Study on Inland River Vessel Fuel-oil Spillage and Emergency Response Strategies

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Abstract. by making statistics and conducting regression analysis on the carrying volume of vessels navigating on inland rivers and coastal waters, the linear relation between the oil volume carried by a vessel and its gross tonnage (GT) is found. Based on the linear relation, the possible spillage of a 10,000 GT vessel is estimated by using the empirical formula method which is commonly used to measure oil spillage from any vessel spill incident. In the waters downstream of Yangtze River, the trajectory and fates model is used to predict the drifting paths and fates of the spilled oil under three weather scenarios, and then, the emergency response strategies for vessel oil spills are put forth. The results of the research can be used to develop an empirical method to quickly estimate oil spillage and provide recommendations on oil spill emergency response strategies for decision-makers.

1. Introduction

Ever since 1967 when an oil-spill happened on the oil tanker Torrey Canyon, oil spill incident spillage more than 10,000 ton happened almost every year worldwide. Though severe oil spills are generally caused by vessels shipping cargo oils, spills of vessel fuel oils happen in the highest frequency, among vessel oil spills incidents. Oil pollution can cause heavy damage to water environment and aquatic resources, owing to its special polluting properties. Since inland waters are more closed than marine waters and most of inland water bodies are sources of drinking water, oil spills on inland waters will cause far more severe damage to the ecologic environment and societies than marine waters.

2. Technical route to study fuel oil spill risks of inland vessels

Study on fuel oil spill risks of inland vessels can be carried out in three phases: 1) prediction of spillage, 2) prediction of effects for typical scenarios, and 3) study on emergency response strategies, as shown in Figure 1. For prediction of spillage, such factors as vessel traffic and tonnage shall be considered firstly and then the type and volume of fuel oil carried by the vessel be analyzed; for prediction of effects of typical scenarios, the trajectory and fates model are applied to simulate and predict pollutants' drift path and fates under the weather conditions such as directions of prevailing winds in a whole year, winter and summer after basic hydrodynamic conditions of waters are investigated; finally, on the basis of predicted effects, strategies such as locations of equipment stations, types of emergent equipment and contingency plans will be developed.

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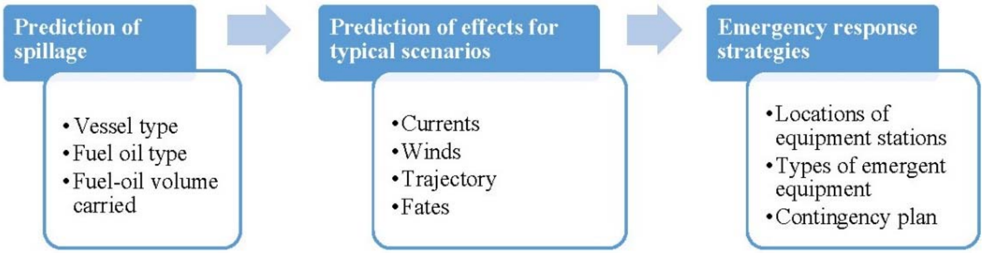

Figure 1. Technical route to study fuel oil spill risks of inland vessels

3. Vessel fuel-oil volume and possible spillage prediction methods

In general, there are two kinds of methods to estimate spillage from vessel pollution incidents: the spillage prediction method applicable to risk assessment and the method applicable to estimate spillage from occurred incidents, as shown in Table 1 [1].

Table 1. Overview of Methods for Estimation of Spillage.

Category	Method	Basic Assumptions or Principles	Main Areas of Application
Methods to predict oil spillage	Empirical formula method	Assume that all oil in a cargo oil side tank or fuel-oil tank is leaked out	Risk assessment, development of contingency plan and emergency response
	MARPOL Method [2]	based on the pressure balancing principle and considers comprehensively the positions of tank breaks, tidal variation and tank structures etc	Risk assessment, development of contingency plan and emergency response
	CFD-based numerical model calculation method [3]	CFD numerical simulation of oil-water-gas 3-phase flow when a vessel is broken	Risk assessment, development of contingency plan and emergency response
Post-incident spillage estimation methods	Monitoring &surveillance-based estimation method [4]	Estimating spillage with the oil spill area, thickness and density acquired from such monitoring and surveillance approaches as site manual observations and remote sensing techniques	Emergency response and guidance to incident investigation
	An estimation method based on detection of oil volume of incident vessels [5]	Estimate the minimal spillage by differences between the loaded volume, the offloaded volume and the residual volume etc. accurately inspected and recorded by authorities	Incident investigation

