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FULL PAPER

Water Quality Evolution of Rio de Janeiro City Beaches

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Abstract:

Rio de Janeiro city is famous worldwide for its beaches. Therefore, it is necessary to analyze the monitoring of water quality data, since the pollution is a risk to the population health. It was made a temporal evolution analysis of the recreational water quality of Rio de Janeiro city main beaches. Thermotolerant Coliforms' (TtC) data collected by the Instituto Estadual do Ambiente (INEA) from 1995 to 2015 were related with the CONAMA 274/2000 Resolution limits criteria. It was observed that Barra da Tijuca western portion, Leblon, Ipanema, Arpoador, Copacabana, Leme, Vermelha and Urca beaches showed an overall improvement of their water quality conditions over the analyzed period. São Conrado and the eastern corner of Barra da Tijuca beach have shown worsening. Joatinga beach remained stable. Flamengo and Botafogo beaches showed variable conditions over time, but always presenting poor water quality conditions. It was verified that the determining factors for a beach having inappropriate water quality were the existence of canals that dump sewage and urban runoffs. Another relevant factor was the location of beaches within the confined and polluted waters of Guanabara Bay. This study can be used as a useful tool for a more efficient management for urban beaches.

Keywords: coastal management; Guanabara Bay; recreational water quality; sewage; thermotolerant coliforms; urban pollution

1. Introduction

Rio de Janeiro is a coastal city with a population of approximately 6.5 million inhabitants. It's the second most populous city in Brazil, where 83.1% of the residences are connected to sewage systems but only 44.5% of the generated sewage receives treatment [1]. This means that sewage of about 3.6 million people is dumped without any kind of treatment in the water bodies of the city, including rivers, canals, lagoons, coastal bays and sea, potentially affecting the beaches.

Beaches in Rio de Janeiro can be classified into oceanic or inner water beaches. Oceanic beaches are faced towards the open sea, while inner water beaches are located inside bays. The Urca, Botafogo and Flamengo inner water beaches are located inside Guanabara Bay, being more protected from waves and currents, and possessing less water renovation ability. Due to their location, these inner beaches end up being indirectly contaminated by the pollution of other cities surrounding the bay. However, as there is discharge of untreated sewage directly on these beaches, the influence of this direct pollution is much higher than the influence of the polluted waters of Guanabara Bay. The oceanic beaches have greater hydrodynamics, which makes the dispersion of pollution to the open sea easier. Thus, these oceanic beaches recover more quickly after an event that causes a worsening of their water quality indexes, such as caused by rains due to urban runoff.

Guanabara Bay had 11.5 million inhabitants in 2012. From them, 57.5% is covered by sewage systems but only 35.9% of the generated sewage received some kind of

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treatment, being the majority of the sewage collected and treated from Rio de Janeiro city [2]. All cities surrounding Guanabara Bay, with the exception of Niterói city, have much lower percentages of sewage treatment, as shown in Table 1.

Table 1. Sewage treatment in percentage for every city surrounding Guanabara Bay [2].

City	Sewage Treatment (%)
Rio de Janeiro	49.4%
Nilópolis	0.0%
Mesquita	7.0%
São João de Meriti	0.0%
Belford Roxo	23.9%
Nova Iguaçu	0.4%
Duque de Caxias	10.5%
Magé	0.0%
Cachoeira de Macacu	0.0%
Rio Bonito	0.0%
Tanguá	0.0%
Itaboraí	2.9%
São Gonçalo	9.8%
Niterói	100.0%
Baía de Guanabara	35.9%

There are many sewage connections in canals and rainwater network and even in sewage treatment plants the treatment is only preliminary or primary, or a few times secondary, with a small part of this sewage discharged through submarine outfalls [3]. It results in poor water quality conditions, which can cause several environmental impacts [4].

Therefore, Rio de Janeiro beaches are potentially vulnerable to water contamination by untreated sewage. Contact or ingestion of this seawater can cause various diseases, such as gastroenteritis, diarrhea, infections, cholera, typhoid fever, botulism and hepatitis [5]. Children are more vulnerable as well as individuals with low immunity, which can be caused by diseases, genetic predisposition, age, pregnancy, lack of acquired immunity to local endemic diseases (e. g. tourists), among others [6]. Since Rio de Janeiro beaches are visited by millions of people every year, including a great number of tourists, beaches contamination could lead to a major public health problem.

The CONAMA Resolution No. 274/2000 defines the criteria for recreational water quality conditions in Brazil [7] according to the density of organisms that indicate water contamination by feces. These organisms indicate the presence of human pathogens in the water, being greater the risk to get a disease as the higher the density of these indicators. According to this resolution, three different groups of indicator organisms can be used: thermotolerant coliforms (TtC), enterococci and *Escherichia coli*. Thermotolerant coliforms (previously referred as fecal coliforms) are gram-negative bacteria present in human and homoeothermic animals feces, but also occur in soils, plants and organic matter that have not been contaminated by feces [7, 8]. Enterococci are bacteria that belong to the genus *Enterococcus*, in which most of the species originate from human feces [7]. *Escherichia coli* are the only thermotolerant coliforms that live exclusively in the human and homoeothermic animals' intestine, where they occur in abundance [8]. Since this species survives for a very limited time outside the host body, their presence in the water indicates a recent fecal contamination [7].

The CONAMA Resolution No. 357/2005 establishes as primary contact recreation when the bather has direct and prolonged contact with water, such as in the activities of sea bathing, swimming and diving, where the possibility of water ingestion is high. Secondary contact recreation is defined as one in which contact with water is sporadic or accidental and the chance of ingesting water is low, as in fishing and navigation activities. The limit of TtC density for primary contact is 1,000 MPN.100mL^{-1} and for secondary contact is 2,500 MPN.100mL^{-1}. According to this resolution a beach is considered suitable for bathing if 80% or more of a set of five samples obtained in the last five weeks of collection have presented at maximum 1,000 MPN.100mL^{-1}.

In Rio de Janeiro State, water quality monitoring is performed by Instituto Estadual do Ambiente (INEA - State Environmental Institute) using thermotolerant coliforms and enterococci collected data as indicators. Data of TtC have a longer period of monitoring available (1995-2015), while the monitoring using enterococci data only started in 2011.

This paper aimed to analyze water quality conditions of Rio de Janeiro city main beaches between 1995 and 2015 using TtC data collected by INEA. The analysis of temporal series of these monitoring data is important to evaluate the evolution of the water quality conditions of beaches over time.

2. Results and Discussion

The water quality conditions result for each analyzed beach in the present study will be shown in two figures, relating the results found in this study with CONAMA's limit of TtC density for primary contact (1,000 MPN.100mL^{-1}) and secondary contact (2,500 MPN.100mL^{-1}).

From 1995 until 2002 INEA's monitoring of water quality of the beaches of Rio de Janeiro city collected samples only once a week or less, with a mean of 40 to 50 samples per year. In 2002, INEA started sampling twice a week and with more regularly spaced sampling, increasing the monitoring accuracy. Table 2 shows the quantity of data analyzed for each sample location and the total for its respective beach.

Table 2. Quantity of samples analyzed for the sample locations of each studied beach.

