An Overview of Potential Health Hazards in Recreational Water Environments and Monitoring Programme in Porto Belo Bay, Brazil

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Abstract

The Porto Belo Bay region is formed by Itapema and Porto Belo cities, both considered important beaches from southern Brazil. During the summer, these cities welcome large numbers of tourists, fomenting their economies that are largely based on tourism activities. Given the poor sewage treatment in this region (60 % in Itapema City and none in Porto Belo City), a high population increase over the summer period can influence the water quality within Porto Belo Bay. The aim of this study was to evaluate the microbiological, chemical, and physical aspects within this area. Water samples were collected from 14 sites in the Perequê-Áçu River (five sampling stations) and in nine beach sampling stations from October 2000 to March 2014. The physical parameters (pH, salinity, DO, temperature), inorganic nutrients (NH^{4+}, PO_4^{3-}), organic compounds (POC, TOP, SPM), and biological and microbiological indicators (BOD_5, chlorophyll-*a*, total coliforms, and *E. coli*) indicated that areas close to the river discharge displayed lowest water quality, with a greater amount of inorganic and organic nutrients. On the other hand, better water quality was observed in two beach sites far from river or storm water discharges.

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Recreational coastal water and freshwater environments are defined as areas where any type of recreational activities is undertaken by an expressive number of users. The use of these areas is diverse; contact with water may be direct, thorugh the practice of sports such as swimming, surfing, and diving, or indirect, such as fishing, sailing, walking, and picnicking. However, activities with direct contact with water is of more concern in polluted waters due to the risk of ingestion (WHO 2000, 2003).

The social and economic importance of recreational uses of waters has increased over the last years (WHO 2000). The pursuit of leisure activities in contact with the natural environment, in order to counteract the urban way of life, is believed to be the main driver for this pattern.

Recreational swimming is a popular activity in many places, the European Union, the United States, Peru, China, Brazil, and others. Americans make an estimated 928 million trips to the beach each year (NOAA 2005).

Brazil has a vast coastline, composed of over 2000 beaches, along over 7000 km of coastline, making it a natural attraction for domestic and foreign tourists. In the south, beach tourism occurs in the summer (December–March) due to its subtropical climate. For its natural beauties, and services offered, the estate of Santa Catarina consolidates itself as the largest center of beach tourism in southern Brazil, attracting mainly Brazilian, Argentinean, Chilean, Uruguayan, and Paraguayan nationals (CUNHA 2010).

10.1 Coastal Waters

The marine coast is a fragile environment due to its intense dynamics. Coastal environments are subject to the action of tides, marine currents, and waves which together shape the coastline (Philippi Junior 2010). Coastal waters are used in various ways by societies including: leisure, transportation, food production, and sewage receiver of domestic and industrial waste. At times however, such uses of coastal waters may be incompatible with one another.

Recreational swimming in coastal waters is a popular activity in Brazil, supporting the tourist activity on the coast and moving economic resources both within states and between countries (WHO 2003; IBGE 2004). However, tourism activities have directly and indirectly caused serious environmental impacts. For instance, the construction of holiday homes and tourist facilities can disrupt the balance existing between the acting natural forces, increased water consumption, and production of sewage in large quantity (Vasconcelos and Coriolano 2008).

The release of untreated sewage to waterways may introduce pollutants to the environment, posing a risk to the health of local population and water users. Human sewage or other animal sources, for instance, can cause health problems due to the presence of contagious microorganisms (Boehm et al. 2009). Furthermore, pollution of coastal waters reaches estuarine environments such as mangroves, also affecting the fishery. Therefore, the monitoring of this indicator has implications on the health of the population, tourism, and sea fishing (IBGE 2004).

10.2 Factors Affecting the Quality of Recreational Coastal Waters

In densely populated areas, the water quality closely reflects human activity located not only along the beaches or rivers but also within its whole upstream watershed (Billen et al. 2001).

Water pollution occurs when substances or energy is directly or indirectly added to a water body, changing its natural characteristics.

Common pollutants are nutrients (eutrophication), pathogens, organic matter (nonbiodegradable and biodegradable), heavy metals, and suspended solids (Parsons and Takahashi 1998; Von Sperling 1996).

The general idea of pollution includes several processes of change in water quality, such as bacteriological, chemical contamination and eutrophication (Moraes and Jordão 2002). The resultant impact on human health by these contaminants originates mainly from the release of industrial and domestic wastewater, agricultural use of fertilizers, combustion of fossil fuels, and storm water flow into rivers, beaches, and lakes. Thus, the polluted water environment involves chemical, biological, and physical processes (WHO 2000; Segerson and Walker 2002).

Human activity significantly influences the cycling of nutrients, especially the movement of nutrients to estuaries and coastal waters (Billen et al. 2001).The polluting effect of effluent discharges in coastal waters offer a variable polluting effect that is dependent on the composition and quantity of the effluent as well as the water body depuration capacity. Thus, enclosed water systems with high residence time of water will be more readily affected by sewage discharges (Pilson 1985; Horita and Carvalho 1999; WHO 2000). The abundance of pathogenic microorganisms and nutrient concentration are strongly influenced by the environmental dispersion capacity through physical processes of vertical diffusion, overturning, ultraviolet radiation from sunlight, and current systems (Talley et al. 2011).

10.3 Water Quality Evaluation

Water quality can be evaluated in accordance with the components or substances contained therein, i.e., its composition. Parameters used to describe and classify water include: physicochemical parameters, such as water temperature and turbidity; chemical parameters, such as biochemical oxygen demand (BOD), dissolved oxygen (DO), nitrogen and phosphorus, and potential of hydrogen ion (pH); and biological parameters including the coliform group and nonpathogenic organisms, such as phytoplankton and zooplankton.

