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RESEARCH ARTICLE

Screening of pollution control and clean-up materials for river chemical spills using the multiple case-based reasoning method with a difference-driven revision strategy

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Abstract In-depth filtering of emergency disposal technology (EDT) and materials has been required in the process of environmental pollution emergency disposal. However, an urgent problem that must be solved is how to quickly and accurately select the most appropriate materials for treating a pollution event from the existing spill control and clean-up materials (SCCM). To meet this need, the following objectives were addressed in this study. First, the material base and a case base for environment pollution emergency disposal were established to build a foundation and provide material for SCCM screening. Second, the multiple case-based reasoning model method with a difference-driven revision strategy (DDRS-MCBR) was applied to improve the original dual case-based reasoning model method system, and screening and decision-making was performed for SCCM using this model. Third, an actual environmental pollution accident from 2012 was used as a case study to verify the material base, case base, and screening model. The results demonstrated that the DDRS-MCBR method was fast, efficient, and practical. The DDRS-MCBR method changes the passive situation in which the choice of SCCM screening depends only on the subjective experience of the decision maker and offers a new approach to screening SCCM.

Keywords Environmental pollution emergency disposal · Spill control and clean-up materials · Screening · Multiple case-based reasoning method · Difference-driven revision strategy

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Highlights
• Proposed a completed solution framework for emergency management;
• Established a DDRS-MCBR method model and screening program for SCCM;
• Established a database and case base of SCCM via laboratory experiments;
• Verified the screening method, material base, and case base through actual cases.

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Abbreviations

SCCM	Spill control and clean-up materials
MCBR	Multiple case-based reasoning
DDRS	Difference-driven revision strategy
WC	Wood charcoal
CC	Coal charcoal
CSC	Coconut shell charcoal
NSC	Nut shell charcoal
PAC	Polyaluminum chloride
PFC	Polyferric chloride
PAS	Polyaluminum sulfate
PFS	Polyferric sulfate
PAM	Polyacrylamide
DE	Diatomaceous earth
BG	Bone glue

Introduction

Water pollution accidents frequently occur worldwide (Fu and Wang 2011; Shi et al. 2014) and are a topic of great concern, particularly in developing countries such as China (Fu et al. 2014), India (Jyoti et al. 2010), and Argentina (Avigliano et al. 2015) among others. Many studies of emergency decision management for sudden environmental pollution accidents have been performed that primarily address emergency preparedness and response (Mavrommati et al. 2013; Starkl et al. 2013) and environmental risk decision management (Fan et al. 2015; Jiang et al. 2012; Ştefănescu et al. 2013). In the emergency response phase, selection of the most appropriate emergency disposal technology (EDT) and the corresponding spill control and clean-up materials (SCCM) that can control the pollution sources is highly important to prevent pollutant spread and provide safe emergency disposal.

Currently, emergency disposal technologies such as adsorption, coagulation, oxidation, neutralization, chemical precipitation, ion exchange, water dilution, and damming, among others, are commonly used in environmental pollution accidents (Fu and Wang 2011; Lakherwal 2014; Saravanan et al. 2013). For example, a novel pre-hydrolysed coagulant was applied to the decolorizing treatment for textile wastewater (Verma et al. 2012). In most cases, two or more technologies were used in conjunction. For example, chemical precipitation and water dilution were used together in the cadmium pollution accident in Longjiang River, Guangxi, China (Zhang et al. 2013). Many materials can be used as SCCM in adsorption technology, such as activated carbon, activated alumina, silicone, molecular sieve, etc., and an even greater number of materials are available in coagulation technology, which is divided into inorganic coagulants and organic coagulants. Therefore, a method for quick and accurate selection of the appropriate materials from existing EDT and SCCM for pollution cases is an important topic that became timely when the pollution accident occurred for further study.