Beach	Sample location	Quantity of samples	Latitude	Longitude
Barra da Tijuca	BD003	1262	23º00'45.90"	43º22'47.98"
	BD005	1388	23º00'42.62"	43º21'54.78"
	BD007	1257	23º00'42.09"	43º20'06.54"
	BD009	1254	23º00'57.33"	43º18'15.04"
	BD010	1239	23º00'55.50"	43º17'53.00"
	Total	**5138**	-	-
Joatinga	JT000	387	23º00'53.24"	43º17'21.73"
	Total	**387**	-	-
São Conrado	PP010	1648	23º00'04.50"	43º16'10.00"
	GV001	697	23º00'00.02"	43º15'27.10"
	GV002	1660	22º59'57.31"	43º15'12.55"
	Total	**4005**	-	-
Leblon	LB000	1653	22º59'21.00"	43º13'35.00"
	LB003	1651	22º59'15.50"	43º13'02.00"
	Total	**3304**	-	-
Ipanema	IP003	1648	22º59'15.00"	43º12'51.00"
	IP006	1653	22º59'15.00"	43º12'33.50"
	IP010	1644	22º59'15.48"	43º12'18.24"
	Total	**4955**	-	-
Arpoador	AR000	1583	22º59'22.00"	43º11'30.00"
	Total	**1583**	-	-
Copacabana	CP004	1581	22º58'56.24"	43º11'20.02"
	CP005	1656	22º58'27.46"	43º11'03.46"
	CP008	1651	22º58'12.67"	43º10'46.08"
	Total	**4888**	-	-
Leme	LM002	1538	22º57'50.63"	43º10'02.83"
	TOTAL	**1538**	-	-
Vermelha	VR000	1568	22º57'19.08"	43º09'51.77"
	Total	**1568**	-	
Urca	UR000	1563	22º56'52.24"	43º09'48.76"
	TOTAL	**1563**	-	-
Botafogo	BT000	1640	22º56'40.47"	43º10'47.45"
	BT001	695	22º56'53.43"	43º10'48.93"
	Total	**2335**	-	-
Flamengo	FL000	577	22º56'06.67"	43º10'15.71"
	FL004	1573	22º55'44.56"	43º10'14.20"
	Total	**2150**	-	-

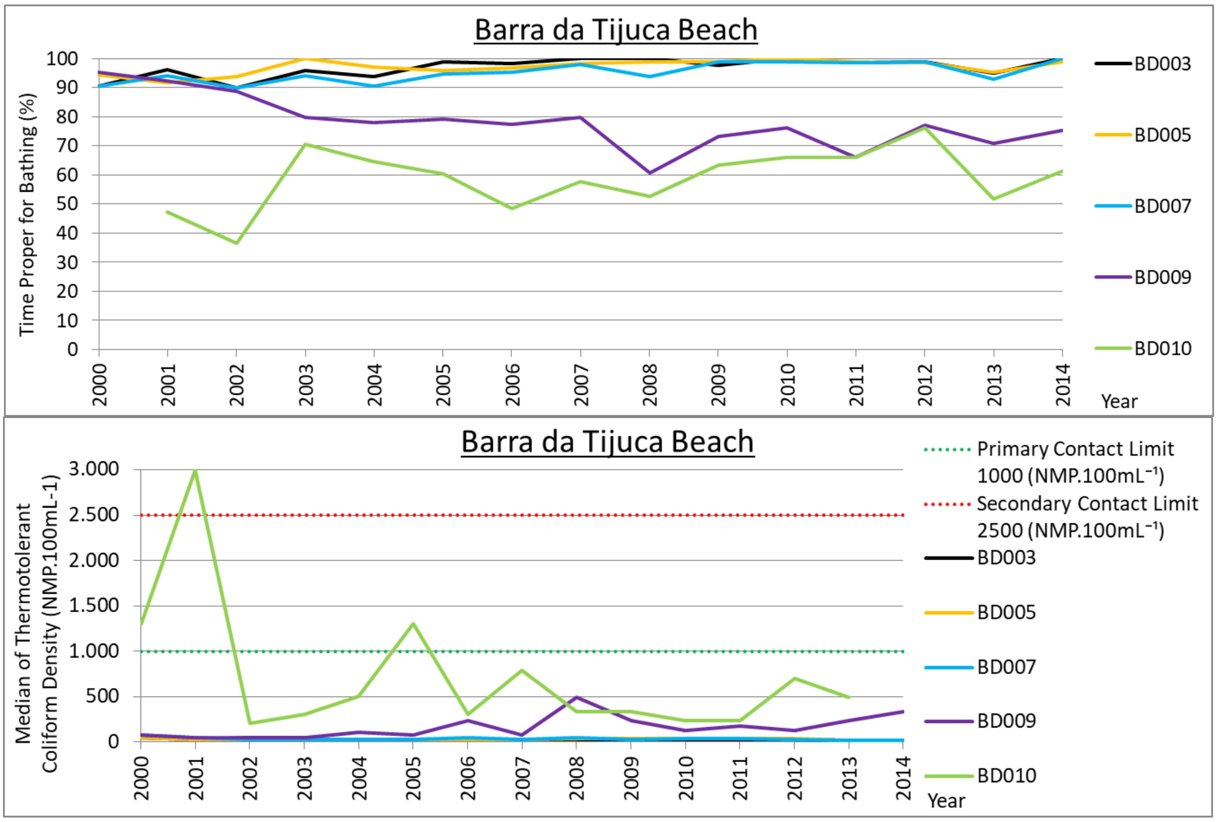

Figure 1. Recreational water quality evolution of the Barra da Tijuca beach. The first graph shows the percentage of time the sampling location was proper for bathing (TtC density < 1,000 MPN.100mL^{-1}). Each value represents water quality conditions showed by the sampling location over a year. The second graph shows the annual median of TtC density in MPN.100mL^{-1} in the analyzed period. Each median represents the year mean condition of water quality in a sampling location.

Barra da Tijuca beach (Figure 1) had the highest variation of water quality conditions along its extension. Sampling locations BD003, BD005 and BD007 (end of Reserva to Posto 5) had a considerable stability of good water quality indexes over the analyzed period, remaining in the range of 90% to 100% of the time proper for bathing, always with median of TtC density below 100 MPN.100mL^{-1}. Sampling location BD009 (Pepê), from 2000 to 2002, had water quality results as good as the extension of Reserva to Posto 5. After 2003, BD009 showed significant worsening results, even reaching 60% of the time being proper for bathing. Sampling location BD010 (Quebra-mar) showed variable conditions over time, with short periods of improvement or worsening, but always having a low standard value, currently with about 60% of the time proper for bathing.