Most aquatic creatures such as fish, bacteria, and protozoa are aerobic and need oxygen to survive (Butkus and Manous 2005). Though dissolved oxygen will not have a direct effect on users, but it will directly influence aquatic life, chemical oxidation state of metals, and microbial activity (Baumgarten et al. 2010). Oxygen may enter the water through the roots of aquatic plants and algae, which undergo photosynthesis, and through the air-water interface. The water's ability to hold dissolved oxygen is directly dependent on the temperature, salinity, and pressure. However, aquatic environments under extreme conditions where oxygen concentrations are below 4 mg.L−1 are considered critical for aquatic organisms (Arana 1997; Esteves 1988).

A combination of bacteria and excess organic material in aquatic environments may lead to eutrophic conditions. As organic matter decays, bacteria can consume oxygen, thus depleting the available oxygen supply. The amount of dissolved oxygen consumed by microorganisms in water during the oxidation of organic matter is known as the biochemical oxygen demand (BOD_5). Sources of BOD_5 are biodegradable organic carbon and ammonia, common metabolic by-products of plant and animal wastes, and human activities. Some issues associated with the discharge of wastes containing high levels of BOD_5 are poor water quality, severe dissolved oxygen depletion, and fish kills (Butkus and Manous 2005).

Potential impacts to recreational users of water bodies may arise from extreme pH levels. Very acidic or very basic water conditions may cause skin, eye, hair, and mucous membrane irritation. However, the impact will also be dictated by the buffering capacity of the water, mainly saline water (WHO 2003).

Humans are not the only ones affected by pH. Extreme pH levels in water can also cause detrimental environmental effects by affecting the solubility and toxicity of chemicals and heavy metals, stress animal systems, reduce hatching and survival rates, and ultimately cause the death of aquatic organisms. For instance, a slight change in the pH of water can increase the solubility of phosphorus and other nutrients, making them more accessible for phytoplankton and increase growth of aquatic plant. As a consequence, algal blooms may occur and result in eutrophication of the water body (Baumgarten et al. 2010).

Natural occurring elements, such as phosphorous and nitrogen, are essential for the growth of plants and animals. Although these elements do not represent direct risks to human health, extreme concentrations (high or low) of these elements in the environment can lead to ecological disequilibrium (Carmouze 1994; Braga et al. 2000).

Extreme levels of phosphorus and nitrogen are usually result from anthropogenic input (i.e. domestic wastewater supply). While phosphorus is naturally released from decaying vegetation and soils, it is also present in industrialized products such as household detergents, soaps, and sewage (Carmouze 1994). Nitrogen naturally exists in the aquatic environment in many forms, including ammonia. Some potential exogenous sources of this Nitrogen to water bodies are: municipal effluent discharges, excretion from animals, nitrogen fixation process, air deposition, and runoff from agricultural lands and cities (Vitousek et al. 1997; Valigura et al. 2000).

Water quality can also be monitored using biological parameters.Indicator bacteria, including Escherichia coli and intestinal Enterococcus, are used for the monitoring of recreational waters. The coliformbacteria group are not pathogens, nontheless, large numbers of these organisms are found in the intestinal contents of warm-blooded animals and humans. Therefore, their use as an indicator of faecal contamination provides a good indicator of potential pathogens in water (Da Cunha 2006).

10.4 Health Hazards in Coastal Waters

Recreational coastal waters may offer a diverse range of hazards to human health. Health hazards may include physical hazards, such as contamination of beach sand, cuts and bruises from sharp objects, and exposure to microalgae, or chemical and physical agents which include presence of harmful aquatic organisms, poor water quality, as well as the presence of pathogenic microorganisms in recreational water (WHO 2003). Considering the risks posed to human health due to prolonged and direct exposure to hazards, it is required that recreational waters meet specific standards of water quality.

The link between water quality and diseases is very well studied. Contamination of natural waters represents one of the leading public health risks, particularly the increase in infant mortality (IBGE 2010). Basic sanitation is fundamental to life quality; it refers to the provision of facilities and services and the maintenance of hygienic conditions through services like sewerage system, water supply, garbage collection, and urban drainage (Philippi Jr. 2010).

In Brazil only 38.7 % of the total sewage generated is treated (SNIS 2014). Urbanization rapidly resulted in the informal settlement of low-income residents in neighborhoods without access to sanitation. Such arrangements generate concentrated pollution and serious drainage problems due to a number of factors (e.g., inadequate waste disposal, siltation, and consequently decrease in the speed of runoff), helping to disseminate diseases (Moraes and Jordão 2002).

The lack of basic sanitation and minimum hygiene conditions increase the exposure of the population to many types of illnesses. Some diseases associated with water pollution are cholera, gastrointestinal infections, diarrhoea, typhoid fever, amebiasis, schistosomiasis, hepatitis, and leptospirosis. The transmission of these infectious diseases occurs normally by contaminated water ingestion or direct contact with the upper respiratory tract, eyes, or skin (Da Motta et al. 1994; FUNASA 2010; Barsano et al. 2014).

In touristic cities there is a seasonal fluctuation of the population. A population rise during summer holidays and long weekends, for example, may overload the existing sewage systems, so the excess is released in streams many times, compromising bathing (CETESB 2010) and therefore increasing the number of pathogen load in the water. Furthermore, the higher water temperatures observed during this period may enhance the proliferation of certain types of these pathogens (Van Asperen et al. 1995).