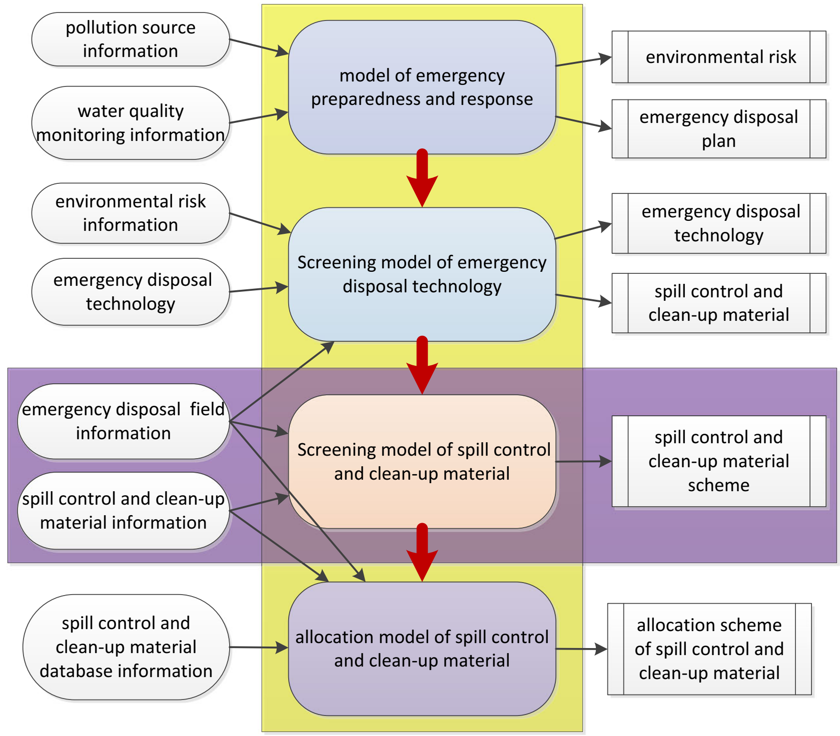
The research on screening of EDT is fairly new and is experiencing rapid growth. Shi applied group decision technology based on an improved analytical hierarchy process to screen EDT in the aniline pollution accident in Zhuozhang River, Changzhi, Shanxi, China, and the results were quite satisfactory (Shi et al. 2014). Liu developed an evaluation framework based on the dynamic fuzzy grey relational analysis method and applied it in a case study to evaluate emergency arsenic treatment technology and demonstrate its applicability and feasibility for emergency arsenic pollution under two scenarios associated with different arsenic levels (Liu et al. 2015a).

After choosing the EDT, the appropriate disposal materials require further confirmation based on the field situation. SCCM must be screened due to many alternative materials. For instance, in the past process of screening EDT for environmental pollution, the screening result is usually "activated carbon adsorption" or "additional coagulant," but many types of activated carbon and coagulant are available. The choice of which specific activated carbon or coagulant to use is commonly decided based on the decision maker's subjective experience, and no corresponding material database, case base, or screening model method is available for decision support. Additionally, no relevant references exist in the literature for this research field. This study applied the developed case-based reasoning (CBR) method to deeply screen SCCM used in emergency technology based on the foundation of technology screening.

CBR is a reasoning technology based on experiences with artificial intelligence that first appeared in the 1980s and is also a reasoning model for obtaining a problem solution that is similar to the current case based on the process of human cognitive psychology through simulation of the process of human problem solving and access to a historical case base (Armaghan and Renaud 2012). The CBR method was based on experience, but revision must be conducted to obtain additional suitable solutions to new problems. Therefore, two strategies were used to establish a successful CBR system. One strategy was to establish a comprehensive case base, and the other was to establish a powerful case correction function. Based on these two strategies, this study established a case base for environmental pollution emergency disposal and proposed a better case correction method.