The poor water quality indexes of sampling location BD010 (Quebra-mar) can be explained by the influence of the polluted waters of Joatinga Canal. This canal connects the Jacarepaguá Lagoon Complex to the sea and receives the overwhelming majority of the untreated sewage produced in the basin of Baixada de Jacarepaguá. Thus, the Joatinga Canal dumps a large amount of pollution into the sea, especially in rainy days when the urban runoff is greatly increased. The aggravating water conditions at sampling location BD009 (Pepê) can be explained by the increase of the pollution discharge by the Joatinga Canal. This increase was caused due to the population growth not followed by sewage collection and treatment in the region of Baixada de Jacarepaguá in the last two decades (1995 to 2015). On the other hand, sampling locations BD003, BD005 and BD007 (end of Reserva to Posto 5) do not appear to be influenced by the Joatinga Canal. This part of the beach showed excellent water quality conditions, having over 99% of the time proper for bathing during 2015. It is justified by most of the coastal area of Barra da Tijuca being covered by a sewage system and the existence of an Environmental Protection Area in the western region known as Reserva.

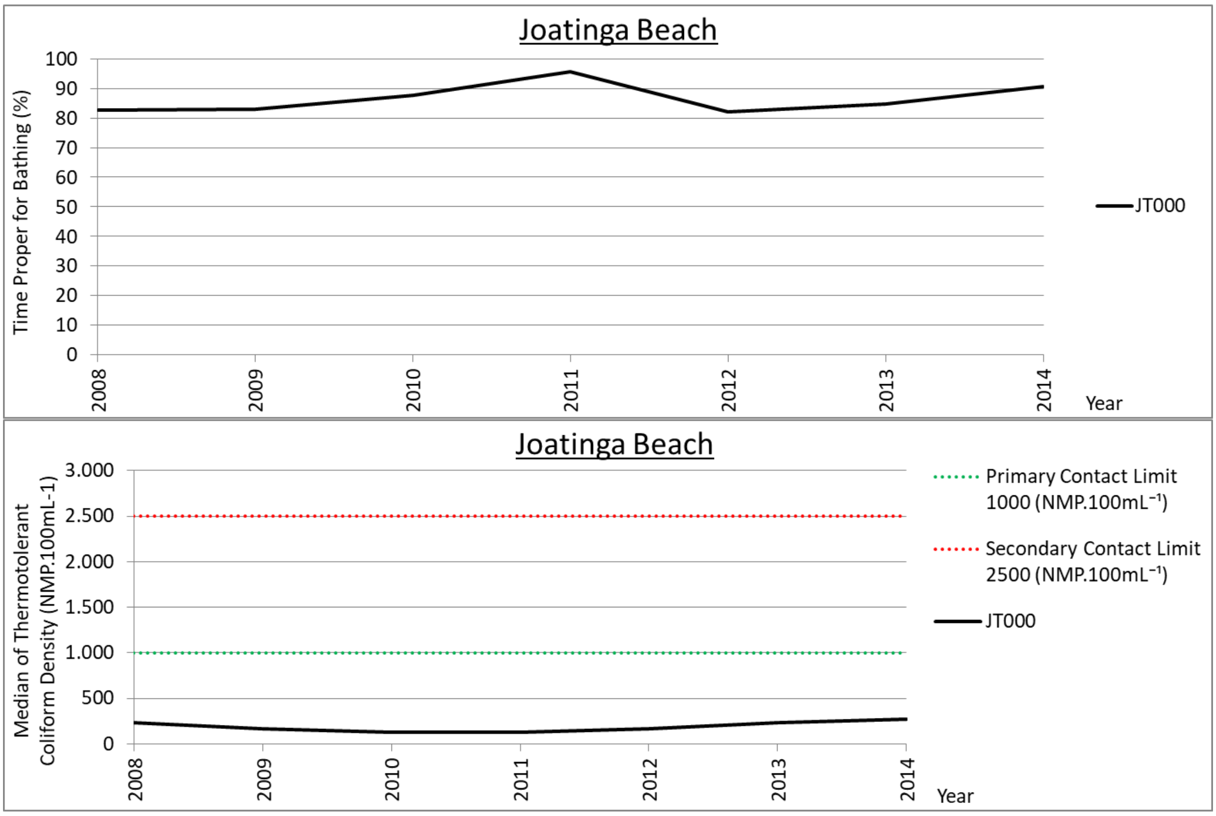

Figure 2. Recreational water quality evolution of the Joatinga beach.

Joatinga beach (Figure 2) had the highest stability in the analyzed period. Its water quality conditions were maintained always above 80% of the time proper for bathing and annual medians of TtC below 300 MPN.100mL^{-1}. However, the monitoring of this beach started only in 2008, totalizing just seven years of analysis, not being possible to notice worsening or improvement of water quality indices in this short period.

São Conrado beach (Pepino and Gávea) (Figure 3) showed a great improvement of the water quality between 1995 and 2002. In 1995, it was observed 45% to 50% of the time proper for bathing, which these indexes growing until to reach more than 90% in 2002. However, from 2003 to 2015 the indexes fell sharply. In 2015, sampling locations GV001 and GV002 (Gávea) showed their worst conditions during these 20 years, with only 25% to 30% of the time proper for bathing and with a mean density of 5,000 MPN.100mL^{-1}. Sampling location PP010 (Pepino) also suffered a worsening during this period. Therefore, it was in a much better condition than the other sampling locations of São Conrado beach, having 66% of the time proper for bathing in 2015.

São Conrado beach suffers a chronic problem of pollution with several illegal sewage connections to the urban runoff systems that exit in the beach. At the end of 2001, a detour was made in order to eliminate an undesired pollution stain in the eastern part of the beach, near sampling location GV002. The construction was useless in solving the poor water quality standards of the beach, once it only transferred the pollution to a less visible area. This canal dumps sewage produced in the Rocinha slum without any kind of treatment. In addition, especially during rainy days, this canal discharges into the sea a large amount of garbage.

At the end of 2005, a River Treatment Unit (RTU) was inaugurated in São Conrado. It was designed to treat the Rocinha Canal sewage during dry weather. However, São Conrado RTU remains months or even years out of operation, resulting in no improvements in the water quality indexes of the beach. Anywise, the RTU does not function during periods of rainfall, since these are designed to operate with dry time volumes.

