Water Science & Technology

 Water Science & Technology Vol 84 No 9, 2318 doi: 10.2166/wst.2021.445

Research on emergency treatment technology for water pollution accidents where the pollutants are not included in the emergency database

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ABSTRACT

At present, emergency treatment methods are selected based on case or technical database, and it is limited to chemicals in pollution accidents covered by the database. Based on the existing emergency treatment technical database, this paper adds a new chemical characteristics database from the physicochemical properties of chemicals such as toxicity and solubility. Combining the weight of characteristic indexes calculated by the Criteria Importance Though Intercriteria Correlation method combined with the Entropy Weight (CRITIC-EW) method and Manhattan distance, a model is constructed to preliminarily select alternative technologies for a target pollutant. Then, Decision-Makers (DMs) can evaluate alternative technologies using the compound language combined comparative language based on hesitant fuzzy linguistic term set (HFLTS) and single language. And alternative technologies are ranked by applying Technique for order performance by similarity to ideal solution (TOPSIS) method. The closest alternative technology is the most suitable. Taking Bisphenol A (BPA) pollution accident as an example, this method is verified. By analyzing physicochemical properties, forms, and uses between similar chemicals and BPA, as well as applicability of alternative technologies, the emergency treatment method proposed in this study is proved feasible.

Key words: CRITIC-EW, emergency treatment technology, HFLTS-TOPSIS, similarity

HIGHLIGHTS

- Constructed a system to search emergency treatment technology when a pollutant is not included in the existing database.
- Proposed the CRITIC method combined with the Entropy Weight method (CRITIC-EW method) to calculate objective weights.
- Proposed the compound language combined comparative language based on hesitant fuzzy linguistic term set (HFLTS) and single language to evaluate alternative technologies.

ABBREVIATIONS

Abbreviations	Nomenclature
CRITIC	Criteria Importance Though Intercriteria Correlation
EW	Entropy Weight
HFLTS	Hesitant Fuzzy Linguistic Term Set
TOPSIS	Technique for order performance by similarity to ideal solution
DMs	Decision-Makers
BPA	Bisphenol A
CBR	Case-Based Reasoning

INTRODUCTION

Since the reform and opening-up, China's society and economy have experienced world-shaking changes and achieved remarkable achievements. It took China only 30 years to industrialize, while it took western industrialized countries more than 100 years. However, industrialization is accompanied by various environmental pollution problems, and sudden water pollution has entered a high incidence period, making emergency treatment even more demanding and challenging (Duan *et al.* 2011; Xu *et al.* 2019). At present, research on sudden water pollution accidents focuses on macro-management measures, emergency plans, risk assessment, and emergency monitoring (Dibike *et al.* 2018; Gashi *et al.* 2018; Mandaric *et al.* 2018; Ramos-Quintana *et al.* 2019), and so on, and there is little research on emergency technology decision-making.

Fan *et al.* (2014); Liu *et al.* (2015); Liu *et al.* (2016); Zheng *et al.* (2020) calculated the similarity between sudden pollution accidents and historical cases based on case-based reasoning (CBR) by taking the contaminated state of accident sites (such as pollutant type and concentration, etc.) as indexes and obtained emergency treatment technology. For some sudden pollution accidents with less frequency, there are limited historical cases for reference. With the emergence of new technology, the emergency technologies used in historical cases may not be optimal. Given the limitations of the case database above, Luo *et al.* (2019); Luo *et al.* (2020b); Du *et al.* (2021) set up an emergency treatment technology database of heavy metals and organic chemicals by combining historical cases with examples of water pollution control engineering and new technology. Five indexes (Water Discharge, pH Range, Temperature, Range of Treatable Concentrations, and Reliance on Engineering) that can be objectively measured and quantified by monitoring and investigating the accident scene are established as primary identification indexes to preliminarily select alternative technologies. Then, comprehensive evaluation and screening of alternative technologies are conducted according to the technical evaluation index. The above studies are only applicable to accidents when pollutant chemicals are included in the database; however, they can do nothing when it is not included (Luo *et al.* 2019, 2020b; Du *et al.* 2021).

Therefore, physicochemical properties are used as the characteristic indexes of chemicals in the database of emergency treatment technology. The Criteria Importance Though Intercriteria Correlation (CRITIC) method combined with the Entropy Weight (EW) method is used to calculate the attribute weights of the chemical characteristic indexes. The CRITIC method (Diakoulaki *et al.* 1995) can comprehensively measure the objective weight of indexes based on the comparative strength and conflict of evaluation indexes. However, it fails to measure the degree of dispersion between indexes, while the Entropy Weight method can, so they are perfectly complementary. The combination of the two methods can fully consider the variability of data and the existing characteristics of objective weight assignment of each index. Finally, according to the Manhattan distance, the characteristic similarities between the target pollutant and the chemicals in the database are calculated. And chemicals with high similarity are obtained. The emergency treatment technologies of these chemicals are taken as alternative technologies.

In the traditional decision-making process, the evaluation value is completely determined. However, the optimization of sudden accident treatment technology is a complex group decision-making problem, which needs to comprehensively consider engineering, technical, environmental, and other indexes (Li 2012). However, human thinking is fuzzy, so it is a complicated problem for Decision-Makers (DMs) to carry out accurate numerical evaluation of indexes. Using language evaluation instead is more likely to express their thoughts. Li (2012) built an emergency disposal technology optimization model based on triangular fuzzy number multi-criteria decision-making technology, which reduced the cognitive burden of DMs in the emergency disposal group decision-making process. Liu *et al.* (2015); Liu *et al.* (2016) built a multi-attribute group decision-making model based on interval fuzzy numbers, which solved the problem that intuitionistic fuzzy numbers were difficult to determine the precise values of the upper and lower limits. However, none of the above methods can reflect DMs' judgment when they struggle between several possible linguistic terms. Luo *et al.* (2020a) proposed a method of hesitant fuzzy linguistic term set (HFLTS) to study the site selection of waste incineration plants. Çalış Boyacı *et al.* (2021) identified suitable locations for waste vegetable oil and waste battery collection bins based on HFLTS. Liu *et al.* (2020) evaluated the communication ability of Sci-tech journals by using the HFLTS. Based on HFLTS, Buyukozkan & Guler (2020a, 2020b) studied how enterprises could carry out digital transformation on a digital maturity model and guide organizations to conduct an effective smartwatch selection process. The above studies show that using language phrases provided by the HFLTS can better take the preference of DMs into account and make evaluation closer to the truth than using a single language. Therefore, this study adopts a compound language expression method by combining single language and comparative language. Then, the Technique for order performance by similarity to ideal solution (TOPSIS) method is used to evaluate, screen, and make decisions on alternative technologies. Lastly, the emergency treatment technology with the highest closeness degree is obtained as the most suitable treatment technology of the target pollutants. At the end of the study, an example is given to verify the feasibility of this emergency treatment technology search method.

METHOD

Primary selection of emergency treatment technology

Chemical characteristics database

Based on the team's previous study establishing the emergency treatment database (Luo *et al.* 2019, 2020b; Du *et al.* 2021), this study expanded the database into 96 chemicals, according to 'Environmental Emergency Response and Practical Handbook' written by the SEPA, List of China Priority Control Pollutants in Water Environment and the Priority List of Potentially Toxic Chemicals in China proposed by the CRAES. This study also added indexes to the database from the physicochemical properties of chemicals, including molecular weight, melting point, boiling point, density, flash point, and vapor pressure data (CAS 1978-2020). The grading basis and evaluation criteria of toxicity, water solubility, and combustion properties are shown in Table 1.

