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# Rapid assessment of coastal water quality for recreational purposes: Methodological proposal

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A B S T R A C T

Coastal waters and beaches are the main tourist attraction in the Caribbean, reporting an estimated income of US $ 25 billion dollars a year. However, sewage discharge, solid waste leachates, and oil spills threaten these resources, requiring management strategies to control water quality, which sometimes is difficult given the lack of adequate technical tools. The present article proposes a quick methodology to determine the quality of coastal waters for recreational purposes, using San Andrés Island, Colombian Caribbean, as a study case. The proposal includes seven variables indicative of water quality, in three scenarios: normative, permissive and restrictive. The methodology initially uses a univariate weighting that qualifies the water quality at each sampling station by parameter, then a multivariate weighting to determine the quality with the set of indicator variables and its comparison with a general pollution scale. The application is presented with a dataset of 15 sampling stations between 2001 and 2016 from the systematic coastal monitoring network implemented by CORALINA. The results lead us to conclude that the proposed methodology is a useful tool for a rapid assessment of coastal water quality in areas destined to recreation by primary and secondary contact. It is also an input for the elaboration of management plans in coastal zones.



## 1. Introduction

The Caribbean Sea is recognized for its biodiversity (Miloslavich et al., 2010), characteristic that plays a fundamental role in the maintenance of life on the planet and human well-being, as it is linked to different functions, processes and properties, such as production, biomass, transfer, storage and matter recycling (Chapin et al., 1998; Tilman, 1999; Loreau and Hector, 2001; Mancera-Pineda et al., 2013). Biodiversity also provides services that are the base of highly profitable industries such as fisheries and tourism (Salm et al., 2000; Boris et al., 2006; Worm et al., 2006).

The economy of the Caribbean region is currently based on tourism (Kingsbury, 2005; Pantojas, 2006), with an estimated income of 25 billion US dollars per year (Burke and Maidens, 2005). Tourism in the Caribbean would not be as high as 20% of GDP (Gross Domestic Product) without its coral reefs, sandy beaches, and blue waters which attract tourists from all over the world (UNEP, 2013). However, there is increasing concern over the quality of coastal waters and potential microbial contamination. Tourism is an important driver for socio-economic development but also a source of environmental challenges (von Glasow et al., 2013). The major threats to coastal sanitation in much of the Caribbean are domestic sewage and industrial discharges (Constanza et al., 1997; Gavio et al., 2010).

Coastal water contamination not only diminishes the potential of recreational ecosystem services but may also generate problems related to public health by the presence of pathogenic microorganisms causing waterborne diseases (WHO, 1998; Shuval, 2003). It has been found that pathogenic microorganisms in coastal areas contribute to the outbreak of acute infections, including gastroenteritis, dermatitis, otitis, and respiratory illnesses (Shuval, 2003; Craun et al., 2005; Santoro and Boehm, 2007; Bauer et al., 2010; Coldford et al., 2012). Health effects are usually costly, due to medical treatment and temporal loss of labor, calling for efficient management of marine resources (Xie et al., 2017).

In the Caribbean, the heavy environmental loads from tourists, in addition to other anthropic activities, are challenging the ecological conditions at the land-water interfaces, compromising

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the sustainability of natural ecosystem functions (UNEP, 1997; Mallin et al., 2000; Xie et al., 2017). Considering the high complexity of the ecological interactions in marine environments, where land, atmosphere, and ocean meet (von Glasow et al., 2013), and the variety of ecosystem services characterizing the coastal zone, its management faces holistic challenges that must be aimed at sustaining social benefits without risking ecological structure and functioning (de Jonge et al., 2003; Elliott, 2011; Turner and Schaasfsma, 2015).

The coastal zone of San Andrés island has been affected by direct sewage discharge without any type of pre-treatment, generating nutrient enrichment (Gavio et al., 2010) and microbial contamination (Abdul azis, 2010). Likewise improper disposal of solid wastes, oil spills from vessels and excessive exploitation of marine resources, have been recognized as sources of coastal water quality deterioration in the island (Abdul azis, 2005).

Unlike other coastal regions of the world where the government has developed management tools and agreed strategic plans to fulfill management objectives (European Commission, 2005; Craun et al., 2005; Mansilha et al., 2009; Elliott et al., 2017; Elofsson and von Brömssen, 2017), the Caribbean region lacks a risk assessment and management framework to facilitate the environmental decision-making process. Marine pollution is not always evident to environmental managers, a fact that impedes planning and implementation of preventive actions, justifying the development of simple, user-friendly tools to help identify and prioritize problems and guide efforts to prevent or resolve them. The goal of this paper was to develop a new modelling tool for rapid assessment of coastal water quality for recreational purposes, using indicator variables associated with microbial and nutrient contamination. The methodological approach employs microbiological, physical, and chemical variables for coastal water quality assessment, based on a 16-year record analysis. The data used correspond to San Andrés Island coastal water monitoring, however, the methodology may be used for similar coastal ecosystems.