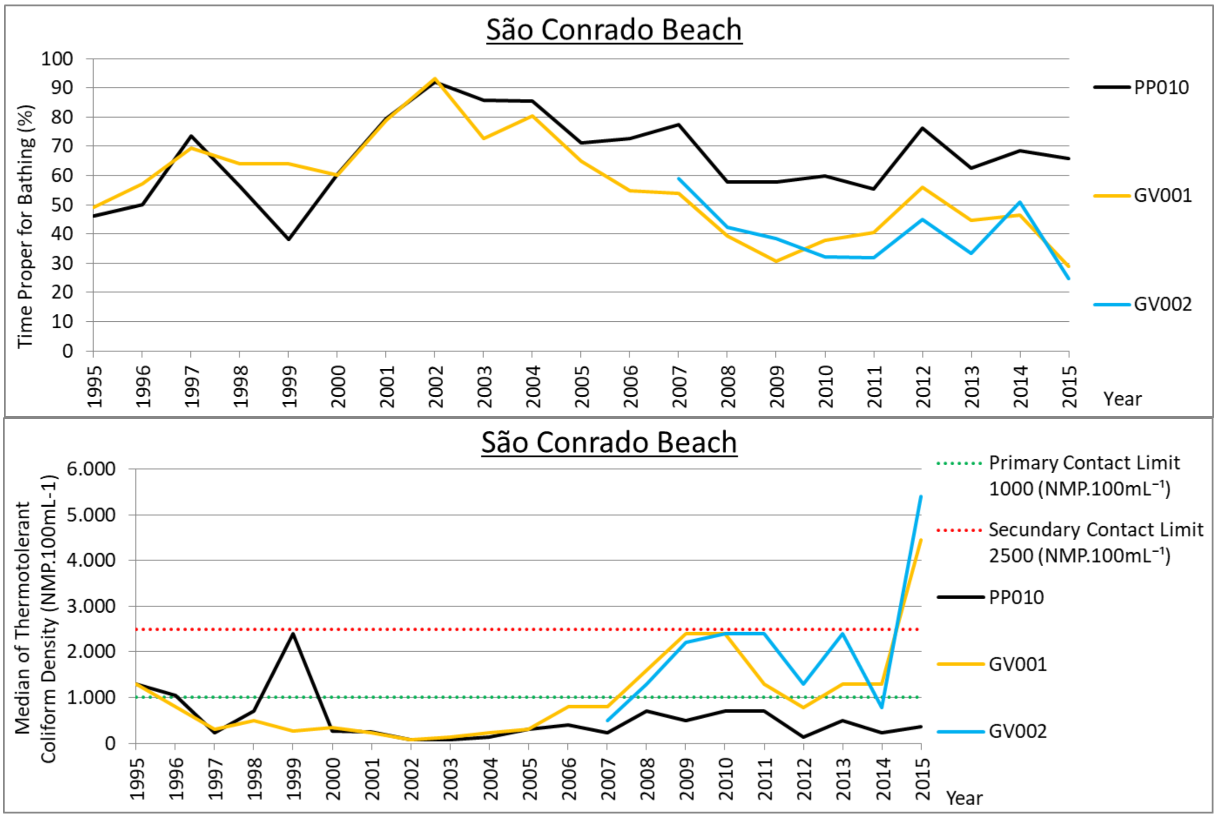

Figure 3. Recreational water quality evolution of the São Conrado beach.

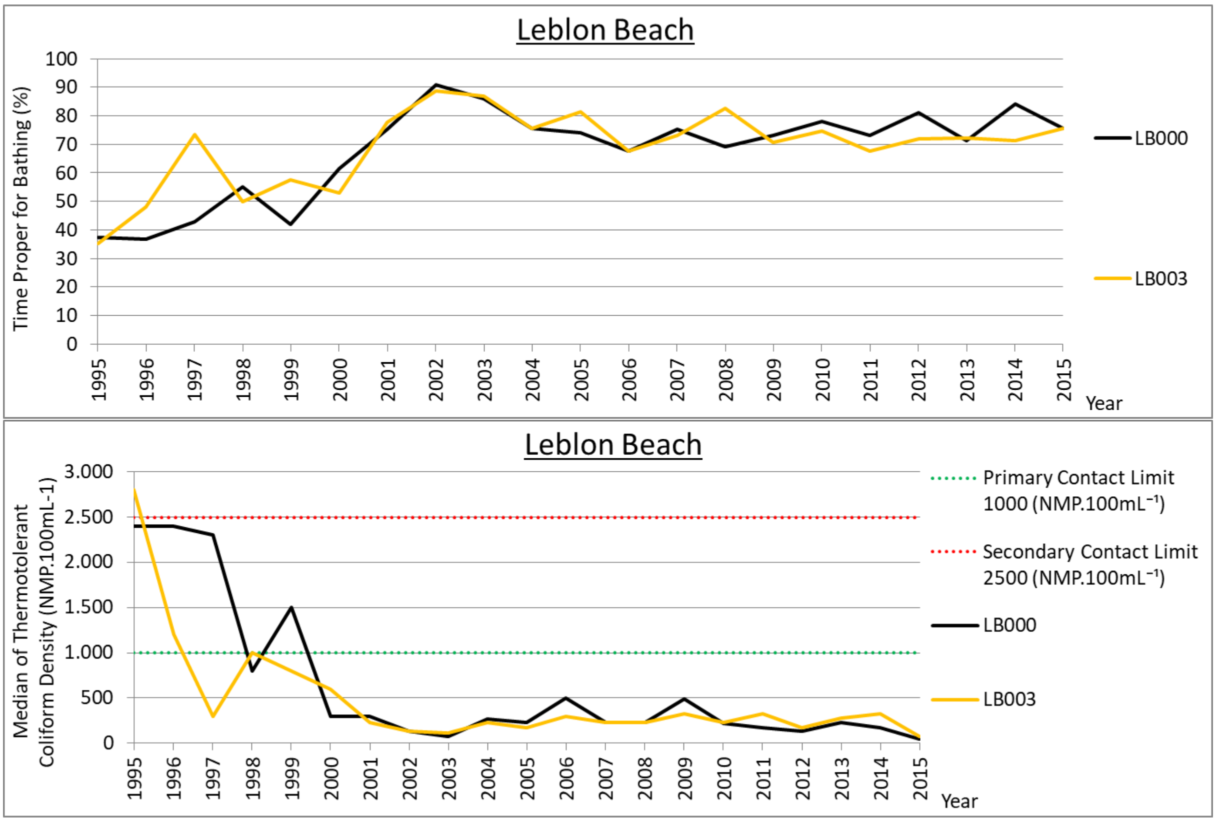

Figure 4. Recreational water quality evolution of the Leblon beach.

The oceanic beaches of the South Zone, which are Leblon (Figure 4), Ipanema and Arpoador (Figure 5), Copacabana and Leme (Figure 6) and Vermelha (Figure 7), showed a significant improvement in water quality conditions from 1995 to 2001/2003, followed by certain stability until 2015. This pattern can be explained by the large investments in sanitation infrastructure done in the area over the analyzed period. The removal of illegal sewage connections, the expansion and reform of the sewage system, refurbishment of Ipanema's submarine outfall, among other improvements, were fundamental in increasing the water quality conditions in these beaches.

Leblon beach had a great improvement of water quality conditions, being proper for bathing in about 70% to 80% since 2004 until 2015. Despite of the considerable improvement in the analyzed period, it could have better rates, but due to the pollution brought to the beach by the Jardim de Alah Canal, as well as the Visconde de Albuquerque Canal, Leblon continues to suffer from occasional sewage that is discharged through these canals.

Ipanema and Arpoador beaches remained in a good condition since 2001, with indexes around 80% to 95% (IP006, IP010 and AR000) of the time proper for bathing. IP003 has been experiencing worse conditions than other sampling locations since 2006, requiring more attention due its location close to the Jardim de Alah Canal.