The characteristics of the chemicals were assigned according to Table 1. The chemical characteristics database is shown in Table 2. Molecular weight, melting point, boiling point, density, toxicity, water solubility, and combustion characteristics were taken as the calculation indexes of similarity.

Indexes weights modeling by the CRITIC-EW method

There are 96 chemicals in the chemical characteristics database in this study, and seven chemical characteristics are used as evaluation indexes. The original index data matrix is formed:

$$A = [a_{ij}]_{m\times n} = \begin{bmatrix} a_{11} & \cdots & a_{1m} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nm} \end{bmatrix} \tag{1}$$

a_{ij} the jth evaluation index of the ith chemical; m represents the number of evaluation indicators; n represents the total number of chemicals.

Table 1 | Classification standard of chemical characteristics database

Index	Index level	Gradation basis	Value	Basis
Toxicity	Practically non-toxic	Oral $LD_{50} > 5{,}000$ mg/kg	1	EPA toxicity categories
	Slightly toxic	Oral $LD_{50} \in [500, 5{,}000]$mg/kg	2	
	Moderately toxic	Oral $LD_{50} \in [50{,}500]$mg/kg	3	
	Highly toxic	Oral $LD_{50} < 50$ mg/kg	4	
Water solubility	Poorly soluble in water	Solubility < 0.01 g	1	Chemistry: the central science, 11th Ed. Prentice Hall, 2008
	Slightly soluble in water	Solubility $\in [0.01{,}1]$g	2	
	Soluble in water	Solubility $\in [1{,}10]$g	3	
	Easily soluble in water	Solubility > 10 g	4	
Combustion characteristic	Non-combustible	Non-combustible	1	Technical Guidelines for Environmental Risk Assessment of Construction Projects (HJ/T169-2004)
	Combustible	Liquid with a flash point below 55 °C, which maintains its liquid state under pressure, will cause major accidents under high temperature and high pressure.	2	
	Easily combustible	Liquid with a flash point below 21 °C and boiling point above 20 °C	3	
	Inflammable and explosive	A substance that can explode under the influence of flame or that is more sensitive to impact or friction than nitrobenzene	4	

Table 2 | Chemical characteristics database

Chemicals	Abbr.	Molecular weight	Melting point (°C)	Boiling point (°C)	Relative density (Water) (g/cm^3)	Water solubility	Toxicity	Combustion characteristic
1,1,1-trichloroethane	1,1,1-TCA	133.42	−33	74	1.32	1	2	2
1,1,2-trichloroethane	1,1,2-TCA	133.5	−35	114	1.44	3	3	2
1,2-dichloroethane	1,2-DCE	98.96	−35	83.5	1.26	2	4	3
1,2,4-trichlorobenzene	TCB	181.45	17.2	221	1.45	1	1	2
2,4,6-trichlorophenol	2,4,6-TCP	197.44	246	68	1.4901	4	2	2
2,4-dinitrotoluene	2,4-DNT	182.13	65.5	300	1.52	2	3	3
2,6-dinitrotoluene	2,6-DNT	182.14	66	300	1.2833	1	3	4
2-chlorophenol	2-CP	128.56	7	174.5	1.24	4	1	2
acetone	AC	58.08	−94.9	56.53	0.8	4	2	4
acrylonitrile	AN	53	−83.6	77.3	0.81	2	4	3

Complete information can be seen in the supplementary material (https://doi.org/10.6084/m9.figshare.15185298).

STEP 1: Standardize each index through min-max normalization:

$$a_{ij}^{'} = \frac{a_{ij} - \min(a_{1j}, a_{2j}, \cdots a_{nj})}{\max(a_{1j}, a_{2j}, \cdots a_{nj}) - \min(a_{1j}, a_{2j}, \cdots a_{nj})} \tag{2}$$

$a_{ij}^{'}$ is the value of the jth characteristics of the ith chemical after dimensionless $i = 1, 2, 3, \cdots, n$; $j = 1, 2, 3, \cdots m$. For convenience, the non-dimensional data still denote as a_{ij}; standardized matrix still denote as A.

STEP 2: Calculate the weights on the CRITIC method:

S_j is the standard deviation of the evaluation index a_{ij}, which measures the contrast strength of the jth evaluation index.

$$S_j = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(a_{ij} - \overline{a_j})^2} \tag{3}$$

In the equation, $\overline{a_j}$ is the mean value of the jth evaluation index,

$$\overline{a_j} = \frac{1}{m}\sum_{i=1}^{m} a_{ij} \tag{4}$$

r_{kl} is the correlation coefficient between the evaluation indexes k and l, representing the degree of correlation among the evaluation indexes.

$$r_{kl} = \frac{\sum_{i=1}^{m}(a_{ik} - \overline{a_k})(a_{il} - \overline{a_l})}{\sqrt{\sum_{i=1}^{m}(a_{ik} - \overline{a_k})^2 \sum_{x=1}^{m}(a_{xl} - \overline{a_l})^2}} \tag{5}$$

In the equation, $k = 1, 2, \cdots, n$; $l = 1, 2, \cdots, n$; a_{ik} and a_{il} represent the evaluation index values of the kth and lth in the standardized matrix A, respectively; $\overline{a_k}$ and $\overline{a_l}$ represent the mean values of the evaluation index of the kth and lth of the ith chemical in the standardized matrix A, respectively.

Calculate the confliction ξ_j between the jth evaluation index and other evaluation indexes.

$$\xi_j = \sum_{k=1}^{n} (1 - |r_{kj}|) \tag{6}$$

In the equation, $j = 1, 2, \cdots, n$; r_{kj} is the correlation coefficient between the kth evaluation index and the jth evaluation index.

Calculate the information C_j of the jth index,

$$C_j = S_j \sum_{k=1}^{m} (1 - (1 - |r_{kj}|), j = 1, 2, \cdots, n \tag{7}$$

r_{ij} is the correlation coefficient between the evaluation index i and j.

The CRITIC weight W_j^C of the jth index:

$$W_j^C = \frac{C_j}{\sum_{j=1}^{m} C_j} \tag{8}$$

STEP 3: Calculate the weight by the EW method:

First, calculate the information entropy e_j of the jth characteristic.

p_{ij} is the proportion of the ith chemical in the jth characteristic:

$$e_j = -\frac{1}{\ln(n)} \sum_{i=1}^{n} p_{ij} \ln(p_{ij}) \tag{9}$$

$$p_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{10}$$

According to Equation (9), the information entropy of each characteristic can be calculated as $e_1, e_2, e_3 \ldots e_k$, and the entropy weight W_j^e of each index can be calculated from the information entropy:

$$W_j^e = \frac{1 - e_j}{\sum_{j=1}^{m} (1 - e_j)} \tag{11}$$

STEP 4: The final weight $W_j = (w_j)_{1\times 7}$ can be obtained by combining two weights with the method of continuous multiplication accumulation combination:

$$W_j = \frac{W_j^C W_j^e}{\sum_{j=1}^{m} W_j^C W_j^e} \tag{12}$$

$W_j = (w_j)_{1\times 7}$, w_j is the weight of the jth characteristic.

Index weights calculation

After standardizing the characteristic value of 96 chemicals in Table 2 according to Equation (2), the weight W_j^C of the CRITIC method can be calculated by Equations (3)–(8). Then the entropy weight W_j^e can be calculated by Equations (9)–(11). Combine the two weights by Equation (12), and finally, get the weight W_j of each feature in the chemical characteristic database. The specific calculation results are shown in Table 3. This article relies on EXCEL and MATLAB to realize the algorithm.

