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# An index-based method for coastal-flood risk assessment in low-lying areas (Costa de Caparica, Portugal)

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ABSTRACT

The coastal area of Costa de Caparica is an important territory representing one of the main affected areas by storms such as Hercules in 2013 and 2014. This paper propose a new coastal risk assessment to coastal floods, combining GIS-based inundation analysis over the last 35 years, coastal vulnerability model based on geological and physical variables and, valuation of surface' elements exposed to storms considering territorial and human components. Along with the methodology proposed for local scale, this paper points out strengths and weakness, comparing the results with another simple method to achieve coastal risk by floods. Based on this study, the paper identifies potential directions for future research contributing in management, rescue and safety decisions with local authorities.

## 1. Introduction

As consequence of extreme weather events and sea-level rise, the level of risk and impacts from flooding, overtopping and erosion in Europe have become more evident throughout the 20th and 21st centuries (Nicholls and Cazenave, 2010; Weisse et al., 2014). Between 1994 and 2004 almost 60,000 people were killed in one-third of 1562 coastal flood disasters suggesting a threat increment depending on the combination of high tides, storm surges and/or high river flows (McGranaham et al., 2007). It is known that large number of people, resources and goods are exposed to coastal flooding (Bosello and De Cian, 2014), but this is expected to increase with the growing population and economic relevance of coastal cities, mainly in developing countries (Nicholls et al., 2008).

Risk is generally referred to the probability of future damage and loss associated with the occurrence of natural catastrophic events, where levels and types of loss are determined by the levels of exposure and vulnerability to society (Newton and Weichselgartner, 2014). The World Meteorological Organization (WMO, 1999) defines risk as “expected loss of lives, people injured, damage to property and disruption of economic activities due to a particular hazard in a given area and referenced period”. Julião et al. (2009) describe as the probability of occurring a dangerous process (or action) and its estimated effects on people, property or environment, expressed in direct or indirect materials and functional damages and/or loss of life, being expressed by the product of hazards and potential damage. In this general description, the last component (potential damage) turns into the product of this vulnerability by the value of exposed elements.

In any case, “risk” should include the interaction of hazard and vulnerability of an affected area, particularly if significant changes are observable in the territories. The European Commission incorporates the terms “exposure” and “vulnerability” (Komendantova et al., 2014). In this context “exposure” is directly related to an evaluation of elements exposed to hazards, assuming an analysis of the economic value of elements at risk assumed their recovery. In case of impossibility to make this complex evaluation, the alternative is to identify and arranged the elements by effort level in recovering those lost. It should include an estimation of (in) direct economic losses of termination and/or interruption of

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activity, functionality or laboring (Julião et al., 2009). In this paper, we discuss exposure as the number of people and elements at risk that can be affected by a particular event of hazard (Benassai et al., 2015).

As for "vulnerability" there is no common definition, but different views, meanings and consequently different studies and results (Tapsell et al., 2010). Vulnerability can attribute the degree to which a system is modified or affected by an internal or external disturbance or set of disturbances (Gallopín, 2006). Also, it measures the propensity of exposed human beings and assets to suffer damage and loss when impacted by hazard events (Weichselgartner, 2001). Or even, assign a degree of "expectable" loss of elements exposed resulting from the magnitude of certain hazard (Crozier and Glade, 2005). In sum, vulnerability can classify the ecosystem components according to a degree scale, assuming the occurrence of natural hazard events without placing them spatially.

The spatial and temporal representation is assumed by "hazard" which differs from "natural hazard". While natural hazard is a dangerous phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption or environmental damage (UNISDR, 2009), hazard expresses the spatial and temporal probability of occurrence of a natural phenomenon with negative consequences for society (Rebelo, 2003). Thus, it depends on the trend of an area to be affected by a particular event without considering their probability of occurrence (Julian et al., 2009), but its composition and repeated infringement, representing the tendency of an area to be affected by a particular event, assumed the probability of hazard occurrence' based in past events and knowledge.

The recent findings on Martinez-Graña et al. (2016), Sano et al. (2015), Seenath et al. (2016) and Fakhruddin and Rahman (2015) demonstrate how different interpretations of the same concept led to different studies and conclusions, where the comparison among them will led to incorrect assumptions. Due to this fact, the literature review was based mostly on the definitions and specific points to assess the present method.