In this study, the empirical formula method which aims at potentially possible vessel pollution incidents is used to predict possible spillage of vessel fuel oil by assuming that all oil in a cargo oil side tank or fuel-oil tank is leaked out, and the method may be used in regional risk assessment. This method is a statistic analysis method based on the fuel oil volume carried by vessels, with its accuracy depending on the reliability of statistic datum. To understand the weights of fuel oil that vessels of different tonnages carry, in this study, fifty 500 ~ 20,000 GT vessels that navigate on inland rivers and coastal waters are tallied for the weights of their carried fuel oil, and the relation between gross tonnage and the carried fuel oil volume is analyzed as shown in Figure 2. The result indicated that the relation between the carried fuel oil volume F and the vessel gross tonnage GT appears to be linear approximately as shown in Equation (1).

$$F=0.1035GT-43.503 \tag{1}$$

Where, F is the carried fuel oil volume, in ton; and GT is the gross tonnage of a vessel in gross tons.

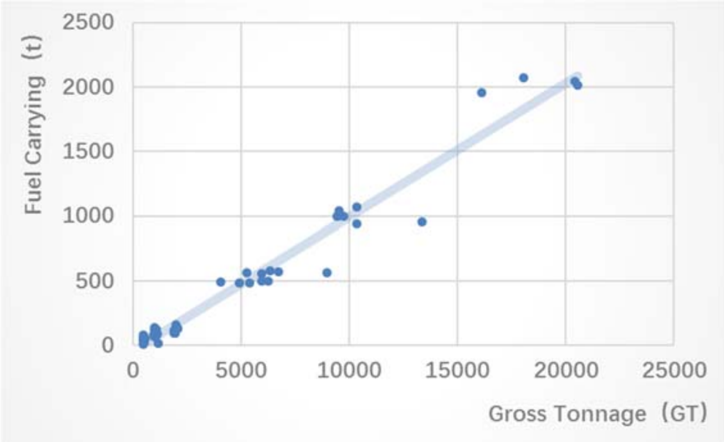

Figure 2. Relation of Vessel GT versus its carried fuel oil volume

4. Prediction of effects based on trajectory and fates model

Oilmap is a trajectory and fates model developed by Applied Science Inc., USA. The trajectory model of Oilmap generalizes spilled oil into oil particles having mass and each oil particle represents a proper fraction of total oil spillage. Joint action of wind force, water current, wave and gravity current on floating oil is considered in the oil slick drift algorithm applied in the model, and the current-driving process is calculated with Lagrange particle tracking while the dissipation process is calculated with the Random Walk method. For the particle's drifting speed $\vec{U}_{oil}$ (m/s) equation, see Equation (2) [6].

$$\vec{U}_{oil}=\vec{U}_w+\vec{U}_t+\vec{U}_r+\alpha\vec{U}_e+\beta\vec{U}_p \quad (2)$$

Where, $\vec{U}_w$ is the speed component generated due to action of wind and wave, in m/s; $\vec{U}_t$ is the speed component due to the action of water current, in m/s; $\vec{U}_r$ is the speed component due to residual currents (e.g. gravity current), in m/s; $\vec{U}_e$ is the speed component due to action of Ekman flow, in m/s; $\vec{U}_p$ is the speed component due to action of squirt flow, in m/s; α is 0 for floating particles and 1 for underwater particles; β is 0 for non-squirt spill and 1 for squirt spill.

The Oilmap fates model is used to calculate the results of oil spill weathering process which includes extension, evaporation, water carrying, emulsion and shoreline adsorption. Following the Law of Mass Conservation, the calculation process covers oil spills on water surface, in water bodies and substrates, in atmosphere, those absorbed on shorelines, and those manually contained and removed.