## 2. Methods

### 2.1. Study area

San Andrés is located in the southwestern Caribbean, between 12° 28′ 58″ and 12° 35′ 55″ N and 81° 40′ 49″ and 81° 43′ 23″ W (Fig. 1); it is the main island of San Andrés, Providencia, and Santa Catalina Archipelago, which is part of *Seaflower*, an International Biosphere Reserve declared by UNESCO (CORALINA, 2003; Gómez-López et al., 2012), with 65,000 $km^2$ of Marine Protected Areas, and the third more extensive reef barrier of the world. San Andrés is a small oceanic island (27 $km^2$) separated from the nearest platform by depths greater than 1000 m. It is influenced by the Caribbean current which originates temporal convergent whirlpools affecting the distribution and concentration of sediments (Garay et al., 1988).

North-east trade winds determine the predominant currents around the island, intercepting it from the northeast, running through the barrier reef and diverging to the south. The barrier reef reduces the marine current velocity, which becomes weaker on the coast (4–5 m/min).

San Andrés lies in the transition zone between tropical dry and wet tropical climates (Díaz et al., 1996). The average annual temperature is 27.4 °C, reaching a maximum from May to June and a minimum in February. The north-east trade winds determine a dry season from January to April and a rainy season from October to December when 80% of the mean annual rainfall occurs (1800 mm) (Gavio et al., 2010).

San Andrés is an overpopulated island (2600 inhabitants/$km^2$), mainly in the northern sector, where 70% of the local population lives. In this sector is also located the largest beach of the island and most hotels and commerce, and therefore concentrates the majority of the 600,000 tourists who visit the island each year (Guerra-Vargas and Mancera-Pineda, 2015).

### 2.2. Model development

The first step to develop the modelling tool for rapid assessment of recreational coastal water quality in San Andrés Island was the selection of variables following technical criteria based on scientific literature. Following the Colombian legislation complemented with international standards, we established for each variable, a weighting scale to estimate contamination level at 15 sites around the island. To qualify the pollution status at each site, we developed a multivariate weighting model, obtaining a coastal water contamination scenario of San Andrés Island according to the current Colombian legal framework. Finally, to explore different management alternatives, we generated two other potential scenarios. We express the results of each scenario, in maps according to their multivariate weighting (Fig. 2).

#### 2.2.1. Variable selection

According to the scientific literature, the recreational safety of water bodies is established mainly through the microbiological examination of water samples (Bonilla et al., 2007; Ortega et al., 2009). Fecal coliforms and total coliforms are among the most frequently used indicator microorganisms and have been historically used to establish bathing water quality. Fecal microorganisms, residing both in the water column and in the sediments, represent the major contamination signature and have been extensively used to determine standards for pollution status (Ryan et al., 2004; Mansilha et al., 2009; Xie et al., 2017).

High levels of indicator microorganisms have been associated with changes in physical and chemical variables like salinity, light, and nutrients (Ortega et al., 2009; Jayakumar et al., 2013; Sassoubre et al., 2015; Kalkan and Altug, 2015; Amin et al., 2017). During the past decades export of nutrients to coastal waters has been increasing around the world causing marine pollution (Amin et al., 2017). Particularly, nitrogen and phosphorus have increased, leading to a wide range of negative impacts including, but not limited to, eutrophication, harmful algal blooms, hypoxia, and fish kills (Keppler et al., 2015). Hence, to evaluate coastal water quality for a recreational purpose we selected seven variables based on their relevance (microbial contamination and nutrient enrichment) and availability.

We obtained historical data of San Andrés Island from 2001 to 2016 corresponding to total coliforms (TC), fecal coliforms (FC), biochemical oxygen demand (BOD), total suspended solids (TSS), ammonium ($NH_4$), nitrates ($NO_3$) and soluble phosphorus ($PO_4$). The data were obtained from the systematic water quality monitoring carried out by CORALINA, the Corporation for the Sustainable Development of the Archipelago; a description of this monitoring program is to be found in Gavio et al. (2010).

Considering the environmental characteristics of San Andrés Island, the entire coastal area was considered of potential recreational use, and the data from all 15 sampling sites of the monitoring network were used in the present study (Table 1).

#### 2.2.2. Univariate weighting

In 1984 the Colombian government adopted the directive 1594, establishing permitted values of water quality indicators according to water use (Decreto 1594 de 1984 Ministry of Agriculture). For recreational purposes, this directive defined specific threshold values only for total and fecal coliforms. Consequently, we went to the literature to compare values used in health risk assessments in

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