The establishment of a case base for environmental pollution emergency disposal events is designed to provide a foundation for screening SCCM. In fact, in most cases, it is difficult to find a similar referred case from the limited historical cases for a current pollution accident due to non-detailed historical case information or a lack of useful cases. At this point, the only solution is to find a case that is similar to the non-solved problem, and therefore, the retrieved cases must be modified. Case revision is an essential component of the CBR system, which forms the method and process for solution of a current problem through reasonable revision of retrieved similar cases. Theoretically speaking, if the modified function of the CBR system were sufficiently powerful, the revision process is still applicable even only one or a few cases are available. Case revision has presented a difficulty and a hotspot for relay searching in the CBR system in recent years, and no general case revision method is available due to the different requirements of various field and different modified methods of various cases. In recent years, selected new revision methods have been successively applied, such as the weighted mean (Kwong et al. 1997), equal mean (Shepperd and Schofield 1997), closet analogy (Walkerden and Fo 1999), median (Angelis and Stamelos 2000), genetic algorithm (Passone et al. 2006), multivariate regression analysis (Ji et al. 2012), anchor mapping algorithm (Minor et al. 2014), and grey relational analysis (Hu et al. 2015). In addition, a

Fig. 1 General framework for emergency disposal decision-making



previous researcher presented an adaptation method for solutions using feature values of retrieved cases by introducing an adaptability value to improve the adaptation performance (Qi et al. 2012).

In summary, this study proposes a complete solution framework for SCCM screening problems in environmental pollution emergency disposal and establishes the multiple CBR method (MCBR) with a difference-driven revision strategy (DDRS) for screening materials. The remainder of the paper is structured into four sections: (1) a detailed introduction to the research background and significance, (2) an overview of MCBR that contains the modeling steps of the method

Fig. 2 Working process of the MCBR model with DDRS

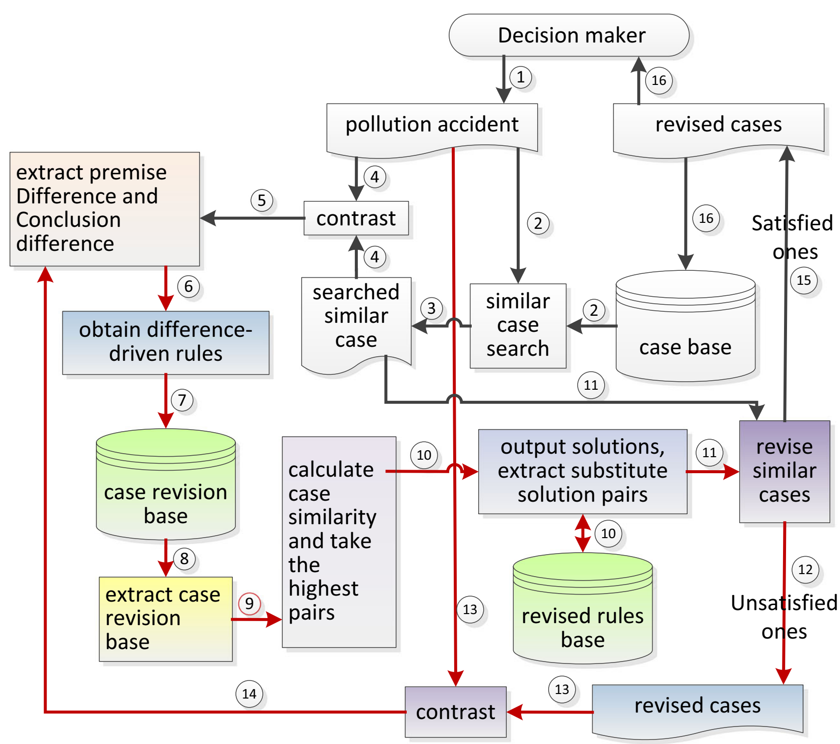


Table 1 Material base

Serial number of the material	Activated carbon *a*	Inorganic coagulants *b*	Organic coagulant *c*
1	Wood charcoal (WC)	Polyaluminum chloride (PAC)	Polyacrylamide (PAM)
2	Coal charcoal (CC)	Polyferric chloride (PFC)	Diatomaceous earth (DE)
3	Coconut shell charcoal (CSC)	Polyaluminum sulfate (PAS)	Bone glue (BG)
4	Nut shell charcoal (NSC)	Polyferric sulfate (PFS)	

and the established process for the SCCM database and case base, (3) a case study based on the aniline pollution accident in the Zhuozhang River of Changzhi, Shanxi, China, and (4) a discussion and future prospects for MCBR with DDRS.