Table 3 | Weight of chemical characteristics

Algorithms	Molecular weight	Melting point	Boiling point	Relative density (Water)	Water solubility	Toxicity	Combustion characteristic
CRITIC	0.1329	0.0685	0.0904	0.0856	0.26	0.116	0.2467
Entropy Weight	0.0894	0.17864	0.16974	0.17711	0.23531	0.07224	0.07757
CRITIC-EW	0.11115	0.12357	0.13007	0.13135	0.24765	0.09412	0.16214

Obtain similarity and primary select alternative technologies

First, calculate the Manhattan distance $dis\left(\breve{X}, A\right)$ between the characteristics of the target pollutant $\breve{X}$ and the chemical characteristics in the characteristic database. The Manhattan distance is the sum of the absolute wheelbases of two points in the standard coordinate system. It has the characteristics of fast calculation speed and high stability.

Assume that the target pollutant

$$dis\left(\breve{X}, A\right) = |a_{ij} - b_{ij}| \tag{13}$$

Calculate the similarity $Sim\left(\breve{X}, A\right)$ between target pollutants $\breve{X}$ and A:

$$Sim\left(\breve{X}, A\right) = \frac{\sum_{i=1}^{n}\left[1 - dis\left(\breve{X}, A\right)\right] \times w_j}{\sum_{j=1}^{m} w_j} \tag{14}$$

b_{ij} is the value of the jth evaluation index of the target pollutant $\breve{X}$.

After the similarity is calculated, the three chemicals with the highest similarity are obtained. Consider these chemicals' emergency treatment technologies from the database as alternative technologies.

Optimal selection of emergency treatment technology

Decision model based on HFLTS-TOPSIS method

Linguistic expression transformation based on HFLTS.

Let $S = \{s_0, s_1, \ldots, s_g\}$ be a linguistic term set. HFLTS, $H_s = \{s_i, s_{i+1}, \ldots, s_j\}$, is an ordered finite subset of consecutive linguistic terms of S. Trapezoidal membership function $A = T(a, b, c, d)$ is used as comparative linguistics expressions based on HFLTS.

Suppose f is a function to convert linguistic expressions into HFLTS, H_s. HFLTS transformation rules are as follows (Rodriguez *et al.* 2012; Rodríguez *et al.* 2013):

$$f\,(s_i) = \{s_i\} \tag{15}$$

$$f\,(\text{at most } s_i) = \{s_j | s_j^* \leq s_i^*\} \tag{16}$$

$$f\,(\text{at least } s_i) = \{s_j | s_j^* \geq s_i^*\} \tag{17}$$

$$f\,(\text{between } s_i \text{ and } s_j) = \{s_k | s_i^* \leq s_k^* \leq s_j^*\};\ \ s_i^*, s_k^*, s_j^* \in S \tag{18}$$

The calculation steps of the fuzzy envelope of the HFLTS, $env(H_s)$:

STEP 1. Obtain the aggregation elements.

In this study, all linguistic terms $s_k \in S = \{s_0, s_1, \cdots, s_g\}$ are defined by trapezoidal membership functions $A^k = T(a_L^k, a_M^k, a_M^k, a_R^k),\ k = 0, 1, \cdots, g$. T is an ordered set composed of boundary points of membership function corresponding to all linguistic variables.

$$T = \{a_L^i, a_M^i, \cdots, a_M^j, a_R^j\} \tag{19}$$

STEP 2. Calculate a, b, c, d from the trapezoidal fuzzy membership function, A.

The definition domain of $A = T(a, b, c, d)$ is the same as $H_s = \{s_i, \ s_{i+1}, \ \ldots, s_j\}$. a and d from trapezoidal membership function $A = T(a, b, c, d)$ is calculated on the min and the max operator (Liu & Rodriguez 2014).

$$a = \min\{a_L^i, a_M^i, \cdots, a_M^j, a_R^j\} = a_L^i \tag{20}$$

$$d = \max\{a_L^i, a_M^i, \ldots, a_M^j, a_R^j\} = a_R^j \tag{21}$$

b and c are obtained from the aggregation of the remaining elements. Therefore, the OWA operator is required to calculate because of its re-ordering aspect (Liu & Rodriguez 2014):

$$b = OWA_{W^s}\{a_M^i, a_M^{i+1}, \ldots, a_M^j\} \tag{22}$$

$$c = OWA_{W^t}\{a_M^i, a_M^{i+1}, \ldots, a_M^j\} \tag{23}$$

STEP 3. Calculation of the OWA.

Let $OWA(a_1, \ a_2, \ \cdot \ \cdot \ \cdot \ , \ a_n) \ = \sum_{j=1}^{n} w_j b_j$ be an ordered weighted average operator, $W = (W_1, W_2, \cdots, W_{n-1}, W_n)^T$ be an associated weighted vector (Liu & Rodriguez 2014).

There are two types of OWA weights:

$$W^1 = (\alpha, \alpha(1-\alpha), \cdots, \alpha(1-\alpha)^{n-2}, (1-\alpha)^{n-1})^T \tag{24}$$

$$W^2 = (\alpha^{n-1}, \alpha^{n-2}(1-\alpha), \cdots, \alpha(1-\alpha), (1-\alpha))^T \tag{25}$$

From Liu & Rodriguez (2014), types of OWA weights can be selected according to $orness(W)$ measure, and the conclusion can be seen as follows:

When the HFLTS is $f(\text{at least } s_i) = \{s_i, \ s_{i+1}, \ \cdots, s_g\}$, the weight used to compute b and c is W^2,

$$\alpha = \frac{i}{g} = \frac{i}{(g+1)-1} \tag{26}$$

When the HFLTS is $f(\text{at most } s_i) = \{s_0, \ s_1, \ \cdots, s_i\}$, the weight used to compute b and c is W^1, the way to calculate α is the same as Equation (26).

When the HFLTS is $f(\text{between } s_i \text{ and } s_j) = \{s_i, \ s_{i+1}, \ \cdots, s_j\}$, the weight used to compute b and c according to the following two cases:

If $i + 1 = j$, the OWA is not required, and b and c can directly obtain,

$$b = a_M^i \tag{27}$$

$$c = a_M^{i+1} \tag{28}$$

If $i + 1 < j$, then the weight used to compute b is W^2, α_1 represents α in Equation (25).

$$\alpha_1 = \frac{g-(j-i)}{g-1} \tag{29}$$

And the weight used to compute c is W^1, α_2 represents α in Equation (24).

$$\alpha_2 = \frac{(j-i)-1}{g-1} \tag{30}$$

STEP 4. Obtain the fuzzy envelope,

$$env(H_s) = T(a, b, c, d) \tag{31}$$

Rank based on the TOPSIS method. Assume that have preliminarily selected m alternative methods in the primary selection process, and there are n indexes in the optimal selection process. Assume the evaluation language of the jth index of the ith alternative technology is set as x_{ij}, and the language decision matrix is $X = [x_{ij}]_{m\times n}$. After being transformed into a fuzzy envelope, the decision matrix $P = [P_{ij}]_{m\times n}$ can be obtained.

The calculation steps for the ranking of alternative technologies using the TOPSIS method are as follows:

STEP 1: Calculate the weighted fuzzy matrix $\tilde{P}$.

