Multi-criteria Decision Analysis for Desired Contaminated Groundwater Remediation Strategies based on TOPSIS method

F. Shao[a], L.X. Ren[b], L.Liu[c] and H.W. Lu[d] *

Canada-Sino Research Academy for Resources & Environment, North China Electric Power University, Beijing 102206, China

[a]fs0556@126.com, [b]renlixia381173896@163.com

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Abstract. This study introduced a multi-criteria decision making TOPSIS method to identify the compromised groundwater remediation strategies in 10 and 20 years periods. Based on the PAT technology, the model is applied to a real-world area located in northeastern China where groundwater system has been contaminated severely. Four influential criteria (i.e. total pumping volume, total cost, average remaining contaminant concentration and maximum excess life time cancer risk) are considered for 10 potential pumping alternatives. Results from the case study indicate that A5(10-year) and A8(20-year) are the desired remediation strategy during remediation process.

Introduction

Vulnerable natural groundwater resource has been threatened and deteriorated seriously during the last two decades. Pump and treat (PAT) have been identified as one of the established techniques to improve the remediation effectiveness of contaminated aquifers. In this system, contaminated groundwater is extracted from the subsurface by pumping, then treated it on the ground through remediation technologies and finally injected it back to confine the pollutant plume and decontaminate groundwater environment effectively.

In recent years, many researchers have been applying MCDA method in remediation technologies selection and risk analysis of subsurface pollution. For instance, Huang and Mayer [1] introduced a dynamic formulation of the multi-period optimization management model, where the well locations are incorporated in the model as explicit decision variables; He et al. [2] put forward an integrated simulation, inference, and optimization method for optimizing groundwater remediation systems in western Canada; Parsi et al. [3] proposed an optimization approach based on the firefly algorithm (FA) combined with a finite element simulation method (FEM) to determine the optimum design of pump and treat remediation systems. In this study, we develops a hybrid algorithm by integrating the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and PAT to solve the design problem.

Methodology

TOPSIS method, known in the technical literature as Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), represents a decisional method for prioritizing solutions that has been development since 1981 by C.L. Hwang and K. Yoon [4]. The basic steps of this model can be described as following:

(1) Consider the problem of groundwater remediation and set up a finite set for actions set $A=\{a_1,a_2,\ldots,a_n\}$,criteria set $C=\{c_1,c_2,\ldots,c_m\}$, and x_{ij} represents how $a_i(i=1,2,\ldots,n)$ performs on criterion $c_j(j=1,2,\ldots,m)$, their property values are described as shown in Eq. 1. Standardized matrix can be obtained as shown in Eq. 2.

$$X=\left[x_{ij}\right]_{n\times m} \tag{1}$$

$$X'=\left[x'_{ij}\right]_{n\times m} \tag{2}$$

(2) Nondimensionalize and normalize the index data using the formula (Assuming all the criteria are cost type)

$$a_{ij}=(1/x'_{ij})/(\sqrt{\sum_{i=1}^{n}\left(1/x'_{ij}\right)^2}) \tag{3}$$

(3) Assign the weights $w = \{w_1, \ldots w_j, \ldots\}$to the related criteria $C = \{ C_1, \ldots C_j,\ldots\}$ in this groundwater remediation periods, which represents the relative important degrees of the criteria and $w_j \in R$，R represents a set of incomplete information on the criteria weights given by the decision maker.

(4) Correlation method is used to construct weighted normalized matrix, w_j is corresponding weight coefficient

$$A^*=\left(a_{ij}{}^*\right)_{n\times m} \qquad a_{ij}{}^*=w_j\times a_{ij},\ i=1,2,\ldots,n;\ j=1,2,\ldots,m. \tag{4}$$

(5) Select the positive ideal plan and the negative one from limited plan proposed according to matrix A^*

$$A^+=\left(a_{i1}^+,a_{i2}^+,\ldots,a_{im}^+\right) \qquad a_{ij}^+=\max\left(a_{ij}\right)$$
$$A^-=\left(a_{i1}^-,a_{i2}^-,\ldots,a_{im}^-\right) \qquad a_{ij}^-=\max\left(a_{ij}\right) \tag{5}$$

(6) Calculate the Euclidean distance from the evaluation objects of each index to the positive and negative ideal solutions, which can be marked as D_i^+ and D_i^-

$$D_i^+=\sqrt{\sum_{j=1}^{m}\left(a_{ij}^+-a_{ij}\right)^2} \qquad D_i^-=\sqrt{\sum_{j=1}^{m}\left(a_{ij}^--a_{ij}\right)^2} \tag{6}$$

(7) Calculate the relative approximation and rank the solutions based on the numerical magnitude of Ci

$$C_i=D^-/(D^++D^-) \tag{7}$$

Results

The developed multi-objective method above has been applied to the remediation of a contaminated area located in northeastern China. The detailed evaluation of each alternatives for four criteria for the 10-year and 20-year remediation durations are calculated as shown in Table 1, respectively. Total pumping rate (TPR), total costs (TC), average remaining contaminant concentration (ARCC) ,maximum excess life time cancer risk (MELCR) are considered.

