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Short Communication

On real-time risk evaluation of accident in water quality control zone

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ABSTRACT

The sudden water pollution is a main type of environmental accident. The time evolution risk of sudden water pollution accident is very important to select real-time measures to effectively reduce the temporal growing risk. The traditional evaluation methods have shortages of describing the evolution process of accident. This paper proposes a real-time risk evaluation method with real-time weight and index to predict the temporal growing risk of sudden pollution accident. The open channel of the Luanhe water supply system in Tianjin is selected as an example to evaluate the temporal risk evolution of the accident. The study provides a reasonable and effective method for the real-time evaluation of sudden pollution accident.

1. Introduction

With the rapid development of economy, sudden water pollution accident has become a serious environmental problem and the risk assessment attracts more and more attention.

The risk assessment is mainly potential ecological risk assessment (Qin et al., 2013; Limayem and Martin, 2014), ecological health risk assessment (Zhang et al., 2013; Takashi, 2014), degraded water quality risk assessment (Sangchan et al., 2014), population health risk assessment (Iqbal and Shah, 2013; Celebi et al., 2014) and so on. Bi and Si (2012) established an integrated risk evaluation system to study the risk of oil spill in Three Gorges Reservoir, which the environmental damage, economic loss, health and social impacts was studied by the weight index and the level criteria of risk classification. They took each index and weight as the fixed value, and could not show the dynamic risk change of the process. In fact, the importance degree of each evaluation index and weight is changing in different time periods after the sudden water pollution incident, so the index and weight should be also considered as change with time. The real-time risk evolution is of great significance to the formulation of pollution emergency treatment scheme, the design of risk prevention facilities and the arrangement of emergency facilities. Therefore, an evaluation theory of real-time weight and index is needed to predict the real-time evolution of risk.

The 3-D Environmental Fluid Dynamics Code (EFDC) with the successful applications of hydrodynamics (Xu and You, 2017), toxic contaminant transport (Wu and Xu, 2011), and water quality (Zhang and You, 2017) was proposed to calculate the real-time (temporal) indexes. A real-time evaluation theory based on the real-time weights and indexes was proposed to evaluate the temporal evolution of risk. The water supply system of Tianjin was selected as an example to apply the proposed method.

2. Methods

2.1. Determination of evaluation indexes

2.1.1. Primary level index

Two level indexes called primary level index A and secondary level index B were used in the risk evaluation. Primary level index A was classified as three indexes. The index of accident regional overview (A_1) shows the basic information on local meteorology and emergency response capability. The index of accident scale (A_2) shows the impact area and strength of accident. The index of accident risk loss (A_3) shows the loss of accident in ecology, economy and society. The weights of the primary level index A were determined by the harm extent of the accident, which is divided into catastrophic accident, major accident, moderate accident and minor accident. The harm extent was determined by the experience of experts combined with multiple accidents.

2.1.2. Secondary level index

Each primary level index A was separated into three secondary level indexes shown in Table 1. In the method of traditional risk analysis, the primary and secondary level indexes are fixed (constant) values in the risk evaluation. The fixed indexes cannot reflect the temporal risk evolution of accident.

If the three secondary level indexes (B_4, B_5 and B_6) of the primary level index accident scale (A_2), were taken as real time (variable)

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Table 1
The risk evaluation indexes of water pollution accident.

Primary index	Name	Secondary index	Name	Property
A_1	Accident regional overview	B_1	Meteorological condition	Fixed
		B_2	Monitoring ability	Fixed
		B_3	Treatment ability	Fixed
A_2	Accident scale	B_4	Time ratio of water recovery and arrival pump	Variable
		B_5	Ratio of water polluted volume	Variable
		B_6	Maximum multiple of water quality standard	Variable
A_3	Accident risk loss	B_7	Ecological loss	Fixed
		B_8	Economic loss	Fixed
		B_9	Social loss	Fixed

indexes which are changing with the temporal evolution of accident, the temporal risk evolution of accident was described. Meanwhile, the corresponding weight of the real time index is also real time variable. It depends on the relative importance of the corresponding index in the temporal development of accident. The other primary level index of the accident regional overview (A_1) and accident risk loss (A_3) were only influenced weakly by the evolution of accident. They were assumed to be fixed values here.

2.2. Risk assessment method

The risk score of secondary index was divided into five grades as 1 to 5, respectively. The assessment standard of the index was shown in Table 2. The risk index R was defined as follows:

$$R = \sum_{i=1}^{N} W_i B_i \tag{1}$$

where W_i and B_i are the weight and score of index, respectively. N is the number of index. The risk index R may change with time and large R represents a big risk.

