SOCIO-ENVIRONMENTAL VULNERABILITY OF WATER IN THE ESTUARY OF THE METROPOLITAN REGION OF SANTOS (BRAZIL)

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Abstract: Santos and São Vicente Estuarine Complex (SSEC) is a densely populated coastal area that houses the main port in Latin America and the most prominent Brazilian industrial complex. Irregular occupations in preservation areas result in a disorderly increase in population, with negative social and environmental impacts. We evaluated the average annual growth of 74 slums occurring in this area and variations in water quality from 2005 to 2018. We monitor the growth of the occupied areas and estimate their respective populations. The average annual population growth was over 6% per year (p.a.). Invasions of new areas and verticalisation of already occupied areas represent 85% of the growth seen. The monthly polluting loads exceeded 450 tonnes or 2,086,000 m^3, compromising the waters and local and regional public health. We strongly recommend re-urbanising the area using the resource savings caused by water loss to reduce the risks of ecosystem degradation, damage to health and disease spread.

Keywords: population growth, slums, shantytown, coastal zone, urban slums, urban vulnerability

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Introduction

According to the United Nations, the world population growth rate will be more pronounced in the coming decades, with an increase of 2.5–3 billion people by 2050, and with that, there will be an increase in the need for water, sanitation and hygiene (Leridon 2020). This phenomenon will boost vulnerability in socio-environmental, urban, economic and political spheres (Cutter et al. 2003). The United Nations Department of Public Information Report showed that in 2012, approximately 828 million people lived in slums with a growth rate of 6% per year (p.a.), and by 2020 it should reach 889 million in the urban migration process (UN 2012 and 2013). Coastal zones are more densely populated than inland areas and exhibit higher rates of population growth and urbanisation. The development of coastal areas has increased considerably in recent decades, producing socioeconomic changes and generating high pressure on ecosystems due to the exploitation of natural resources and pollution. Land use and urbanisation are also related to

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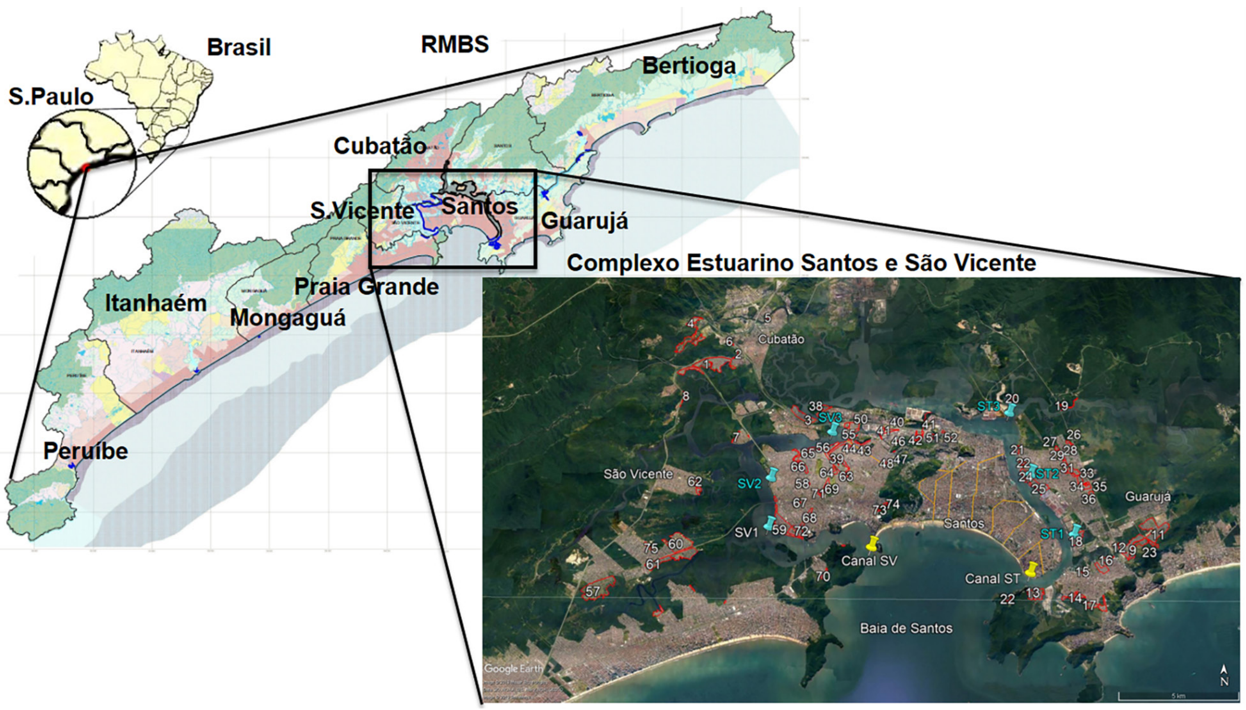

Fig. 1. Location of the SSEC area. Red polygons limit areas of high vulnerability; cyan markers show localities of six water sample collection points (3 in Santos (ST1-3) and 3 in São Vicente (SV1-3)); orange lines represent artificial drainage canals; yellow markers define natural channels entry to the estuary in the municipalities of Santos (ST) and São Vicente (SV).
Source: Google Earth, adapted by the author, 2018.
SSEC – Santos and São Vicente Estuarine Complex.

increasing population exposure and vulnerability along the coasts, especially in developing countries (Small, Nicholls 2003; Balk et al. 2009; Kron 2013; Neumann et al. 2015). In these zones, we can find vulnerable nuclei (VN), subnormal agglomerations, precarious settlements and slums, characterised by populations with low incomes and lack of access to safe drinking water, sanitation, and public housing and health policies, who live in non-conforming housing (NH) (IBGE 2010; SAO PAULO 2010; AGEM 2015; UN-BR 2018).

