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Geoindicator-based assessment of Santa Catarina (Brazil) sandy beaches susceptibility to erosion

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ABSTRACT

In the actual scenario of progressive coastal occupation man-made infrastructure is increasingly threatened by natural hazards. As a consequence, in the last two decades different methodologies have been proposed to assess coastal vulnerability to the potential impacts of storm surges on developed areas. In this study, the susceptibility of sandy beaches to erosion was assessed by using an analytical approach based on geoindicators survey. This framework considers that a selected set of variables can express short-term environmental dynamics and be used, therefore, as proxies for the multiplicity of factors acting over coasts. Geoindicators are site-specific and rely on the description of coastal geomorphic features, both natural or man-induced. Santa Catarina State, located in southern Brazil, was selected as case study. Its shoreline contains beaches of different extents that alternate with headlands and a wide continental shelf on the adjoining Atlantic Ocean. It is regularly under influence of extra-tropical cyclones and other storm systems that frequently reach southern Brazil. Due to the occurrence of high energy episodes, damages resulting from short-term coastal erosion and inundation have been increasingly reported over the years. In this research, 302 points were surveyed during 40 days of field work and 32 geoindicators were considered representative of susceptibility. They were identified in the field, ranked in risk levels, weighted using AHP (Analytic Hierarchy Process) and tabulated, resulting in an index expressing local susceptibility in five progressive classes. In average, most of Santa Catarina sampled points were classified around intermediate degrees of susceptibility (High + Medium + Low = 82%), with a slight tendency to higher levels. Very Low levels of susceptibility were identified in 10% of the points, while Very High in 8%. Spatial distribution of data indicates that lower susceptibility values dominate in the south of the area while in the north prevails an alternating distribution of susceptibility classes, with a tendency to higher values. The different levels of coastal indentation along the state, a result of the regional geological setting, and the induced susceptibility resulting from sectors of dense human concentration close to the shore explain the observed pattern. The selected geoindicators were effective to evaluate the erosional propensity of Santa Catarina's sandy beaches, and allowed a relatively fast and low-cost approach for susceptibility assessment and monitoring analysis, with a potential practical use in coastal zone planning and management.

1. Introduction

Beaches are transitional features over which terrestrial, oceanic and atmospheric systems dynamically interact. Hydrodynamic and sedimentary processes arise from this interaction and may result in shoreline displacement, expressed in terms of complex patterns of erosion or accretion which cover different spatial and temporal scales (Komar, 1983).

Those environments dominate an extensive length of the world's coasts, being estimated by Mclachlan and Brown (2006) that two thirds of the world's non-glaciated shorelines are composed of beaches. They provide different goods and services that are essential for the use of the coastal zone by society (Defoe et al., 2009), including coastal protection. However, not always

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those uses are fully integrated to the intrinsic transitory characteristics of beaches, where a dynamical equilibrium state prevails in which coastal areas continuously adjust their morphology and sediment distribution to newly imposed conditions (Woodroffe, 2002).

In the case of extreme events, for example after high-energy waves have hit the coast, sandy beaches may lose considerable amounts of sediment and appear threatened. However, in most cases, it can be anticipated that they will recover to a state close to the one prior to the damage. The exposure of human assets to a coastal hazard, on the other hand, tends to result in more permanent changes and therefore to induce a certain economical loss (Bonetti et al., 2013).

Some coastal hazards may cause coastal retreat and/or episodic flooding, processes that are closely related. Hazards include processes that range from short-term events, such as severe storms, to slow trends, such as multi-century sea-level rise (IPCC, 2014). Storm surges, in particular, are weather-related drivers with good spatial representativeness and, thus, can be very well described and assessed by means of spatial analysis techniques using GIS (Rangel-Buitrago and Anfuso, 2015; Bonetti and Woodroffe, 2017).

Since the 90's different methodologies have been proposed aiming at recognition of sections of coast that are more vulnerable to coastal hazards (Gornitz, 1990; Cooper and McLaughlin, 1998), in particular to the potential impacts of sea-level rise and storm surges on human assets. In a scenario of climate change, and appearing increment in the number and effects of storms (IPCC, 2014), it is strategic to develop predictive tools that could allow the assessment of coastal exposure to erosion and flooding. This is particularly significant in developed areas where the proximity of human infrastructure to the shoreline can benefit from the formulation of operational policies for reducing the adversity of impacts and minimize socioeconomic losses (Bonetti and Woodroffe, 2017).