Risks of microbial contamination in coastal waters are usually associated with the type of recreational activity involved, volume of water ingested, and periods of contact. Humans involuntarily swallow some water while practicing water sports. In recreational activities with limited water contact, such as fishing, kayaking, motor boating, canoeing, and rowing, the volume of water ingested is approximately 3–4 mL (Dorevitch et al. 2011). Surfing in contaminated water offers high risk for contracting gastrointestinal illness especially through ingestion; the mean exposure is 170 ml of water ingested per activity day (Stone et al. 2008). Recreational water users with whole-body contact such as a swimmer can expect to ingest 100–200 ml of water in one session, probably more than sailboard riders and water-skiers (WHO 2003).

Divers may run a higher risk of infection with waterborne pathogens than bathers due frequent and intense contact; in marine waters, they accidentally swallow around 9.4 ml per dive (Schijven and Husman 2006), considering the serious health hazards associated with aquatic pollution.

10.5 Monitoring Programs

Monitoring programs are designed to understand how the environment changes over time and, besides this, allow the evaluation and diagnosis of the environment in question. Long-term monitoring lets us evaluate information on conservation and environmental degradation of the region studied.

The concentration analysis of nutrient inputs to coastal waters and estuaries is necessary for the management of water quality. Often, nutrient inputs are estimated as part of some scientific research project and are published only in scientific literature. But the results must be used for management too (Valigura et al. 2000; Howart et al. 2002).

Many places of recreational waters suffer from population growth and pollution increase. Monitoring programs are used in few locations facing these problems worldwide, standing out as successful examples to follow. Some examples are: Marine Conservation Society, England; Beach Water Quality – Environmental Protection Department, Hong Kong, China; Calidad de agua de las playas de Montevideo, Uruguay; and Programa Integral de Playas Limpias, Mexico.

At Lake Geneva, located between France and Switzerland, we have another example. Tourism, trade, and wine growing constitute the main activities within the region, which are generally in conflict with the natural environment. After swimming was prohibited in many areas due to local pollution, integrated management between France and Switzerland was required. Domestic and industrial sewage systems have been installed resulting in significant improvement in water quality (WHO 2000).

The Ganga River is the largest and the most important river in India. The densely populated Ganga Basin is inhabited by 37 % of India's population; domestic and industrial wastes characterize the principal source of pollution. The Ganga Project started in June 1985 and was perceived as an investment providing demonstrable effects on river water quality. After finding pollution sources, mainly domestic and industrial wastes, the first step was the creation of facilities for interception, diversion, and treatment of the wastewater (WHO 1997). Results obtained during the Ganga monitoring program, 1995–2011, indicated that the bacterial contamination continued to be critical in the Ganga River. The municipal corporations at large are not able to treat the increasing load of municipal sewage. But the success of the program is visible through to the number of improvements commissioned (CPCB 2011).

The beach monitoring program in Lima, Peru, initiated in 1986, was essential to confirm the pollution sources and convince the authorities of the real necessity of the implementation of management actions (WHO 2000).

Hong Kong began a monitoring program in 1986 and currently uses a ranking to reflect the water quality of the beach. Under the dual rating system, beaches are categorized into "good," "fair," "poor," or "very poor." Those ranked "good" and "fair" have necessary conditions for bathing waters. In 1986 only 23 % of their beaches had good conditions, and 25 % were unsuitable to swimming; at the last report released in 2013, this number increased to 58.5 %, and no improper point for swimming was recorded (HKWQRC 2013).

The Australian Gold Coast has a water quality monitoring program; currently, approximately 230 sites are used for analyzing ocean beaches, rivers, creeks, estuaries, canals, freshwater, and tidal lakes. The water quality information is used for a range of purposes including information on the ecological health, identifying trends in water quality and assessing changes in water quality in association with landscape modification (HWDEHP 2013).

A comprehension about the dynamics of water systems, including chemical, physical, and biological interactions, the perceptions of the beach users, and economic and tourism interests, is essential for a successful management of coastal waters. Certainly, there are conflicts between these factors, but many of these conflicts can be resolved through effective communication and environmental education activities (WHO 2000; HKWQRC 2013).

10.6 Porto Belo Bay Program

Porto Belo Bay is a thriving touristic area, with a local population of nearly 70,000 people. The beaches are used for recreation as well as for and seafood extraction. The sea surrounding them is also the home of miscellaneous marine species, from microscopic phytoplankton to economic important fish species.

Porto Belo Bay is one of the most important places of summer tourism in southern Brazil. Population number in this area can more than quadruple in the summer months. The cities of Itapema and Porto Belo, located within Porto Belo Bay, presented a disordered growth both in population numbers and in real estate over the last decade. This has led to uncontrolled increase in sanitation problems due to the rise of domestic sewage and the lack of planning in the infrastructure to support such a discharge. As a consequence, raw sewage ends up being dumped on beaches and negatively influencing the quality of its waters.

Poor water quality as a result of increased wastewater discharge in the summer months has been reported by several authors in Porto Belo Bay (Vasques 2002; Marin 2007; Biavatti 2014). While Itapema currently has a wastewater treatment plant (WWTP) that serves up to 60 % of the population, Porto Belo City doesn't have a WWTP and therefore only uses septic tanks or releases its untreated effluents into water bodies. The population growth and tourism contribute to the city economical growth, however the absence of a WWTP causes negative effects to habitats as well as to public health. Consequently, local beaches have been hampered by the large amount of pathogenic organisms due to the inadequate disposal of municipal domestic wastewater.

Dividing the cities of Itapema and Porto Belo lays the Perequê-Áçu River, the largest river that flows into the Porto Belo Bay. While the Perequê-Áçu River is used to discharge treated effluent from the WWTP, untreated sewage is introduced to this water body through clandestine sewage connections from both Itapema and Porto Belo. Physicochemical and/or biological changes in estuarine and coastal waters undertake ecological balance and offer hazards to human health (Carmouze 1994; CETESB 1995; De Miranda et al. 2002; Pereira Filho et al. 2003).