Port, industrial and tourist activities drive the Baixada Santista Metropolitan Region (BSMR) located in the Santos and São Vicente Estuarine Complex (SSEC) and induce invasions in flooded areas, where we find the largest slum on stilts in Brazil (Fabiano, Muniz 2010; Sampaio et al. 2011). The main actors behind this problem are the municipal governments who do not draw up adequate master plans for popular low-income occupations and parallel power organisations that rent out these irregular areas for the occupation of precarious housing. Housing changes and urban regularisation imply better sanitary conditions since the houses are now supplied by a regular water and sewage distribution system, in addition to allowing other essential services such as regular garbage collection. The improvement is a natural result of the replacement of irregular housing. The water quality of local watercourses automatically improves its indicators from the moment the raw sewage stops being deposited. Sewage discharge, inadequate waste disposal and port accidents compromise the quality of water and sediments. We analysed the population growth of VN in the SSEC and verified the water quality changes between 2005 and 2018.

Methods

Study area

The BSMR, with 1,848,654 inhabitants, is located on the south-eastern Brazilian coast, 2,428,737 km,[2] characterised by 65 km of continuous coastline. Bordered by the Serra do Mar cliffs, with remnants of the Atlantic Forest, there is a great diversity of ecosystems such as mangroves, estuaries, islands, sandbanks, coves, dunes, beaches and rocky shores. Most of these are protected through conservation units or other types of protected areas by law (IBGE 2018). The SSEC have several meandered channels that receive fluvial discharges that flow into Santos Bay through two channels (Fig. 1). On the eastern side, the Santos channel, with a width of 360 m and an average depth of 14 m, is maintained by dredging to navigate great ships. The São Vicente channel is on the west side, with an average depth of 8 m and a width of 585 m, narrowing to 185 m under the 'Pensil' bridge (Sampaio et al. 2011). Sewage, waste and emerging pollutants (salts and nutrients) harm public health in the estuary (CETESB 2017).

Housing and territorial data

We collect housing and population data from formal and informal areas. Each VN's coordinates and territorial space (Fig. 1) were also obtained and complemented by using Google Earth software (AGEM 2015; IBGE 2018; Annex A; Annex B). The study area group (SAG) brings together the number of households, populations and territories in formal and informal areas of Santos, São Vicente, Cubatão and Guarujá municipalities.

We calculate geometric annual growth rate (GAGR) by applying equation (Eq.) (1) (RIPSA 2018):

$$\mathrm{GAGR} = \left[\sqrt[n]{\frac{(Pn+1)}{Pn}} - 1\right] \times 100 \tag{1}$$

where
- $Pn+1$: future population (inhabitants, households)
- Pn: current population (inhabitants, households)
- GAGR: geometric annual growth rate (% p.a.)
- n: number of years (years)

Growth clusters

We calculated the GAGR for the number of non-compliant houses and the areas of occupancy of the VN (GAGR_{NH} and GAGR m^2) so that it was possible to identify four types of growth, as shown in Table 1. The type 1 cluster, with the increase in the number of houses and occupied areas, represents irregular and recurring occupations. Type 2, shows an increase in accommodation and a decrease in the area. The type 3 group indicates the preparation of a new irregular occupation. Type 4 represents the government's relocation actions but is not necessarily associated with the inspection and recovery of degraded areas.

Table 1. Housing growth clusters (GAGR_{NH}) and territorial (GAGR_{m^2}).

Type	Growth clusters		
	Dwellings (GAGR_{NH})	Territorial (GAGR_{m^2})	Features
1	+	+	Invasions and reinvasions
2	+	–	Verticalisation and densification
3	–	+	Demobilisation and pre-invasion
4	–	–	Demobilisation

GAGR – geometric annual growth rate; GAGR_{NH} – geometric rate of annual growth of the population in non-conforming housing.

Water quality

Based on the data available in the National Sanitation Information System (NSIS), we calculate the sewage flow rate (Q) generated by human dwellings (HD) as 80% of water (Von Sperling 2014) according to Eq. (2), and the released pollutant load (PL) in the body of water according to equation (3):

$$(\mathrm{IN053} \times \mathrm{IN051} \times \mathrm{NH} \times 0.8) = \mathrm{Q} \tag{2}$$

$$(\mathrm{IN053} \times \mathrm{IN051} \times \mathrm{NH} \times 0.8 \times k) = \mathrm{Q} \tag{3}$$

where
- Q: sewage flow per HD – $m^3 \cdot year^{-1}$,
- PL: polluting load – $m^3 \cdot year^{-1}$,
- IN051: loss ratio per house – $m^3 \cdot house^{-1} \cdot year^{-1}$,
- IN053: average water consumption per dwelling – $m^3 \cdot dwelling^{-1} \cdot year^{-1}$,
- NH: non-conforming housing – units $\cdot year^{-1}$,
- 0.8: contribution factor of sewage generation by housing,
- k: 54 g per inhabitant daily (value used in this study).