Set the index weight $W = \tilde{P}(w_1,\ w_2,\ \cdots, w_n)^T$

$$\tilde{P} = (p_{ij}\cdot w_j)_{m\times n} \tag{32}$$

STEP 2: The maximum and minimum values of each column in the weighted fuzzy matrix $\tilde{P}$ are respectively taken as the most ideal solution $\widetilde{A^+}$ and the least ideal solution $\widetilde{A^-}$ in the alternative technical optimization:

$$\widetilde{A^+} = \{T^+(a_1, b_1, c_1, d_1),\ \cdots, T^+(a_j, b_j, c_j, d_j),\ \cdots, T^+(a_n, b_n, c_n, d_n)\}, j = 1, 2,\ \ldots, n \tag{33}$$

$$\widetilde{A^-} = \{T^-(a_1, b_1, c_1, d_1),\ \cdots, T^-(a_j, b_j, c_j, d_j),\ \cdots, T^-(a_n, b_n, c_n, d_n)\}, j = 1, 2,\ \ldots, n \tag{34}$$

STEP 3: Calculate the distance D_i^+, D_i^- between each alternative technology and the most ideal solution $\widetilde{A^+}$, the least ideal solution $\widetilde{A^-}$. The distance equation is as follows (Liu & Rodriguez 2014):

$$D_i^+ = \frac{1}{4}\sum_{j=1}^{n} \mathrm{d}(\widetilde{p_{ij}}, T^+(a_j, b_j, c_j, d_j)) \tag{35}$$

$$D_i^- = \frac{1}{4}\sum_{j=1}^{n} \mathrm{d}(\widetilde{p_{ij}}, T^-(a_j, b_j, c_j, d_j)) \tag{36}$$

$$\mathrm{d}(A, B) = \frac{1}{4}(|a_1 - a_2| + |b_1 - b_2| + |c_1 - c_2| + |d_1 - d_2|) \tag{37}$$

STEP 4: Obtain the relative closeness degree C_i between the alternative technology and the optimal solution according to D_i^+ and D_i^-:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{38}$$

STEP 5: Calculate the average closeness degree $\widetilde{C_i}$ of each alternative technology evaluated by DMs and select the optimal alternative according to the ranking of the average closeness degree $\widetilde{C_i}$ of each alternative technology.

Technology roadmap

The technical roadmap of the water pollution emergency treatment system established in this study is shown in Figure 1 below.

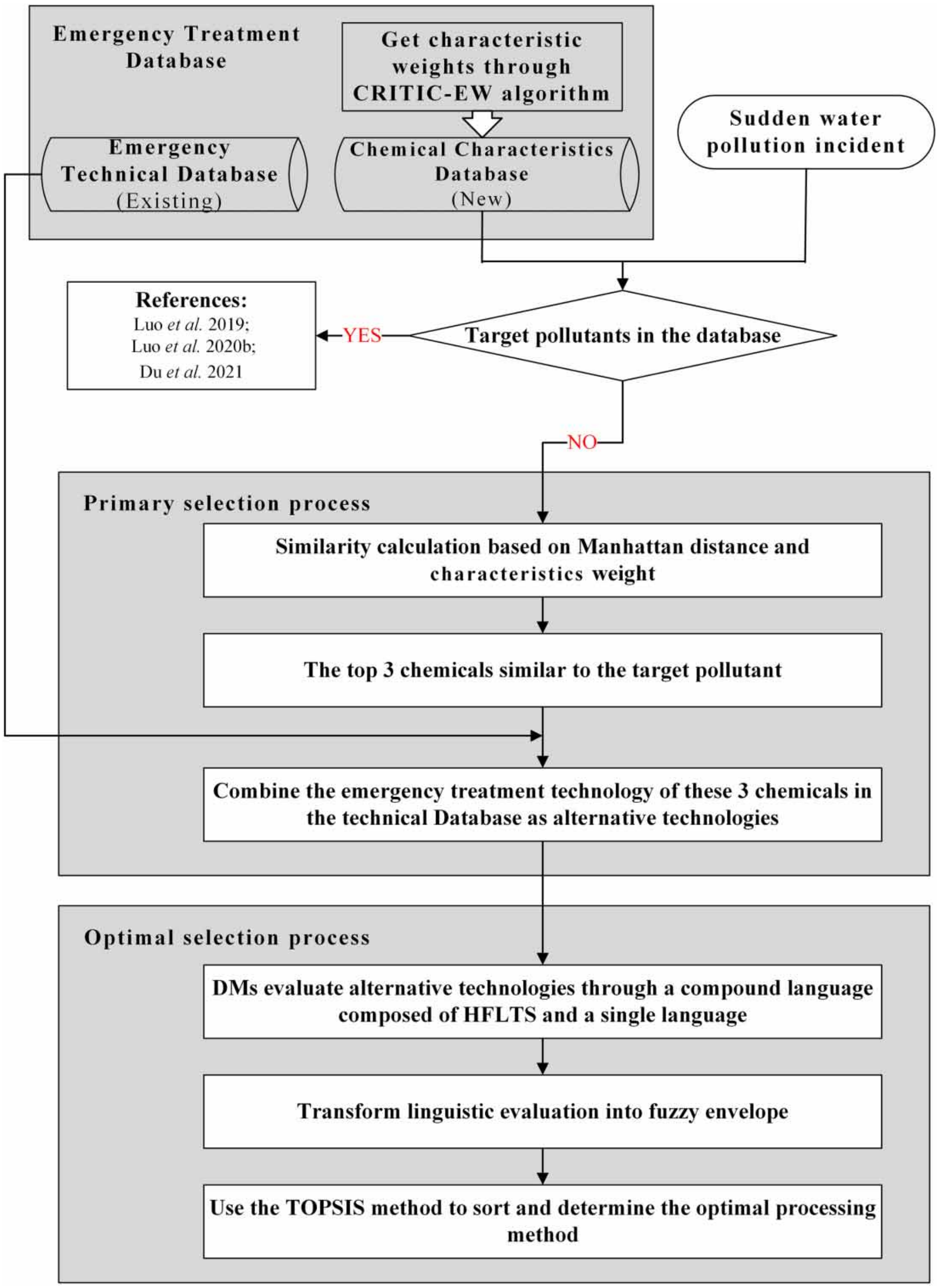

Figure 1 | Technology roadmap.

RESULTS AND DISCUSSION

Case study

Introduction to the accident

The study took a hypothetical case of BPA (bisphenol A) leakage pollution accident as an example to verify the method. An enterprise producing plastic products in the Meishan Economic Development Zone, Sichuan Province, in the middle reaches of the Minjiang River, was selected as the research area. BPA is an environmental hormone that is carcinogenic. It is combustible with high heat and open flame, has low toxicity, is slightly soluble in water, and has a density greater than water. There are Minjiang Second Bridge, Minjiang Bridge, and Tangba Hydropower Station downstream of the accident site. Fences can be set up at these three places, and explosion-proof pumps can be used to suck the BPA that sinks into the water. Most of the BPA can be directly recovered. However, the concentration of BPA in the water measured at the monitoring point of the Meishan Minjiang Bridge reached 10 mg/L, which exceeded the limit of 100 times the limit of China's 'Sanitary Standards for Drinking Water GB 5/49-2006', and the length of the pollution group was 22 km. The summer water temperature of the Meishan section of the Minjiang River is about 25 °C, the average flow is about 222 m^3/s, and the pH is 7.5–8.1. The location map of the BPA pollution accident can be seen in Figure 2.