Methodology

General framework for emergency disposal decision-making

From the perspective of emergency management, this study establishes a new framework for emergency disposal decision-making that includes "emergency preparedness and response - screening of EDT - screening of SCCM - allocation of SCCM," according to the characteristics of a sudden water pollution accident. This study was designed to apply the new modeling method for deep screening of the SCCM in EDT based on emergency treatment technology. The solution framework for SCCM screening and its positioning in the broader emergency disposal decision-making process are shown in Fig. 1.

CBR-based solution for SCCM screening

A difference-driven case revision method was adopted by considering the various significant characteristics of environmental pollution accidents to establish an MCBR method with a DDRS.

DDRS implies that the case base contains a certain amount of cases, and different results from various cases caused by different occurrence conditions can be obtained by comparing the attributes and solutions between similar cases, which also implies revision rules for the case solutions. The process of case revision based on difference-driven methods is primarily composed of two tasks. First, the difference attribute and its corresponding solution is extracted to obtain the rules of the difference-driven method, and second, the solution of these difference attributes are applied to a case revision process that uses difference rules to modify the cases (Policastro et al. 2007).

Origin of the algorithm

Based on the traditional CBR method, Duan proposed and implemented a revision method for similar cases based on the generalized operator models to establish a two-CBR system. The essence of this method was that one CBR system uses another CBR system to modify itself (Duan and Dai 2006). In addition, a number of scholars have divided one case base of a traditional CBR system into multiple case bases, and these multiple case bases work together to form a complete system (Leake and Sooriamurthi 2002). Based on these research results, this study developed the two-CBR system into a MCBR system (Policastro et al. 2007) that uses a difference-driven revision method to modify the CBR cases and establish the MCBR model with a DDRS. The working process is shown in Fig. 2.

Modeling steps

Steps for establishing a MCBR model with a DDRS (Zhang 2012):

Step 1: Generate the case revision base. Suppose the number of case feature vectors is m, i.e., $f_i = \{f_1, f_2 \cdots,$