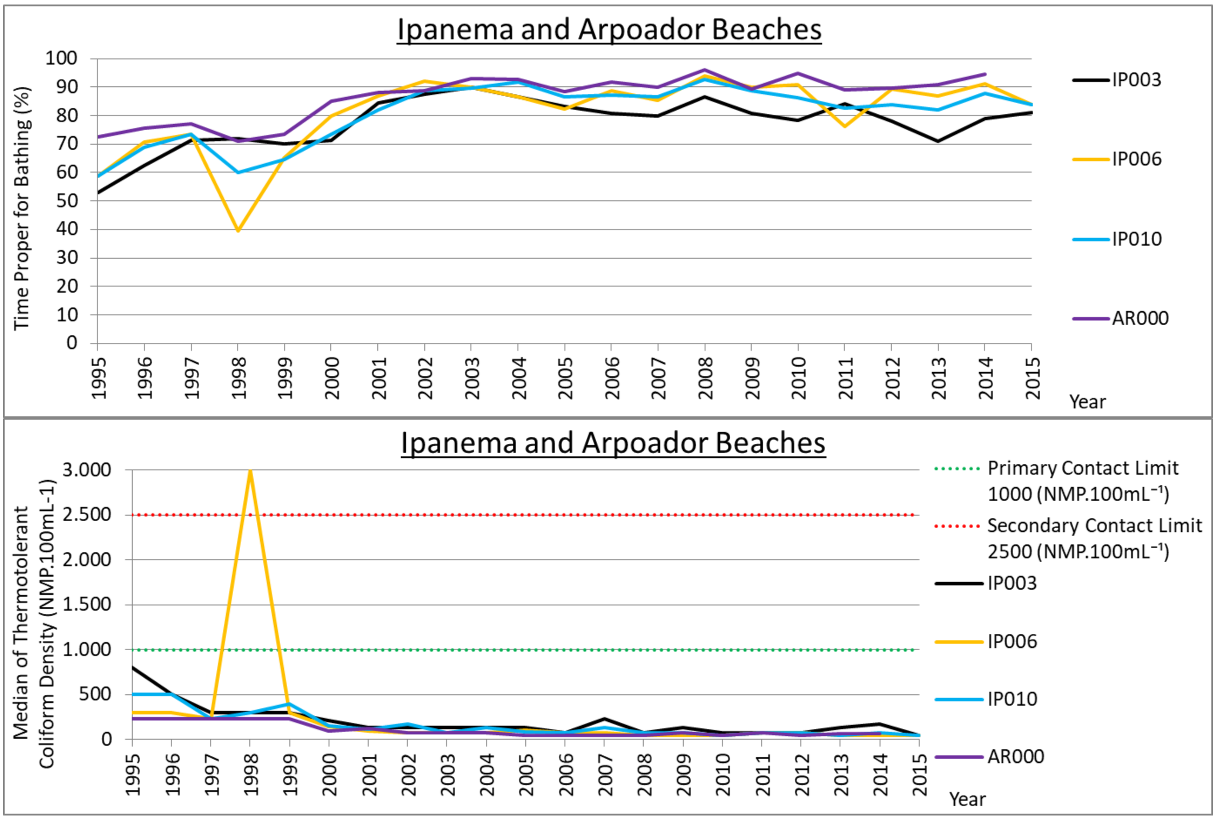

Figure 5. Recreational water quality evolution of the Ipanema and Arpoador beaches.

Copacabana beach maintained excellent water quality indexes in all sampling locations since 2001, with time proper for bathing around 90% to 100% during almost all of the analyzed period. Leme beach (LM002) showed the same pattern, except for the years 2011 and 2012, when it reached respectively 78% and 72% of the time proper for bathing, recovering its water quality conditions in the following years.

Vermelha beach had the best improvement during the analyzed period. In 1995, it had a median of TtC density above the limit for primary contact in only 45% of the time. In 2014, it reached 98% of the time proper for bathing, with an improvement of 53% over the analyzed period. That is explained by the implantation and recovery of sewage systems in the neighborhood region.

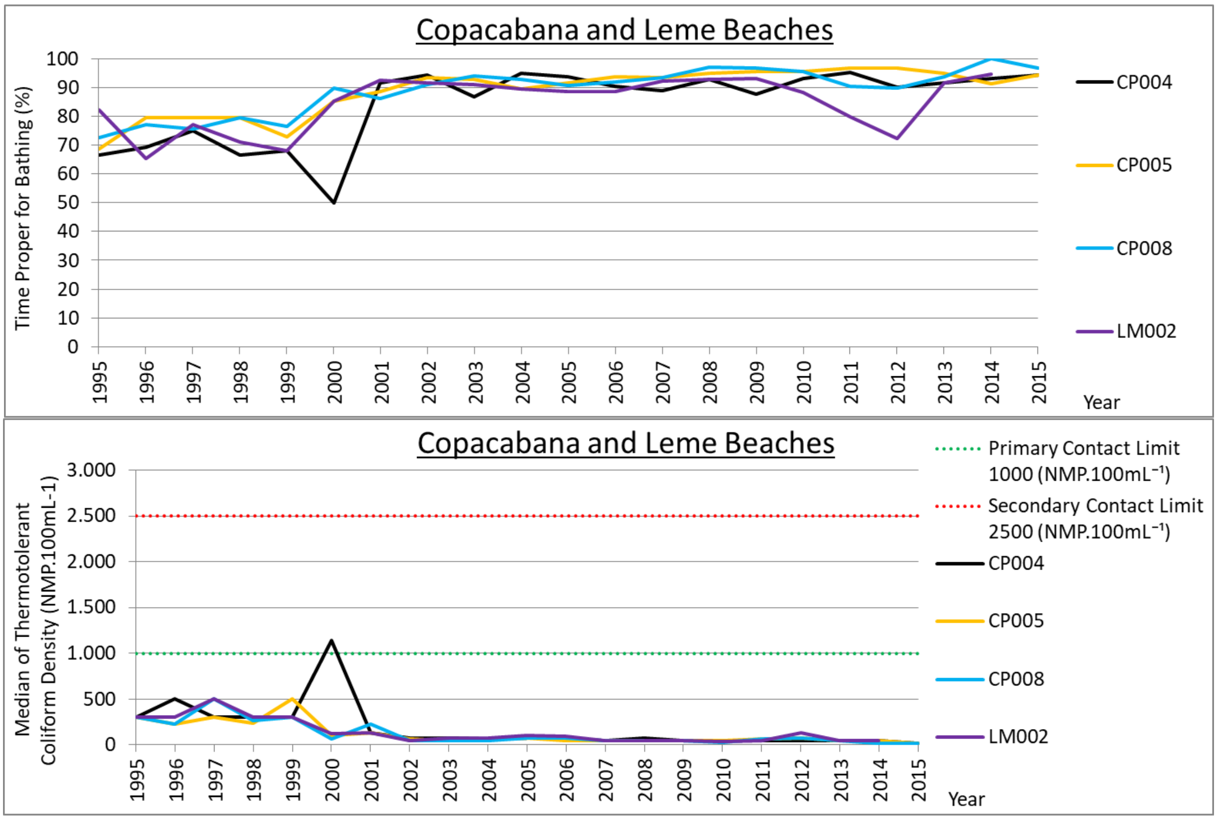

Figure 6. Recreational water quality evolution of the Copacabana and Leme beaches.