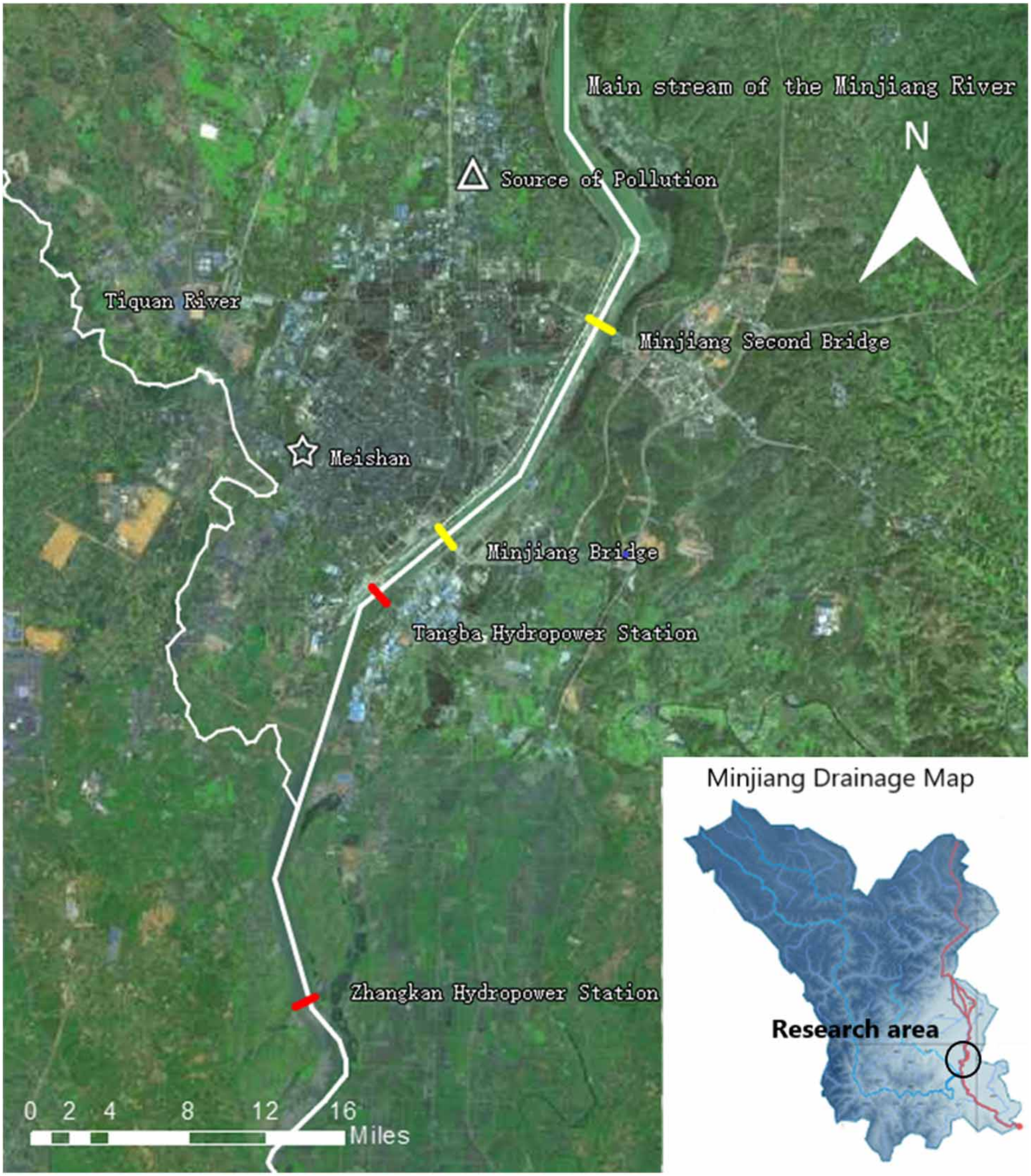

Figure 2 | Location map of BPA pollution accident.

Primary selection of emergency treatment technology

Since the emergency treatment technology for BPA was not included in the technical database, it was necessary to calculate the similarity between the target pollutant BPA and chemicals in the database to screen out the chemicals with the highest similarity. Alternative technologies are obtained by combining emergency treatment technologies of chemicals with the highest similarity.

Similarity calculation

The results of characteristic similarity calculated by Equations (13) and (14) are as follows (Table 4).

The top three chemicals characteristic similarity in the list were Diethyl Phthalate (0.9859), Fluoranthene (0.9850), and Dimethyl Phthalate (0.9828). The corresponding treatment methods for similar substances in the emergency treatment database can be seen in Figure 3. Seven emergency treatment technologies were combined to obtain BPA's alternative technologies: Powder Activated Carbon Adsorption, Bentonite Adsorption, Granular Nutshell Carbon Adsorption, Activated Carbon Fiber Adsorption, Fenton Reagent Oxidation, Persulfate Oxidation, Photocatalytic Oxidation.

Table 4 | Characteristic similarity between BPA and chemicals in the database

Chemicals	Characteristic similarity
Diethyl Phthalate	0.985859
Fluoranthene	0.984952
Dimethyl Phthalate	0.982844
Diphenyl Ether	0.962146
Naphthalene	0.953251
4-Nitrotoluene	0.941257
1-Naphthylamine	0.939513
1,4-Dichlorobenzene	0.935412
4-Nitroaniline	0.934499
2,6-Dichloro-4-Nitroaniline	0.925426

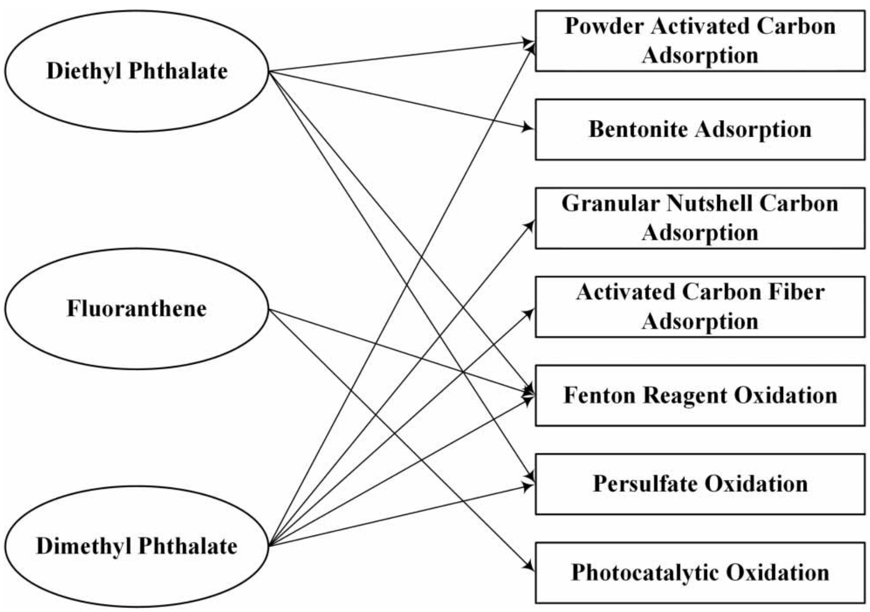

Figure 3 | The corresponding treatment method of the chemical in the database.

Optimal selection of emergency treatment technology

Technology evaluation indexes. In alternative technology optimization, from teams' prophase research (Luo *et al.* 2019; Luo *et al.* 2020b; Du *et al.* 2021), 9 evaluation indexes and their weights are Application (0.1826), Removal Efficiencies (0.1079), Removal Rate (0.1510), Manpower Cost (0.0739), Material Cost (0.1014), Transportation Cost (0.0709), Waste Disposal Cost(0.0705), Environmental Impact of Waste(0.1094), and Environmental Impact of Residues (0.1314).

