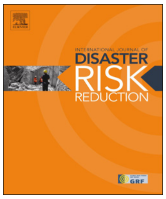
International Journal of Disaster Risk Reduction 7 (2014) 1–8

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

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



Propagation of impacts after oil spills at sea: Categorization and quantification of local vs regional and immediate vs delayed impacts

Berrin Tansel *

Florida International University, Civil and Environmental Engineering Department, Miami, FL, United States

A R T I C L E I N F O

Article history:
Received 19 June 2013
Received in revised form
2 November 2013
Accepted 4 November 2013
Available online 4 December 2013

Keywords:
Oil spills
Coastal ecosystems
Cause and effect
Contaminant transport
Environmental impacts
Risk analysis
Impact analysis

A B S T R A C T

The propagation of the water quality impacts after oil spills at sea were analyzed and quantified in relation to transformation and transport characteristics of oil over time as the impact radius expands depending on the characteristics of the spill. The potential impacts were categorized in time domain as immediate and delayed impacts and in spatial domain as local and regional impacts. Transformation and transport characteristics of the oil were analyzed based on the interactions between different media (air, water, sediments) over time. Knowledge based scoring system was used for the impact intensity and duration of impacts based on the interactions between different media. The potential impacts were quantified over time in relation to spill characteristics (i.e., oil type, spill size, spill location). The methodology was demonstrated to compare the potential impacts after a gasoline spill and a crude oil spill of similar quantities at the same location. The impact scoring methodology can be used for planning and resource allocation and planning purposes for developing oil spill response as well as assessing and communicating mitigation needs in time and geographical scales.

1. Introduction

Despite the efforts to prevent spills, almost 14,000 oil spills are reported each year in the United States [1]. Impacts from an oil spill could be significant depending on the location of the spill and amount spilled [2]. After petroleum based oil enter a water body, they are transformed and transported with water currents, wind effects, and biochemical processes. For example, the emulsified oils in natural waters have different transport characteristics than oil slicks since they have significantly higher sorption potential by sediments due to increased contact area. Oil spills near coastal areas can have significant impacts in coastal and estuarine ecosystems.

Although oil spills on land has significantly lower mobility due to limited turbulence effects and ground coverage (i.e., vegetation, structures); conditions at sea can result in rapidly increasing and significantly larger impact radius due to the high mobility and phase transfer of oil fractions (e.g., by volatilization, sorption). Oil spills at sea undergo several processes including spreading, evaporation, dissolution, emulsification, and sedimentation. Due to wind effects and currents, oil spills at sea have significantly different persistence and transformation profiles in comparison to those on land. The intensity of mixing due to wind and sea conditions, absence of surface coverage (e.g., vegetation), dynamic nature of the air–water interface; and significantly large air–water interface due to waves create favorable conditions for transfer of volatile organic compounds (VOCs) by evaporation and stripping; dissipation of VOCs in air phase by wind action; dissolution of soluble fractions in water phase; formation of oil-in-water droplets in e water phase

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* Tel.: +1 305 348 2928; fax: +1 305 348 2802.
E-mail address: tanselb@fiu.edu

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http://dx.doi.org/10.1016/j.ijdrr.2013.11.001

(oil-in-water emulsion); and maintaining aerobic conditions in the mixing layer.

Significant amount of research is available on risk assessment to evaluate the potential hazards prior to an event. However, studies on the expansion of the impact radius over time in relation to geographical location there is limited. The impacts after an oil spill can be observed over time and over large geographical areas. Spatiotemporal dynamic model frameworks have been developed for analysis of the factors that influence temporal changes after specific disaster such as water flooding after underground mining disasters [3]. However, these approaches require detailed information, and extensive data. Fuzzy analyses are often to describe the probability distribution of disaster prevention and mitigation [4].

Human health risk assessments are performed with definitive end points (for example, cancer) and species (humans, animals, plants) are targeted [5]. Ecological impact studies are often performed at a geographical location and based on the inherent species at that location. However, spills at a specific location can have significant impacts over large geographical areas which may experience the impacts at different intensities over time [6]. Water bodies are vulnerable for initiating domino effects which can impact the well being of coastal communities. The impact radius of these effects can increase over time due to the mobility of water systems, transfer of contaminants from one phase to another, and significance of the water body as a natural resource for coastal communities (i.e., fishing, sports, and tourism) [7].