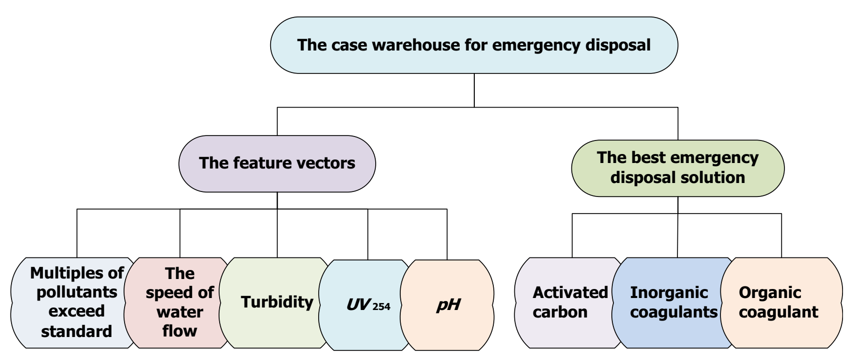


Fig. 3 Framework for the environmental pollution emergency disposal case base

Table 2 Case base

Case no.	Feature vectors					Best emergency disposal solution		
	Multiples of pollutants that exceed standard	Speed of water flow (*m/s*)	Turbidity (*NTU*)	UV_{254}	*pH*	Activated carbon	Inorganic coagulants	Organic coagulant
0001	10	0.5	25	1.2	7	CSC	PAC	PAM
0002	10	0.9	45	2.4	11	CSC	PAS	PAM
0003	50	0.1	5	0.3	3	CC	PAS	PAM
0004	50	0.9	45	2.4	11	NSC	PAS	PAM
0005	90	0.1	5	0.3	3	CSC	PFC	DE
0006	90	0.5	25	1.2	7	WC	PFS	BG
0007	50	0.1	25	1.2	7	CC	PFS	PAM
0008	90	0.1	45	2.4	11	NSC	PFC	BG
0009	10	0.5	5	0.3	3	CC	PFC	DE
0010	90	0.5	45	2.4	11	CSC	PAC	BG
0011	10	0.9	5	0.3	3	CSC	PFS	PAM
0012	50	0.9	25	1.2	7	CSC	PFC	PAM
0013	50	0.5	5	1.2	7	CC	PFC	BG
0014	90	0.9	5	2.4	11	NSC	PFS	PAM
0015	10	0.1	25	0.3	3	CSC	PAS	BG
0016	90	0.9	25	2.4	11	CSC	PAC	DE
0017	10	0.1	45	0.3	3	WC	PAS	PAM
0018	50	0.5	45	1.2	7	NSC	PFC	PAM
0019	50	0.5	25	0.3	7	WC	PFC	DE
0020	90	0.9	45	0.3	11	CC	PAC	PAM
0021	10	0.1	5	1.2	3	WC	PAS	DE
0022	90	0.9	45	1.2	11	CSC	PFS	DE
0023	10	0.1	5	2.4	3	WC	PAC	PAM
0024	50	0.5	25	2.4	7	CC	PAC	DE
0025	50	0.5	25	1.2	3	WC	PFS	PAM
0026	90	0.9	45	4.5	3	NSC	PAS	DE
0027	10	0.1	5	0.3	7	CSC	PFS	BG
0028	90	0.9	45	2.4	7	CSC	PAC	PAM
0029	10	0.1	5	0.3	11	CSC	PFC	DE
0030	50	0.5	25	1.2	11	CC	PAS	PAM

$f_m\}$. For those cases in the case base, with each feature vector f_i and the scheduled class number k, use the projection pursuit cluster model based on the chaos ant colony optimization algorithm to generate the case revision base $\mathrm{CBR}_A(f_i) = \{\mathrm{CBR}_A(f_i = f_i(1)), \cdots, \mathrm{CBR}_A(f_i = f_i(k))\}$. After clustering, each feature vector corresponds to a case revision base $\mathrm{CBR}_A(f_i)$, the point of which is to re-cluster each feature vector of the original case base.

Step 2: Extract the case revision base. Suppose the pollution accident is "A." From the case bases, select the

Table 3 Feature vectors of pollution accidents and searched maximum similarity degree case No.0018

The feature vectors	Multiples of pollutants that exceed standard	The speed of water flow (*m/s*)	Turbidity (*NTU*)	UV_{254}	*pH*	The solution	Note
The pollution accidents	23.7	0.4	50	1.6	5.5	unknown	
The most similar cases	50	0.5	45	1.2	7	NSC+ PFC+ PAM	The case No.: 0018

Table 4 Standard of classification of the contaminated water

Feature vectors	Standard of classification		
	I	II	III
Multiples of pollutants that exceed standard	<30	30 ~ 70	>70
Speed of water flow (*m*/*s*)	<0.3	0.3 ~ 0.7	>0.7
Turbidity (*NTU*)	<15	15 ~ 35	>35
UV_{254}	<0.6	0.6 ~ 1.8	>1.8
pH	<5	5 ~ 9	>9

case "B" that has the highest degree of similarity with pollution accident "A." Assume "*m*" feature vectors, a number of feature value differences of the pollution accident "A," and if the similar case "B" is *j*, then $f_j \in f_i (1 \leq j \leq m)$. For each feature vector, *fj* with different values of "A" and "B," respectively, extract the corresponding case revision base $\mathrm{CBR}_A(f_j = f_{cj})$ and $\mathrm{CBR}_A(f_j = f_{sj})$, where f_{cj} is the feature value of feature vector f_j in "A," and f_{sj} is the feature value of feature vector f_j in "B."

