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Research article

Can a GIS toolbox assess the environmental risk of oil spills? Implementation for oil facilities in harbors

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ABSTRACT

Oil spills are one of the most widespread problems in port areas (loading/unloading of bulk liquid, fuel supply). Specific environmental risk analysis procedures for diffuse oil sources that are based on the evolution of oil in the marine environment are needed. Diffuse sources such as oil spills usually present a lack of information, which makes the use of numerical models an arduous and occasionally impossible task. For that reason, a tool that can assess the risk of oil spills in near-shore areas by using Geographical Information System (GIS) is presented. The SPILL Tool provides immediate results by automating the process without miscalculation errors. The tool was developed using the Python and ArcGIS scripting library to build a non-ambiguous geoprocessing workflow. The SPILL Tool was implemented for oil facilities at Tarragona Harbor (NE Spain) and validated showing a satisfactory correspondence (around 0.60 RSR error index) with the results obtained using a 2D calibrated oil transport numerical model.

Tool availability

Name SPILL Tool
Developer Environmental Hydraulics Institute of the University of Cantabria "IH Cantabria"
Contact puentea@unican.es
Year first available 2015
Hardware required ArcGIS 10.1 for Desktop system requirements
Software required Python 2.4 or later; ArcGIS 10.1; FWTools (http://fwtools.maptools.org/)
ArcGIS extensions required Spatial Analyst 10.1 ©1999–2012 Esri Inc.
Program languages Python
Toolbox size 191 KB
Availability: Download http://marport.ihcantabria.es/en/descargas/
Cost Free

1. Introduction

Environmental risk assessment (ERA) on aquatic systems has traditionally focused on point contaminant sources, but in coastal areas, diffuse sources are also an important introduction of pollution (Preston, 2002; Gómez, 2010). This fact is highly noted in port areas, where the water quality is a consequence of the uses and activities conducted in these environments (Darbra and Casal, 2004). Previous studies and records of contaminating events in port areas have noted that accidental spills are the main cause of water pollution, with a great proportion of oil spills in these areas occurring due to the loading and unloading of bulk liquid (Darbra and Casal, 2004; Peris – Mora et al., 2005).

Many of the critical problems that arise in dealing with the pollution of aquatic systems by diffuse contaminant sources in port areas are inherently spatial issues. On many occasions, the interaction of possible influences complicates the precise identification of surrounding hazards (stressors), their multiple effects, and consequently, the pathways to resolution (Gómez et al., 2015). These interactions are more pronounced in port areas, where there

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is a heavy industrialization and, therefore, a high number of sources of diffuse pollutants. Several authors (Sieber et al., 2010; Su et al., 2009; Rioux et al., 2010) have implemented the response-distance method to establish the impact of air or soil pollution (Gómez, 2010). Radial proximity, assuming linear agent dispersion, has been widely applied while ignoring environmental variability and agent characteristics. However, a spatial description of environmental risk is essential to answer the following questions: i) is it possible to localize contaminant sources (both point and non-point)?; ii) is it possible to know these sources' contribution to the global environmental pollution for a specific area?; iii) what is the true impact on the environment, and where this impact is located?; and iv) where should the monitoring strategy be focused if an environmental monitoring program is conducted? Therefore, 'inventories and maps' are essential aspects of the ERA process in risk management context because they can be used to support contingency planning, environmental monitoring program design and decision-making.

An ERA process for any diffuse oil source requires the study of the evolution of the oil in the marine environment to calculate the trajectory of the spill and the final potential affected areas (Valdor et al., 2015). Currently, calibrated numerical models are used extensively to simulate the movement of oil via wind, surface currents and turbulent diffusion. As Otero et al. (2015) recognized, most of the available tools that permit drift trajectories to be visualized are Lagrangian models that must be run by a qualified technician (e.g., GNOME; MEDSLINK-II, De Dominicis et al., 2013; ROFF, Carr et al., 2008) and provide outputs that are difficult for a non-expert to understand (Roberts et al., 2010). In addition, these models involve, in most cases, a huge computational cost (Roberts et al., 2010) and require a detailed characterization of contaminant sources and environmental conditions. For these reasons, there is an increasing tendency to design tools with low computational costs to predict responses of products released on aquatic systems.