Table 2. Identification of the channels of Santos and São Vicente and collection points in SSEC.

County	Coordinates (UTM)		Distance from mouth of Santos (km)	Distance from mouth of São Vicente (km)
st1	369,107 E	7,347,706 S	3.1	31.9
st2	367,145 E	7,350,411 S	6.2	31.8
st3	366,363 E	7,353,172 S	9.0	26.0
sv3	355,832 E	7,347,793 S	21.4	13.6
sv2	355,575 E	7,349,873 S	27.3	7.7
sv1	358,418 E	7,352,163 S	29.7	5.3

Source: Google Earth, adapted by the author, 2018.

Sewage flow and polluting load (mainly phosphate) information was related to the estuarine water quality in six points (Fig. 1 and Table 2), obtained in 2011 and 2017 (CETESB). We compare results to the limits established in the Brazilian Law 357 CONAMA Resolution (BRAZIL 2005).

Results

Growth of formal and informal areas

From 2005 to 2018, in urbanised areas, SAG municipalities presented a GAGR of 0.77% p.a., lower than the BSMR growth rate, which was 1.28% p.a. In the same period, 74 VN informal areas presented a geometric rate of annual growth of the population in non-conforming housing ($GAGR_{NH}$) of 5.60% p.a., below the BSMR growth rate of 6.07% p.a. in 525 VN (Table 3).

Growth clusters

VN growth clusters shown in Table 4 demonstrate a lower growth outlook for $GAGR_{NH}$ than that for RMBS. The positive double growth for dwellings and occupied areas (type 1) shows intense invasion dynamics, together with the densification and verticalisation process expressed in type 2 growth, which presented a $GAGR_{NH}$ of 7.25% p.a.; moreover, this presented a reduction of the occupied area of −1.94% p.a., representing 85% of the VN present in SSEC. The VN's demobilisation process, represented by cluster type 3 with a $GAGR_{NH}$ of −3.01% p.a. and $GAGRm^2$ of

Table 4. Housing and territorial growth clusters.

Type	NH	m^2	Qty VN	$GAGR_{NH}$ (% p.a.)	$GAGR_{m^2}$ (% p.a.)
1	+	+	51	8.94	5.73
2	+	−	12	7.25	−1.94
3	−	+	3	−3.01	1.47
4	−	−	8	−4.54	−8.48
SAG		74	5.60	0.09	
BSMR		599	6.07	(*)	

BSMR – Baixada Santista Metropolitan Region; GAGR – geometric annual growth rate; $GAGR_{NH}$ – geometric rate of annual growth of the population in non-conforming housing; NH – non-conforming housing; p.a. – per year; SAG – study area group; VN – vulnerable nuclei.
Source: AGEM (2015); Annex A, adapted by the author, 2018.
(*) not available.

Table 3. Formal and non-conforming population (NH) between 2005 and 2018 in SAG municipalities.

	Population (residents)			GAGR (% p.a.)		NH (AGEM)	NH (SABESP)	$GAGR_{NH}$ (% p.a.)
	2005	2014	2018	2005/2018	2005/2014	2005	2018	2005/2018
Santos	418,610	423,779	432,957	0.26	0.14	8,018	15,732	5.32
Cubatão	113,271	123,785	129,760	1.05	0.99	8,620	2,935	−7.95
São Vicente	317,459	346,492	363,173	1.04	0.98	8,992	29,079	9.45
Guarujá	276,945	303,397	318,107	1.07	1.02	19,300	39,345	5.63
SAG	1,126,285	1,197,501	1,243,997	0.77	0.68	30,581	62,090	5.60
BSMR	1,567,581	1,750,990	1,848,654	1.28	1.24	54,343	116,941	6.07

GAGR – geometric annual growth rate; $GAGR_{NH}$ – geometric rate of annual growth of the population in non-conforming housing; NH – non-conforming housing; p.a. – per year; SAG – study area group; BSMR- Baixada Santista Metropolitan Region.
Source: IBGE 2018.

1.47% p.a., shows demobilisation and new areas in preparation for invasion. Cluster type 4, with a $GAGR_{NH}$ −4.54% p.a. and $GAGR_{m}{}^{2}$ −8.48% p.a., which, in addition to cluster type 3, represents 15% of the sampling plan, emphasises the disproportion between invasion and demobilisation/enforcement actions.

SSEC water quality and Santos Bay beaches

Table 5 shows VN units that release sewage and influences water quality on monitoring points.