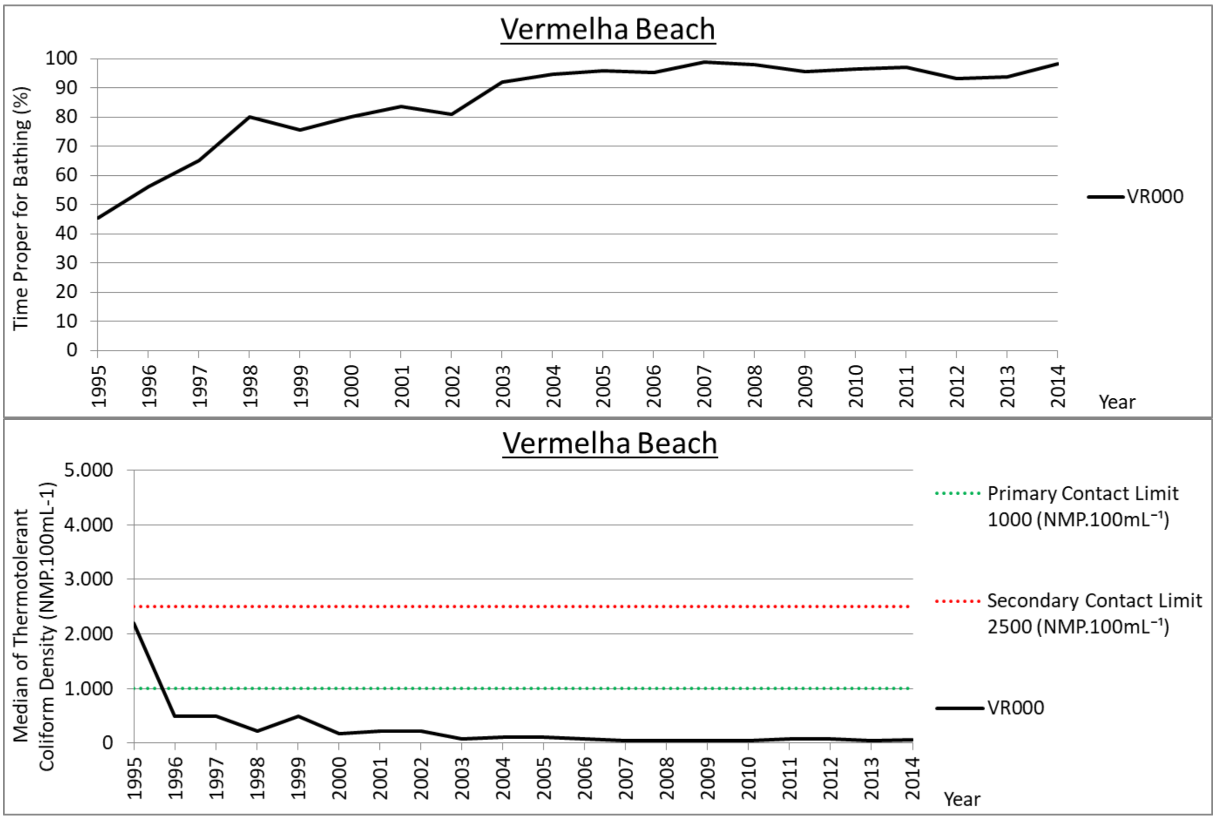

Figure 7. Recreational water quality evolution of the Vermelha beach.

Urca beach (Figure 8) showed an improvement in its water quality conditions over time, with an increase of about 15% of the time proper for bathing from 1995 to 2014. It was due to investments made in the sanitation infrastructure in the area. However, the beach continues to have poor water quality indexes, with only 40% of the time proper for bathing. This is justified by the direct discharge of sewage near Urca beach, in addition of its protected location inside Guanabara Bay, resulting in low water renewal.

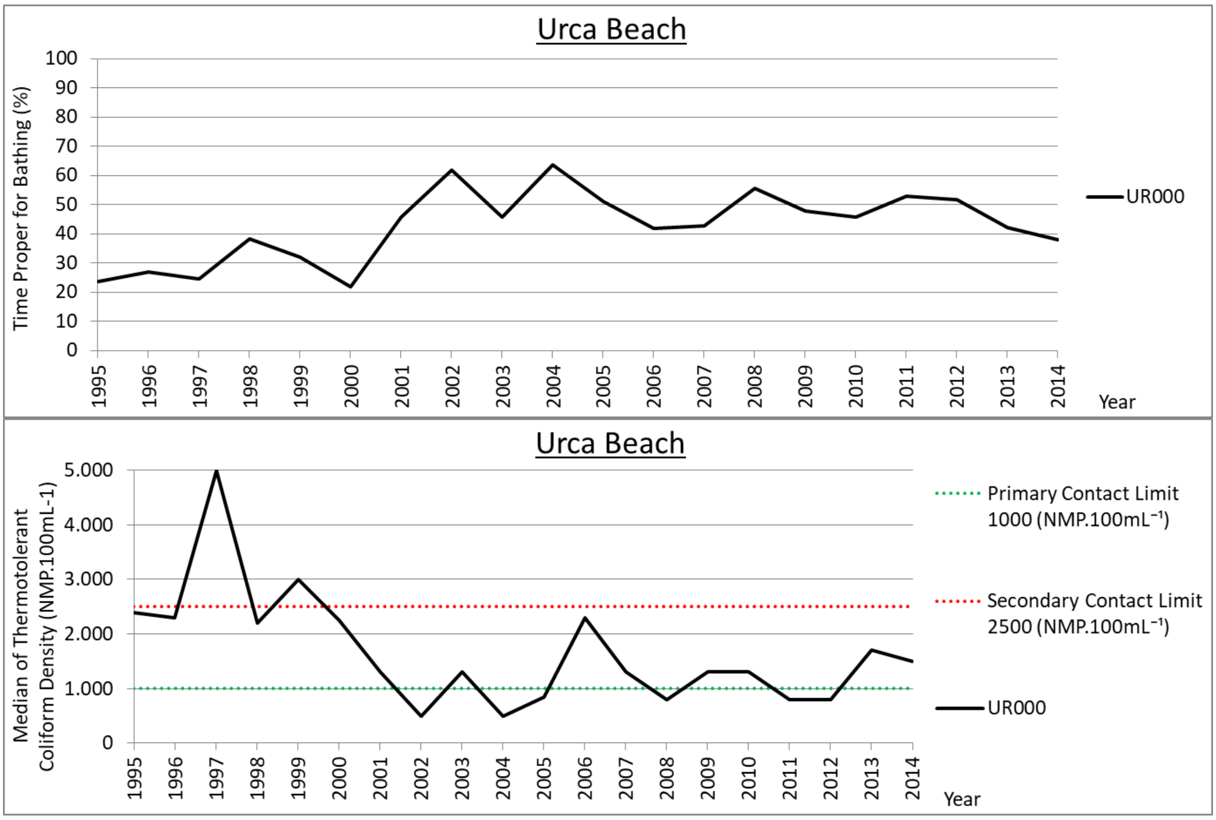

Figure 8. Recreational water quality evolution of the Urca beach.