Table 1 Performance of each alternative action during 10 and 20 years period

Actions	TPR	TC	ARCC	MELCR	Actions	TPR	TC	ARCC	MELCR
A1-10	1.482	4.445	0.691	3.238	A1-20	2.963	8.889	0.191	2.144
A2-10	0.971	2.912	1.686	8.412	A2-20	1.941	5.824	0.191	1.586
A3-10	1.243	3.729	1.499	9.155	A3-20	2.486	7.459	0.166	1.693
A4-10	0.851	2.554	1.026	3.765	A4-20	1.703	5.109	0.274	2.673
A5-10	1.277	3.832	0.346	1.634	A5-20	2.554	7.663	0.13	1.574
A6-10	1.056	3.167	0.772	3.988	A6-20	2.112	6.335	0.255	3.489
A7-10	1.209	3.627	0.718	2.936	A7-20	2.418	7.255	0.223	2.581
A8-10	0.647	1.941	1.77	3.985	A8-20	1.294	3.883	0.651	7.832
A9-10	0.903	2.708	1.583	6.909	A9-20	1.805	5.415	0.341	2.609
A10-10	1.056	3.167	0.694	4.111	A10-20	2.112	6.335	0.209	2.884

Table 2 Weight distribution among four index of different periods

Weight	TPR	TC	ARCC	MELCR
10-year	0.105	0.316	0.263	0.316
20-year	0.143	0.429	0.143	0.286

These weights for each remediation periods are determined based analytical hierarchy process (AHP) method which is the best known and most widely used in MCDA approach, as well as the preference of the related experts and stakeholders, as shown in Table 2.

Table 3 Rank of each alternative action during different remediation periods

Actions-10	Relative proximity	Rank	Actions-20	Relative proximity	Rank
A5	0.773	1	A8	0.244	1
A7	0.442	2	A2	0.220	2
A1	0.410	3	A5	0.216	3
A10	0.378	4	A4	0.192	4
A6	0.362	5	A3	0.190	5
A8	0.358	6	A9	0.175	6
A4	0.356	7	A10	0.150	7
A9	0.208	8	A1	0.149	8
A2	0.170	9	A7	0.135	9
A3	0.133	10	A6	0.132	10

What are described in Table 3 are the ranking of 10 repair schemes under two remediation periods respectively in accordance with their relative approximation with positive and negative ideal solution. In detail, in the first group, A5 is the optimal, its score (0.773) holds a safe lead compared to the worst, A3 of 0.133 in this group. In the second group, A8 outshines others, its value is 0.244, however A6(0.132) in the same group occupies the worst, ranks last.

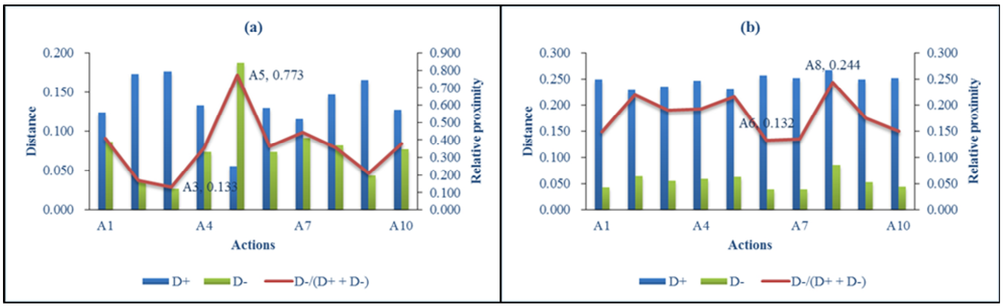

Fig.1 The overall performance of 10 actions in10-year(a) and 20-year(b) under the comparison of the relative distance

Fig.1(a) depicts the comparison of distances coming from the algorithms mentioned, concluding 10 remediation plans in group 1. As is seen visually in the figure, A5(0.773) is the best solution that we need, its low expense and environment protection meet the new tenet of energy-saving and sustainability very well. By contrast, A3(0.133) does not accord with energy conservation and efficient purpose. In Fig.1(b), it describes another 10 evaluation objects. According to the results, it is obvious that A8 is the first during the ranking of outranking flow, which means that A8 is the optimal remediation strategy under 20-year period, but on the other hand A6 is the worst. In practice, specialists should consider corresponding parameters of A5 such as pumping rate as a standard, so as to make the groundwater repair work more efficient and low consumption.

Conclusions

In this study, ten alternatives and four criteria in 10-year and 20-year remediation periods were considered in the numerical example to examine the modified TOPSIS model outputs against different set of weights. According to the complete ranking of results, optimal choice can be easily sorted out as the expected. But in terms of the application and improvement of the method, to make decision method more scientific and effective, many aspects deserve attention and to strengthen.

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