There are conflicts about water uses in Perequê-Áçu River. Upstream, the river is used to provide drinking water to Porto Belo, Itapema, and the neighbouring City of Bombinhas (around 500,000 people in summer time). Downstream, as well as receiving untreated effluents from Itapema and Porto Belo, waters are used for irrigation in rice cultivation, navigation and fishing (Marin 2007).

During 2013, the WWTP received and treated by upflow anaerobic sludge blanket - UASB reactor equivalent to 2,060,897.08 m^3 of effluents. The average inlet and outlet BOD$_5$ was 216.91 mg/L and 36.77 mg/L, respectively (CONASA 2014), with a mean removal of 83 %.

Usually, the BOD$_5$ of wastewater varies from 100 to 300 mg/L, with posttreatment usually aiming to achieve a reduction of BOD$_5$ to a range of 20–30 mg/L (Jordão and Pessoa 1995). Thus, it is concluded that the WWTP is showing very good results in removal since the expected efficiency for UASB reactors (Teixeira et al. 2009).

The values quoted are removed from carbonaceous matter within the limits established by the Brazilian Law in CONAMA Resolution 430 that complements with 357 and provides for a minimum reduction of 60 % BOD$_5$.

At summer time in the years 2013 and 2014, the Perequê-Áçu River suffered a major drought which, together with the receipt of large organic load from the sewage, resulted in the deaths of dozens of species, including some tougher catfish and crabs, culminating in a negative image of the city and the interdiction of stretches of beach (Caldas and Felix 2013; Basso 2014). From this situation, population demanded actions of authorities and from the water company.

Thereby, the monitoring program in Porto Belo Bay emerged and put together university and water company in February, 2014, to start chemical, microbiological diagnoses of this environment. It serves the following purposes: (1) reveal water quality of marine and river waters and (2) provide a basis for the planning of pollution control strategies.

The monitoring program includes 14 water sampling stations, 9 in the bay and 5 along the Perequê-Áçu River (Fig. 10.1). Chemical and physical parameters, including temperature, salinity, pH, and dissolved oxygen, were measured in situ by a Yellow Springs 6600 V2 sonde.

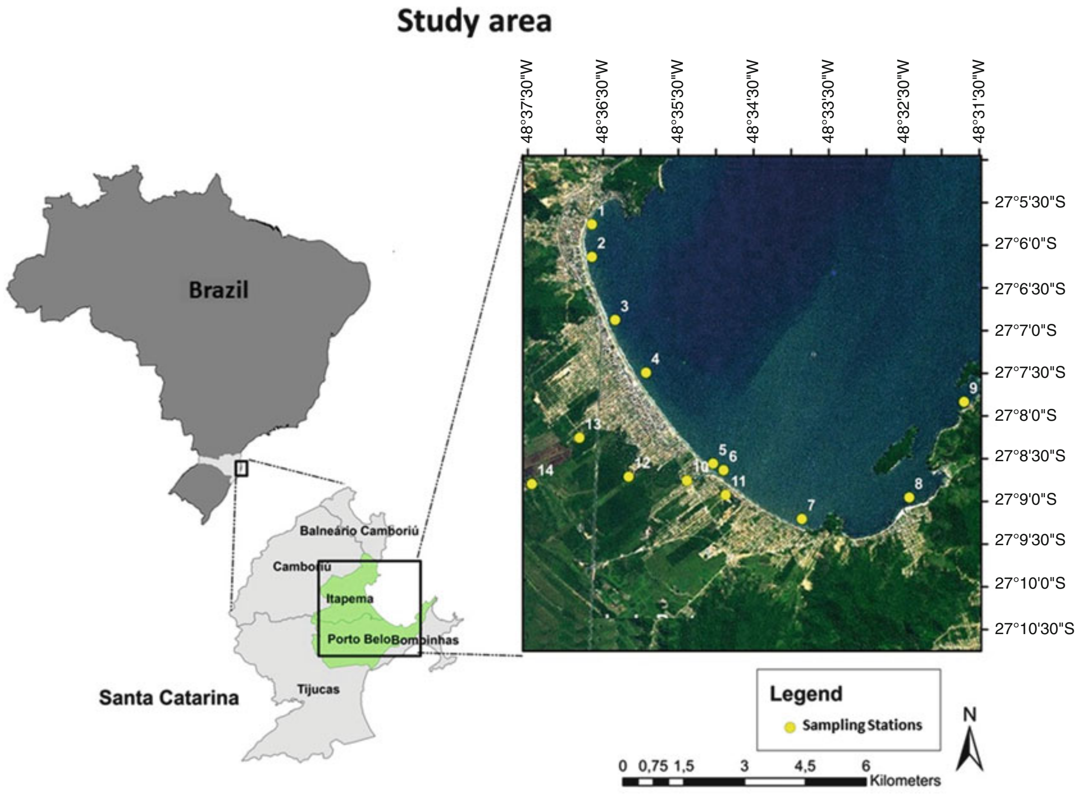

Fig. 10.1 Location of the 14 sampling sites at the Porto Belo Bay, SC, Brazil

Water samples were collected and sent to the university laboratories for the analysis of inorganic nutrients (NH_4^+, PO_4^{3-}), suspended particulate matter, particulate organic carbon, phosphorus organic, chlorophyll concentration, biochemical oxygen demand, and coliform bacteria. The methodologies for determining these parameters were followed, and the recommendations are described in American Public Health Association (APHA), the American Water Works Association (AWWA), and the Water Environment Federation (WEF) (1999). Water quality monitoring is generally conducted once a month and in summer time every week.

