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Classifying risk zones by the impacts of oil spills in the coastal waters of Thailand

Nuanchan Singkran *

Faculty of Environment and Resource Studies, Mahidol University, 999 Moo 5, Sai 4 Phuttamonthon Road, Salaya, Phuttamonthon, Nakhon Pathom 73170, Thailand

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ABSTRACT

Risk zones that could be subject to the impacts of oil spills were identified at a national scale across the 23 coastal provinces of Thailand based on the average percentage risk of critical variables, including frequency of oil spill incidents, number of ports, number of local boats, number of foreign boats, and presence of important resources (i.e., protection area, conservation area, marine park, mangrove, aquaculture, coral reef, seagrass, seagull, seabird, sea turtle, dugong, dolphin, whale, guitar fish, and shark). Risks at the local scale were determined based on the frequency of simulated oil slicks hitting the coast and/or important resources. Four zones with varied risk magnitudes (low, moderate, high, and very high) were mapped to guide the preparation of effective plans to minimize oil spill incidents and impacts in coastal waters. Risk maps with sufficient information could be used to improve regulations related to shipping and vessel navigation in local and regional seas.

1. Introduction

Oil spills are a worldwide problem and are considered one of the most critical forms of marine pollution, with high risks to coastal environments in many coastal regions (e.g., Chiau, 2005; Janeiro et al., 2008; Liu et al., 2009; Liu and Wirtz, 2010; Ihaksi, 2011). Over the last 30 years, oil spills have contributed significantly to coastal and marine pollution, causing coastal environmental disturbance. This recurrent hazard has increasingly been addressed through prevention plans and integrated coastal zone management. Numerous studies have attempted to analyze vulnerable areas and the impacts of oil pollution. Operational tools have also been widely developed to classify coastlines within the context of oil spill management. These tools include sensitivity or vulnerability maps of coastal and offshore areas in many countries (Danchuk and Willson, 2010; Fattal et al., 2010; Ihaksi et al., 2011).

According to the International Tanker Owners Pollution Federation database (ITOPF, 2004), approximately 10,000 oil spills from tankers and oil carriers occurred from 1970 to 2001. Oil spills are considered a serious environmental problem and often have significant, long-term impacts on wildlife, fisheries, coastal habitats, socioeconomics, and human activities in affected areas, where environmental recovery may take several years (e.g., Page et al., 2002; Ivanov and Zatyagalova, 2008; Janeiro et al., 2008; Guo et al., 2009; Danchuk and Willson, 2010; Fattal et al., 2010). Oil-related activities, such as single-point mooring, vessel navigation, marine transportation, and oil exploration, have the potential to cause oil spills and pose major threats to coastal ecosystems (Kankara and Subramanian, 2007). Because preventive measures cannot absolutely eliminate oil spills in water sources, effective planning is necessary to estimate the risk of being impacted by oil spills in vulnerable areas.

Similar to other parts of the world, many countries in the East Asia seas region, including Thailand, have been increasingly concerned about oil spill problems. Of the total 239 oil spill incidents observed from 1973 to 2011 in Thailand and nearby areas, 227 occurred in coastal areas, seven occurred farther than 150 kilometers (km) from the coastline, one occurred beyond Thailand's marine territory, and four occurred in inland areas (Marine Department, unpublished data). Oil spills in the Gulf of Thailand have mainly been observed in navigation areas along the main shipping routes and around the mouths of the large rivers located on the Bangkok Bight, such as the Chaopraya, Thachin, and Maeklong rivers (Ivanov and Zatyagalova, 2008). The major causes of oil spills in the coastal areas of Thailand are (1) boat accidents, crashes, or sinking; (2) oil transfer from ships to small boats in the open sea and from ships to ports; and (3) the illegal discharge of wastewater contaminated with oil from ships into the sea (Marine Department, unpublished data).

Oil spill pollution has affected aquatic ecosystems, coastal resources, aquaculture, and the tourism business of Thailand, leading to considerable damage to the socioeconomic and ecological values of the country. Consequently, the Thai government established the National Oil Prevention and Elimination Committee (NOPEC) in 1982, which included the following governmental agencies: the Marine Department, Hydrographic Department, Royal Thai Navy, Royal Thai Air Force, Royal Thai Army, Marine Police Division, Department of Civil Aviation, Thai Meteorological Department, Office of Natural Resources and Environmental Policy and Planning, Pollution Control Department, Department of Fisheries,

* Tel.: +662 441 5000x2215; fax: +662 441 9509-10.
E-mail address: nuanchan.sin@mahidol.ac.th

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Department of Marine and Coastal Resources, Customs Department, Department of Treaties and Legal Affairs, Comptroller General's Department, Ministry of Transport's Office of the Permanent Secretary, Bureau of Royal Rainmaking and Agricultural Aviation, Department of National Parks, Wildlife, and Plant Conservation, Immigration Bureau, Department of Disaster Prevention and Mitigation, Department of Mineral Fuels, Department of Industrial Works, Port Authority of Thailand, Communications Authority of Thailand, and Tourism Authority of Thailand.