Geographic Information System (GIS) is becoming an increasingly common tool for analyzing spatial distributions and supporting decision makers via environmental risk assessment. In this context, Lu et al. (2014) divided the existing GIS-based environmental models into two groups: i) models that primarily use GIS to visualize model results over a geographical area (Dixon, 2005; Pathak and Hiratsuka, 2011; Reshmidevi et al., 2009; Vafai et al., 2013) and ii) models that are encapsulated into GIS with a shared GIS interface or GIS components embedded into the developed system (Akbar et al., 2011; Giordano and Liersch, 2012; Martin et al., 2004; Vairavamoorthy et al., 2007). However, GIS-based environmental models are limited to expert users and still require very complex input information (Otero et al., 2015), which is generally unavailable for diffuse contaminant sources.

To overcome these gaps, Gómez (2010) proposed a general methodology to assess the impact of diffuse contaminant sources based on GIS techniques (Juanes et al., 2013). This method obtains the contaminant source extension as a function of three categorized factors: product aggregation state (liquid/solid), released product density, and magnitude of release. The same transport processes were considered for all types of products while ignoring specific physical and chemical processes.

In summary, the main gaps of the previous works are that methodologies developed ignores the environmental variability as well as the physical and chemical characteristics of products spilled. At the same time, numerical models that do not ignore them are limited to expert users.

The main novelty of this work is the advancement of knowledge in the developing of a GIS tool that can provide the spatial and temporal environmental risks of potential oil spills in port areas based on different spilled volumes, discharge source locations, product released and environmental conditions. All this developed through a simple and quick procedure.

2. Study site and data

Tarragona Harbor is located in the Mediterranean Sea on the NE Spanish coast (1°14′E, 41°05′N) (Fig. 1a). Tarragona Harbor is an industrial bulk carrier port that is surrounded by an extensive petrochemical cluster, which includes one of the largest Spanish oil refineries and an advanced chemical complex, all of which are located within the port jurisdiction area. Since 1975, Repsol Petróleo, S. A., has operated its own oil terminal (Fig. 1b) with six moorings. On the one hand, there is a 1489-m-long dock with 5 moorings (11S, 35T, 35S, 80–100T, 80–100S, Fig. 1c) for vessels of 11 000, 40 000 and 10 0000 deadweight tonnage (DWT). On the other hand, there is a floating dock (monobuoy, Fig. 1d) for the mooring and unloading vessels of up to 250 000 DWT under normal conditions and up to 325 000 DWT and 40 m draft in special conditions. Both facilities, i.e., the long dock and the monobuoy, are highly active sites, with 3.4 and 33.6 tonnes of goods traffic in 2012, respectively. These six moorings can be unified in four potential discharge points: P11 (representing 11S mooring); P35 (representing 35T and 35S moorings); P80-100 (representing 80–100T and 80–100S moorings); and monobuoy (Fig. 1c and 1d).

The hydrodynamic in this area is governed by a mixed and microtidal regime, with a mean tidal range of 0.2 m and northwest winds (Gómez et al., 2014). According to Valdor et al. (2015), the four most-probable hydrodynamic conditions are i) northwest winds (312°, 5.6 m/s) and −0.09 m of sea level; ii) west winds (277°, 2.6 m/s) and −0.05 m of sea level; iii) east winds (79°, 5 m/s) and 0.04 m of sea level; and, iv) calm conditions (301°, 0.1 m/s) and −0.14 m of sea level.

3. Material and methods

3.1. SPILL Tool description

A user-friendly toolbox was developed in ArcGIS (10.1) (SPILL Tool) by using the Python and ArcGIS scripting library. The tool is easy to load through the ArcToolbox of Geographical Information System (GIS) software (ArcGIS 10.1 by ESRI™) and is easy to operate through the autogenerated Graphical User Interface (GUI). It is a custom script tool that has been fully integrated under the ArcGIS Geoprocessing Framework; therefore, it can easily be reused and combined inside new workflows and models with ArcGIS ModelBuilder. The Tool provides a raster output of probabilistic potential affected areas for a specific scenario (spill type and met-ocean conditions).

The results obtained through the SPILL tool are calculated considering four main processes (Figs. 2 and 3):

1. *Oil spill initial area process*: SPILL Tool uses the Direction-Distance tool (Editor Tool from ESRI ArcGIS 10.1) for a first oil spill displacement, considering the direction and intensity of currents at the discharge point location (Fig. 2 (1), Fig. 3 (1)). The oil spill initial area process considers a circumference as the initial shape, with the radius a function of the spilled product volume and density (Lehr, 2001) (Eq. (1)).

$$\mathrm{r_{ini}} = 1.84\left(\frac{\Delta w \cdot Q^5}{\nu^2}\right)^{1/8} \tag{1}$$

where r_{ini} is the oil spill initial radius (m); Δw is the reduced gravity, calculated as $\Delta w = (\rho w - \rho oil)/\rho w$, where ρ_w is the water density (kg/