10.7 Data Collection

Prior to the commencement of the Porto Belo Bay monitoring program, other scientific research projects have estimated nutrient inputs; however, continuous data has never been collected in this area. Though the Porto Belo program is a continuing monitoring study, only one sampling month over the summer period (February–March 2014) and sampling points coinciding with previous studies were selected for the scope of this chapter. All existing data for this area was compiled and compared in Table 10.1.

The Porto Belo Bay monitoring program collected 99 samples throughout the year. However, in order to compare findings with previous studies, only the summer period will be presented here.

These projects (we used only the data that were collected at the same points of the current project) can be seen in Fig. 10.2, the equivalence of sample points.

Water samples were collected from 14 sites in the Porto Belo Bay (9 beach samples, 5 river samples), between October 2000 and March 2014 (Table 10.2). Each sample was then processed and their physical, chemical, and microbiological properties determined.

10.7.1 Physicochemical Parameters

The average water temperature during the sampled years was 24.9 °C for both areas, beach and river, with a maximum of 31.50 °C (March 2001) and minimum of 15.60 °C (July 2001).

The mean observed salinity for beach and river was 25.9 $g.L^{-1}$ and 25.4 $g.L^{-1}$, respectively. Ocean water normally has a mean salinity of 35. This observation is an indication of how dynamic this environment is, low values observed in Porto Belo Bay can be explained through entries of freshwater in some sampling stations. In the river, salinity was observed between 0 and 35.3, the low values being found upstream the river and high values downstream.

The mean neutral pH values observed in both river and beach are consistent with estuarine waters (Lau and Chu 1999). The lowest pH values observed on the beach always occurred during periods of low salinity, with dominance of fluvial environment or storm water discharges, possibly associated with excess nutrients (Table 10.2). Thus, the variation in pH levels observed in the beach sampling can be explained

Table 10.1 Summaries of the projects with their respective dates of beginning and end and the periodization and the points that were used for sampling

Project	Start date	Final date	Periodicity	N° sample stations	Total number of samples
Vasques 2002	October 2000	February 2002	Monthly	7	48
Univali 2003 (unpublished)	July 2001	February 2003	Monthly	2	82
Marin 2007	January 2007	March 2007	Weekly	8	48
Univali 2008 (unpublished)	January 2008	April 2008	Weekly	2	26
This program	February 2014	March 2014	Weekly	14	84
Total					288

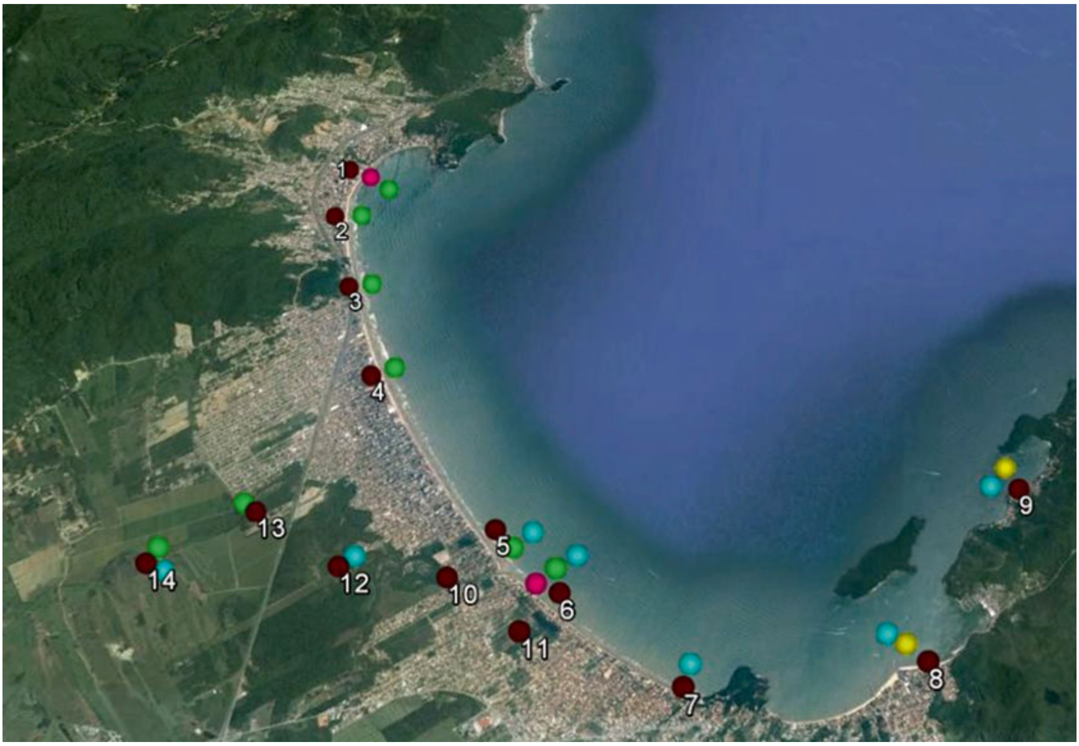

Fig. 10.2 Summary of collection points and each previous project. *Blue* (Project 1-2000 ~ 2002), *pink* (Project 2-2001 ~ 2003), *green* (Project 3-2007), *yellow* (Project 4-2008), *dark red* with numbers (Project 5-2014)

by the presence of freshwater in the bay and consequently its weak buffer capacity.

For dissolved oxygen (DO), vital for the survival of aquatic organisms, the mean oxygen value for the entire study period was 7.1 mg.L^{-1} for beach and 6.9 mg.L^{-1} for river. This parameter is the one that best reflects the state of degradation of a water body. The annual mean surface water dissolved oxygen in beach ranged from 3.7 to 10.8 mg.L^{-1} and in river from 0.8 to 8.2 mg.L^{-1}.

