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Optimising statistical models to predict faecal pollution in coastal areas based on geographic and meteorological parameters

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ABSTRACT

This article describes a methodology for optimising predictive models for concentrations of faecal indicator organisms (FIOs) in coastal areas based on geographic and meteorological characteristics of upstream catchments. Concentrations of FIOs in mussels and water sampled from 50 sites in the south of Brazil from 2012 to 2013 were used to develop models to separately predict the spatial and temporal variations of FIOs. The geographical parameters used in predictive models for the spatial variation of FIOs were human population, urban area, percentage of impervious cover and total catchment area. The R^2 of models representing catchments located within 3.1 km from the monitoring points was up to 150% higher than that for the nearest catchment. The temporal variation of FIOs was modelled considering the combined effect of meteorological parameters and different time windows. The explained variance in models based on rainfall and solar radiation increased up to 155% and 160%, respectively.

1. Introduction

Recreational use of sewage-polluted coastal waters and consumption of raw or lightly steamed filter-feeding bivalve shellfish harvested from such waters pose a significant human health risk worldwide (Prüss et al., 2002). To reduce these risks, public health officials and water resource managers are increasingly using mathematical models to predict water quality and communicate to the public when pathogenic microorganisms in hazardous levels are likely to be present in the waters. These predictive models usually integrate variables that represent the sources of sewage contamination impacting the waters, concentrations of faecal indicator organisms (FIOs) (faecal coliforms, *E. coli*, enterococci) and/or pathogens measured in the waters/shellfish and the environmental conditions at or near the time of sampling (Francy et al., 2013; Olyphant and Whitman, 2004). The model output is an estimate of water/shellfish quality that is relevant in space and time to the risk of human exposure to the pathogen(s).

Regression-based models (RBMs) have been widely adopted to predict FIO levels in water. The main advantages of RBMs are that they rely on relatively basic statistical concepts and are easy to implement (de Brauwere et al., 2014). The environmental variables commonly used in RBMs to predict the spatial variations in FIO levels include land use or land cover characteristics of the catchment(s), resident human or animal populations, urbanized area and percentage of impervious cover (Campos et al., 2013; de Brauwere et al., 2014). The variables commonly used to predict temporal variations of FIO levels include meteorological and hydrological parameters (Campos et al., 2013; de Brauwere et al., 2014).

While changes in the spatial variation of FIOs in waters in response to changes in land use have been well documented for freshwater systems, few studies have been carried out in estuarine environments (Van Dolah et al., 2008). Where these studies exist, they are generally limited to shallow headwater portions of tidal creeks and it is unclear whether the associations detected are also valid for deeper areas of estuaries (Van Dolah et al., 2008). The water quality of estuaries is commonly influenced by multiple sources of pollution on the shoreline or upstream areas of the different catchments. Thus, the concentrations of FIOs and pathogens in the water/shellfish within a given estuary can vary significantly over short spatial scales (Beliaeff and Cochard, 1995; Kelsey et al., 2004).

Concerning temporal variation, rainfall is commonly associated with the variations in FIO levels in rivers and coastal waters. To study the cumulative effect of this parameter, time windows ranging from 24 h to 30 days before water sampling are reported in the literature

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(Ferguson et al., 1996; Lipp et al., 2001; Mallin et al., 2001; Pandey et al., 2012). The justification for selecting such windows is not usually provided. The predictive power of models that have tested the effect of rainfall on FIOs for different time windows varies considerably (Hose et al., 2005; Kelsey et al., 2004). It is therefore important to understand the dynamic contributions of different climatic, geographic and demographic factors at appropriate spatial and temporal scales to study microbial levels in coastal waters.

This work describes a methodology for optimising the performance of RBMs in predicting faecal pollution in coastal areas. The approach was tested using FIO levels measured in water/molluscs at 50 coastal sites and environmental data relating to geographical and meteorological characteristics of upstream catchments. The proposed approach allows for the development of RBMs in coastal sites influenced by multiple catchments and pollution sources. It also allows for a better understanding of the role of climatic factors in determining the levels of FIOs in coastal areas by considering the cumulative effect of those factors within appropriate time windows.

