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Support mechanisms for oil spill accident response in costal lagoon areas (Ria de Aveiro, Portugal)

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A B S T R A C T

Oil spill accidents can be caused by several risk factors associated to maritime transport and port activities, which cannot always be predicted or controlled. Therefore, it is essential to support prevention and contingency plans, whose effectiveness is crucial to produce adequate responses and minimize resulting impacts.

Ria de Aveiro (Portugal) is a wide coastal lagoon, within a densely populated area, representing a concentration of important biodiversity resources and several economic activities. This paper presents alternative methodologies to support the optimization of civil protection assets in the occurrence of oil spill events and the results of their application on a section area of the Aveiro Lagoon, using an established geographic information system database containing crucial data.

The presented methodologies are based on the Environmental Sensitivity Index developed by the North American National Oceanic and Atmospheric Administration (USA) and the Global Vulnerability Index which were applied on the Bay of Biscay (Spain). However, during the development of this work, neither of these methodologies was considered to entirely assess the study area in its full extent, which led to the need to adapt and define a bespoke approach. The introduced changes include extra categories in shoreline classification, an adapted physical vulnerability index for coastal lagoons, differentiated aspects for highly protected status areas, qualitative assessment of socioeconomic features and an access and operability index created to support emergency operation response.

The resulting maps are the subject of analysis, in which considerations regarding control and cleanup methods are introduced, together with guidelines for further integration in local risk management strategies.

1. Introduction

Maritime transport and port activities are amongst the major sources of oil pollution affecting coastal areas (OECD, 1997). According to the International Tanker Owners Pollution Federation (ITOPF, 2012), the list of large acute oil spill accidents is mostly associated with port operations, collisions, fires and explosions.

Due to their configuration, coastal lagoons are particularly exposed to the pollutants' negative impacts, not only because of their ideal location to accommodate large maritime ports, but also because they often concentrate important biologic and socioeconomic resources, posing special problems for cleanup operations (Newton et al., 2012, in press; O'Sullivan and Jacques, 1998).

Oil spill accidents may vary according to a range of factors, from: spill size, location, type of oil, or weather conditions (ITOPF, 2002; Santos and Andrade, 2009; White, 2002). Since they cannot always be predictable or controllable, prevention is usually the only available first line of defence (EPA, 1999).

Experience from previous cases has shown that for effective counter-pollution actions during oil spill events, it is essential to identify the most sensitive areas in terms of location and specific values, establish priorities for direct intervention, and select the most adequate control or cleanup methods. Otherwise, resulting impacts can get worse if adequate containment and cleaning measures are not promptly taken (Pincinato et al., 2009; Vafai et al., 2013).

1.1. Case study

The present case study introduces the Ria de Aveiro, a wide coastal lagoon located on the Central Region of Portugal. Covering almost 12,000 ha, it includes a large multifunctional port and it is considered as an area of ecological significance, including a nature reserve and a wide range of habitats used as nursery areas by several species that include bivalves, crustaceans, fish and birds (Sousa et al., 2013). Located in a highly populated area, it concentrates several types of anthropogenic activities, including fisheries, tourism, harbour, leisure and recreation. The main hydrodynamic circulation is driven by the oceanic tide and

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freshwater river intakes, although water circulation can also be affected by frequent strong wind events (Azevedo, 2010; Dias and Lopes, 2006).

1.2. Sensitivity and vulnerability maps

In 1979, United States National Oceanic and Atmospheric Administration (NOAA) introduced the Environmental Sensitivity Index (ESI) maps. Since then, this approach remains as one of the most broadly used, contributing to reduce environmental consequences of spills and cleanup efforts (NOAA, 2002). The concept of Sensitivity is often referred as the degree to which a system is affected (IPCC, 2001), or according to the oil spill point of view, the likelihood of a resource to be affected by an oil event even without direct contact (Michel et al., 1994). Applicable to coast, estuaries and river environments, ESI maps compile a set of key features such as a shoreline geomorphology sensitivity rank to oiling, and biological and human-use at-risk resources. ESI maps also provide complementary guidelines for decision-making support systems in oil spill contingency plans (NOAA, 2002; Vafai et al., 2013).

NOAA proposed an alternative methodology for application in small rivers and streams. The Reach Sensitivity Index (RSI) integrates the original ESI methodology, with other elements: navigation, water flow patterns, stream size, suitable collection points, channel leakage, bifurcation and oil persistence time (Hayes et al., 1997).

Another concept under the scope of risk assessment is vulnerability. The definition of vulnerability is often referred to the extent to which a system is susceptible to sustain damage (IPCC, 2001), or the degree of loss of a community or an area towards defined hazards (ESPON, 2003; Kumpulainen, 2006; Santos et al., 2013).

Castañedo et al. (2009) developed an oil spill vulnerability assessment integrating physical, biological and socioeconomic dimensions, for the Cantabrian coast in Spain. Unlike NOAA's ESI maps, this method includes a quantitative approach, based on three specific indexes, applied to shoreline segments and compared with each other.