Table 6 Results of revision

	Solution	Note
Most similar cases	NSC + PFC + PAM	Primary solution
Revision	"CSC" instead of "NSC"	Substitute solution
Pollution accidents	CSC + PFC + PAM	Final solution

Step 3: Calculate the case similarity degree. For a feature value f_j with a difference, calculate the similarity degree $sim(c_j, s_j)$ between each case of the two case revision bases, where $c_j \in \mathrm{CBR}_A(f_j = f_{cj})$, $s_j \in \mathrm{CBR}_A(f_j = f_{sj})$
Step 4: Obtain the substitute solutions. Take the highest similarity degree cases $\max(sim(c_j, s_j))$ and output the corresponding solutions $c_j = \left(a^{jc}_{x_a}, b^{jc}_{x_b}, \cdots, e^{jc}_{x_h}\right)$ and $s_j = \left(a^{js}_{y_a}, b^{js}_{y_b}, \cdots, e^{js}_{y_h}\right)$. Respectively, extract the different components from each solution as a substitute solution, such as $b^{jc}_{x_b} \leftrightarrow b^{js}_{y_b}$, $d^{jc}_{x_f} \leftrightarrow d^{js}_{y_f}$
Step 5: Revise the cases with the highest similarity degree. Respectively, substitute the most similar case "B"

Table 5 Storage of case revisions for multiples of pollutants that exceed the standard

Case no.	The feature vectors					The solution			Note
	Multiples of pollutants that exceed standard	Speed of water flow (*m*/*s*)	Turbidity (*NTU*)	UV_{254}	*pH*	*a*	*b*	*c*	
0001	10	0.5	25	1.2	7	CSC	PAC	PAM	
0002	10	0.9	45	2.4	11	CSC	PAS	PAM	A pair of cases can replace each other
0009	10	0.5	5	0.3	3	CC	PFC	DE	
0011	10	0.9	5	0.3	3	CSC	PFS	PAM	
0015	10	0.1	25	0.3	3	CSC	PAS	BG	
0017	10	0.1	45	0.3	3	WC	PAS	PAM	
0021	10	0.1	5	1.2	3	WC	PAS	DE	
0023	10	0.1	5	2.4	3	WC	PAC	PAM	
0027	10	0.1	5	0.3	7	CSC	PFS	BG	
0029	10	0.1	5	0.3	11	CSC	PFC	DE	
0003	50	0.1	5	0.3	3	CC	PAS	PAM	
0004	50	0.9	45	2.4	11	NSC	PAS	PAM	A pair of cases can replace each other
0007	50	0.1	25	1.2	7	CC	PFS	PAM	
0012	50	0.9	25	1.2	7	CSC	PFC	PAM	
0013	50	0.5	5	1.2	7	CC	PFC	BG	
0018	50	0.5	45	1.2	7	NSC	PFC	PAM	The most similar case
0019	50	0.5	25	0.3	7	WC	PFC	DE	
0024	50	0.5	25	2.4	7	CC	PAC	DE	
0025	50	0.5	25	1.2	3	WC	PFS	PAM	
0030	50	0.5	25	1.2	11	CC	PAS	PAM	
–	–	–	–	–	–	–	–	–	

Fig. 4 GIS of environmental pollution emergency disposal

according to each substitution scheme to obtain the revised solution CBR(f^1).

Step 6: Use the revised solution CBR(f^1) to substitute the most similar cases to generate the revised cases. Go back to step 3 and continue to revise the second feature value with a difference to obtain the revised solution CBR(f^2). If many feature values with differences remain, repeat steps 3–5 until the final revised solution CBR(f^i) is obtained.

Step 7: After case revision, if the output cases still cannot satisfy the requirement, then the revised output cases can be used as a source case for the substitute correction algorithm for iterative computation until the requirement is satisfied. This process is known as MCBR.

Material base and case base

Establishment of the material base

Taking "addition of coagulant, activated carbon dam intercept technology" as an example, we select active carbon and coagulant (which are widely used, easily obtained, and well disposed) to establish the corresponding SCCM base of active carbon and coagulant (please see Table 1).