Some of these frameworks are based on the evaluation of coastal physiographic characteristics as indicators of local propensity to erosion. As noted by Berger (1996), geoindicators are representative of short-term environmental dynamics and can be considered proxies of the variables on which processes depend. They are, thus, based on the spatial representation of a set of independent elements (i.e. the geoindicators) reckoned representative of the multiplicity of factors acting over a specific site. One example of this approach was originally proposed by Bush et al. (1999) which suggested the use of geoindicators as a management tool for rapid assessment of natural hazard risk potential.

The basic idea behind geoindicators is that a selected group of descriptors can express the predisposition of a coastal segment to be affected by rising seas and/or storms. In this methodology, site-specific features (dune height, fetch exposure, vegetation cover, shoreline stability, beach character, inlet proximity, etc.) are selected in a case-by-case basis as the primary indicators of threatening hazards (Bush et al., 1999). Selected variables are identified and described in the field, ranked in risk levels and tabulated, resulting in an index expressing local susceptibility. The combination of different types of variables into a single measure provide a simple quantitative basis for ranking sections of the coast and index-based classification procedures have been extensively applied to identify specific locations where risks may be relatively high (McLaughlin and Cooper, 2010; Nguyen et al., 2016).

A positive aspect of this approach is its local representativeness, since variables are observed, not retrieved from a generic dataset. Moreover, it facilitates permanent updating through long-term monitoring in contrast to the more static picture provided by other methodologies. On the other hand, some of the proposed geoindicators are very transitory and not necessary represent a trend or an average state of the system (Rudorff and Bonetti, 2010).

This paper applies this methodology, with improvements detailed in the Materials and Methods, and adopts the concept of susceptibility, i.e. the system's potential to be affected, either adversely or beneficially, by a hazard. This approach is primarily derived from environmental (physical) conditions (UNDP, 2004) and does not consider the exposure of socioeconomic assets, as do the vulnerability or risk assessments. However, it must be noted that the multiple uses of the coastal zone (e.g. presence of protective structures) may induce higher degrees of susceptibility and thus produce new geoindicators.

Instead of susceptibility, some authors prefer the terminology “sensitivity” (e.g. Abuodha and Woodroffe, 2010) or the (bio) physical vulnerability (Cutter, 1996) which, in practice, refer to the same concept. Vulnerability is a key concept in hazards and disasters literature and here is considered as a combination of susceptibility and exposure (the elements at risk from a given hazard), mediated by aspects of adaptive capacity (the combination of strengths and resources available to reduce the effects of a hazard) (Bonetti and Woodroffe, 2017).

In this research, our main objective is to assess sectors of Santa Catarina State (southern Brazil) where erosional trends are more significant as they induce recognizable morphological features in the landscape. The development and application of geoindicators framework on local sandy beaches is discussed and the distribution of susceptibility classes along the state is quantified.

Moreover, beyond the local interest of the investigation, it is our intent to propose the geoindicator approach as a cost-effective management tool for rapid assessment of natural hazard risk potential by showing its efficiency to represent different degrees of susceptibility in regional level. For this, obtained results will be compared to historical data of storm effects along the state to evaluate the representativeness of the proposed susceptibility map.

2. Study area

As observed by Bird (1985), signs of beach erosional can be observed worldwide. Particularly in Brazil, coastal segments suffering progressive erosion apparently overcome those stable or under progradation (Muehe, 2006), being considered the main cause of this the significant human presence along the coast, which locally can produce or accelerate erosional processes on beaches by inducing additional elements of higher susceptibility (McLaughlin et al., 2002).

In a state level assessment Rudorff et al. (2014) spatially described the impact of coastal storms in Santa Catarina based on damage reports registered by state's Civil Defense. Analyzing data from 1997 to 2010 the authors identified an unsystematic variation in the number of annual events, oscillating from zero to 12 with an average of almost 4 events per year, concentrated in the months of May, June and July. Coastal degradation, mostly related to urban expansion and inadequate management plans were considered the main sources of the high susceptibility detected in some sectors to erosion and flooding along the coast (Bonetti et al., 2013).

Santa Catarina coast is located in southern Brazil between latitudes 25°57′ and 29°24′ S (Fig. 1). It trends from south then southwest for about 922 km of open coasts and bay shorelines. Sandy beaches are the most present geomorphic feature in Santa Catarina's shoreline, accounting for almost 58% of its extent (Klein et al., 2016). The state has a narrow coastal plain, rising inland to escarpments disposed approximately parallel to the coast. Its 246 individual sandy beaches alternate with headlands and a wide continental shelf on the adjoining Atlantic Ocean.

Nearby deepwater waves range from 0.5 to 2.0 m and come predominantly from east to southeast while storm waves may

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