Dissolved oxygen can be produced during the photosynthetic processes or by input gas through the atmosphere-water interface, mainly during low temperature. The consumption can occur by various means such as the decomposition of organic matter, respiration of aquatic organisms, loss to the atmosphere-water interface, and oxidation of metallic ions (Esteves 1988). Low concentrations of dissolved oxygen, observed in the river, may be indicating a contribution of large amounts of organic matter in this environment, inducing its decomposition. It is important to note that the DO concentration of smaller than 4 mg.L^{-1} is critical to aquatic organisms (Arana 1997). While mobile animals, like fish, can usually avoid hypoxic and anoxic areas, they sometimes become trapped against the shore and cannot escape. In some other situations, wind and tidal mixing may be so weak and respiration rates so high that even the surface waters can become hypoxic or anoxic (rarely) and cause fish kills (Nixon and Fulweiler 2009).

10.7.2 Inorganic Nutrients

The ammonium nutrient (NH_4^+) showed minimum and maximum values in the beach between 0,34 and 170 μmol.L^{-1} and in the river between 0,57 and 2034 μmol.L^{-1}. The concentrations of orthophosphate phosphorus (PO_4^{2-}) in water in

Table 10.2 Chemical and microbiological parameters evaluated between October 2000 and March 2014 in Porto Belo Bay, Brazil. Number of samples (N), mean, standard deviation (SD), minimum (min), and maximum (max) are displayed for each determined variable: temperature (T °C), salinity, pH, dissolved oxygen (DO), ammonium (NH_4^+), phosphate (PO_4^{2-}), total organic phosphorus (TOP), particulate organic carbon (POC), suspended particulate matter (SPM), biochemical oxygen demand (BOD_5), chlorophyll-a concentration, total coliform, and fecal coliform

		Place	N	Mean	SD	Min	Max
Physicochemical parameters	T (°C)	Beach	238	24.9	3.1	15.6	31.5
		River	50	24.9	3	18.3	30.2
	Salinity ($g.L^{-1}$)	Beach	238	25.9	11.9	1.4	37.6
		River	50	25.4	12.2	0	35.3
	pH	Beach	238	7.6	0.7	4.1	8.9
		River	50	7.5	0.7	5.1	8.4
	DO ($mg.L^{-1}$)	Beach	238	7.1	1.2	3.7	10.8
		River	50	6.9	1.5	0.8	8.2
Inorganic nutrients	NH_4^+ ($\mu mol.L^{-1}$)	Beach	232	38.3	149.9	0.3	170.2
		River	50	56.7	207	0.57	2034.8
	PO_4^{2-} ($\mu mol.L^{-1}$)	Beach	222	0.7	1.3	0.05	2.53
		River	50	0.8	1.3	0.1	13.3
Organic compounds and SPM	TOP ($\mu mol.L^{-1}$)	Beach	158	3.8	4.9	0.1	28
		River	37	4	4.8	0.4	42.7
	POC ($mgC.L^{-1}$)	Beach	163	1	1.3	ND	13.3
		River	41	1.1	1.5	0.6	6.2
	SPM ($mg.L^{-1}$)	Beach	131	53.3	39.2	1	285
		River	29	53.1	39.1	0.67	76.7
Biological and microbiological indicators	BOD_5 ($mg\ O_2.L^{-1}$)	Beach	148	24.5	93	0.1	12.2
		River	42	30.7	48.2	0.3	594.9
	Chlorophyll-*a* ($\mu g.L^{-1}$)	Beach	206	1.2	1.7	0.001	10.2
		River	47	1.3	1.8	0.1	11.3
	Total coliform (MPN/100 ml)	Beach	124	10,140.3	19,214.5	10	68,670
		River	35	21,318.4	48,279.4	100	241,960
	Fecal coliform (MPN/100 ml)	Beach	54	1265.6	3255	0	24,196
		River	30	9773.5	21,634.6	73	120,330

Porto Belo Bay ranged from 0.05 to 2.53 $\mu mol.L^{-1}$ on the beach and 0.5 to 13.27 $\mu mol.L^{-1}$ on the river (Table 10.2).

High ammonium (NH_4^+) values observed in this study, in both environments, river and beach, could be related to the pollution of water through the input of organic matter and consequently bacterial decomposition. Thus, high levels of NH_4^+ may be indicating excess organic matter and pollution resultant from continental drainage. Phosphorus (PO_4^{2-}) is a nutrient of vital importance in aquatic systems, has origin of the dissolution of the compounds derived from the soil or decaying organic matter, but may also have anthropogenic origin, mainly due to domestic and industrial wastewaters, especially from detergents (Von Sperling 1996). These, together with the continual urban development stress around the estuary and beach, adversely affect the existence and survival of many biological species (Lau and Chu 1999).

The highest levels of inorganic nutrients (i.e., $NH_4^+$and PO_4^{2-}) were observed in the river sample from station number 13 during March 2014. These extreme levels can be explained by the high influx of tourists in Porto Belo Bay for the carnival holiday resulting in a greater production of effluent and significant increase in their supply to the environment. Similar results have been observed in the estuary Saco da Mangueira, where high levels of $NH_4^+$and PO_4^{2-} resulted from anthropogenic inputs of organic matter or nutrient-rich domestic and industrial effluents (Baumgarten et al.2001).

10.7.3 Organic Compounds and Suspended Particulate Matter

For total organic phosphorus (TOP) on the beach, values oscillated between 0.1–28 µmol.L^{-1} and 0.4–42.7 µmol.L^{-1} in the river.

Particulate organic carbon (POC) in the aquatic ecosystem can originate as fragments of dead plants and animals, suspended sediments, and water exchanges with adjacent systems or because of the contribution of effluents, particularly domestic (Carmouze 1994). Similar to inorganic nutrients, high levels of total organic phosphorus (TOP) and particulate organic carbon along the beach in Porto Belo Bay were associated with river discharges.

