Marine Pollution Bulletin xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

A three-step model to assess shoreline and offshore susceptibility to oil spills: The South Aegean (Crete) as an analogue for confined marine basins

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ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Oil-spill predictions
GIS
Shoreline susceptibility
Bathymetry
Geology
Oceanography

ABSTRACT

This study combines bathymetric, geomorphological, geological data and oil spill predictions to model the impact of oil spills in two accident scenarios from offshore Crete, Eastern Mediterranean. The aim is to present a new three-step method of use by emergency teams and local authorities in the assessment of shoreline and offshore susceptibility to oil spills. The three-step method comprises: (1) real-time analyses of bathymetric, geomorphological, geological and oceanographic data; (2) oil dispersion simulations under known wind and sea current conditions; and (3) the compilation of final hazard maps based on information from (1) and (2) and on shoreline susceptibility data. The results in this paper show that zones of high to very-high susceptibility around the island of Crete are related to: (a) offshore bathymetric features, including the presence of offshore scarps and seamounts; (b) shoreline geology, and (c) the presence near the shore of sedimentary basins filled with unconsolidated deposits of high permeability. Oil spills, under particular weather and oceanographic conditions, may quickly spread and reach the shoreline 5–96 h after the initial accident. As a corollary of this work, we present the South Aegean region around Crete as a valid case-study for confined marine basins, narrow seaways, or interior seas around island groups.

1. Introduction

Accidental oil spills account for 10–15% of all oil that enters the world's oceans, the major source of anthropogenic marine pollution being land-based discharges (European Environmental Agency, 2013). Yet, oil spills derived from maritime accidents, or from oil and gas platforms, comprise a major environmental and financial threat to local communities, particularly when resulting in the release large volumes of unrefined hydrocarbons, or crude oil, to the sea (Palinkas et al., 1993a; Arata et al., 2000; Gill et al., 2012; Sammarco et al., 2013). A particular issue with large oil spill accidents is that their impact significantly increases in confined marine basins, where spill arrival times to the shoreline are relatively short. This vulnerability of confined basins is further enhanced by significant demographic and environmental pressures, with the livelihood of coastal populations depending on sea resources, tourism and in the maintenance of open maritime routes (Danovaro et al., 1995; Peters et al., 1999; Pavlakis et al., 2001; Kingston, 2002). In these regions, large oil spills also challenge the best-laid contingency plans, as clean-up and recovery operations require a great number of specially trained emergency teams (Doerffer, 1992; De la Huz et al., 2005; Kirby and Law, 2010).

One of the most widely documented examples of the impact of oil spills on relatively confined, environmentally sensitive shorelines is the *MV Exxon Valdez* accident of 1989, South Alaska (Petterson et al., 2003). The effects of the *MV Exxon Valdez* on biodiversity, and on the health of the cleaning personnel, were felt in the Prince William Sound for decades after its sinking (Palinkas et al., 1993b; Piatt and Anderson, 1996; Petterson et al., 2003). Nevertheless, the published literature chiefly refers to open-sea accidents such the *Deepwater Horizon* explosion in the Gulf of Mexico (Camili et al., 2010; Kessler et al., 2011), or the *MV Prestige* and *MV Erika* oil spills in the North Atlantic Ocean (Tronczynski et al., 2004; Franco et al., 2006; Gonzalez et al., 2006). This narrow pool of information poses important constraints to emergency authorities, as open sea

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http://dx.doi.org/10.1016/j.marpolbul.2014.06.034
0025-326X/

accidents require emergency responses distinct from oil spills occurring in topographically confined seas. Oil spills in open seas have the potential to unfold relatively slowly, but spreading through large areas to hinder any spill containment procedures (see Galt et al., 1991; Carson et al., 1992). In contrast, oil spills in confined marine basins will potentially reach the shoreline in just a few hours, as shown by the models in this paper, but potentially dispersing through relatively small areas.

In the topographically confined Mediterranean Sea, to quickly assess shoreline susceptibility to oil spill accidents is paramount to the management of human resources and emergency plans by civil protection authorities. Moreover, the coordination of emergency teams in all countries bordering the Mediterranean Sea requires a swift methodology to predict oil spill spreading, dispersion and advection in sea water. This paper presents a new method to help emergency-team response to oil spills in confined marine basins, using the island of Crete as a case-study (Fig. 1a and b). The method was developed under the umbrella of European Commission's NEREIDs project to assist local authorities operating in Crete and Cyprus, Eastern Mediterranean Sea. The method results from the urgent need to coordinate local authorities and civil protection groups in this region when of maritime and offshore platforms accidents. Such a need is particularly pressing at a time when hydrocarbon exploration and production are being equated in deep-water regions of the Eastern Mediterranean (Cohen et al., 1990; Roberts and Peace, 2007).

This paper uses a three-step approach to assess shoreline and offshore susceptibility for two (2) accident scenarios chosen by their proximity to oil and gas depots (Kaloi Limenes) and heavily populated areas (Ierapetra), both in Southern Crete (Fig. 1b). We combine oceanographic, bathymetric and geological data to: (a) assist emergency response plans and (b) to predict the behaviour and fate of oil spilled in the marine environment.