Establish the linguistic term set. The study designed and selected the language term set, $S = \{s_0, s_1, s_2, s_3, s_4\}$, according to the Likert five-level scale. Quantified each of the 9 technology evaluation indexes and established corresponding evaluation guidelines, as shown in Figure 4. According to the progressive logical relationship of each linguistic variable, let $s_i^* = i/g$, $s_0^* = 0$, $s_1^* = 0.25$, $s_2^* = 0.5$, $s_3^* = 0.75$, $s_4^* = 1$. Based on S, DMs can also evaluate by using comparative phrases 'at least s_i', 'at most s_i', and 'between s_i and s_j'.

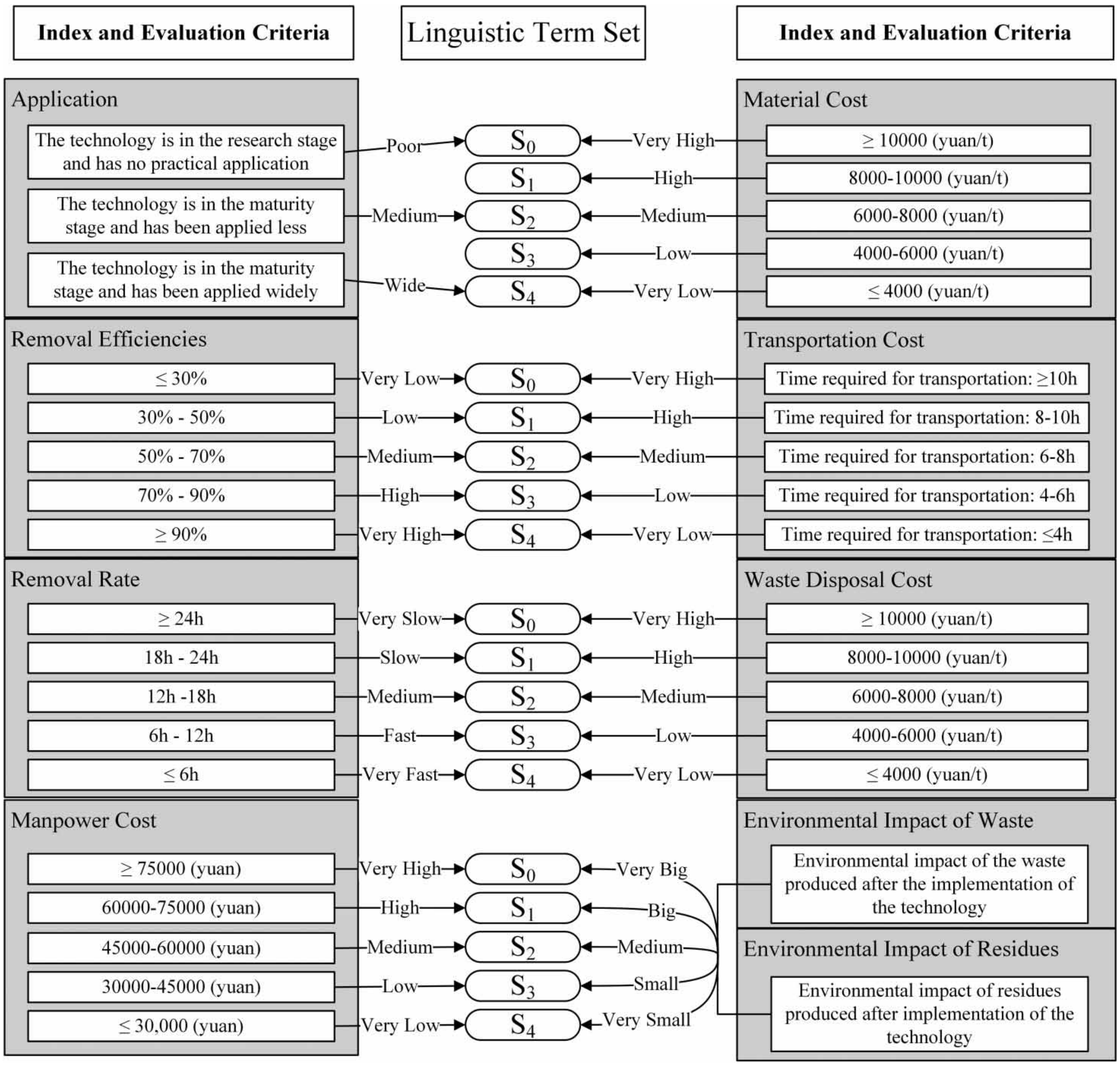

Figure 4 | Index evaluation guidelines.

Obtain the optimal alternative technology based on the HFLTS-TOPSIS method. Ten emergency-response experts as DMs from environmental protection departments, CAS, and environmental protection companies, were invited to evaluate this sample according to the evaluation guidelines (Figure 4) and the specific situation of the accident scene. Taking DM-7 as a sample, the evaluation is as follows (Table 5):

The comparison language and single language were converted into HFLTS and the corresponding linguistic decision matrix X_{DM-7} is as Equation (39):

$$X_{DM-7} = \begin{pmatrix} \{s_2, s_3, s_4\} & \{s_2\} & \{s_0, s_1, s_2\} & \{s_0, s_1, s_2\} & \{s_2, s_3, s_4\} & \{s_0, s_1, s_2\} & \{s_0, s_1, s_2\} \\ \{s_3\} & \{s_3\} & \{s_3\} & \{s_2, s_3\} & \{s_3\} & \{s_3\} & \{s_2, s_3\} \\ \{s_4\} & \{s_3, s_4\} & \{s_4\} & \{s_4\} & \{s_3\} & \{s_3\} & \{s_2, s_3\} \\ \{s_2\} & \{s_2\} & \{s_2\} & \{s_2\} & \{s_0, s_1, s_2\} & \{s_0, s_1, s_2\} & \{s_2\} \\ \{s_1\} & \{s_1, s_2\} & \{s_1\} & \{s_1\} & \{s_1\} & \{s_1\} & \{s_2\} \\ \{s_1\} & \{s_1\} & \{s_1\} & \{s_1\} & \{s_1, s_2\} & \{s_1, s_2\} & \{s_1\} \\ \{s_1\} & \{s_1\} & \{s_1\} & \{s_1\} & \{s_1, s_2\} & \{s_1\} & \{s_1, s_2\} \\ \{s_3\} & \{s_3\} & \{s_3\} & \{s_3\} & \{s_3, s_4\} & \{s_3, s_4\} & \{s_3\} \\ \{s_3\} & \{s_3\} & \{s_3\} & \{s_3\} & \{s_3, s_4\} & \{s_3, s_4\} & \{s_3, s_4\} \end{pmatrix} \quad (39)$$

Table 5 | Language evaluation form from DM-7

	Emergency treatment technology						
Evaluation indexes	**Powder Activated Carbon adsorption**	**Bentonite adsorption**	**Granular Nutshell Carbon adsorption**	**Activated Carbon Fiber adsorption**	**Fenton oxidation**	**Persulfate oxidation**	**Photocatalytic oxidation**
Application	Between Medium and Wide	Medium	At most Medium	At most Medium	Between Medium and Wide	At most Medium	Between Poor and Medium
Removal efficiencies	High	High	High	Between Medium and High	High	High	Between Medium and High
Removal rate	Fast	Between Fast and Very Fast	Very Fast	Very Fast	Fast	Fast	Between Medium and Fast
Manpower cost	Medium	Medium	Medium	Medium	At Most Medium	At Most Medium	Medium
Material cost	High	Between Medium and High	High	High	High	High	Medium
Transportation cost	High	High	High	High	Between Medium and High	Between Medium and High	High
Waste disposal cost	High	High	High	High	Between Medium and High	High	Between Medium and High
Environmental impact of Waste	Small	Small	Small	Small	Between Small and Very Small	Between Small and Very Small	Small
Environmental impact of residue	Small	Small	Small	Small	Between Small and Very Small	Between Small and Small	Between Small and Very Small

