the thresohlds of 800 and 2,000 MPN/100ml.

CONCLUSIONS

Data analyzed showed a positive evolution of the sewerage system to the population between 2004 and 2014. However, its universalization is yet to occur, foreseen for 2025, with the conclusion of the second phase of the Onda Limpa Program. Among the four most populous sub-basins, each one holds about 90,000 people without a sewerage system, considering urbanized and irregular areas. This factor, added to a high level of rainfall in the region still incurs the poor water quality in the studied sub-basins. Thus, besides the universalization of sewerage system and land regularization, needing further assessments of the impact of diffuse pollution on the SSVES and mitigating actions of this impact.

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