The paper starts with a summary of the past behaviour of oil slicks in the Mediterranean Sea. After listing the new datasets and methodologies utilised, we review the geological setting of Crete prior to presenting the results of our shoreline susceptibility analysis and oil spill modelling. Later in this work, we discuss guidelines for oil-spill mitigation in coastal areas, and the importance of the South Aegean as a case-study for confined maritime basins. We compare and discuss the two accident scenarios modelled with hypothetical scenarios for Northern Crete (Heraklion). Part of this discussion on Northern Crete is based on previous risk analyses undertaken by Kassomenos (2004). As discussed later, the proposed accident scenarios result in distinct geographic distributions and time lengths of spilled oil, parameters that influence any subsequent containment and mitigation work. We then propose that potential impacts differ for two distinct oil spills sources; oil spills during drilling operations, and oil spills caused by maritime accidents.

2. Past behaviour of oil spills in the Mediterranean Sea

2.1. Eastern Mediterranean

The semi-arid climate of the Eastern Mediterranean Sea, in which sun irradiation is high and surface sea temperatures reach 30 °C during the summer months (Coppini et al., 2011), can result in the consumption of up to 93% of spilt oil through emulsification and oxidation processes (Burns and Saliot, 1986). In general, rapid in-situ oxidation is expected in warm waters, imposing an important seasonal control on oil movement and advection in the Eastern Mediterranean (see van Vleet and Reinhardt, 1983 for similar data from semi-tropical estuaries). As a result of rapid oxidation during the summer months, there is little evidence of large-scale accumulations of hydrocarbons in shoreline sediments across the Mediterranean Sea. However, locally there are important accumulations of hydrocarbons where burial rates are high or petroleum inputs are large (Burns and Saliot, 1986). In the Cretan Sea, for instance, *in situ* hydrographic observations demonstrated that important amounts of floating tar enter the Cretan Sea through the Khythira Strait, Western Crete (Kornilios et al., 1998) (Fig. 1a).

The July 2006 Lebanon oil spill allowed the acquisition of important data on the holding capacity of sandy and rocky shorelines in the Eastern Mediterranean (Adler and Inbar, 2007; Coppini et al., 2011). For the Lebanon oil spill, the MEDSLIK model predicted almost 80% of the original oil spilled at sea to have landed after six days along the Lebanese and South Syrian coasts (Coppini et al., 2011). In turn, 20% of the original oil was estimated to have been evaporated within the first days after the spill, whereas less than 1% of the oil remained in the sea. Surface currents were recorded as moving to the east and north in July–August 2006, with velocities

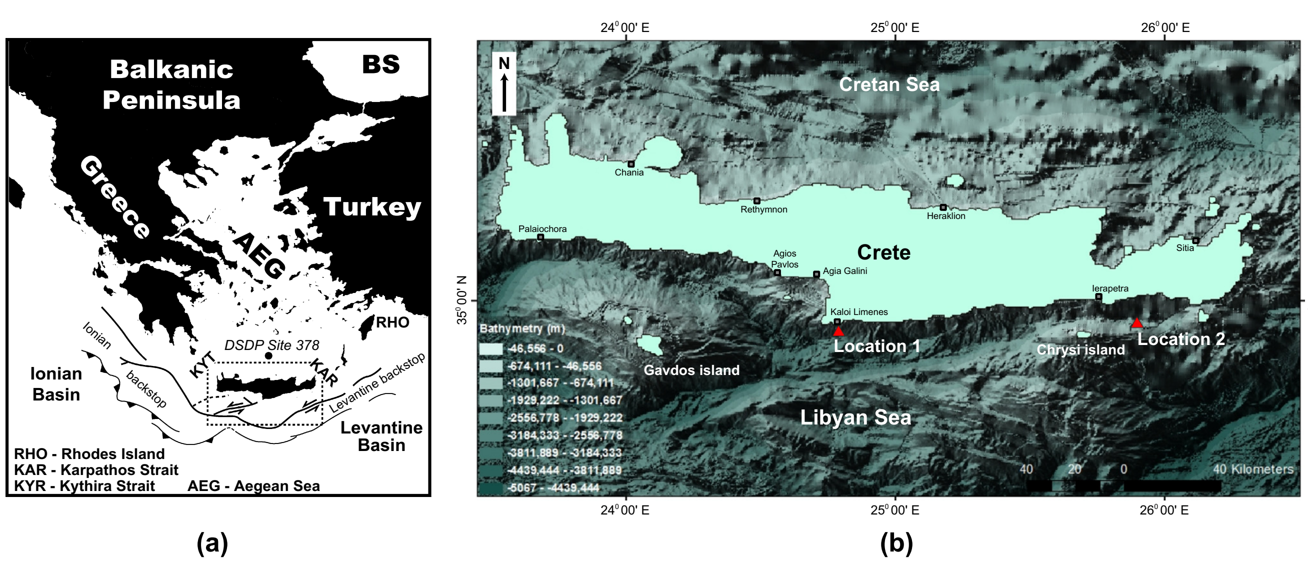

Fig. 1. (a) Location of the study area in the South Aegean Sea. The area considered in this paper is highlighted by the box surrounding the island of Crete. (b) Bathymetric map of the Libyan and Cretan Seas surrounding the island. Note the relative position of Locations 1 and 2 in Southern Crete. Main towns and cities referred to in this paper are highlighted in the figure.

Please cite this article in press as: Alves, T.M., et al. A three-step model to assess shoreline and offshore susceptibility to oil spills: The South Aegean (Crete) as an analogue for confined marine basins. Mar. Pollut. Bull. (2014), http://dx.doi.org/10.1016/j.marpolbul.2014.06.034