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Impacts of a high-discharge submarine sewage outfall on water quality in the coastal zone of Salvador (Bahia, Brazil)

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ABSTRACT

Carbon and nitrogen stable isotopic signatures of suspended particulate organic matter and seawater biological oxygen demand (BOD) were measured along a coastal transect during summer 2015 to investigate pollution impacts of a high-discharge submarine sewage outfall close to Salvador, Brazil. Impacts of untreated sewage discharge were evident at the outfall site by depleted $\delta^{13}C_{org}$ and $\delta^{15}N$ signatures and 4-fold increased BOD rates. Pollution effects of a sewage plume were detectable for more than 6 km downstream from the outfall site, as seasonal wind- and tide-driven shelf hydrodynamics facilitated its advective transport into near-shore waters. There, sewage pollution was detectable at recreational beaches by depleted stable isotope signatures and elevated BOD rates at high tides, suggesting high bacterial activity and increased infection risk by human pathogens. These findings indicate the urgent necessity for appropriate wastewater treatment in Salvador to achieve acceptable standards for released effluents and coastal zone water quality.

1. Introduction

The discharge of municipal sewage into coastal waters represents a major cause of marine and estuarine pollution in many countries around the world (Rahaman and Varis, 2005; Lotze et al., 2006; Mara, 2013). In particular, the common dumping of sewage without primary treatment is of great concern, as these effluents not only contain high concentrations of suspended solids and nutrients, but often also carry substantial amounts of human organic waste products (e.g. feces) (Ramírez-Álvarez et al., 2007; Law et al., 2013). The discharge of untreated sewage alters the physico-chemical properties of coastal waters and may cause severe contamination of the marine environment (Teodoro et al., 2010; Lapointe et al., 2011), often characterized by high microbial loads, including human pathogens (Lyon et al., 2005; Despland et al., 2012; Wang et al., 2014). Visitors of recreational areas such as bathing beaches affected by sewage outfalls (i.e. swimmers and bathers) are at increased risk for various types of diseases and infections, most commonly gastroenteritis or skin infections, posing a serious threat to human health in urbanized coastal regions (Griffin et al., 2001; Betancourt et al., 2014; Cheung et al., 2015).

Particularly in Latin America, the demographic explosion is absorbed by coastal or estuarine megacities (Cepal, 2000). With some of the highest coastal population densities in South America, most Brazilian cities are not equipped with facilities to collect, treat and dispose sewage in an environmentally sustainable manner (Abessa et al., 2005). In 2007, only 42% of all sewage in Brazil was collected, whereas only 32.5% of the collected volume was eventually treated (SINS, 2009). The common practice of draining raw sewage in the nearest body of water prevails (Salas, 2000), and in larger cities this is often implemented by means of a submarine sewage outfall. One of Brazil's largest submarine sewage outfalls belongs to the Oceanic Disposal System of Rio Vermelho (ODSRV) located off the coast of Salvador (Bahia), a city with ca. 2.7 million inhabitants (IBGE, 2010). The ODSRV was part of a state sanitation development program in the late 1970s, which involved the installation of a 2.35 km long concrete-steel pipeline with an inner diameter of 1.75 m. The Rio Vermelho outfall discharges 8.3 $m^3 s^{-1}$ of pre-filtered (10–30% of suspended solids removed), but otherwise untreated (Feitosa, 2007; de Souza, 2011), municipal sewage into shallow waters (27 m depth) close to the inlet of Todos os Santos Bay. Nearly four decades after its first operation, Rio Vermelho still ranks among the largest submarine sewage outfalls in the world (Feitosa, 2007),

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and the extent of its plume can even be observed by open-access time series satellite imagery (Google Earth, 2015).

To date, information on potential impacts by the Rio Vermelho outfall on water quality in adjacent coastal environments is scarce and difficult to access. This study is the first to analytically address concerns raised by previous oceanographic and hydrographic studies that tidal currents may transport sewage-derived organic matter associated with high microbial loads into near-shore waters and close to popular recreational beaches (Cirano and Lessa, 2007; de Souza, 2011). These concerns are based on knowledge of shelf hydrodynamics around the sewage outfall site that are affected both by the local wind field and tides (Cirano and Lessa, 2007; Amorim et al., 2012). While southerly winds induce water flow to the northeast during winter, northeasterly winds cause southwestward coastal currents during summer. Close to the inlet of Todos os Santos Bay these coastal currents become highly modulated by rising tides (Cirano and Lessa, 2007), which during summer promote rapid westward water flows and a potential transport of discharged sewage into near-shore waters (Fig. 1). Under these conditions, water flow close to the outfall site may reach up to 0.5 m s^{-1} (Cirano and Lessa, 2007). A recent numerical model has simulated shelf hydrodynamics around the Rio Vermelho outfall projecting the presumed transport of sewage, in particular fecal bacteria, from the outfall site towards the inlet of Todos os Santos Bay (de Souza, 2011). Although this model demonstrated that the Rio Vermelho sewage plume reaches the city beaches of Salvador, reliable model confirmation based on essential in situ water quality measurements is still lacking.