Using the concept of SSEC average water renewal time, according to Leitão and Mateus (2008), the Santos Channel (with a width of 360 m and a depth of 14 m) and the São Vicente channel (with a width of 585 m and a depth of 8 m) are subject to a hydrodynamic regime of the seas in periods of 6 hours. According to Sampaio et al. (2011), the channels' velocities vary between 0 m $\cdot s^{-1}$ and 0.5 m $\cdot s^{-1}$, and within SSEC currents, around 0.1 m $\cdot s^{-1}$ (Harari et al. 2007). In terms of water renewal flow under the influence of the tidal regime, the estimated range is 6 km and gives worse results at points sv3 and st3. The st3 point 9 km distant from the Santos channel is influenced by ship traffic in the Santos estuary channel, while the sv3 point does not receive large draft vessels. The average flow through the Santos channel is approximately 1,260 $m^3 \cdot s^{-1}$, and the average flow through the São Vicente channel is 1,170 $m^3 \cdot s^{-1}$. Table 6 presents the flow and polluting load of sewage discharged into water bodies in 2005 and 2018. The SAG received 451 tonnes $\cdot$ $month^{-1}$ of pollutants in 2018, much higher than 137 tonnes $\cdot$ $month^{-1}$ in 2011.

Table 7 shows the non-conforming occurrences in water quality parameters recommended by Brazilian environmental legislation CONAMA 357 (BRAZIL 2005; CETESB 2011; Campuzano et al. 2013; CETESB 2017). During 2011, we verified 42 occurrences of non-compliance with quality standards, while in 2017 the number of occurrences rose to 56, with several new occurrences in the São Vicente channel, which receives increasing loads of sewage from the northwest of Santos-São Vicente Island.

Table 5. Number of VNs in growth clusters, housing and territorial growth rates correlated with collection points.

Cluster	st1	st2	st3	sv3	sv2	sv1
1 (+/+)	14	2	8	16	3	8
2 (+/−)	3	1	2	3	1	2
3 (−/+)	2				1	
4 (−/−)			3	3	1	1
NH (2005)	9,170	1,986	3,471	6,888	3,308	5,758
NH (2018)	15,172	4,846	5,012	20,633	3,659	12,768
$GAGR_{NH}$	3.95% p.a.	7.10% p.a.	2.87% p.a.	8.81% p.a.	0.78% p.a.	6.32% p.a.
New invasions	4	0	4	11	2	5

GAGR – geometric annual growth rate; $GAGR_{NH}$ – geometric rate of annual growth of the population in non-conforming housing; NH – non-conforming housing; p.a. – per year.
Source: Annex A, adapted by the author, 2018.

Table 6. Sewage flow and PL released in SSEC in 2005 and 2018.

County	IN051 ($m^3 \cdot month^{-1}$)	IN053 ($m^3 \cdot month^{-1}$)	Total ($m^3 \cdot month^{-1}$)	HD Number of irregular dwellings		Flow rate ($m^3 \cdot month^{-1}$)		Polluting load (tonnes $\cdot month^{-1}$)	
				2005	2018	2005	2018	2005	2018
Cubatão	17	20	37	5,674	2,935	90,784	86,876	20	19
Guarujá	22	21	43	12,818	22,887	215,342	787,313	47	170
Santos	8	45	53	3,826	7,275	137,736	308,460	30	67
São Vicente	19	19	38	8,263	29,042	125,598	882,877	27	191
SAG	16	26	42	30,581	62,090	636,085	2,086,224	137	451
BSMR	11	18	30	54,343	116,941	782,539	2,806,584	169	606

BSMR – Baixada Santista Metropolitan Region; PL – pollutant load; SAG – study area group.
Source: AGEM 2015; Sperling 2014; SNIS 2017; Annex B, adapted by the author, 2018.

Table 7. Water quality measurements in non-conformity (“1” in yellow cells) with CONAMA 357.

Year	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011	2011
Station-Season	st1-S	st1-W	st2-S	st2-W	st3-S	st3-W	sv1-S	sv1-W	sv2-S	sv2-W	sv3-S	sv3-W	Total
DO		1	1		1	1			1	1	1	1	8
P_{TOTAL}		1	1	1	1	1		1			1	1	8
NH_4	1				1			1	1	1	1	1	7
TOC	1		1	1	1	1	1		1	1	1		9
Ecotox.													0
Chlorophyll											1		1
Enterococcus	1	1	1	1	1			1		1	1	1	9
Total 2011	3	3	4	3	5	3	1	3	3	4	6	4	42
Year	2017	2017	2017	2017	2017	2017	2017	2017	2017	2017	2017	2017	2017
Station-Season	st1-S	st1-W	st2-S	st2-W	st3-S	st3-W	sv1-S	sv1-W	sv2-S	sv2-W	sv3-S	sv3-W	Total
DO					1		1	1	1	1	1		6
P_{TOTAL}	1	1	1	1	1	1	1	1	1	1	1	1	12
NH_4	1		1		1			1	1		1	1	7
TOC	1	1	1	1	1	1	1		1		1	1	10
Ecotox.	1	1	1	1	1	1	1	1	1	1	1	1	12
Chlorophyll							1		1		1		3
Enterococcus	1		1		1		1				1	1	6
Total 2017	5	3	5	3	6	3	6	4	6	3	7	5	56

DO – dissolved oxygen; NH_4 – ammonia nitrogen; P_{TOTAL} – total phosphorus; S – summer; TOC – total organic carbon; W – winter; Ecotox. (*Vibrio ficheri*), Chlorophyll A, and Enterococcus.
Source: BRAZIL 2005; CETESB 2011; CETESB 2017.

