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Pollution risk assessment of oil spill accidents in Garorim Bay of Korea

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ABSTRACT

This study presents a model to assess the oil spill risk in Garorim Bay in Korea, where large-scale oil spill accidents frequently occur. The oil spill risk assessment is carried out by using two factors: 1) The impact probability of the oil spill, and 2) the first impact time of the oil that has been spilt. The risk assessment is conducted for environmentally sensitive areas, such as the coastline and aquaculture farms in the Garorim Bay area. Finally, Garorim Bay is divided into six subareas, and the risks of each subarea are compared with one another to identify the subarea that is most vulnerable to an oil spill accident. These results represent an objective and comprehensive oil spill risk level for a specific region. The prediction of the oil spill spread is based on real-time sea conditions and can be improved by integrating our results, especially when sea conditions are rapidly changing.

1. Introduction

It is expected for the industrialization caused by economic growth to proceed more actively in coastal areas than in inland areas (FAO, 1998). Recently, the frequency of oil spill accidents has increased as maritime transportation activity has increased, damaging not only the economics of coastal communities but also marine ecosystems. South Korea is not an exception and has suffered from oil spill accidents in the past. In 1995, the oil spill accident of Sea Prince occurred near Sori Island, Yeo-Chun, Jeon-Nam Province while seeking refuge from typhoon "Faye" (Cho, 2007). Approximately 5000 tons of Arabian crude oil were spilt, ~230 km of coastline was contaminated, and the clean up effort lasted ~5 months. In 1995, the oil spill accident of Yuil No. 1 occurred near Nam-Hyeong-Jae Island while being towed toward the port of Busan (Shim et al., 2001). More than 2000 tons of oil were spilt. Also the Honam Sapphire spilt over 1000 tons of crude oil near Yeo-Cheon harbor in 1995 where Sea Prince's collision had happened 4 months before. The Hebei Spirit oil spill was Korea's worst oil spill, and it began on 7 December 2007 (Lee et al., 2009). The Hebei Spirit collided with a crane barge owned by Samsung Heavy Industry near the port of Daesan in Taean County on the Yellow Sea. As a result of the collision, ~10,800 tons of oil were spilt. The port of Daesan is located at the entrance of Garorim Bay, which is the area for which the pollution risk assessment is performed in this study.

The following response strategies are essential to minimize the pollution damage caused by oil spills: initial response, effective prevention methods including oil boom and recovery, and rapid aid transport. Effective prevention methods require for adequate response strategies to be established in advance of an oil spill accident, and a risk assessment map should include the location and importance of resources that are to be protected, the areas with a high risk of oil spill accidents, the impact probability of spilt oil, and the first impact time of spilt oil in order to establish an effective response strategy.

An accurate estimation of the trajectory of the spilt oil is very important to effectively undertake a response to oil spill, and many studies have focused on developing oil spill trajectory modeling and simulation systems (Reed et al., 1999; French-McCay, 2004; Castanedo et al., 2006; Delgado et al., 2006; Guo et al., 2009; Alves et al., 2014; Lan et al., 2015; Melaku Canu et al., 2015; Nixon and Michel, 2015). Since spilt oil is transported by external environmental forces such as the current, waves and wind, the trajectory of the spilt oil is usually estimated using real-time meteorological and oceanic conditions. However, in the case of quickly-changing sea conditions, there is a high probability of an error in the trajectory of the spilt oil that is estimated using real-time observations of the conditions at sea. Although the trajectory estimation of the spilt oil comes with individual uncertainty, the collection and analysis of data from past oil spill accidents can provide statistical guidance to reducing the damage caused by oil pollution. In other words, an oil spill estimation system should be accompanied with a comprehensive risk assessment in order to reduce the negative impact of the spill (Skognes and Johansen, 2004; Elshorbagy and Elhakeem, 2008; Grifoll et al., 2010; Olita et al., 2012). However, most results that

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provide an oil spill trajectory modeled using real-time conditions at sea have been limited to specific oil spill accidents in Korea, which means that a comprehensive risk assessment is not yet available.

The configuration of our preliminary study (Lee and Kim, 2009) is used to develop a model to assess the pollution risk of oil spill accidents. The purpose of this study is thus to offer a comprehensive and objective risk assessment model based on statistical methods in order to address the shortcomings of oil spill trajectory systems, especially in the case where sea conditions change quickly, to provide assistance in establishing a response strategy in advance. In this study, the coastline and aquaculture farms in the Garorim Bay area are considered as the risk assessment target area. The history of past spill accidents around Garorim Bay was reviewed to select the site where oil spill accidents have most frequently occurred. We assess the pollution risk of an oil spill in two aspects, 1) the impact probability of the spilt oil, and 2) the first impact time of the spilt oil. To make a quantitative assessment of the pollution risk, the oil spill trajectories are simulated 80 different times. In other words, many oil spill trajectories are statistically simulated based on past sea conditions to analyze and assess the oil spill hazard on coastlines and aquaculture farms. These trajectories are then collected and analyzed to produce a comprehensive and objective risk assessment. The Garorim Bay area was divided into six subareas, and the subarea most vulnerable to oil spills was then determined.

2. Assessment of oil pollution risk

2.1. Risk indicators of oil pollution

The risk of oil pollution can be evaluated according to the impact probability and the first impact time of the spilt oil. The impact probability is a very important information when deciding which area to protect from spilt oil. This information can thus be used to effectively allocate resources and plan a response for an oil spill. The first impact time of the spilt oil can provide information on the response priorities. Therefore, it is essential to set priorities due to the limited availability of resources.

The impact probability of spilt oil is quantitatively defined as the average ratio of the amount of oil spilt in each specific area to the total amount of oil spilt, which can be expressed using Eq. (1),

$$P = \frac{1}{N}\sum_{i=1}^{N}\frac{A_i}{A_{total}} \tag{1}$$

where, P is the impact probability and N is the number of oil spill events, A_i is the amount of oil spilt from the ith event in each specific area and A_{total} is the total amount of oil spilt from the ith event.

The first impact time of the spilt oil is defined as the time that has elapsed to reach a specific area. The elapsed times can be calculated as follows,

$$t = T - T_0 \tag{2}$$

where, t is the first impact time, T is the first attached time of oil to the area, and T_0 is the time of the oil spill incident. T and T_0 are in local standard time.

2.2. Study area (Garorim Bay)

2.2.1. General feature

Garorim Bay has been designated as the risk assessment target area because huge petrochemical plants and transporting ships are populated and plied. Garorim Bay is located on the western coast of the Korean Peninsula, as shown in Fig. 1, and it is famous for laver and oyster cultures and has rich spawning grounds for important species. The Daesan industrial complex includes large-scale petrochemical plants and Daesan harbor is located in the northeast coast outside of the Bay. Due to the narrow entrance of Garorim Bay, once the spilt oil is entrained in the Bay area, the oil will remain in the Bay area, and there is a low

Fig. 1. Location of Garorim Bay.