Therefore, this study investigated a set of water quality parameters, including suspended particulate organic carbon and nitrogen stable isotope signatures ($\delta^{13}C_{org}$ and $\delta^{15}N$), dissolved oxygen (DO) concentrations and biological oxygen demand (BOD) of seawater at potentially impacted sites within the coastal zone of Salvador (Chapman and World Health, 1996; Rožič et al., 2014; Mancinelli and Vizzini, 2015). Sampling was conducted on a long-shore transect across the Rio Vermelho sewage outfall towards the inlet of Todos os Santos Bay and aimed at answering the following research questions: (1) Are impacts of untreated sewage discharge detectable directly at the Rio Vermelho outfall site? (2) Are these impacts traceable along the coastal transect

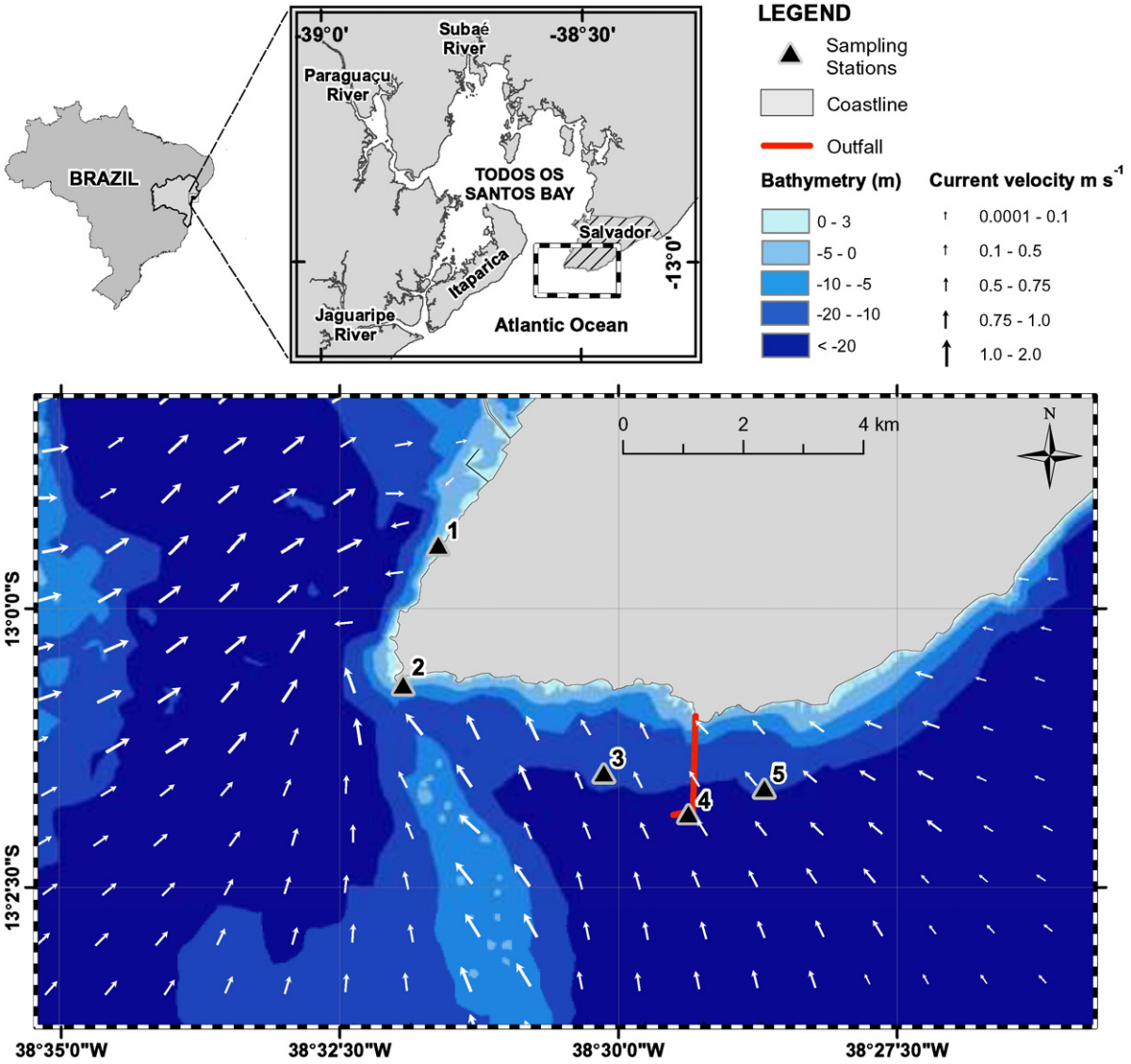

Fig. 1. Bathymetric map of the study site in the coastal zone of Salvador indicating the sampling stations, the Rio Vermelho sewage outfall site and the tidal current profile during high tide. Current vectors are derived from a numerical simulation using the Regional Ocean Modeling System (ROMS) (500 m grid resolution), projecting maximum flood currents during a typical summer spring tide. For the model simulation, temperature boundary conditions were obtained from a Moderate Resolution Imaging Spectroradiometer (MODIS) 2003–2012 sea surface temperature series, while water level, external currents and salinity boundary conditions were extracted from HYCOM (Hybrid Coordinate Ocean Model). Calculated averages encompassed the years 2003–2009 (HYCOM, 2011).