Establishment of the case base

Many factors affect the disposal process in the process of environmental pollution emergency disposal, such as

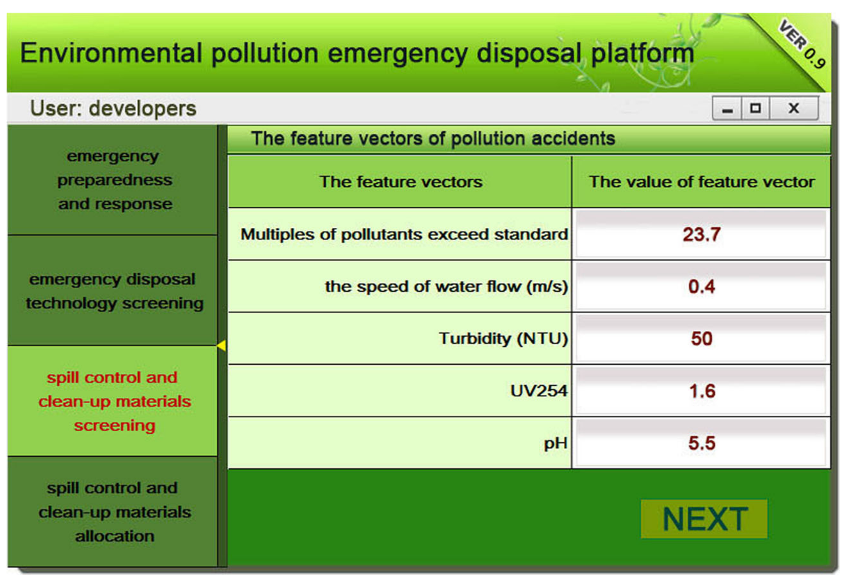


Fig. 5 Input interface of SCCM screening

"Multiples of pollutants exceed standard," "speed of water flow," turbidity, UV_{254}, *pH*, etc. We take the environmental pollution emergency disposal events with significant impact as the feature vectors to establish the framework of the environmental pollution emergency disposal case base, as shown in Fig. 3.

Based on the above framework for the material of the SCCM base, we take a variety of different combinations of the feature vectors that influence the emergency disposal process as different cases for experimentation to obtain the SCCM combination with the best disposal effects for their corresponding cases. The experimental results are filed in the case base for environmental pollution emergency disposal and are shown in Table 2.

Case study

The aniline pollution accident in the Zhuozhang River in Changzhi, Shanxi, China was selected as a case study to verify the methodology described in Section 2. The best screening solution of emergency disposal technology for this aniline pollution accident was "activated carbon adsorption + adding coagulant" (Liu et al. 2015b). The feature vectors of the pollution accidents and the searched maximum similarity degree case No. 0018 are shown in Table 3. The output is the solution that is the most similar: {NSC + PFC + PAM}.

According to Table 4, comparing the output cases similar to the pollution accident, the value of the feature vector of "multiples of pollutants exceed standard" does not belong to the same class under the classification standards. Therefore, the revised case bases CBR_A (multiple pollutants exceed standard) were used for substitution. At first, because of the cases in the case base, the feature vector of "multiple pollutants exceed standard," and the scheduled class number (three classes), the projection pursuit cluster model based on chaos ant colony optimization algorithm was used to generate the case revision base, as shown in Table 5.

The similarity degree of each case between CBR_A (multiple pollutants exceed standard = 23.7) and CBR_A (multiples pollutants exceed standard = 50) was computed to find a pair with the highest similarity degree cases (case 0002 and case 0004), and the output solutions of these two cases are the following:

$$\{CSC + PAS + PAM\} \text{ and } \{NSC + PAS + PAM\}$$

In this pair of similar cases, the concluded difference between "CSC" and "NSC" is due to the condition difference, which can be used as substitute solution pairs for each other. We use "CSC" to substitute "NSC" of solution {NSC + PFC + PAM} in similar case 18 to obtain the revised solution {CSC + PFC + PAM}, as shown in Table 6 and Fig. 4.