Water quality: Contributing rivers and Santos Bay (beaches)

The deterioration of the bathing water also increased between 2005 and 2017 (Table 8), with the discharge of domestic sewage being the main factor for the low water quality of the beaches of Santos, São Vicente and Guarujá (CETESB 2017).

Table 8. Concentration of total coliforms in waterways urban effluent to beaches.

County	2005	2017
Cubatão (*)	10^1	10^1
Guarujá (*)	to	10^3 to 10^5
Santos (*)	10^4 to 10^5	10^3 to 10^6
São Vicente (*)	10^4 to 10^5	10^3 to 10^6
Bertioga	10^3	10^3 to 10^4
Mongaguá	10^3 to 10^4	10^3
Itanhaém	10^3 to 10^4	10^3
Praia Grande	10^4 to 10^5	10^3 to 10^6
Peruíbe	10^2 to 10^3	10^3 to 10^4

Source: CETESB 2017, adapted by the author, 2018.
(*) Municipality contemplated in SAG.

Discussion

The evolution of GAGR from 2005 to 2014 in urbanised areas was 0.68% p.a. in SAG and less than 1.24% p.a. BSMR and other regions of the world, such as 1.52% p.a. in Latin America and the Caribbean (LAC), are at a rate of 4.57% p.a. in sub-Saharan Africa and at a rate of 4.53% p.a. in Western Asia (IBGE 2010; UN 2016; IBGE 2018). Paradoxically, in informal areas from 2005 to 2018, $GAGR_{NH}$ in SAG 74 VN was 5.60% p.a., while BSMR 525 VN reached 6.07% p.a., higher than all other areas in LAC (−0.75% p.a.), sub-Saharan Africa (3.12% p.a.) and Western Asia (3.89% p.a.) (Young, Fusco 2006; AGEM 2015; UN 2016; Annex A; Annex B). Except for Cubatão municipality, with a negative $GAGR_{NH}$ (−7.95% p.a.), the municipalities of SSEC presented VN with growth types 1 and 2, in non-conforming dwellings and the occupied area or areas of verticalisation and population concentration. Intense urbanisation has significantly altered the physical environment, and the conservation of natural areas near urbanised areas remains to be considered of little importance to the government. Young 2009; Moreira et al. 2017 emphasise that the lack of conservation of natural areas in BSMR contributes strongly to environmental degradation and the impacts related to urban activities. On the other hand, in Cubatão, housing policy is based on housing production through partnerships with the state and federal governments. Some projects only include new units, while others have joint urbanisation and housing production actions. In addition to the construction of about 10,000 houses, the projects foresee urban areas occupied by families. The Organic Law of the Municipality of Cubatão establishes in Article 7(2) the municipality's concurrent competence, together with the State of São Paulo and Brazil, to execute housing production programmes. Combining this provision with the relevant chapter on municipal housing policy (Arts. 207 to 211) is the foundation in the local legal system for such sectoral policy and competence that enables the municipality to conclude agreements with other federative entities (Gillan, Charles 2019).

There are significant social impacts of daily releases of *in natura* effluent of approximately 2,086,000 $m^3 \cdot month^{-1}$, PL of 450 tonnes $\cdot$ $month^{-1}$, in addition to the inadequate disposal of garbage in water bodies (estuaries, beaches, canals and rivers), as well as the presence of emerging pollutants requiring advanced treatment that is not available from RMBS. Sewage discharges and inadequate waste disposal in the rivers' innermost areas modify estuarine waters' hydrodynamics and cause urban flooding, especially in the summer, when there is a more generous river contribution caused by heavy rains (Berbel et al. 2015). Other locations globally, also densely populated and with a population problem in unstable housing exposed to urban and industrial contaminants, are also affected. For instance, in India, the effects of anthropogenic stress on the Ganges River show increased biochemical oxygen demand (BOD), reduced salinity and pH, as well as the presence of high concentrations of Hg and Pb, attributed to discharges from manufacturing and industrial processes (Sarkar et al. 2007). Additionally, in India, on the Ganges delta in Bengal, there was evidence of *Vibrio cholera* concentrations associated with discharges, temperature and salinity of waters in the estuary (Batabyal et al. 2016). In Cameroon, cholera risk factors are associated with slums, poor sanitation and hygiene. There are high cholera risks in Douala, which demonstrates that the issue goes beyond public health to the point of a humanitarian disaster (Ndah, Ngorah 2015).

The relationship between economic growth and the release of contaminants has been known for some time. Garcia Occhipinti (1986) presented the most relevant aspects for analysing an ocean waste disposal system (OWDS), where he emphasised the tidal regime's interference in the gradient of contaminant concentrations. High concentrations of persistent organic pollutants (POPs) and polycyclic aromatic hydrocarbons (PAHs) are also associated with anthropogenic effects on SSEC (Fontanelle et al. 2019).

The sustainable development goal aims related to the environment, biodiversity and sustainable cities have encountered resource constraints and ineffective government actions (Shibata et al. 2015; WHO 2017; UN-HABITAT 2018). Insufficient urban land tenure regularisation in RMBS cities corroborates VN's 'invisible' growth and exerts negative impacts on transforming the urban environment and public health in SSEC waters and sediments. It is of great complexity to study a natural phenomenon that intensifies due to anthropic activities' interference in coastal environments, especially those that cause eutrophication. The potentially harmful impact portrays this complexity, avoiding an alarmist attitude. We cannot avoid this phenomenon, but we must minimise its causes for maintaining tourism, fishing and improving public health.