Suspended particulate matter (SPM) concerns the amount of suspended solids which interferes directly in water transparency and consequently to primary production. Physical factors such as wind regime, water circulation, and rainfall can cause the movement of the water column or increased river discharge and therefore influence the levels of solids suspended in the water column. For this parameter, a maximum of 285 mg.L^{-1} and a minimum of 0.67 mg.L^{-1} were found, considering both environments, river and beach.

10.7.4 Biological and Microbiological Indicators

Levels of biochemical oxygen demand (BOD_5) in Porto Belo Bay varied greatly throughout the sampling period (Table 10.2), reflecting the fluctuation in the presence of biodegradable material in the environment. The highest BOD_5 recorded (594.9 mg OD.L^{-1}) was observed in the river (station number 13) during the summer sampling of March 2014, after the carnival holiday, indicating harmful conditions for the environment, aquatic organisms, and humans that may have contact with water.

Chlorophyll concentrations showing primary produce levels, as measure of the biomass of phytoplankton. The mean water chlorophyll-a in beach ranged from 0.001 to 10.2 µg.L^{-1} and in river from 0.1 to 11.3 µg.L^{-1}. Similar values were found in Biscayne Bay, USA, which ranged from 0.001 to 9.18 µg.L^{-1} (Caccia and Boyer 2005).

Traditionally, bacteriological indicators are used to describe water quality. The fecal coliform in Porto Belo Bay displayed a gradual increase over the sampled years (Table 10.2). The highest values of coliforms in both beach and river environments were observed in the summer of 2014 (sampling station number 13), during which levels were larger (hundred times greater) than those determined in the Brazilian legislation (maximum of 2500 MPN/100 ml). As with previous parameter, such drastic increase may be associated with the increased population density in the region during the summer period. Results from beach stations varied widely, with low levels observed in sampling stations numbers 3 and 9, possibly because they are more distant areas from river and storm water discharges.

10.7.5 Final Analysis

Water quality assessment is usually made by indicator parameters such as nutrient levels and fecal indicator organisms. However, total coliforms and fecal coliforms do not necessarily correlate well with the presence of pathogenic organisms (Ferguson et al. 1996); the stability of the natural populations of fecal coliforms is affected and can be drastically inactivated in a few hours when exposed to sunlight (Fujioka et al. 1981). However, enhanced nutrient loading alone might also influence the abundance and survival of pathogens that are already resident in aquatic ecosystems (Smith et al. 1999).

Water quality is influenced by many natural factors interacting in the drainage basins (biological, meteorological, geological, topographical, and hydrological). Human influence on water quality is significant too and may be from several sources; the discharge of sewage and agricultural fertilizer runoff are the most common examples (Cood 2000).

Human activities have also profound impacts upon the biogeochemical cycles of carbon, phosphorus, and nitrogen (Vitousek et al. 1997; Smith et al. 1999). Phosphorus and nitrogen are essential nutrients for the plants and animals, but input increases in the marine environment represent a potential pollution problem (De Jong 2006).

There are many sources of phosphorus in aquatic systems, including wastewater, wastewater treatment plants, runoff from fertilized soil, and the widespread use of detergents, which have important contributions to the phosphorus loads (Carpenter et al. 1998; De Jong 2006; Baumgarten et al. 2010).

Nitrification is carried out in two steps. First, ammonium is converted to nitrite by ammonia-oxidizing bacteria. In the second step, nitrite-oxidizing bacteria convert nitrite to nitrate, resulting to the high oxygen demand for ammonium oxidation. High ammonium concentration can be found especially in municipal wastewater (Ruiz et al. 2003).

The water quality varies around the world. Some places have low nutrient levels; the high values are associated to high population density (Table 10.3).

The indicator ammonium is chosen for the comparison of coastal water quality around the world on the map (Fig. 10.3).

In Itapema beach, river and storm water discharges are the most important factors influencing its water quality, with chemical, physicochemical, and microbiological aspects.

The sample stations that showed better water quality were Praia Central (site 2) and Caixa d’Aço (site 9) located far away from river discharges, without its influences. The lowest water qualities were represented in the northern Itapema beach (site 1), Praia do Morretes (site 3), and Praia do Perequê (site 6) which have a great discrepancy in chemical and microbiological characteristics, both located much closer to discharges and with a high population density.

During all the periods monitored, the nutrients were very high, and this area was classified to eutrophic system, according to Lau and Chu (1999), Ingole and Kadam (2003), and Baumgarten et al. (2001).

The supervision of the outputs of rainwater on the beach is recommended, since they appear to contain illegal sewage. The illegal sewage also appears to be responsible for the poor water quality of the river.

Around Perequê-Áçu River over the last 10 years, many people without access to sanitation have set and dumped their sewage directly into the river. It is important to remember that Porto Belo City does not possess an effluent treatment plant.

We must make an environmental education work and awareness actions with the population, mainly scholar children, explaining the importance of treating sewage and pollution damages and its influences to human and environmental health.