NOPEC's oil spill contingency plan and the operation center for oil spill prevention and elimination were set up and fully staffed with dedicated officials at both the central and local governmental levels. However, oil spill management and mitigation in Thailand are still inefficient for several reasons. First, NOPEC lacks sufficient information on vulnerable areas with respect to resource management and risk magnitude to accurately predict the impacts of oil spills. The Pollution Control Department (2010) created an environmental sensitivity index (ESI) map of coastal resources for addressing oil pollution in 1998, and the map was partly updated in 2010. However, the ESI map still needs to be improved because it mainly emphasizes physical resources, whereas important living resources (e.g., coral reefs and certain endangered wildlife and aquatic species) in the coastal areas were not considered. Second, NOPEC does not adequately collaborate with entities from the private sector and local communities to prevent and monitor oil spills. Only the Oil Industry Environmental Safety Group has been involved in addressing oil spill problems. NOPEC must increase collaboration with the public entities at all levels, especially local community networks in vulnerable areas.

To provide practical information for improving the oil spill prevention and management policies of the Thai government, the objectives of this study were the following: (1) to develop an integrated approach for determining the magnitudes of the risk being impacted by oil spills in the coastal areas of Thailand at the national and local scales and (2) to map the zones with these varied risk magnitudes along the coastline of Thailand. Five critical variables were selected to determine the risk magnitudes: frequency of oil spill incidents, number of ports, number of local boats, number of foreign boats, presence of important resources (i.e., protection area, conservation area, marine park, mangrove, aquaculture, coral reef, seagrass, seagull, seabird, sea turtle, dugong, dolphin, whale, guitar fish, and shark), and frequency of simulated oil slicks hitting the coast and/or important resources.

2. Materials and methods

2.1. Study area and coastal boundary determination

Thailand is located in the tropical zone of Southeast Asia between 5°30′ and 20°30′N latitude and 97°30′ and 105°30′E longitude. The country is bounded by mountain ranges in the north, west, and east and by the South China and Andaman seas in the south, with a total coastline of approximately 2600 km (Cheevaporn and Menasveta, 2003). The climate is generally warm and humid, with a typical southwest monsoon that prevails from May to September and a northeast monsoon that prevails from November to February. The transitional periods between the two monsoons occur in October and March–April, respectively. The study area is located along a coastline that is approximately 1840 km long (Yaiprasert et al., 2005), covering 23 provinces, between 6°0′ and 13°30′N latitude and 97°30′ and 103°0′E longitude.

A geographic information system (GIS) was used to create a marine area boundary for each studied province within a 50-km radius reaching from the coast into the sea. In each marine provincial area, five consecutive 10-km radial layers were created. However, only two or three layers were created for some provinces with small marine areas, e.g., Chachoengsao, Samutprakarn, Bangkok, Samutsakhon, and Samutsongkhram (Fig. 1). The methods used to determine the marine area boundaries for Chonburi, Chachoengsao, Samutprakarn, Bangkok, Samutsakhon, Samutsongkhram, and Phetchaburi provinces followed the Upper Gulf Province Boundary B.E. 2502 Act (Krisdika Committee Office, 2006). The determination of marine area boundaries for the remaining coastal provinces was based on the Hydrographic Department guidelines (unpublished data).

The Gulf of Thailand has been a major location for the shipment of oil and goods, navigation routes, port and fishery activities, oil refineries and exploration, facility storage, and so forth. The gulf is a shallow, tropical, semi-enclosed marine embayment of approximately 350,000 km^2 with mean and maximum depths of 45 and 80 m, respectively. The gulf is bounded on the east by the coastlines of Cambodia, Vietnam, and the South China Sea and on the west by the coastlines of southern Thailand and Malaysia. Water circulation in the gulf is complex because it is dominated by the combination of wind-driven currents, tides, density gradients, and its bottom topography. Oil spill incidents in the gulf resulting from oil-related activities will likely increase in the future because of increased demand for petroleum and its products. In addition to oil spills, rapid industrialization and community development have placed considerable stress on the marine environment in the gulf in terms of water quality deterioration, eutrophication, and trace metal and petroleum hydrocarbon contamination (Douglas and Johnston, 1998; Wattayakorn, 1998; Cheevaporn and Menasveta, 2003; Yaiprasert et al., 2005).

2.2. Data collection

The data used to determine the risk zones in this study were obtained from Thai government agencies; these data included oil spill incident information during 1973–2011 (Pollution Control Department and Marine Department, unpublished data), the number of ports during 1996–2008, the number of local boats in 2011 (Marine Department, unpublished data), the number of foreign boats during 2007–2011 (Customs Department, unpublished data), and the availability of 15 important resources (Pollution Control Department, 2010; Department of Marine and Coastal Resources, 2006, 2008a,b,c; Land Development Department, unpublished data).

2.3. Risk zone determination

2.3.1. National scale

The risk zones likely to be affected by the impacts of oil spills in the coastal areas of the 23 coastal provinces of Thailand were identified using the average percentage risk (*APR*), as follows:

$$APR = \frac{\sum_{k=1}^{N} PR_k}{N} \quad (1)$$

PR_k is the percentage risk for each critical variable k. N is the total number of critical variables considered at the national scale, as follows.

(1) Percentage risk due to oil spill incidents ($PR_{incident}$)

$$PR_{incident} = \left[\sum_{i=1}^{n} w_i \times Nfi_i\right] \times \frac{100}{\sum_{i=1}^{n} w_i \times NFI_i} \quad (2)$$

According to NOPEC's oil spill contingency plan (unpublished data), the amount of oil leak is classified into three tiers: tier 1: $x \leqslant 20{,}000$, where x = amount of oil leak in liters; tier 2: $20{,}000 < x \leqslant 1{,}000{,}000$; and tier 3: $x > 1{,}000{,}000$. In this study, w_i are assigned weights of 0.02 (i.e., 20,000 ÷ 1,000,000), 0.51 (i.e.,