Sixty-five percent of the area (Baixada Santista) is occupied by areas of permanent environmental preservation (APPs) with mangroves, *restingas* and forests in rugged mountains (https://www.diariodolitoral.com.br/cotidiano/baixada-tem646-do-territory-in-preservation-area/122420/). Permanent environmental preservation is defined by the Brazilian Forest Code (Law No. 12,651 of May 25, 2012) as untouchable areas, where it is not allowed to build, cultivate or economically exploit. For it to exist, it is enough that the geographical condition is met, regardless of the domain of the existing area or vegetation. The limits of the areas of permanent environmental preservation (APPs), which should be strictly monitored, are, in practice, abandoned as a result of the scrapping policy of the inspection bodies (Oliveira et al. 2020). The result is constant invasions, rapidly increasing the vulnerable population and causing conflicts between public institutions, where investments by the concessionaires in infrastructure works are prevented by legal uncertainty, resulting from the condition of a permanent preservation area. Therefore, it is necessary to change the current environmental management system so as to allow human activities integrated with the responsibility of maintaining processes, phenomena and riverside resources. In other words, we must encourage the concession of riverside resources within management plans with guidelines and responsibilities to conserve water and the environment.

Conclusion

The geometric rate of annual growth of the population in non-conforming housing ($GAGR_{NH}$) is approximately five times higher than that of the compliant population in the Baixada Santista Metropolitan Region (BSMR). It exceeds all world growth rates, even in the poorest regions of Latin America and sub-Saharan and West Africa.

The vulnerable nuclei (VN) growth clusters show that 85% of the VN result from invasions, reinvasions, densification and verticalisation, while 15% represent the government's areas' demobilisation actions, without actions to recover degraded areas.

The release of sewage in the Santos and São Vicente Estuarine Complex (SSEC) by the study area group (SAG) exceeds 450 tonnes $\cdot$ month^{-1} and a flow of 2,650,000 m^3 $\cdot$ month^{-1}, and the negative impacts from the release and disposal of waste on the banks of water bodies pose risks to public health.

Estuary hydrodynamics do not promote the renewal of SSEC waters and turn its water into a large receptacle for sewage and emerging pollutants. As this is a port region, the contamination of these water bodies has potential risks of contamination and the spreading of diseases worldwide.

A comparison of these historical data clearly shows the escalation of nutrient entry into SSEC and increased concentrations associated with the growth of informal populations in the Santos metropolitan region beyond the limit of the estuarine system's carrying capacity, revealing the enormous pressure on the ecosystem.

The results show accelerated degradation of ecosystems, damage to public and environmental health, and potential risks of spreading disease in SSEC.

The re-urbanisation of the area using economic resources caused by the loss of water must be taken to reduce the risks of ecosystem degradation, damage to health and the spread of diseases.

This study has great potential to solve problems of urbanisation and sanitation in slum areas using resources from the economy generated by non-waste of treated water in irregular distribution. In a global scenario, this proposal could also be used in other regions of irregular housing in Brazil, and even studies of this nature in other parts of the world in less developed countries can lead to similar results and, consequently, solve water contamination problems.

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Annex A. Territorial and housing growth in VN in the studied area.