Ever since 1984 when McCay Deborah French [7] applied the Oilmap model to assess damage to natural resources, the model has enjoyed many applications in assessment of oil spill risks, and was used in simulated demonstration of the oil spill incident by the ship Exxon Valdez [8].

5. Case study

5.1. Assumptions of incident scenarios

In the study, it is assumed that an oil spill incident happens on a 10,000 GT vessel in the downstream waters of Yangtze River. In general, the 10,000 GT vessel has 6 fuel oil tanks carrying 991.5 tons fuel oil in total according to Equation 1, and in the case that all oil inside a single oil tank is leaked out, then the possible fuel oil spillage is 165 tons.

Once a fuel oil spill happens in the vessel, the oil slick's drift trajectory path is mainly impacted by the surface current and the water-surface wind as oil spilled is floating on water. The incident is assumed to happen in the waters where the annual prevailing wind is ESE, the summer prevailing wind is SE, the winter prevailing wind is NW and the annual mean wind speed is 3.3 m/s, as the simulated scenarios shown in Table 2.

Table 2. Scenarios for simulated wind conditions.

No.	Wind direction	Wind speed
1	Annual prevailing wind: ESE	3.3 m/s
2	Prevailing wind in summer: SE	3.3 m/s
3	Prevailing wind in winter: NW	3.3 m/s

5.2. Analysis of results from simulated prediction

It is known from the simulated results that, in the case of an oil spill during the annual prevailing wind ESE, the pollutants will reach onshore in 8 hours and be adsorbed over the shoreline on the south side of Yangtze River, and in 24 hours, 72 % of oil spillage will pollute the shoreline; in the case of an oil spill during the summer prevailing wind SE, the pollutants will reach the shore in 18.5 hours polluting the shoreline of the north side, and in 24 hours, 32 % of oil spillage will pollute the shoreline; in the case of an oil spill during the winter prevailing wind NW, the pollutants will reach the shore in 3 hours and be adsorbed over the shoreline on the south, and all pollutants are adsorbed over the shoreline on the south except a very small amount which is evaporated. The processes of simulated predictions for each scenario are shown in Figure 3 ~ 5, and three cases of pollutant fates (floating, ashore and evaporating) from 24 hours' weathering and fates simulation are presented in Table 3.

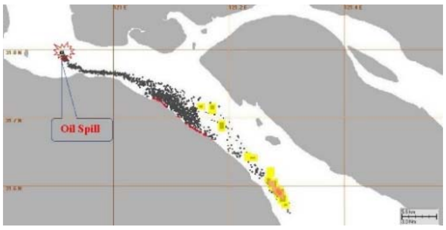

Figure 3(a). Trajectory in 24 hours (annual prevailing wind ESE)

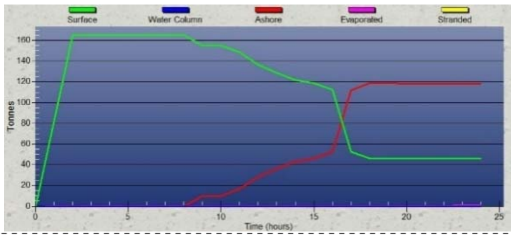

Figure 3(b). Weathering/Fates for fuel oil (ESE)

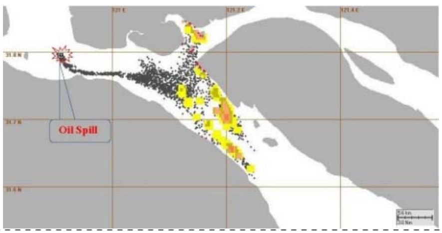

Figure 4(a). Trajectory in 24 hours (winter prevailing wind SE)

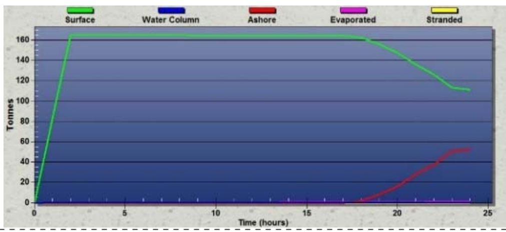

Figure 4(b). Weathering/Fates for fuel oil (SE)

