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Hindcast, GIS and susceptibility modelling to assist oil spill clean-up and mitigation on the southern coast of Cyprus (Eastern Mediterranean)

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ABSTRACT

This study uses new oil-spill models, bathymetric, meteorological, oceanographic, geomorphological and geological data to assess the impact of distinct oil spill scenarios on the southern coast of Cyprus, Eastern Mediterranean. This approach results from the urgent need to predict oil spill dispersion after new oil terminals and depots were built at Vasilikos, southern coast of Cyprus. The terminals have been able to receive tankers with ~500,000 deadweight tonnes from November 2014. The new geomorphological and geological data in this work show the shoreline of Cyprus to be of high susceptibility due to: (a) the presence of a narrow continental shelf capable of trapping large quantities of hydrocarbons; (b) the existence of uplifted wave-cut platforms, coastal lagoons and pools forming natural traps for oil, and (c) the presence of important tourist and Natura 2000 sites. Under particular weather and oceanographic conditions, oil spills offshore Larnaca Bay will quickly spread and reach the shoreline ~46 h after the initial accident. Significantly, the models in this paper show a reduction from 84% to 19% in the volume of oil trapped on the coast if dispersants are applied, with the latter 19% being potentially kept at bay using booms and mechanical removal techniques. Based on these results, we suggest the early use of dispersants, booms and mechanical removal procedures to prevent the spreading of oil spilt in the broad area of Larnaca Bay.

1. Introduction

The Mediterranean Sea is one of the busiest shipping corridors in the world, with 30% of all international maritime trade by volume originating in, or having Mediterranean ports as final destination (Pavlakis et al., 2001; REMPEC, 2002; Ferraro et al., 2007). A quarter of the total oil transported annually by sea passes through its waters i.e., ~360 million tonnes of oil and refined products (UNEP, 2006). As a result of such an intense traffic, close to 750,000 t of oil are introduced annually into the Mediterranean Sea, chiefly as minor near-coast spills and high-frequency discharges from ships navigating in international waters (Burns and Saliot, 1986; European Environmental Agency, 2013). Coastal refineries add to the risk of oil spills as they treat, and store, large quantities of Middle East oil that is later shipped to markets in Europe and North America (U.S. Energy Information Administration, 2014).

The recent opening (November 2014) of new liquefied natural gas and oil depots in Vasilikos, on the southern coast of Cyprus, made urgent the modelling of oil spill dispersion to assist civil protection authorities in case of future shipping and industrial accidents (e.g., Sadeghi, 2007; Shaffer, 2011; Belopolsky et al., 2012). In fact, a higher risk of oil spills is expected offshore Cyprus from an increase in ship traffic, and from the accommodation of tankers with ~500,000 dwt at Vasilikos. This increase in ship traffic follows the ongoing enlargement of the Suez Canal (Abbas et al., 2015). As an example of this increased risk, the northern part of Ammochostos Bay in Cyprus experienced an oil spill in July 2013 during the upload of crude oil from a tanker. Other maritime and industrial accidents recorded in the Eastern Mediterranean region include: (a) large oil spill accidents offshore Greece in 1980 (Bay of Pylos), 2000 (Lefkandi and Kythira) and other common, but smaller, accidents recorded in the Aegean Sea (IMO/UNEP, 2004, Giziakis et al., 2013); (b) the Adriatic IV jack-up rig explosion in

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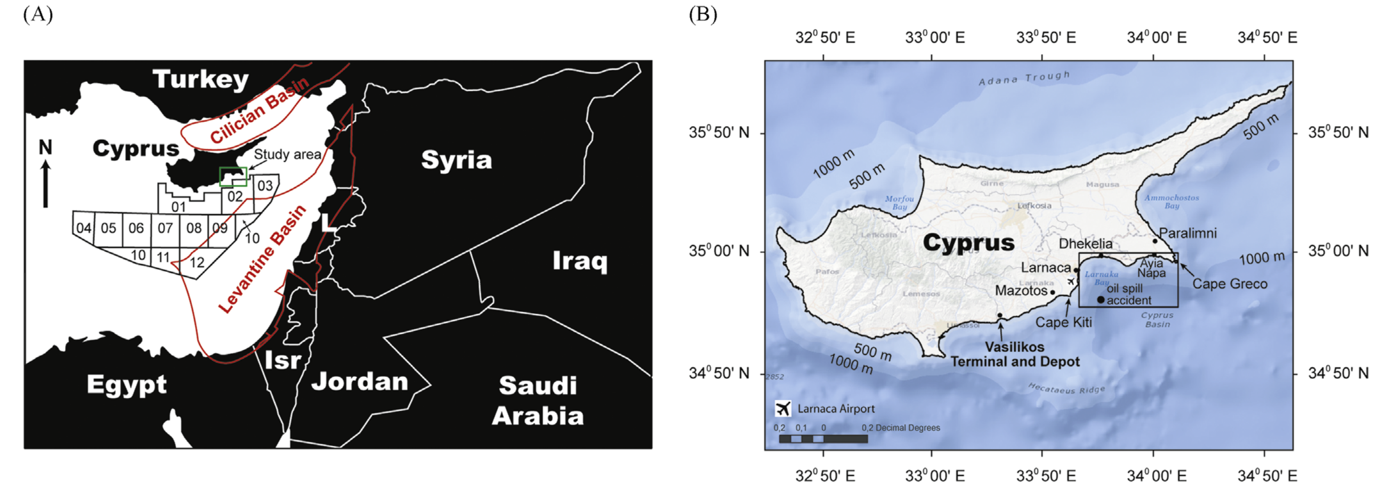