Id	UTM (E;S)	County	VN	Area – 2005 (m^2)	HD 2005	Area – 2018 (m^2)	HD 2018	$GAGR_{NH}$ (%/a.a)	$GAGR_m{}^2$ (%/a.a)
1	352,171; 7,355,944	Cubatão	Vila Esperança	655,700	2,534	827,979	1,342	−4.77%	1.81%
2	354,036; 7,356,544	Cubatão	Costa Muniz	177,500	401	58,848	0	−100.00%	−8.14%
3	357,356; 7,353,247	Cubatão	V, Pescadores	2,877,100	1,520	282,143	1,064	−2.71%	−16.36%
4	351,666; 7,358,099	Cubatão	Pinhal do Miranda	289,900	1,118	178,154	204	−12.27%	−3.68%
5	355,328; 7,358,445	Cubatão	Beira Rio	0	0	8,555	40	1.43%	1.43%
6	353,475; 7357,148	Cubatão	Vila Noel	0	0	36,219	161	1.43%	1.43%
7	354,069; 7,352,270	Cubatão	Ilha Caraguata (*)	25,200	101	23,016	124	1.59%	−0.69%
8	351,701; 7,354,366	Cubatão	Vale Novo	0	0	33,977	70	1.43%	1.43%
9	371,803; 7,347,426	Guarujá	Morro da Cachoeira	47,600	113	118,224	879	17.09%	7.25%
10	372,895; 7,348,238	Guarujá	V, Edna/Selma (*)	141,500	1,025	330,442	1,631	3.64%	6.74%
11	372,663; 7,347,696	Guarujá	Vila Zilda (*)	152,300	692	187,999	952	2.48%	1.63%
12	371,578; 7,347,426	Guarujá	Cachoeira (*)	333,000	2,574	354,186	2,094	−1.58%	0.48%
13	367,440; 7,345,505	Guarujá	S,C,Navegantes (*)	200,000	867	216,434	1,268	2.97%	0.61%
14	369,025; 7,345,200	Guarujá	V,Ligia (*)	88,000	746	135,823	875	1.23%	3.39%
15	369,541; 7,346,461	Guarujá	Vila Funchal I e II	0	0	18,157	174	1.43%	1.43%
16	370,508, 7,346,983	Guarujá	Mangue Seco I e II	54,700	220	61,668	371	4.10%	0.93%
17	369,809; 7,344,955	Guarujá	LAS PALMAS	28,700	51	117,179	286	14.18%	11.43%
18	369,250 ; 7,347,791	Guarujá	Sitio Conceiçãozinha	251,700	1,083	216,780	2,865	7.77%	−1.14%
19	369,150; 7,353,976	Guarujá	Monte Cabrão	56,300	70	36,636	74	0.43%	−3.25%
20	366,852; 7,354,530	Guarujá	Ilha Diana (Santos)	18,500	54	24,593	98	4.69%	2.21%
21	366,926; 7,351,960	Guarujá	Santense	6,600	43	2,063	90	5.85%	−8.56%
22	366,272; 7,345,243	Guarujá	Praia do Góes	34,700	72	34,044	255	10.22%	−0.15%
23	372,238; 7347,471	Guarujá	M,Engenho (*)	200,800	724	96,717	775	0.53%	−5.46%
24	367,237; 7,350,687	Guarujá	Prainha (*)	344,700	1,394	427,672	4,043	8.54%	1.67%
25	367,737; 7,350,122	Guarujá	Marezinha (*)	104,800	549	108,853	713	2.03%	0.29%
26	369,250; 7,352,352	Guarujá	Vargea Gde (*)	0	0	55,748	141	1.43%	1.43%
27	368,724; 7,352,046	Guarujá	Favela do Caixão	55,800	519	49,697	1,593	9.01%	−0.89%

Id	UTM (E;S)	County	VN	Area – 2005 (m^2)	HD 2005	Area – 2018 (m^2)	HD 2018	$GAGR_{NH}$ (%/a.a)	$GAGR_{m^2}$ (%/a.a)
28	369,457; 7,352,130	Guarujá	Santa Madalena	50,100	295	19,850	69	−10.57%	−6.87%
29	369,076; 7,351,376	Guarujá	Vila do Padre	14,500	112	30,851	71	−3.45%	5.98%
30	369,183; 7,351,072	Guarujá	Atlântica	0	0	89,573	344	1.43%	1.43%
31	369,411; 7,350,801	Guarujá	Área Verde	0	0	64,191	757	1.43%	1.43%
32	369,498; 7,350,937	Guarujá	N,Republica (*)	30,400	189	74,243	330	4.38%	7.11%
33	369,721; 7,350,436	Guarujá	T, Acaraú (*)	41,800	183	114,735	362	5.39%	8.08%
34	369,892; 7,350,251	Guarujá	Chaparral (*)	87,000	519	86,634	546	0.39%	−0.03%
35	370,162; 7,349,928	Guarujá	República	0	0	44,808	257	1.43%	1.43%
36	370,005; 7,349,703	Guarujá	Rubro Negro	0	0	15,414	80	1.43%	1.43%
37	372,238; 7347,471	Guarujá	M,Engenho (*)	200,800	724	96,717	775	0.53%	−5.46%
38	358,191; 7,353,923	Santos	V, Criadores (*)	52,500	177	77,979	178	0.04%	3.09%
39	358,838; 7,351,402	Santos	V,Gilda (*)	242,700	1,249	302,807	2,521	5.55%	1.72%
40	361,203; 7,352,804	Santos	V, Alemoa (*)	119,900	768	105,480	559	−2.41%	−0.98%
41	360,911; 7,352,779	Santos	V, Alemoa 2 (*)	0	0	95,310	468	1.43%	1.43%
42	362,351; 7,352,311	Santos	S, Maria - gleba I e II	186,700	459	65,966	238	−4.93%	−7.69%
43	359,669; 7,352,179	Santos	Ilheu Baixo (*)	0	0	54,021	74	1.43%	1.43%
44	361,615; 7,352,375	Santos	Chico de Paula (*)	11,700	61	1,496	48	−1.83%	−14.63%
45	361,540; 7,352,251	Santos	Igreja (*)	0	0	9,147	92	1.43%	1.43%
46	361,369; 7,351,767	Santos	Cam,Part, S,Jorge (*)	0	0	11,433	57	1.43%	1.43%
47	361,032; 7,351,226	Santos	Vila Ayrton Senna	0	0	10,873	71	1.43%	1.43%
48	359,203; 7,353,017	Santos	Jd, Bom Retiro (*)	0	0	68,120	65	1.43%	1.43%
49	359,542; 7,352,940	Santos	Lot, S,Manoel (*)	0	0	148,857	289	1.43%	1.43%
50	363,098; 7,352,460	Santos	Cam, Maria Rosa (*)	0	0	1,487	54	1.43%	1.43%
51	363,894; 7,352,491	Santos	Pacheco (*)	99,100	459	201,161	1,010	6.25%	5.60%
52	363,119; 7,352,625	Santos	Penha (*)	0	0	1,676	63	1.43%	1.43%
53	362,486; 7352,498	Santos	Pantanal (*)	59,100	320	78,047	819	7.50%	2.16%
54	359,313; 7,352,562	Santos	S,Manoel (*)	115,000	333	81,895	669	5.51%	−2.58%
55	358,378; 7,351,880	S,Vicente	Sambaiatuba (*)	336,500	810	319,237	4,050	13.18%	−0.40%