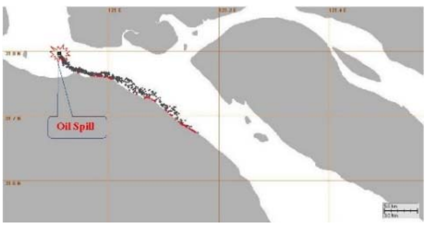

Figure 5(a). Trajectory in 24 hours (summer prevailing wind NW)

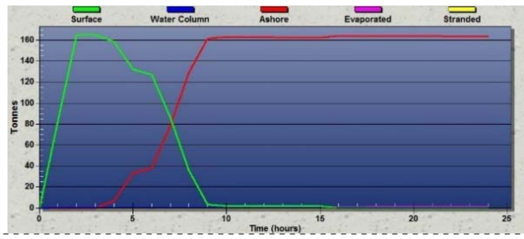

Figure 5(b). Weathering/Fates for fuel oil (NW)

Table 3. Results of weathering/fates simulation in 24 hours (Ton)

Wind direction	Floating	Ashore	Evaporating
Annual prevailing wind: ESE	46.1	118.3	0.6
Prevailing wind in summer: SE	111.4	52.4	1.2
Prevailing wind in winter: NW	0	163.6	1.4

5.3. Emergency response strategies

The emergency response to vessel oil spills includes measures such as monitoring and surveillance, containment and diversion, mechanical recovery and dispersing & adsorption etc. Monitoring and surveillance provides technical support to detect and report early any oil spill to buy time for taking response timely, and it is recommended to monitor oil spills all round by setting up oil spill detection & alarm devices at key navigation aids of inland rivers, key berths for oil products and on tank vessels, and combining aerial survey and satellite remote survey; containment is not only a main measure to protect sensitive resources but also is to gather floating oils early before mechanical recovery of pollutants, and the type, location, orientation and timing of oil containment booms need to be determined on the basis of the trajectory and fates of oil spills predicted with the trajectory and fates model; mechanical recovery and dispersing & adsorption is to recover and remove oil spilled.

6. Conclusion and recommendations

By making statistics and conducting regression analysis on the carrying volume of 50 vessels navigating on inland rivers and coastal waters, and through linear regression analysis, the study finds the approximate linear relation between the oil volume carried by a vessel and its gross tonnage. The possible spillage of a 10,000 GT vessel is predicted by using the empirical formulation commonly used to measure oil spillage from any vessel spill accident. In the waters downstream of Yangtze River, the trajectory and fates model are used to predict the drifting trajectory path and fates under three weather scenarios (the annual, summer and winter prevailing winds respectively), and then based on the predicted results, the strategies for emergency response are put forth.

In the process of emergency response to any vessel oil spill incident, the results for early warning from prediction with the trajectory and fates model is foundational to control and prevent accidents and makes decisions for emergency responses while determination of oil spillage is critical to predict with the model. The results of the study can be used to develop an empirical method to estimate oil spillage and provide recommendations on emergency response strategies for decision-makers.

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References

[1] Shi N, Chen R C, Wang K S 2017 *Energy Conserving & Environmental Protection in Transportation* **13** 12-15

[2] International Maritime Organization 2011 *International Convention for Prevention of Pollution from Ships 1973, as amended in the Protocol 1978* London

[3] Xu Y 2009 *Collection of Papers at Technical Symposia for Marine Pollution Control &Prevention and Emergent Response* Beijing 182-188

[4] Yang J G, Li M H, Qiu C X 2007 *Collection of Papers of the Academic Annual Conference for Vessel Pollution Prevention* Beijing 23-29
[5] Zhao P 2009 *Marine Environmental Science* **28** 469-472
[6] Applied Science Associates, Inc. 2004 *Technical Manual Oilmap for Windows* South Kingstown
[7] McCay D F 2003 *Marine Pollution Bulletin* **47** 341-359
[8] McCay D F 2004 *Environmental Toxicology and Chemistry* **23** 2441-56