Botafogo beach (Figure 9) showed the worst condition among all analyzed beaches. In 2015, it reached the mark of only 1% of the time proper for bathing. Botafogo beach situation is so critical that the median of TtC density peaked at 1 million MPN.100mL^{-1}, with maximum TtC densities reaching tens of millions of MPN.100mL^{-1}, which is comparable to the values found in the raw sewage. As of 2008, the median graph presents a fixed annual value of 16,000 MPN.100mL^{-1}, due the fact that INEA changed its methodology of TtC counting. In 2008 the TtC densities started to be determined only up to 16,000 MPN.100mL^{-1}. This change appeared only in the Botafogo graphs because this is the only beach with medians that exceed the value of 16,000 MPN.100mL^{-1}.

Botafogo beach has a drainage system that routes the sewage transported by underground canals that used to be rivers (Berquó and Banana Podre) to floodgates that dumps sewage into Botafogo's cove during rainy periods. These gates were installed to be closed in dry weather so the sewage could be led to Ipanema's submarine outfall. However, during rainy periods the floodgates are opened, dumping sewage and garbage carried by the urban runoffs of the region neighborhoods directly in the beach. In addition to being an inner waters beach of Guabanara Bay, the effects of low water renewal are further noticed by the confined waters of Botafogo's cove. All these factors justify why Botafogo beach had the worst water quality conditions of the city.

Flamengo beach (Figure 10) showed the second worst water quality indexes during the analyzed period. It had a variable condition throughout the period, with time proper for bathing varying from about 15% to 55%. In 2015 the beach showed the worst condition since 2000, with time proper for bathing between 25% and 30% and median of TtC density that reached 5,500 MPN.100mL^{-1} at sampling location FL000. The reasons that explain the poor water quality conditions of Flamengo beach are similar to Urca and Botafogo. Besides its location inside Guanabara Bay, Flamengo beach receives sewage from the polluted waters of Carioca River. At September 2002, the Carioca River RTU was constructed to treat this sewage. However, this RTU was not dimensioned to treat the current volume of sewage that is brought by the Carioca River, due to the interception of sewage pipes and urban runoffs from Rio de Janeiro city downtown. Furthermore, as well as São Conrado RTU, the Carioca River RTU does not function during certain periods. Therefore, Carioca River continues to dump sewage directly into the Guanabara Bay. The Flamengo beach graphs shows that the construction of the Carioca River RTU did not improve water quality conditions of the beach.

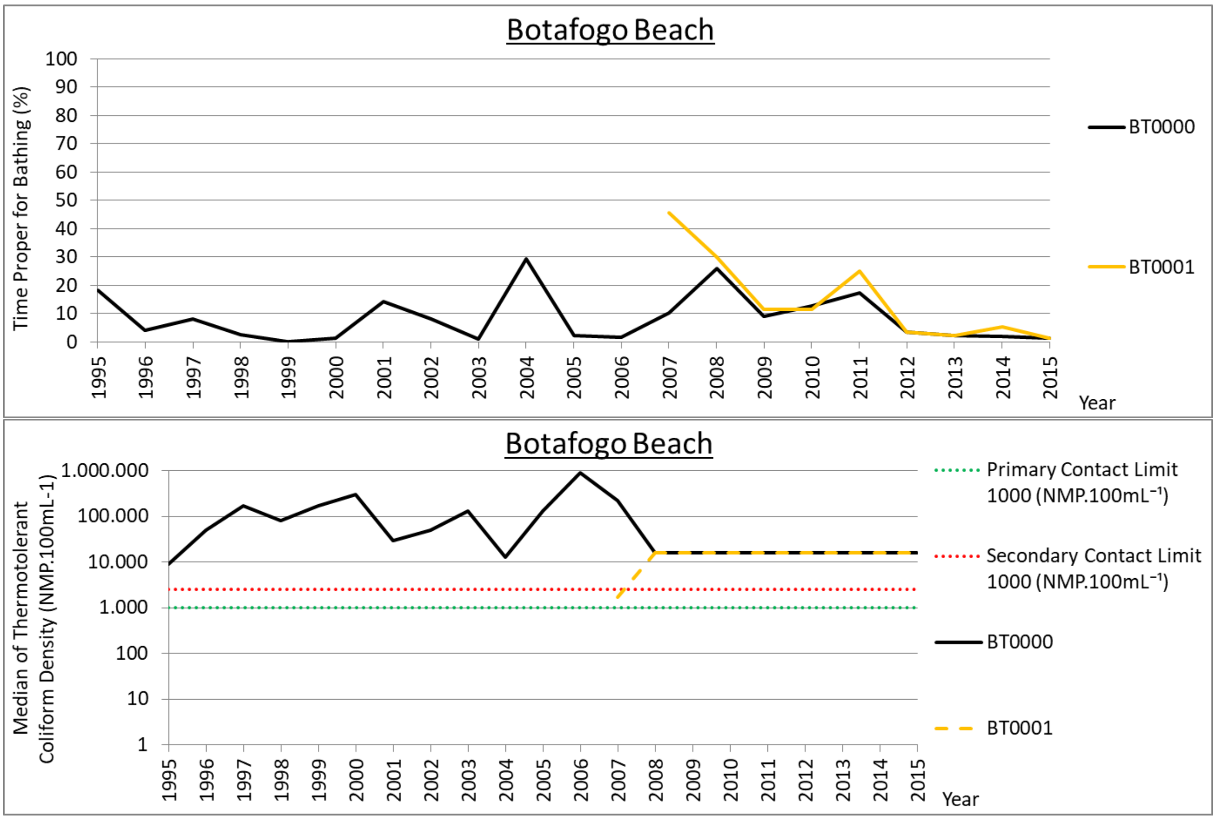

Figure 9. Recreational water quality evolution of the Botafogo beach.

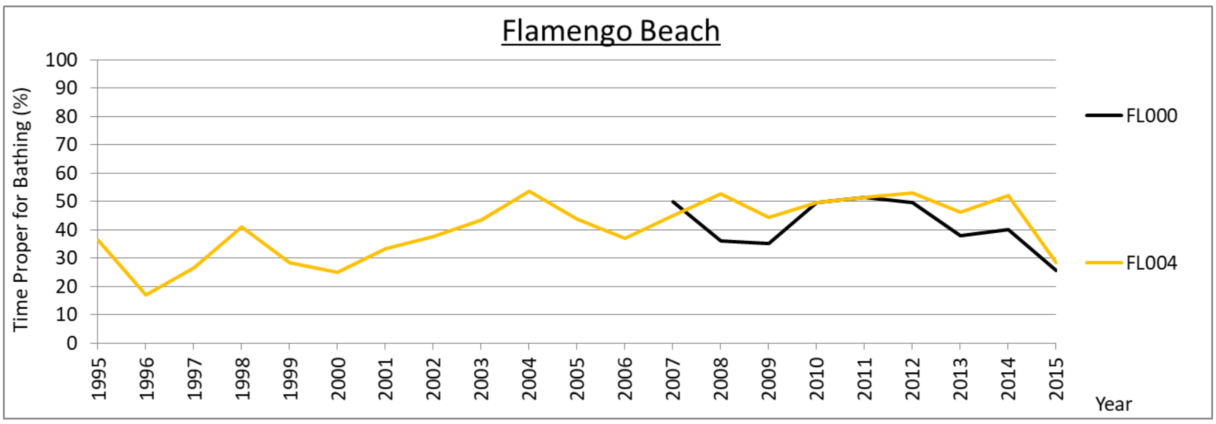

Figure 10. Recreational water quality evolution of the Flamengo beach.