The linguistic decision matrix X_{DM-7} was transformed into the fuzzy envelope, $env(H_s)$, expressed by trapezoidal membership function by Equations (15)–(21), the decision matrix P_{DM-7} is obtained as Equation (40).

$$P_{DM-7} = \begin{pmatrix} T(0.25, 0.67, 0.83, 1) & T(0.25, 0.5, 0.5, 0.75) & T(0, 0.17, 0.33, 0.75) & T(0, 0.17, 0.33, 0.75) & T(0.25, 0.67, 0.83, 1) & T(0, 0.17, 0.33, 0.75) & T(0, 0.17, 0.33, 0.75) \\ T(0.5, 0.75, 0.75, 1) & T(0.5, 0.75, 0.75, 1) & T(0.5, 0.75, 0.75, 1) & T(0.25, 0.5, 0.75, 1) & T(0.5, 0.75, 0.75, 1) & T(0.5, 0.75, 0.75, 1) & T(0.25, 0.5, 0.75, 1) \\ T(0.75, 1, 1, 1) & T(0.5, 0.75, 1, 1) & T(0.75, 1, 1, 1) & T(0.75, 1, 1, 1) & T(0.5, 0.75, 0.75, 1) & T(0.5, 0.75, 0.75, 1) & T(0.25, 0.5, 0.75, 1) \\ T(0.25, 0.5, 0.5, 0.75) & T(0.25, 0.5, 0.5, 0.75) & T(0.25, 0.5, 0.5, 0.75) & T(0.25, 0.5, 0.5, 0.75) & T(0, 0, 0.31, 0.75) & T(0, 0, 0.31, 0.75) & T(0.25, 0.5, 0.5, 0.75) \\ T(0, 0.25, 0.25, 0.5) & T(0, 0.25, 0.5, 0.75) & T(0, 0.25, 0.25, 0.5) & T(0, 0.25, 0.25, 0.5) & T(0, 0.25, 0.25, 0.5) & T(0, 0.25, 0.25, 0.5) & T(0.25, 0.5, 0.5, 0.75) \\ T(0, 0.25, 0.25, 0.5) & T(0, 0.25, 0.25, 0.5) & T(0, 0.25, 0.25, 0.5) & T(0, 0.25, 0.25, 0.5) & T(0, 0.25, 0.5, 0.75) & T(0, 0.25, 0.5, 0.75) & T(0, 0.25, 0.25, 0.5) \\ T(0, 0.25, 0.25, 0.5) & T(0, 0.25, 0.25, 0.5) & T(0, 0.25, 0.25, 0.5) & T(0, 0.25, 0.25, 0.5) & T(0, 0.25, 0.5, 0.75) & T(0, 0.25, 0.25, 0.5) & T(0, 0.25, 0.5, 0.75) \\ T(0.5, 0.75, 0.75, 1) & T(0.5, 0.75, 0.75, 1) & T(0.5, 0.75, 0.75, 1) & T(0.5, 0.75, 0.75, 1) & T(0.5, 0.75, 1, 1) & T(0.5, 0.75, 1, 1) & T(0.5, 0.75, 0.75, 1) \\ T(0.5, 0.75, 0.75, 1) & T(0.5, 0.75, 0.75, 1) & T(0.5, 0.75, 0.75, 1) & T(0.5, 0.75, 0.75, 1) & T(0.5, 0.75, 1, 1) & T(0.5, 0.75, 1, 1) & T(0.5, 0.75, 1, 1) \end{pmatrix} \quad (40)$$

P_{DM-7} was weighted according to Equation (16) and the weights mentioned in the first subsection of this section. Then, the weighted decision matrix $\widetilde{P_{DM-7}}$ was obtained as Equation (41).

$$\widetilde{P_{DM-7}} = \begin{pmatrix} T(0.05, 0.12, 0.15, 0.18) & T(0.05, 0.09, 0.09, 0.14) & T(0, 0.01, 0.01, 0.03) & T(0, 0.01, 0.01, 0.03) & T(0.05, 0.12, 0.15, 0.18) & T(0, 0.01, 0.01, 0.03) & T(0, 0.01, 0.01, 0.03) \\ T(0.5, 0.08, 0.08, 0.11) & T(0.05, 0.08, 0.08, 0.11) & T(0.05, 0.08, 0.08, 0.11) & T(0.03, 0.05, 0.08, 0.11) & T(0.05, 0.08, 0.08, 0.11) & T(0.05, 0.08, 0.08, 0.11) & T(0.03, 0.05, 0.08, 0.11) \\ T(0.11, 0.15, 0.15, 0.15) & T(0.08, 0.11, 0.15, 0.15) & T(0.11, 0.15, 0.15, 0.15) & T(0.11, 0.15, 0.15, 0.15) & T(0.08, 0.11, 0.11, 0.15) & T(0.08, 0.11, 0.11, 0.15) & T(0.04, 0.08, 0.11, 0.15) \\ T(0.02, 0.04, 0.04, 0.06) & T(0.02, 0.04, 0.04, 0.06) & T(0.02, 0.04, 0.04, 0.06) & T(0.02, 0.04, 0.04, 0.06) & T(0, 0, 0.02, 0.06) & T(0, 0, 0.02, 0.06) & T(0.02, 0.04, 0.04, 0.06) \\ T(0, 0.03, 0.03, 0.05) & T(0, 0.03, 0.05, 0.08) & T(0, 0.03, 0.03, 0.05) & T(0, 0.03, 0.03, 0.05) & T(0, 0.03, 0.03, 0.05) & T(0, 0.03, 0.03, 0.05) & T(0.03, 0.05, 0.05, 0.08) \\ T(0, 0.02, 0.02, 0.04) & T(0, 0.02, 0.02, 0.04) & T(0, 0.02, 0.02, 0.04) & T(0, 0.02, 0.02, 0.04) & T(0, 0.02, 0.04, 0.05) & T(0, 0.02, 0.04, 0.05) & T(0, 0.02, 0.02, 0.04) \\ T(0, 0.02, 0.02, 0.04) & T(0, 0.02, 0.02, 0.04) & T(0, 0.02, 0.02, 0.04) & T(0, 0.02, 0.02, 0.04) & T(0, 0.02, 0.04, 0.05) & T(0, 0.02, 0.02, 0.04) & T(0, 0.02, 0.04, 0.05) \\ T(0.05, 0.08, 0.08, 0.11) & T(0.05, 0.08, 0.08, 0.11) & T(0.05, 0.08, 0.08, 0.11) & T(0.05, 0.08, 0.08, 0.11) & T(0.05, 0.08, 0.11, 0.11) & T(0.05, 0.08, 0.11, 0.11) & T(0.05, 0.08, 0.08, 0.11) \\ T(0.07, 0.10, 0.10, 0.13) & T(0.07, 0.10, 0.10, 0.13) & T(0.07, 0.10, 0.10, 0.13) & T(0.07, 0.10, 0.10, 0.13) & T(0.07, 0.10, 0.13, 0.13) & T(0.07, 0.10, 0.13, 0.13) & T(0.07, 0.10, 0.13, 0.13) \end{pmatrix} \quad (41)$$