Table 10.3 Water quality of some beaches around the world. The symbol * represents estuaries and indicator ammonium is chosen for the comparison of coastal water quality around the world on the map (A to I)

Local		Sal	NH_4^+	PO_4^{3-}	References
			μmol.L^{-1}	μmol.L^{-1}	
Yucatán Bay, México ^{A}	Mean	37.45	4.45	0.51	Aranda-Cirerol et al. 2006
	Range	(24.0 ~ 39.7)	(0.40 ~ 42.26)	(0.03 ~ 1.79)	
Dzilam Lagoon, México	Mean ± SD	25.8 ± 1.4	2.8 ± 0.2	0.05 ± 0.03	Medina and Herrera 2003
Yucatán Bay, México	Range	36 ~ 38,3	4.2 ~ 5,2	0.46 ~ 0.62	Herrera-Silveira et al. 2004
Flórida, USA	Mean	34.25	0.474	0.015	Boyer et al. 2000
Biscayne Bay, USA ^{B}	Range	6.21 ~ 42,3	0 ~ 16.3	0 ~0.68	Caccia and Boyer 2005
Hawaii Beach, USA	Mean ± SD	34.5	0.8 ± 0.4	0.15 ± 0.07	Laws et al. 1999
Mangrove Mai Po, Hong Kong, China ^{C*}	Mean	8	485.7	37	Lau and Chu 1999
	Range	0 ~ 30	37.8 ~ 1450	1.9 ~ 83.9	
East of Hong Kong, China	Mean	30	1.6	0.3	Zhou et al. 2007
Dadar Beach of Mumbai. India ^{D}	Mean	27.9	135.7	25.8	Ingole and Kadam 2003
	Range	15.1 ~ 32.4	57 ~ 207	6.4 ~ 58	
Itacaré to Canavieiras, BA, Brazil	Mean ± SD	36.5 ± 0.51	0.63 ± 0.56	0.07 ± 0.03	Eça 2009
São Vicente Beach, SP, Brazil ^{E}	Range	32.23 ~ 35.56	0.82 ~ 4.94	0.22 ~ 4.42	Braga et al. 2000
São Sebastião, SP, Brazil	Mean ± SD	34.65 ± 0.95	0.71 ± 0.55	0.15 ± 0.11	Gianesella and Saldanha-Corrêa 2003
Conceição Lagoon, SC, Brazil	Mean ± SD	29 ± 1.1	6.0 ± 1.1	0.21 ± 0.15	Fonseca et al. 2002
Pântano do Sul, SC, Brazil	Mean ± SD	34.7 ± 0.82	1.3 ± 0.70	0.6 ± 0.18	Simonassi et al. 2010
North beaches of Santa Catarina, Brazil	Mean ± SD	30.9 ± 2.1	16.3 ± 16.1	0.68 ± 0.32	Kuroshima et al. 2006
Balneário Camboriú, SC, Brazil	Mean ± SD	29.4 ± 4.7	20.0 ± 36.4	0.71 ± 0.7	Kuroshima et al. 2007
Saco do Justino, RS, Brazil ^{F*}	Range	0 ~ 20	1.9 ~ 29.7	0 ~ 5.3	Baumgarten et al. 2005
Saco da Mangueira, RS, Brazil ^{G*}	Range	0 ~ 24	1.7 ~ 47.9	1.3 ~ 13.4	Baumgarten et al. 2001
Porto Belo Bay, this study ^{H}	Range	1.4 ~ 37.6	0.3 ~ 170.2	0 ~ 2.5	This study
Perequê River, this study ^{I*}	Range	0 ~ 35.3	0.6 ~ 2034.8	0.1 ~ 13.3	This study

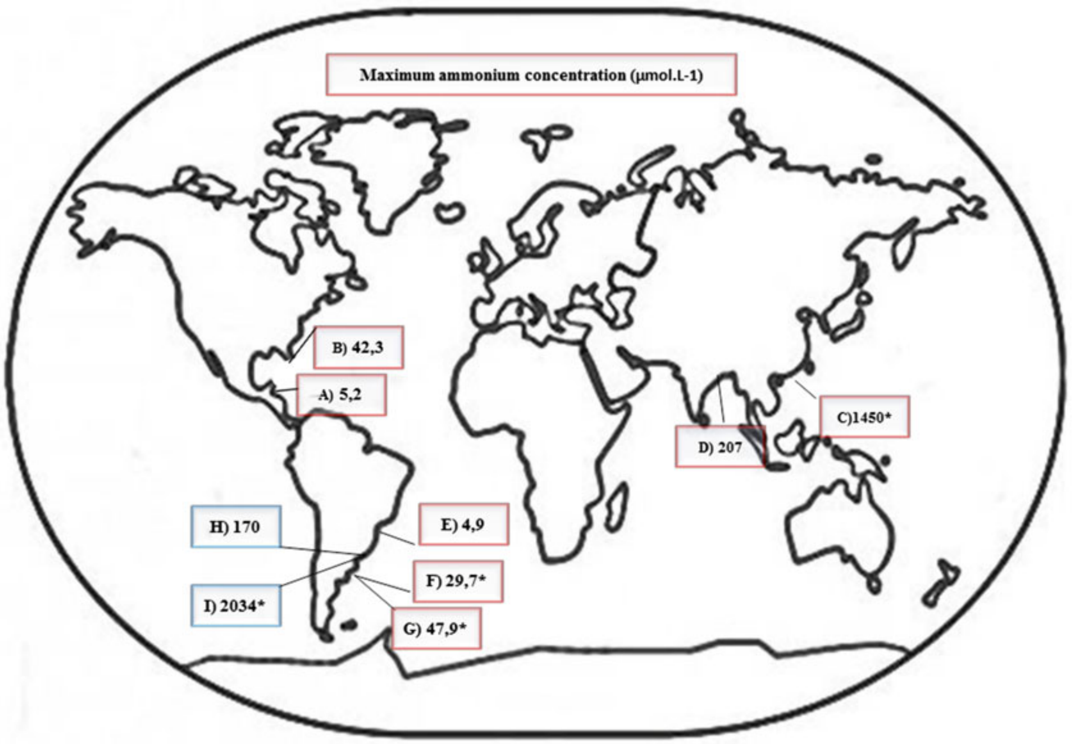

Fig. 10.3 Distribution of maximum values of ammonium. The symbol * represents estuary places. The letters represent places showed on Table 10.3. *Blue* represents this study

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