There are often significant experiences, data and information available from past disasters to characterize the behavior of interconnected systems over time. The knowledgebase can provide a basis for risk analysis for natural systems [8].

The purpose of this study was to develop a methodology to categorically assess the propagation of potential impacts after oil spills at sea. The propagation of the water quality impacts was analyzed in relation to significant transformation and transport routes of oil fractions over time as the impact radius expands depending spill size. The potential impacts were categorized in time domain as immediate and delayed impacts and in spatial domain as local and regional effects. The methodology was used to compare gasoline and crude oil spills with similar quantities at the same geographical location.

2. Methodology

The quantitative impact assessment methodology was developed based on the general quantitative risk assessment methodology presented in Fig. 1. The assessment methodology was modified for the projected impacts based on the characteristics of the oil spill (i.e., cause) and the potential impact scenarios depending on the transport and persistence characteristics of the oil fractions in the water system.

Fig. 1 presents the processes that affect transport and persistence of oil fractions after spills at sea. The petroleum based oil fractions may mobilize with currents, transfer from one phase to another, and/or can be metabolized by marine organisms. For the analyses, the coastal system was defined in relation to the nearest coastline to the spill location. Immediate effects were defined as adverse effects that are expected to occur within 24 h after the contaminant release to water body. Delayed effects refer to adverse effects that are expected to occur after one day. Transformation and transport and mechanisms of oil in water to other media were identified using an interaction network for propagation of potential impacts in water as well as in media that are in contact with water. (Fig. 2).

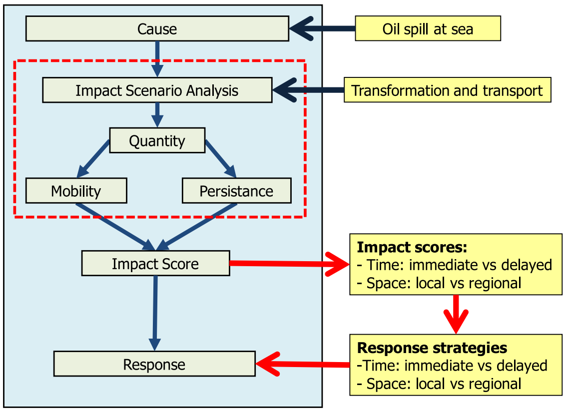

Fig. 1. Schematic of the impact analysis procedure.

The effects of marine and weather conditions on dispersion of oil slick, emulsion formation (i.e., mixing, evaporation, aggregation) compounded with potential natural hazards (i.e., tropical storms and hurricanes) present unique challenges for spill management. The availability of data in the form of aerial photos, satellite images, and monitoring efforts create an opportunity to understand the behavior of oil slicks relative to emulsification rates in subtropical waters, transformation of slick to emulsion form, rate of creaming processes relative to sea conditions, and transport characteristics of disperse phase in coastal and open waters. As the weathering processes continue, larger molecular weight hydrophobic fractions (i.e., asphaltenes) which cannot evaporate easily start forming emulsions. From a spill management perspective, emulsification at sea adversely affects the spill management efforts since emulsified oils can be more viscous than the original oils and droplets can move faster than the slick phase.

Fig. 3 presents the anticipated fate of oil at sea in relation to oil characteristics, current/wave intensity, and sediment interactions during short term and long term states. The impact radius can expand immediately after the spill depending on the sea and current conditions as well as over time depending on the water–sediment interactions.

Fig. 4a presents the interaction diagram for the transport and transformation of oils after spills at sea. Based on the interactions between different phases, an impact diagram can be developed as presented in Fig. 4b to categorize the immediate (I) and delayed (D) effects in time scale as well as local (L) and regional (R) effects in spatial scale.

For the analyses conducted, a local effect was considered as an adverse effect that takes place within the immediate vicinity (less than 20 mile radius) of the spill location. Regional effect refers to an adverse effect that affects the