The three variable secondary indexes, i.e. the time ratio of water recovery and arrival pump (B_4), the ratio of polluted water volume (B_5) and the maximum multiple of water quality standard (B_6), were defined as follows:

$$B_4 = \frac{t}{t^*} \tag{2}$$

$$B_5 = \frac{Q}{V} \tag{3}$$

$$B_6 = \frac{Cm}{Co} \tag{4}$$

where t is the time required to restore the water quality satisfying the standard in the control zone after the accident. t^* is the time which the pollutant reaches the water supply pump station. If the pollutant reaches the pump station, the pollutant is pumped out of the control area and a secondary risk may be caused. It is not the topic of the present approach. Q is the real-time cumulative polluted water volume after the accident, V is the total water volume in the control zone. C_m is the real-time maximum concentration of the pollutant in the control zone and C_0 is the water quality standard of the pollutant. The index of B_4, B_5 and B_6 is dependent on time.

The weight of the above three secondary indexes depends also on time. For this reason, a temporal weight evaluation method was proposed. The method is to partition the period of accident development into a number of key times, and to determine the weight of each variable index by using the method of analytic hierarchy process (AHP) at each key time. After the variable weights are determined at all key times, the temporal weight curve of the index can be fitted by the weight value at the key times. The key time is the critical time that the variable index can be taken as an extreme value or from a state of pollution to a normal or abnormal state.

Table 2
The evaluation standard of risk level of index.

Index	1	2	3	4	5
B1	Very good	Good	Middle	Bad	Very bad
B2	Very good	Good	Middle	Bad	Very bad
B3	Very good	Good	Middle	Bad	Very bad
B4	<1	[1, 2)	[2, 3)	[3, 4)	≥ 4
B5	≤ 0.1	(0.1, 0.2]	(0.2, 0.3]	(0.3, 0.4]	> 0.4
B6	≤ 1	(1, 3]	(3, 6]	(6, 10]	> 10
B7	Negligible	Small	Middle	Large	Very large
B8	Negligible	Small	Middle	Large	Very large
B9	Negligible	Small	Middle	Large	Very large

3. Results

3.1. Study area and model setup

Luanhe open channel is an important part of large-scale inter-basin water transfer project to solve the water shortage in Tianjin. The water pollution accident might be caused by the vehicle transportation on the road closed to the open channel from the Jiuwangzhuang entrance gate to the forebay of Dazhangzhuang pump station. The Daerlu Bridge across the open channel was selected as the location of a supposed pollution accident. The non-volatile soluble substance, secondary alkyl sulfonate, was considered as the representative pollutant. The accident location and open channel structure were shown in Fig. 1.

The 3-D Environmental Fluid Dynamics Code (EFDC) was used to calculate the variable indexes. The EFDC model with Boussinesq approximation and hydrostatic assumption was described in the reference of Hamrick (1992).

The average bottom and water level of the open channel is −3.5 m and 0 m (reference to Yellow Sea elevation), respectively. The roughness coefficient of open channel wall is 0.02. The shelter coefficient of wind is 1.5. The stratification of water body was not considered for the shallow depth. The open channel was divided into 7380 non-uniform grids, which enlarges gradually from the minimum grid 1 m (close to the accident point) to the maximum grid 100 m (far from the accident).

The flow data selected as the boundary condition were shown in Fig. 2. The inlet boundary was at the Jiuwangzhuang gate. The outlet boundaries were at the gates Bin 1, Bin 2 and the north river inverted siphon, the culvert pumping station and the water change gate of the open channel and the Erwangzhuang reservoir.

The accident assumed to be on June 2, 2012. Assuming a traffic rollover accident happened and 5 tons of secondary alkyl sulfonate was poured into the open channel. In order to obtain a reliable flow field at the time of the accident, the calculation began in June 1st. The present traffic rollover accident is a small accident according to the accident classification.

3.2. Traditional risk assessment

In order to illustrate the influence of temporal risk development of the accident, the traditional evaluation (fixed weight) analysis was also applied. The weight of index was calculated by the method of analytic hierarchy process (AHP) with the importance matrix of the indexes. The weight of the primary level index A was found as W = $[0.28, 0.57, 0.15]^T$. By the same way, the weight of the secondary index was found and shown in Table 3. The risk assessment could be finished by the Eq. (1) with the indexes determined by Table 2.