2. Material and methods

2.1. Site description

The North and South Bays (48°33′57″W; 27°35′46″S – Datum Sirgas 2000) are two adjacent bodies of water (total area = 430 km^2) located between the mainland of Brazil and Santa Catarina Island (Fig. 1). The bays are linked by a strait located in the central portion of the island and are connected with the Atlantic Ocean through the northern end of the North Bay (north mouth) and the southern end of the South Bay (south mouth). The bays are shallow (average depth = 3.4 m) and microtidal. The shoreline comprises small coves, sandy beaches, mangroves and promontories. The adjacent catchment covers a total area of 1875 km^2 and it is drained by several rivers and streams. The catchment is included in the humid subtropical climate zone (Alvares et al., 2013) and has uniform soil characteristics (Kobiyama and Chaffe, 2008; Pandolfo et al., 2002). The highest population density occurs around the strait between the North and South bays. The metropolitan area includes four cities (Florianópolis, São José, Palhoça and Biguaçu) which have a combined population of over 800,000. Human population fluctuates considerably during the year because of water-based tourism and recreation activities. This geographical area accommodates an extra 1.5 million people during the summer tourist season (January–March) (SANTUR, 2012). Only ~39% of the catchment population is served by centralised sewerage collection and treatment systems (SNSA/MCIDADES, 2014) and a recently published study showed that the systems in place are not effective in reducing the FIO inputs to the marine environment (Garbossa et al., 2017).

2.2. Database

A database of concentrations of FIOs monitored in shellfish and surface waters at 50 sampling points in the North and South Bays of Santa Catarina from August 2012 to October 2013 was used to study the relationships between FIO levels in seawater/shellfish and of the geographical and meteorological characteristics of upstream catchments. Samples of mussels and surface water were collected at 30 points

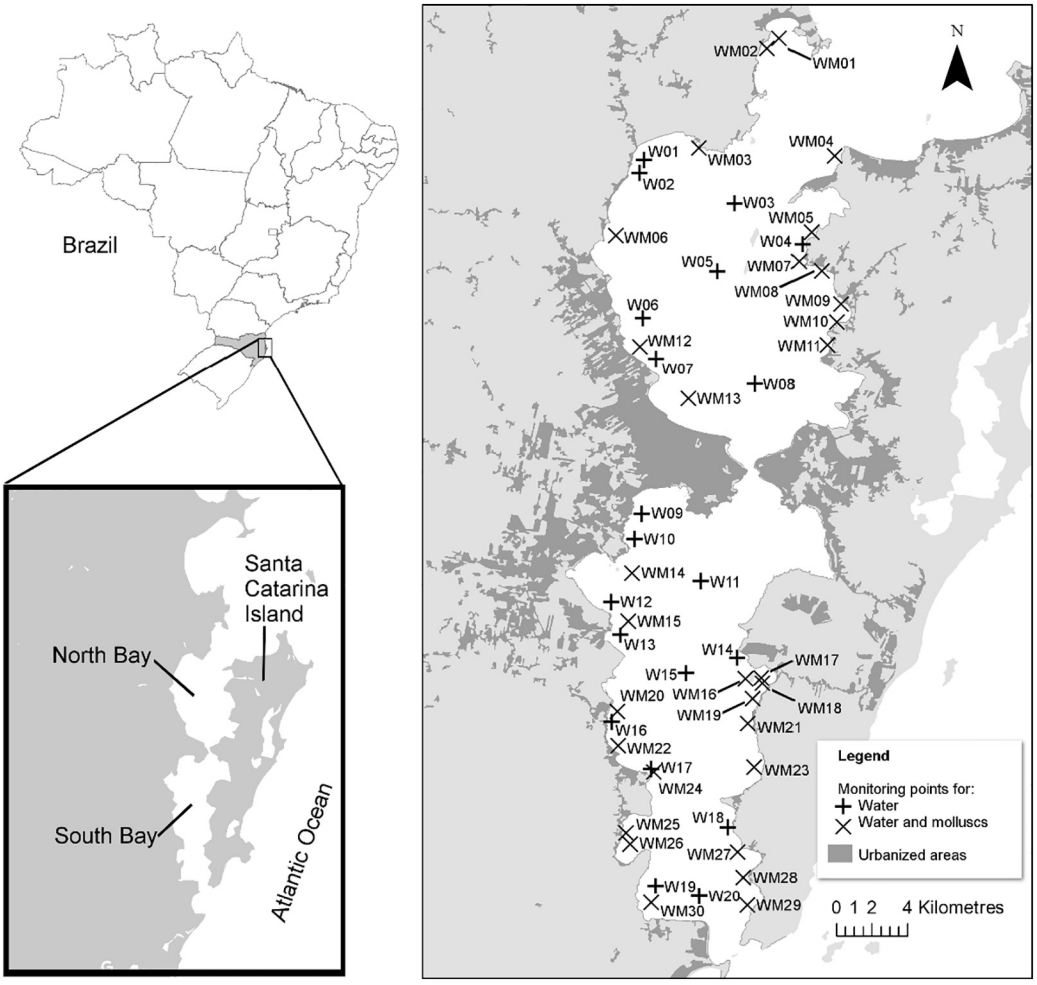

Fig. 1. Location of the study site, showing sampling points in North and South Bays, Santa Catarina, Brazil.