Ng et al. (2008) carried out an oil spill vulnerability assessment of the Pulau Pinang eastern coast (Malaysia). Despite using the term Vulnerability, the authors use a modified version of ESI maps, adjusted with environmental and socioeconomic features. They represent a qualitative assessment of existing biodiversity conservation protection status, and human activities or uses.

Regarding the application of similar studies in Portugal, one of the first methodologies is included in the Portuguese Mainland Coastal Atlas (MARETEC, 2007). Based on NOAA's ESI maps, this study adds a socioeconomic index, established according to five qualitative classes.

Santos and Andrade (2009) compare different assessment approaches for environment sensitivity of the Portuguese coast to oil spill, presenting the advantages and disadvantages of sensitivity maps and algorithm based sensitivity models.

Leal (2011), assessed the sensitivity of hydrocarbons maritime pollution planning and response, applied to a southwest Algarve coastal area. Particularly adapted to high use recreational areas, this study includes accessibilities and beach carrying capacity factors.

More recently, Santos et al. (2013) proposed a quantitative vulnerability assessment and mapping methodology which was validated and applied to the Portuguese mainland coast, using NOAA's ESI maps and other biological and socioeconomic indicators, for the municipality spatial segregation level.

1.3. Oil spill response techniques

The oil industry has registered many records from previous oil spill accidents, including their effects, control and cleanup techniques and cost implication. Al-Majed et al. (2012), describes some of the most commonly used methods and corresponding suitability, strengths and limitations. Although the list of available methods to be applied in open sea is quite extensive and straightforward, it becomes more complex for coastal lagoon areas, where strong currents and wind, shallow water conditions and sensitive resources may be present. Most mechanical techniques, including booms and skimmers, are only effective for calm water and wind conditions, while the use of dispersants, in situ burning and certain sorbent materials are seriously constrained by adverse environmental implications (Al-Majed et al., 2012; Broje and Keller, 2007; Castro et al., 2010; CEPRECO, 2008; Muttin, 2008).

2. Methods

This study results from a bibliographic research over several case studies and post-accident decision-support methodologies (Fig. 1). Methods were tested and applied on a geodatabase containing physical, biological and socioeconomic elements for the study area of the Aveiro Lagoon.

This study combines three independent indexes and respective cartography at a local scale. The results will be focused on a study area section, the Port of Aveiro jurisdiction area, which covers the port land and expansion areas, the adjacent canals and respective banks of the Public Maritime Domain (Fig. 2).

The first index is a modified version of NOAA's ESI maps. Considering the morphological specificities of the study area, it was necessary to include extra shoreline categories.

In this context, code *8F — Vegetated, steeply-sloping bluff* is used, even for non-riverine locations, including certain segments of the Vouga estuary, located near the eastern area of the Aveiro Lagoon (Vaz et al., 2005) (Fig. 2). Also, where smaller streams are present, code *10F — Anastomosing channels* is used, which according to the RSI guidelines corresponds to a case of maximum oil spill sensitivity (Hayes et al., 1997).

As for the rest of biological and socioeconomic resources, the original ESI map methodological guidelines were followed, except for the incorporation of other occurring human-use resources: salt pans and other recreational activities — kitesurfing, paddling, rowing, stand-up-paddle surfing, boat tours, windsurfing and sailing.

The second presented methodology is a modified global vulnerability index. This index, I_G, is given by Eq. (1), corresponding to the weighted average of physical, biological, and socioeconomic indexes — I_P, I_B and I_E. Both physical and biological indexes, are based on the Castañedo et al. (2009) study, and the socioeconomic index, is based on Ng et al. (2008) and MARETEC (2007) methodologies. Individually, I_P and I_B are classified within a scale up to a score of 10, while I_E has a maximum of 5, hence a twofold weight is given to I_E, balancing the importance given to physical, biological and socioeconomic aspects.

$$I_G = (I_P + I_B + 2I_E)/3. \quad (1)$$

According to Castañedo et al. (2009), the physical index assesses the potential impact of an oil spill, based on the self-cleaning capacity of coastal segments, depending on wave exposure and mean shoreline slope. However, for areas such as estuaries, the method assumes the maximum physical vulnerability index value due to their slow self-cleaning capacities. For this case study, its direct application would have failed to distinguish between areas with different physical characteristics. Assuming the contribution of offshore winds in the removal processes of deposited oil (Azevedo, 2010; ITOPF, 2002) and that wave exposure is almost non-existent in estuarine and lagoons environments, this paper suggests an alternative physical index definition, based on the average shoreline slope, *SP*, and dominant wind exposure, *E*, estimated by Eq. (2):

$$I_P = E + SP = O + S + SP. \quad (2)$$

Exposure, *E*, is calculated by the sum of the orientation, *O*, and the sinuosity, *S*, of the assessment unit, considering the changes in shoreline direction as the segmentation criteria.

According to data from the local meteorological station of Casal do Rato (MAOT and INAG, 2011) dominant winds, both in terms of intensity (up to 18 m/s) and frequency (over 35%) come from N–NW direction