Fig. 1. (A) Location of the study area, Eastern Mediterranean. Oil exploration blocks in the southern coast of Cyprus are also shown. The areas enclosed by the red lines highlight the location of the Levantine and Cilician Basins in geological terms. (B) DTM and bathymetric data for the island of Cyprus. Note the relative position of the accident scenario (AS) considered in this work, distant eight (8) nautical miles from the shoreline. Main towns and cities referred to in this paper are highlighted in the figure. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2004 (Christou and Konstantinidou, 2012; Ismail et al., 2014; Vinnem, 2014), and (c) the bombing of the Jiyeh power station in Lebanon in 2006, after which a 15,000–20,000 t oil spill ensued (Coppini et al., 2011).

This paper presents new hindcast, GIS and susceptibility models – complemented by bathymetric, meteorological, oceanographic and geological data – to suggest mitigation and containment procedures for oil spilt in the southern coast of Cyprus (Fig. 1 (A)). The analysis in this work results from the European Commission NEREIDs (www.nereids.eu), which was set up to assist, and train, civil protection authorities in Crete and Cyprus for the eventuality of major oil spill accidents in Mediterranean waters. Oceanographic hindcast data downscaled from FP7 MyOcean2 (myocean.org.eu) were used together with the new setup of MEDSLIK oil spill model adapted for the Med Programme MEDESS4MS project (medess4ms.eu) to demonstrate the positive effect of dispersants when used in the first few hours after a spill accident (Fig. 1(B)). In addition we model the fate of oil under the weather conditions provided by the SKIRON atmospheric prediction system, i.e., with predominant southwest winds and downscaled sea currents affecting the broader area of the Larnaca Bay. Three distinct scenarios are considered in different models: (1) no prevention measures applied, (2) deployment of booms alone, and (3) use of dispersants. In summary, this paper addresses the following research questions:

a) What techniques are the most appropriate to mitigate any oil spills occurring in Larnaca Bay, close to the Vasilikos depot, knowing that quick response times are necessary to protect important Natura 2000 and tourist sites?
b) Are dispersants effective under diverse meteorological conditions, based on the MESLIK models presented in this work?
c) What basic information should be at the full disposal of civil protection authorities, so that a phased response to oil spills is implemented in Cyprus, and other Eastern Mediterranean countries, when large oil spill accidents occur?

This paper is important to environmental studies in the Eastern Mediterranean as organic pollutants have a significant impact on water quality throughout European waters (Prevedouros et al., 2004; O'Driscoll et al., 2013). In the particular case of the Eastern Mediterranean Sea, complex pesticides such as dichlorodiphenyltrichloroethane (DDT), lindane (γ-HCH) and multiple types of hydrocarbons are abundant at several industrial sites and ports (e.g. El-Nemr and Abd-Allah, 2003; Hamed and Said, 2006; Khairy and Lohmann, 2013). Polycyclic aromatic hydrocarbons are particularly persistent and pollutant above certain weight values in benzo[a]anthracene, chrysene, benzo[b]flouranthene, benzo[k] flouranthene, benzo[a]pyrene and benzo[ghi]perylene (Neff, 1985; IARC, 1991; Cotham and Bidleman, 1995; Gogou et al., 2000). These same polycyclic and aromatic hydrocarbons are the primary organic components of crude oil and bunker fuel spilt in shipping and platform accidents (Patton et al., 1981; Reddy et al., 2012; La Rue, 2009; US Patent 8987537-B1, 2015).

In addition to oil pollution events, the published literature recognises coastal refineries as a source of As and Cr in seafloor sediment of the Eastern Mediterranean Sea (Othman et al., 2000; Danovaro, 2003). Offshore Syria, As and Cr were found to be above natural levels, but elements such as Al, Ca, Fe, K, Mg, Mn, Na, Ba and Br and some trace metals (Pb, Zn and Cu) are naturally cleaned and kept under defined limits (Othman et al., 2000). In contrast, Hg has been a recognised pollutant in fauna and seafloor sediment of the Levantine Basin, and is relatively persistent in the food chain and benthic organisms, together with Cd, Pb, Cu and Zn (Hornung et al., 1984; Hornung, 1989; Roditi-Elasar et al., 2003). Significantly, the distribution of some elements sourced from refineries is not affected by local wave and meteorological conditions, in contrast to hydrocarbons in sea water (see also El-Moshelhy and Gabal, 2004; El-Nemr et al., 2006; Barakat et al., 2011).

2. Oceanographic, meteorological and geological settings

2.1. *Typical oceanographic and meteorological conditions in the Eastern Mediterranean Sea*

The Eastern Mediterranean basin is located on the leeward side of the Asia Minor peninsula, where a cyclonic atmospheric circulation predominates (Zavatarielli and Mellor, 1995; Saaroni et al., 1996; Robinson et al., 2001; Rojas et al., 2013) (Fig. 1(A)). This cyclogenetic activity generates a counter-clockwise circulation, initially passing through the Aegean Sea and then blowing over the Levantine Basin (Zodiatis et al., 2005; Milena et al., 2012) (Fig. 1(A)). As a result of this weather pattern, dominant winds in Cyprus are from the northwest to southwest. Winds are predominantly from the southwest-to-north and occasionally from the

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