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Risk assessment for marine spills along European coastlines

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ABSTRACT

A marine-spill risk index is proposed to measure and compare the relative vulnerability of coastal regions to marine spills in European waters. It is applied to 301 spills in European waters between 1970 and 2014 for 429 Eurostat territorial units and 156 regions in Europe's coasts. The results show a high heterogeneity among European coastal regions with areas, predominantly on the Atlantic coast, with high marine-spill risks. In particular, UK coasts are markedly affected as there are only five non-British coastal territories within the first 25 territorial units most at risk from marine spills. Across countries, European Atlantic countries face highest risks versus coastal countries on other European waters that are relatively safer. The index also shows a tendency of sea currents to have positive dispersal effects leading to smaller risks rather than otherwise. The index may help to design protection policies and reduce the vulnerability of sensitive resources.

1. Introduction

A marine spill can be described as the release of seaborne transported or offshore drilled pollutants, such as crude oil, bunker, persistent and non-persistent fuel oil and other hazardous and noxious (HNS) substances, into the oceans. By their very nature marine spills can be very damaging to the environment (Boesch et al., 1974; ITOPF, 2014b; Mann and Clark, 1978) and have serious consequences for many socio-economic aspects in coastal areas (Grigalunas et al., 1988; ITOPF, 2014a; Vanem et al., 2008). As a result, marine spills attract intense media attention and generate strong political debate about the appropriate actions to prevent them from happening and to counteract their environmental and socio-economic impacts (Bradley, 1974; Broekema, 2016).

Parallel to this, there has been in recent years an increasing interest in the analysis of ocean resources for human development and sustainable economic growth. For example, in the European Union (EU), successive marine policies identify marine activities as crucial drivers for the economy (Commission of the European Communities, 2011, 2012, 2013, 2014), yet compatible with the concern for the protection of the ocean or its sustainable management (Commission of the European Communities, 2006; Council of the European Commission, 1992).

In response to all this, a substantial body of international policy improvements, government regulations and even voluntary initiatives from oil and gas firms for preventing marine spills have emerged over the last decades with varying results (Frynas, 2012). However, although these measures have resulted in a decrease of the annual average, large marine spills keep occurring nonetheless with an impact distribution among coastal areas that is far from homogeneous (ITOPF, 2015).

The design of these marine policies, regulations and initiatives needs some sort of monitoring of coastal vulnerability. Data availability allows a scientific approach, besides the political one, to be used in the management of the oceans and coastal areas (Barale et al., 2015). It is because of this that quantitative information is required, in particular, on the relative risks from marine spills involved in each coastal area.

There is a substantial literature on the evaluation and modeling of marine spills that can serve as examples of the prevailing methods for their assessment. Gasparotti (2010) and Suter (2016), for example, provide good manuals on the steps of risk assessment methodology and its importance for risk management. Some other works offer a perspective from the modeling point of view. For example, Stewart and Leschine (1986) compare representative examples of several marine spill risk assessments with regard to decisions about the inputs of the different models. Grigalunas et al. (1988) discuss a damage assessment model for coastal and marine environments that employs an integrated ocean systems/economic model to simulate the physical fates and biological effects of a spill and to measure the resulting economic damages. Vanem et al. (2008)

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incorporate all costs of a shipping accident into a cost model and also reviews previous studies on the costs associated with marine spills.

More specifically, many studies evaluate the large impacts of specific marine spills such as the Exxon-Valdez and Prestige disasters (see, for example, Albaigés et al., 2006; Castanedo et al., 2006; Hartung, 1995; Peterson et al., 2003), but it is also worth mentioning that smaller spills cannot be dismissed due to their long-lasting effects (Blumer et al., 1971).

Risk assessments for specific areas, rather than for actual spills, stress the importance of preemptive risk assessment. To name a few studies among the recent ones, Merrick et al. (2002) present a detailed model integrating system simulation, data analysis and expert judgment for the risk assessment of Prince William Sound, Alaska, in the aftermath of the Exxon-Valdez spill; Dalton and Jin (2010) investigate the size, frequency, and total amount of vessel oil spilled in US marine protected areas; Kirby and Law (2010) consider the importance of impact assessment and monitoring programmes in the wider response cycle of risk, impact, mitigation and monitoring; WSP Canada Inc. (2014) deals with marine spills in Canadian waters using a complex transport model more suitable for large geographical areas that includes variables of oil type, spill size and weather conditions; Singh et al. (2015) use spatial modeling to identify critical areas potentially at risk from oil spills in the form of a potential oil spill risk in the Caribbean sea; Canu et al. (2015) give an assessment of the hazard faced by Sicily coasts by tracking a large number of surface trajectories followed by particles released over six selected areas; Kankara et al. (2016) integrate oil spill modeling with coastal resource information to map the environmental sensitivity of the Chennai Coast in India while Stevens (2015) visualizes the heightened vulnerability of large geographical regions associated with large spills. However, not many works can be found that focus on comparing and ranking the vulnerability of coastal regions by measuring their potential risk from marine spills.