Decision tools

This study not only established a model for screening EDT and SCCM, as verified by an actual case study, but also developed a corresponding software platform that can be used to quickly and accurately screen the appropriate EDT and SCCM when an emergency accident occurs.

The decision tool consists of a platform for emergency preparedness and response, EDT screening, SCCM screening, and SCCM allocation. When a pollution accident occurs, the platform for emergency preparedness and response is used for risk assessment. If the assessed results indicate that emergency disposal is required, then the platform for EDT screening is operated. After determination of EDT, fast input of the hydrological information for the pollution accident is used to screen

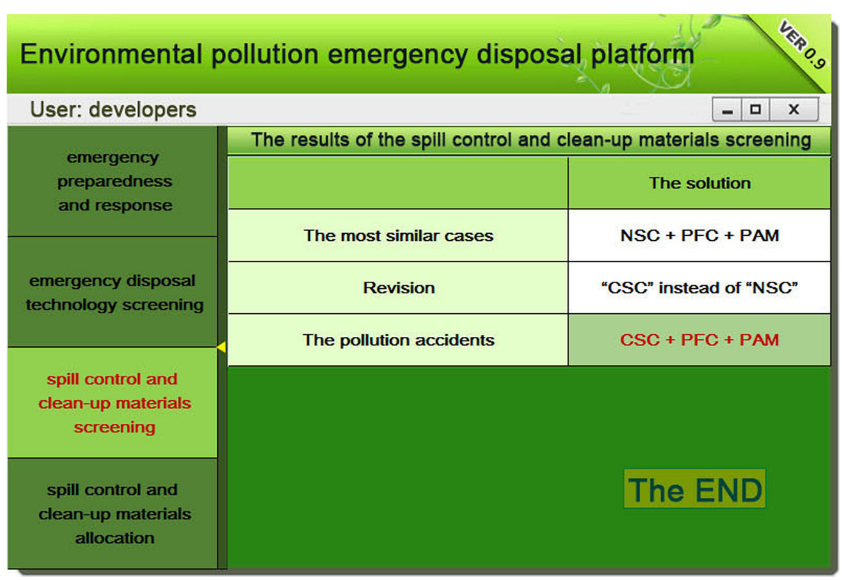


Fig. 6 Output interface of SCCM screening

SCCM. Finally, SCCM is reasonably allocated through the platform of SCCM allocation. The input interface of the SCCM screening platform is illustrated in Fig. 5, and the output interface is illustrated in Fig. 6.

Conclusions and remarks

This study established SCCM screening using an MCBR model based on DDRS as well as the material base and case base for SCCM screening. The case base framework for environmental pollution emergency disposal was established with consideration of factors such as multiple pollutants that exceed the standard, speed of water flow, turbidity, UV_{254}, pH, etc. A series of cases and the best SCCM solutions were obtained in large experiments based on this framework. The MCBR model and case base were verified by many different cases, and the results demonstrated that the MCBR model and case base have strong practicability and feasibility. The verification process of the MCBR model was explained using a case study of the aniline pollution accident that occurred at the Zhuozhang River in Changzhi, Shanxi, China.

The main significance of this study is the application of in-depth screening of SCCM by the MCBR method based on DDRS. It creates scientific guidance for the SCCM selection and allocation. Under the guidance of an artificial intelligence system, the subjective limitation of the decision maker can be avoided.

This study has a wide range of application prospects. Almost all environmental pollution emergency disposal events must use SCCM. Using the MCBR, SCCM can be quickly and accurately determined method, and the efficiency and effect of environmental pollution emergency disposal can be remarkably improved. However, the established material base and case base are only suitable for a limited situation. If the screened materials are not activated carbon or coagulant, then additional experiments must be performed to establish the corresponding case base. Namely, the case base must be completely established before the environmental pollution emergency accident occurs.

SCCM should be stored in the emergency material warehouse. The questions of how to establish the emergency material warehouse, how to choose the warehouse location, and how to allocate the material are highly important, and the process of material screening requires careful consideration because these factors will directly affect the SCCM screening results and the efficiency and effects of emergency disposal.

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