Id	UTM (E;S)	County	VN	Area – 2005 (m^2)	HD 2005	Area – 2018 (m^2)	HD 2018	$GAGR_{NH}$ (%/a.a)	$GAGR_m{}^2$ (%/a.a)
56	348,685; 7,345,198	S,Vicente	Fazendinha (*)	0	0	843,962	2,947	1.43%	1.43%
57	357,551; 7,350,217	S,Vicente	Começa (b)	0	0	15,689	802	1.43%	1.43%
58	356,468; 7,347,982	S,Vicente	México 70 (*)	625,400	3,216	737,058	4,795	3.12%	1.27%
59	351,905; 7,347,424	S,Vicente	Quarentenário Publ,	722,500	1,522	690,601	1,178	−1.95%	−0.35%
60	351,149; 7,346,496	S,Vicente	Rio Negro (*)	482,900	272	682,454	1,525	14.18%	2.70%
61	352,667; 7,349,766	S,Vicente	Vila Feliz	23,100	202	59,145	1,293	15.35%	7.50%
62	359,256; 7,350,595	S,Vicente	Miau	0	0	28,949	598	1.43%	1.43%
63	358,756; 7,350,726	S,Vicente	Charme (a)	0	0	63,838	2,124	1.43%	1.43%
64	357,122; 7,351,254	S,Vicente	Dq Caixeta (*)	181,500	814	158,896	2,624	9.42%	−1.02%
65	357,004; 7,351,005	S,Vicente	Dique do Fátima	24,000	149	29,756	1,690	20.54%	1.67%
66	357,182; 7,349,308	S,Vicente	Fepasa (*)	24,400	164	25,128	1,091	15.69%	0.23%
67	352,454; 7,350,385	S,Vicente	V,Nova Mariana (*)	36,200	94	88,225	635	15.83%	7.09%
68	358,276, 7,350,041	S,Vicente	Sá Catarina Moraes	112,200	680	122,538	1,261	4.87%	0.68%
69	358,441; 7,346,206	S,Vicente	Japuí	0	0	49,500	411	1.43%	1.43%
70	358,031; 7,349,821	S,Vicente	V,S,Bernardo (*)	0	0	18,330	339	1.43%	1.43%
71	358,378; 7,351,880	S,Vicente	Rio d'Avó	61,200	340	184,499	945	8.18%	8.86%
72	360,661; 7,349,014	S,Vicente	Carrefour (Horto)	0	0	8,337	116	1.43%	1.43%
73	360,991; 7,349,339	S,Vicente	Bananal (Horto)	0	0	15,178	251	1.43%	1.43%
74	350,670; 7,347,240	S,Vicente	Jd, Rio Branco	0	0	71,370	367	1.43%	1.43%
Total – Study area				9,885,500	29,857	10,144,527	61,385	5.70%	0.20%
RMBS					54,343		116,941	6.59%	

GAGR – geometric annual growth rate; $GAGR_{NH}$ – geometric rate of annual growth of the population in non-conforming housing; HD – human dwellings; VN – vulnerable nuclei.
Source: AGEM 2005; SABESP 2018, adapted by the author, 2018.
Note: (*) VN grouped by two or more occupied areas.

Annex B: Irregular Housing Count in RMBS

Division of Loss Control of SABESP in 2008 performs irregular area mapping with the help of a drone.

The RMBS has highlighted activities developed in the nine municipalities that seek to reduce the lost water index and loss control in the Business Unit, contributing to its revenue increase. One of the jobs that we highlight in the opportunity is the strong performance of the Baixada Santista Loss Control Division (RSOP) in VN, which are occupied without land regularisation, supporting the recovery of the volume of social use—that is, unbilled consumption.

The unit innovated in the mapping of common areas where water theft is a chronic issue with the help of a drone (operated equipment with a camera attached), and it is possible to photograph 599 irregular areas throughout the Metropolitan Region of Santos—RMBS, from above; this area includes 116,941 irregular dwellings according to a survey conducted from April to December 2018.

Using drones in the locations considered to be at risk due to violence facilitates community growth monitoring while preserving its employees' integrity.

City	VN (qty)	Number of irregular dwellings * (qty)	Examples
Bertioga	46	8,525	Boraceia
Cubatão	8	2,935	Vila Esperança
Guarujá	73	39,345	Cachoeira
Itanhaém	29	4,985	Iemanjá
Mongaguá	27	2,910	Cachoeira V. São Paulo
Peruibe	7	658	Recreio Santista
Praia Grande	53	12,772	Samambaia
Santos	120 + 206 tenements	15,732	Dq.Vila Gilda, Pantanal
São Vicente	30	29,079	Fazendinha
RMBS	599	116,941	

VN – vulnerable nuclei. *Number of irregular dwellings = Total number of dwellings in irregular areas − number of active water connections in irregular areas.