In this paper we present a new risk assessment to floods in the low-lying coastal areas, considering risk as the probability of loss anthropogenic or natural material due the existence of a natural hazard with a certain magnitude and frequency with negative impacts. Hazard, vulnerability and exposure are the three elements on which risk depends (Benassai et al., 2015) and make possible to respond to: How many times the flooding events occurred? What areas were affected in the past? Which areas were more vulnerable, exposed and consequently at risk?

## 2. Case study

### 2.1. Coastal morphology

The risk assessment was assessed in the north area of Costa de Caparica coastal plain incorporated in the coastal zone of Littoral Arc Caparica-Espichel (Ferreira and Laranjeira, 2000). Located at the central zone of Portugal, the study area is limited towards the sea by 6 km of narrow sandy beaches extending from NW to SE in the front Atlantic (Fig. 1A). This plain is an emerged continental platform, with relatively narrow and slight steepness with values below 20 km except the areas in the mouth front of Tagus River where the sediments carried out and built a wider continental shelf sections. Studies using the seismic reflection showed that these sediments came fill old canals, probably related to episodes where the sea level was lower than nowadays. In the submerged area, adjacent to the study area, the Cascais and Lisbon cannons origin' are not fully known. However, these deep incisions are related to tectonics and currents dynamic (Tenedório et al., 2003).

The emerged section is composed by three sectors: the coastal plain of aeolian sands and large sandy dunes systems reaching the maximum of 10 m high; the arriba, a fossil cliff with sharp profile of two sectors (somital of steep slopes > 40% and the basal slope more gentle between 10 and 30%), consisting of Miocene, Pliocene and Quaternary materials; and the littoral platform constituted by relative plane surface lower than 100 m high (Ferreira and Laranjeira, 2000).

Despite the different morphological features, the study area is no longer constituted by intact zones. In fact, the narrow beaches, especially in the central zone of the city (located near to point P7, Fig. 1A) are protected by groins in an attempt to stabilize and/or minimize the coastal retreat and sand loss rate. The beaches, located in the northern and central zone, are characterized by high density of beachgoers during the summer and surfers during the winter. The southern section presents a homogenous lower density of surfers during winter, but high density of beachgoers during the summer despite the distance and accessibility to the main city.

To distinguish the beaches of different sections, 16 profiles from each individual beach were produced through Differential Global Position System (DGPS) using the reference of vertical Datum Cascais 1938. All profiles were collected on April 2014 during the low tides (0.66 m and 0.70 m) guaranteeing minimum security conditions given strong swell conditions registered during the previous months. Fig. 1B represented three profiles: São João da Caparica beach (P13 semi natural beach), Dragão Vermelho beach (P7 urban beach) and Cornélia beach (P3 semi natural beach).

### 2.2. Wave climate

To understand the offshore wave climate conditions we performed the statistical data analysis from European Centre for Medium Range Weather Forecast (ECMWF, 2014) using Wave Atmospheric Model (WAM) with the coordinate position 38°15′0″N 9°45′0″W (Fig. 1A). Assuming their representativeness we considered wave records data characterized by significant wave height, $H_s$, mean wave period, $T_m$ and mean direction, $D_m$, from January 1979 to March 2014, every 6-h intervals (00 UTC+6 h).

The results show the area is frequently affected by moderate wave conditions with significant wave heights lower than 2 m–3 m with dominant section NNW-SSE. However, in the last 35 years during the winter the swell direction is predominant NW-SE with significant wave height of 3 m–4 m (Fig. 2). In long-term wave climate, the extrapolation of significant wave height and mean periods were obtained through Weibull distribution with returns period, $T_r = 1$ year, $T_r = 50$ years and $T_r = 100$ years. Table 1 shows the results obtained from equation (1) (Sarpkaya and Isaacson, 1981):

$$H_{s,\,Tr} = B + A[\ln(\lambda T_r)]^{1/k} \tag{1}$$

where $A$, $B$ and $k$ are scale, position and shape factors and $\lambda$ is the mean of "over-threshold". The $H_s > 3$ m of sea storms observed in 1979 show similar significant wave height in 50 and 100 years, much higher than the result for 1 year return, as it was confirmed in 1980 ($H_s$ maximum = 4.87 m). A similar behavior is observed in mean period according to the statistic correlation among $H_s$ and $T_m$.

In inshore wave climate, the adoption of a numerical wave model (SWAN) was used to simulate only the swell conditions in 10 m bathymetry along with the 16 beach profiles collected. The SWAN model outputs correlated to ECMWF data revealed a strong positive correlation following statistical analyses of Pearson' coefficient ($r_{P3} = 0.83$; $r_{P7} = 0.84$; $r_{P13} = 0.82$) with a general relation of