The closeness degree C_i of each alternative technology was calculated by Equation (22)–(38), and then each alternative technology was ranked according to DMs' average closeness degree, $\widetilde{C_i}$. As the results can be seen in Table 6, among the

Table 6 | Average closeness of each alternative technology

Technologies		Powder Activated Carbon adsorption	Bentonite adsorption	Granular Nutshell Charcoal adsorption	Activated Carbon Fiber adsorption	Fenton oxidation	Persulfate oxidation	Photocatalytic oxidation
C_i	DM-1	0.622	0.622	0.591	0.611	0.655	0.655	0.572
	DM-2	0.510	0.506	0.460	0.448	0.453	0.401	0.415
	DM-3	0.321	0.259	0.348	0.266	0.369	0.411	0.410
	DM-4	0.246	0.344	0.227	0.306	0.247	0.188	0.170
	DM-5	0.326	0.403	0.313	0.428	0.348	0.281	0.193
	DM-6	0.334	0.253	0.249	0.339	0.255	0.246	0.235
	DM-7	0.483	0.460	0.378	0.367	0.487	0.371	0.380
	DM-8	0.421	0.363	0.352	0.394	0.341	0.307	0.339
	DM-9	0.421	0.432	0.407	0.388	0.301	0.302	0.333
	DM-10	0.412	0.386	0.383	0.408	0.370	0.396	0.373
$\widetilde{C_i}$		**0.410**	**0.403**	**0.371**	**0.395**	**0.383**	**0.356**	**0.342**

alternative technologies, Powder Activated Carbon Adsorption> Bentonite Adsorption> Granular Nutshell Charcoal Adsorption > Activated Carbon Fiber Adsorption > Fenton Oxidation > Persulfate Oxidation > Photocatalytic Oxidation.

DISCUSSION

We can see from Table 4 that three chemicals with the highest similarity to BPA are Diethyl Phthalate, Fluoranthene, and Dimethyl Phthalate. From Table 7, we can see these three chemicals have the same water solubility, toxicity, and combustion characteristics as BPA, and the density is also greater than water. The appearance of fluoranthene and bisphenol A is needle-like or flaky crystals, and their molecular structures are similar. Diethyl phthalate, dimethyl phthalate, and the target pollutant BPA are all environmental hormones, which can cause internal secretion disorders in the human body. They are all used in the production of plastics. Therefore, it is possible to screen out chemicals similar to the target pollutants by applying the primary selection system in this study.

In the emergency treatment technical database, emergency treatment methods for three similar chemicals are powder activated carbon adsorption, bentonite adsorption, granular nutshell charcoal adsorption, activated carbon fiber adsorption, Fenton oxidation, persulfate oxidation, and photocatalysis oxidation, of which the first four technologies are adsorption technologies. The remaining three are advanced oxidation technologies.

Although advanced oxidation technology has the advantages of fast reaction speed and high processing efficiency, it is limited to strict conditions and will produce a large amount of secondary pollution. For example, the Fenton oxidation technology generally needs to be carried out under the condition of pH 2 ~ 5, and due to the requirement to add Fe^{2+}, the treated water may be colored. Persulfate oxidation technology is less used in practice and is limited to chemical agents' high price and transportation costs. Photocatalytic oxidation technology has high requirements for selecting light sources,

Table 7 | Physical and chemical properties of the top three similar substances and the target pollutant

Chemicals	Abbr.	Molecular weight	Melting point (°C)	Boiling point (°C)	Relative density (Water) (g/cm^3)	Water solubility	Toxicity	Combustion characteristic
Diethyl Phthalate	DEP	222	−40.5	295	1.116	Poorly soluble in water	Practically non-toxic	Combustible
Fluoranthene	\	202.25	110	367	1.252	Poorly soluble in water	Practically non-toxic	Combustible
Dimethyl Phthalate	DMP	194.19	2	282	1.189	Poorly soluble in water	Practically non-toxic	Combustible
Bisphenol A	BPA	228.29	158.5	220	1.195	Poorly soluble in water	Practically non-toxic	Combustible

which can only react under the action of ultraviolet light, and the material supporting the catalyst is easy to decompose during the treatment process. Therefore, the above three technologies are not very suitable for the examples in this study.

As shown in Table 6, the technology with the highest average closeness is the adsorption technology using different adsorbents. The adsorption technology has an apparent treatment effect, short reaction time and is suitable for various flow conditions. However, these technologies need to consider waste disposal and whether structures can be relied upon within the pollution range. In this example, there are bridges and power stations downstream of the river, building interception dams. Meanwhile, to reduce the difficulty of waste disposal and since the difficulty of processing bagged adsorbed waste is more minor than sediment dredging, packaged adsorbent in woven bags is a better choice.

Compared with the previous studies of the research group (Luo *et al.* 2019; Luo *et al.* 2020b; Du *et al.* 2021), the system proposed in this study solves the situation of powerlessness in the previous study when an accident occurs but the chemical is not in the database. It provides new ideas for the emergency treatment of chemicals that have never occurred in sudden pollution accidents. In the previous research, DMs used scoring for evaluation, which could not fully reflect all the DMs' ideas. However, the HFLTS proposed in this study combines a single-language language evaluation method that can help DMs express their ideas in a more accustomed language and is more capable. Thoroughly consider the preferences of DMs to make the evaluation closer to the facts. The combination of this study and previous studies can form a complete emergency response system for water pollution accidents

CONCLUSION

Based on the new chemical characteristics database, this paper proposes a method for searching the emergency treatment technology of pollution accidents when chemicals not covered in the emergency treatment technical database. Calculate the weights of characteristic indexes in the chemical characteristics database by the CRITIC-EW method. Through the weight of the characteristic index and the Manhattan distance, the three chemicals closest to the target pollutant are obtained. The emergency treatment technologies of these three chemicals in the technical database are combined as alternative technologies. Then, DMs use a compound language that combines HFLTS and a single evaluation language to evaluate alternative technologies. Finally, the emergency treatment technology is ranked by the TOPSIS method, and the optimal treatment technology is obtained.

In the case study of the BPA pollution accident, in preliminary selection, we concluded that the three chemicals with the highest similarity to BPA in the technical database are: diethyl phthalate (0.9859), fluoranthene (0.9850), and dimethyl phthalate (0.9828). And seven alternative technologies from the technical database were selected. Then, through the evaluation of DMs, the powdered activated carbon adsorption with 0.410 was selected to be the best emergency treatment technology for this accident. The physicochemical properties, forms, and uses between these three similar chemicals and BPA are relatively similar. According to the analysis, the powder activated carbon adsorption that was selected in optimization process was better than the other six alternative technologies in comprehensiveness. It can be shown that the method in this paper has high feasibility, as well as providing a suitable emergency treatment technology search system for chemicals that have never happened in water pollution accidents before and a scientific reference for similar sudden water pollution accidents.

ACKNOWLEDGEMENTS

This study was supported by the National Natural Science Foundation of China (Grant No. 51779211, Grant No. 51209178) and the Sichuan Science and Technology Program (Grant No. 2019YJ0233). We sincerely appreciate the editors' and anonymous reviewers' significant comments and suggestions for adding to the quality of the study.

DATA AVAILABILITY STATEMENT

All relevant data are available from an online repository or repositories at https://doi.org/10.6084/m9.figshare.15185298.

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First received 7 April 2021; accepted in revised form 27 September 2021. Available online 8 October 2021