Science of the Total Environment 574 (2017) 234–245

Contents lists available at ScienceDirect

Science of the Total Environment

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

Risk assessment of oil spills along the Mediterranean coast: A sensitivity analysis of the choice of hazard quantification

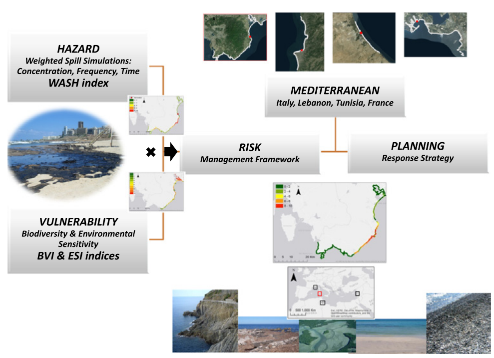
A. Al Shami [a], G. Harik [a], I. Alameddine [a], D. Bruschi [b], D. Astiaso Garcia [b], M. El-Fadel [a,*]

[a] *Department of Civil & Environmental Engineering, American University of Beirut, Lebanon*
[b] *Department of Astronautics, Electrical & Energetics Engineering, Sapienza University of Rome, Italy*

HIGHLIGHTS

- Oil spill risk quantified as a function of oiling susceptibility, concentration, frequency, and beaching time.
- Overall, the average oil beaching time was more conservative than other indicators.
- While hazard metrics agreed along simple morphology shorelines, differences were encountered with complex morphologies.
- These differences affect risk quantification, highlighting the need to examine the multifaceted hazards of oil pollution.
- An integrative hazard index that can be applied across the Mediterranean is proposed.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 22 May 2016
Received in revised form 1 September 2016
Accepted 8 September 2016
Available online xxxx

Editor: Kevin V. Thomas

Keywords:
Oil spill management
Hazard and risk assessment

ABSTRACT

Oil pollution in the Mediterranean represents a serious threat to the coastal environment. Quantifying the risks associated with a potential spill is often based on results generated from oil spill models. In this study, MEDSLIK-II, an EU funded and endorsed oil spill model, is used to assess potential oil spill scenarios at four pilot areas located along the northern, eastern, and southern Mediterranean shoreline, providing a wide range of spill conditions and coastal geomorphological characteristics. Oil spill risk assessment at the four pilot areas was quantified as a function of three oil pollution metrics that include the susceptibility of oiling per beach segment, the average volume of oiling expected in the event of beaching, and the average oil beaching time. The results show that while the three pollution metrics tend to agree in their hazard characterization when the shoreline morphology is simple, considerable differences in the quantification of the associated hazard is possible under complex coastal morphologies. These differences proved to greatly alter the evaluation of environmental risks. An integrative hazard index is proposed that encompasses the three simulated pollution metrics. The index promises to shed light on oil spill hazards that can be universally applied across the Mediterranean basin by integrating it with the unified oil spill risk assessment tool developed by the Regional Marine Pollution Emergency Response Centre for the Mediterranean (REMPEC).

* Corresponding author.
E-mail address: mfadel@aub.edu.lb (M. El-Fadel).

http://dx.doi.org/10.1016/j.scitotenv.2016.09.064

1. Introduction

The Mediterranean basin extends over an area of 2.5 M km^2 representing only 0.8% of the world's sea surface and 0.3% of its volume, but it is characterized with a heterogeneous typology and rich ecosystem that hosts ~8% of the world's biodiversity (WWF, 2015; UNEP-MAP, 2012; Coll et al., 2010; Bazairi et al., 2010; Olson et al., 1998). It is considered an important hub for trade and is known to be one of the busiest waterways worldwide, encompassing 15% of the world's shipping activity and 10% of vessel deadweight tonnage with ~200,000 commercial ships passing through it annually (UNEP-MAP, 2012). As a result, the basin is considered highly vulnerable to pollution (Gürlük, 2009). Its vulnerability stems from its intrinsic physical characteristics and anthropogenic activities along its coastline, with the threat of oil spills being of particular concern due to the presence of offshore rigs, oil-related operations, and heavy oil traffic (Abdulla and Linden, 2008). These factors along with recent important oil and gas discoveries and production in the Levantine basin compel observance for oil spill hazards and risks along the Mediterranean. Whether they occur as a result of tanker accidents, rig explosions, loading/unloading incidents, storage leakage, or acts of war, oil spills represent a serious concern both environmentally, due to their adverse impacts on coastal ecosystems, and socio-economically, given their impacts on activities along the coastline.

In the event of an oil spill, its slick trajectory is of interest to direct available resources towards control and mitigation. The movement of the oil slick is simulated as a function of prevailing winds, currents, and wave conditions, while also accounting for the physical, chemical and biochemical processes affecting the oil (Olita et al., 2012). Mathematical modeling is often relied upon for this purpose to simulate the transport and weathering of oil once an accident occurs (El-Fadel, et al., 2012; Darras, 1982; Baruque, et al., 2010) or to better prepare emergency response plans in anticipation of a potential incident. Moreover, oil spill modeling is used both for hindcasting or forecasting purposes.