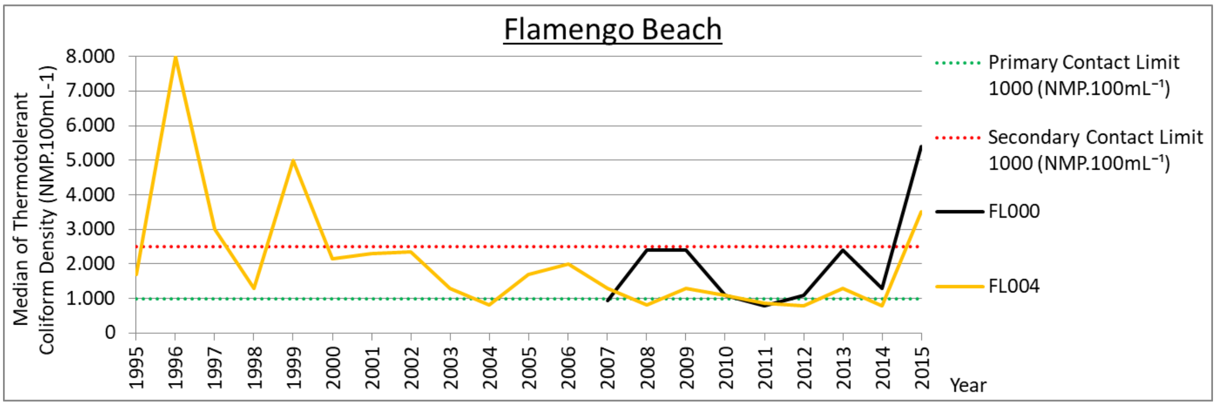

Figure 10. Continued.

3. Material and Methods

The data of this study was obtained from INEA's website [9], which was removed in 2016. These data are composed of sampling location, date and time of sampling and TtC density. Since there were some irregularities in the available data, such as the units of measurement used over the years and frequency, some adjustments were necessary. The unit of measurement was standardized to Most Probable Number per 100mL (MPN.100mL^{-1}) and repeated data was excluded. This unit of measurement represents the mean of TtC density in a volume of 100mL of an analyzed sample, being based on a probabilistic statistical method.

The choice of the analyzed beaches considered the number of visitors, tourism importance, sampling frequency and the available data period, being the latter two dependent on the formers. The sampling frequency of South and West Zones beaches of Rio de Janeiro is currently twice a week. The analyzed beaches were Barra da Tijuca and Joatinga, located in the West Zone, and São Conrado (Pepino and Gávea), Leblon, Ipanema, Arpoador, Copacabana, Leme, Vermelha, Urca, Botafogo and Flamengo, located in the South Zone. Figure 11 shows the location of the analyzed beaches and Figure 12 shows the distribution of sampling locations, which may vary in quantity according with the beach extension.

Figure 11. Location of the analyzed beaches. Where: BD: Barra da Tijuca; JT: Joatinga; PP: Pepino; GV: Gávea; LB: Leblon; IP: Ipanema; AR: Arpoador; CP: Copacabana; LM: Leme; VR: Vermelha; UR: Urca; BT: Botafogo; FL: Flamengo. Source: Modified from Google Earth.

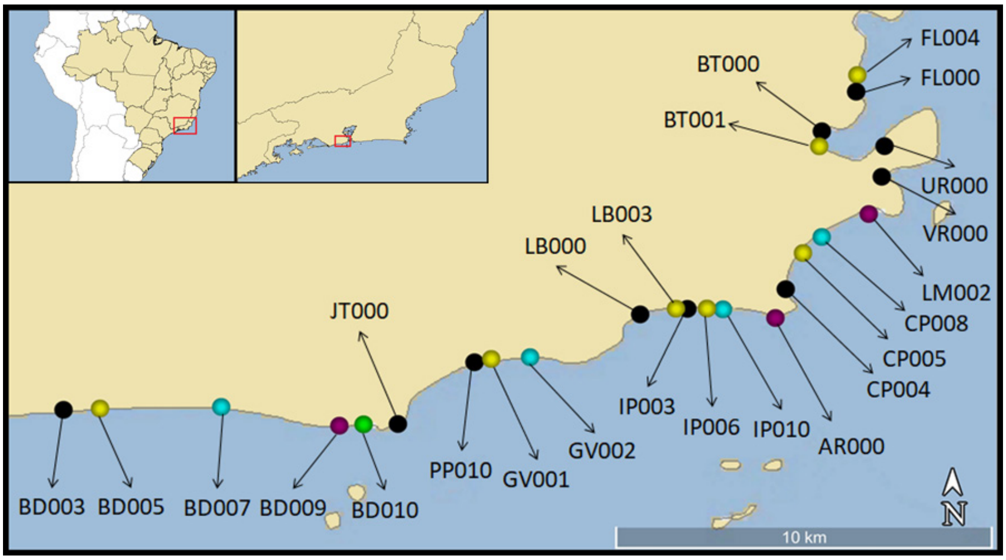

Figure 12. Map of sampling locations of INEA's water quality monitoring in the analyzed beaches. The first two letters of the sampling locations names correspond to the beach code shown in Figure 11, and the dot colors are the same used in the graph lines of the results. Source: Modified from INEA.

Statistical analysis of the water quality data was performed for each sampling location from 1995 to 2015. It was determined the median of TtC density (MPN.100mL^{-1}) and the percentage of the time the location was proper for bathing. In this study, TtC densities less than or equal to 1,000 MPN.100mL^{-1} (limit for primary contact according to CONAMA 274/2000) are considered as "proper for bathing". On the other hand, higher densities are considered as "improper for bathing".

4. Conclusions

The two determining factors for the quality indexes deterioration for recreational purposes in Rio de Janeiro city beaches were the pollution carried by rivers and canals and the influence of Guanabara Bay to inner waters beaches.

It was verified a higher influence of the pollution stain that flows through the Joatinga Canal during the analyzed period, shown by the reduction of the water quality indexes at a sampling location in Barra da Tijuca beach. The study also showed how the sanitation infrastructure investments in the South Zone of Rio de Janeiro were important for the improvement of the water quality of Leblon, Ipanema, Arpoador, Copacabana, Leme and Vermelha beaches.

Investments in São Conrado beach did not bring benefits, since they were directed to palliative measures rather than focusing in the causes of the problem. The results showed by Urca, Botafogo and Flamengo beaches confirmed their precarious water quality conditions. However, the improvement of Urca beach rates proves the effectiveness of sanitation infrastructure investments in its neighborhood, despite of Urca beach didn't achieve good standards of water quality.

In general, this study revealed that most of the oceanic beaches have been improving in terms of water quality conditions, with the exception of the eastern side of Barra da Tijuca beach, close to the Joatinga Canal, and São Conrado beach. On the other hand, inner waters beaches of Guanabara Bay maintained poor water quality conditions. The adopted methodology proved to be a useful tool to guide decisions of the government for the development of sanitation infrastructure and the recovery of coastal urban waters.

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