In contrast to previous literature, this article presents a related but more specific objective, namely to measure the relative risk from marine spills experienced by coastal regions in European waters. The resulting marine spill risk index makes it possible to compare and rank each region's marine spill vulnerability with respect to the rest of regions in the target area.

The paper is organized as follows. Section 2 explains the method for the construction of the proposed marine spill risk index. Section 3 describes the marine spills data and the geographical framework used in this study. The ensuing results for the different levels of hierarchical division of the European territory are shown in Section 4. Finally, Section 5 summarizes the main conclusions.

2. Methodology

In order to quantify the relative risk from marine spills that certain coastal regions may experience four relevant variables will be considered. Firstly, (a) the distance from the coast to the place where the marine incident occurs and (b) the magnitude or size of the spill released as a result of the marine incident. Secondly, (c) the shape and length of the target coastal area and (d) the effect of ocean currents in the time and place of the incident.

Let us first define

$$I_{ij} = \frac{I_{max} + (1 - I_{max})e^{S_0 - S_j}}{1 + D_{ij}} \tag{1}$$

as the impact that spill j has on the geographical area i, where, once the respective geographic coordinates are projected, D_{ij} is the minimum distance in hundreds of kilometers between the coastline of the geographical area i and the marine spill site j; S_j is the size of the j-th accidental spill expressed in 10,000 tonnes per unit of spill, with S_0 as the minimum spill recorded,[1] and I_{max} is the maximum value for the impact index. Thus it is clear that the calculated impact index is inversely proportional to the distance to the marine spill, and increases with the spill size within the range $[1, I_{max}]$.[2]

In principle, a marine spill risk index value for the target coastal area i could be obtained by simply adding all the individual impacts on that coastal area from each of the accidental spills, i.e. $R_i^A = \sum_j I_{ij}$. However, the morphology of coastal areas often differs considerably. Therefore, it is conceivable that it would be more appropriate to consider the risk of marine spill impact taking into account the proportion of the coastline of a target coastal area affected by the marine incident in question.

In brief, the method proposed consists of simulating the range of each marine spill by first of all generating concentric circular geographical zones around the site of the accident for q different impact levels that determine the radius of each zone depending on the magnitude of the spill in the absence of currents. Then, a simple short-range transport model is used to reshape the border of such zones depending on the different velocities of ocean currents around the affected zone[3] (for example, Fig. 1 shows the average current speed and direction in the NE Atlantic during 2002). Finally, the parts of the target area's coastline that at each impact level lie within the range of the marine spill are determined in order to apportion the original impacts.

The following steps summarize the resulting algorithm.

i) Let $I_k = I_{max} \cdot k/q$, $k = q, q-1, \ldots, 1$, be the impacts considered from highest to lowest. For each of them, Eq. (1) can be used to establish the maximum distance D_{kj} reached by a spill with impact I_k in the absence of sea currents. That is, the radius of the circle within which spill j generates an impact I_k is obtained as

$$D_{kj} = \frac{I_{max} - I_k + (1 - I_{max})e^{1-S_j}}{I_k} > 0. \tag{2}$$

ii) Let $C_{kj}[x, y]$ be the coordinates of the circular zone centered at spill j of radius D_{kj}.

iii) Let $P_{kj}[x, y]$ be the coordinates of the marine polygonal zone obtained by pushing the points $C_{kj}[x, y]$ depending on the prevalent sea currents in that zone:

$$P_{kj}[x, y] = C_{kj}[x, y] + \left[C_{kj}[x] \cdot u_j(x, y), C_{kj}[y] \cdot v_j(x, y)\right], \tag{3}$$

where u_j, v_j are, respectively, the annual average of the zonal (W-E) and meridional (N-S) velocities of the sea current at each point (x, y) during the year in which the accidental spill j occurred.[4]

iv) Let L_i^C be the total coastline length of the target coastal area i and let L_{ijk} be the coastline length of this area that lies within the range of spill j for the impact level k, i.e. the intersection of

[1] A unit minimum spill S_0 is assumed in cases where the database used has no record for the actual spill size.

[2] For a marine spill that occurs just on the coast of the geographical area i there would be a distance $D_{ij} = 0$ and an impact $I_{ij} = I_{max} + (1 - I_{max})e^{S_0 - S_j}$, so that $S_j \to S_0 \Rightarrow I_{ij} \to 1$ and $S_j \to \infty \Rightarrow I_{ij} \to I_{max}$.

[3] Third degree eastward and northward sea surface velocities with Ekman and buoyancy components added obtained from the Ocean Surface Current Analyses (OSCAR) Project (ESR, 2009; Bonjean and Lagerloef, 2002).

[4] In practice, inner points of C_{kj} need not be transformed. This saves processing time as the coordinates matrices $C_{kj}[x, y]$ and $P_{kj}[x, y]$ are kept to a minimum determined by the desired edge resolution only. For example, in Section 4 they are evaluated at 200 edge points, i.e. their dimension will be set to $[200 \times 2]$. On the other hand, the corresponding sea surface velocities u_j and v_j are obtained from OSCAR 1/3deg grid depending on the grid cell in which point (x, y) falls and they determine the direction and extent of the transformation at each coordinate but not the number of them.