While oil spill modeling has historically focused on simulating the fate and transport of actual spills, either as part of an oil spill response (Berry et al., 2012; El-Fadel, et al., 2012; Baruque, et al., 2010; Wang et al., 2005; Al-Rabeh et al., 1992; Galt et al., 1991; Al-Rabeh et al., 1989; Darras, 1982) or as part of model validation (Chao et al., 2003; Elhakeem et al., 2007; French-McCay, 2004), the integration of oil spill modeling within national oil spill contingency plans has been gaining ground and is now considered as an essential tool in risk assessment procedures and emergency response planning (IPIECA, 2008, 2015a,b; REMPEC, 2005; UNEP, 2005). Oil spill risk assessments aim to quantify the probability of damaging consequences following a spill over a certain period of time (Castanedo et al., 2009). Various methods have been developed to assess oil spill risks based on empirical and intuitive approaches while others are simulation-based (Stewart and Leschine, 1986).

This study adopts the second approach to examine the risks posed by potential oil spills along the Mediterranean coastline by quantifying the hazards associated with a spill and accounting for the sensitivity of the shoreline. Several hazard indices are developed including the probability of oil slick contact at a given shoreline, the average concentrations of oil stranding onto the shore, as well as the mean time of oil shoring. Differences in risk characterization between these metrics is then assessed and linked to geomorphological characteristics of the coastline. For this purpose, several scenarios covering a range of spill conditions, shorelines, and weathering conditions, were tested at four pilot areas to develop a new assimilative oil spill hazard metric for use along the Mediterranean coastline. The integration of the developed oil spill hazard metric within the existing Mediterranean-wide decision support system is also explored. Emphasis is placed on the opportunity to optimize response following an event with regards to resource deployment.

2. Material and methods

2.1. Study pilot areas

Within the framework of the European Union (EU) Great Med Project, four Mediterranean countries were considered in the analysis, namely France and Italy on the northern Mediterranean coastline, Lebanon on the Eastern coastline, and Tunisia on the southern coastline (Fig. 1). In each country, the coastal vulnerability and exposure to potential oil spills were assessed. In France, the Provence-Alpes-Côte d'Azur (PACA) region was chosen. It includes many protected sites, national parks and reserves, several important wetlands, a significant touristic sector, and established sustainable agriculture practices. The potential oil spill focused on the area in the vicinity of the city of Marseille, which contains four oil refineries, a thermal power plant, the port of Marseille, and the harbor of Toulon (SRADDT, 2014). In Italy, the Gulf of Cagliari was selected; the area is rich in archaeological sites, sensitive and natural protected areas, and touristic attractions with beaches. The coast of Cagliari hosts many oil storage facilities, including an oil refinery, petrochemical plants, numerous oil storage tanks, a gasification combined cycle (IGCC) plant, the Cagliari-Elmas "Mario Mameli" International Airport, and the Port of Cagliari. The Lebanon study area extends from the capital city of Beirut up to the historical city of Byblos, a UNESCO World Heritage Site. Fuel storage tanks, pipelines, and thermal power plants in the area pose a major source of potential oil pollution. The fourth site was the gulf of Gabes in Tunisia, which is the most productive fishing area in the country and is characterized by rich diversity and a multitude of landscapes. Within the Gulf, the 'La Skhira' oil terminal is a potential oil spill source of concern.

Spill scenarios were defined for each pilot area based on potential failure at existing sources. For each scenario, the spill volume as well as the time and duration of the spill were defined along with the type of the oil spilled (Table 1). In France, the spill was presumed to occur at the Marseille Port with heavy crude oil. At the Gulf of Cagliari in Italy, the spill scenario consisted also of a heavy fuel oil with vacuum residues, occurring at a power plant. In Lebanon, the Dora oil storage tanks represent the largest oil handling facility along the pilot area, with light fuel being the most likely spill type. Finally, the Tunisian scenario was defined as a light fuel oil spill occurring at the port of Gabes.

2.2. Spill simulations and hazard assessment

The oil spills were simulated using the deterministic MEDSLIK-II numerical model, adopted by the Regional Marine Pollution Emergency Response Centre for the Mediterranean (REMPEC). The model simulates the fate of oil in the environment based on Lagrangian transport of the spilled slick coupled with weathering factors (Dee et al., 2011; De Dominicis et al., 2013a, 2013b). Wind and currents form the model's main forcing functions. Wind data were acquired from the European Centre for Medium-Range Weather Forecasts (ECMWF) interim global atmospheric reanalysis (Dee, et al., 2011); the data is distributed at a geographic resolution of 0.5×0.5 degrees, with a temporal resolution of 6 h. Currents data were acquired from the Mediterranean forecasting system daily oceanographic analyses (Dobricic et al., 2007); the data are distributed on a 0.0625×0.0625 degrees grid with a daily time step. The year 2013 was selected as the base year for all simulations. A spatial resolution of the simulated domain was set at 50×50 m offshore and between 50 and 10 m resolution near the shoreline. The maximum model runtime possible is 5 days, which were adopted with a temporal resolution of 1 h.

While MEDSLICK-II is a fully deterministic model, recent efforts explored expanding its capabilities to permit stochastic modeling. CranSLIK is currently an experimental stochastic variant of MEDSLIK-II that can probabilistically account for changing wind and current conditions (Rutherford et al., 2015). In this study, a hybrid-modeling approach, which involved both stochastic and deterministic modeling,