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Risk Assessment of Water Pollution in Mountainous Industrial Parks

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Water system security is the basic condition and important factor to promote the stable development of mountain industrial parks. The purpose of this study is to scientifically evaluate the water pollution risks that mountain industrial parks may face. To this end, in this paper a water pollution risk assessment index system was constructed in four aspects such as water supply, water use, drainage and flood control. Then, the analytic hierarchy process (AHP) was applied to calculate the weight of each factor. Finally, based on expert scoring, few water pollution risks in the mountain industrial park were found, of which the flood control facilities, chemical pollution, ground seepage capacity and water pipeline system are potential unsafe factors with high risk, and especially various chemical pollution poses a risk for the water source safety, water supply quality and drainage in the park, which needs to be strictly controlled.

1. Research background

In order to achieve the goal of poverty alleviation, China has vigorously promoted economic construction and social development in poverty-stricken areas. In some poverty-stricken areas, especially for the cold mountainous areas of the north, due to the undulating terrain, poor soil, drought, and the harsh climate, it is more difficult to develop traditional agriculture and achieve poverty alleviation goals. Therefore, in order to successfully fulfil the established poverty alleviation task, new industrial parks should be scientifically developed in the northern cold mountainous areas with poor external conditions by artificial control of the production environment through modern means.

The water system of the mountain industrial park includes four subsystems: water supply system, water system, drainage system and flood control system, which constitute the infrastructure of modern industrial park. Its water pollution prevention and control state directly affect the stability of the industrial park. For this, the water pollution risk related factors of all water system subsystems in the mountain industrial parks were scientifically evaluated, so as to select the key indicators and formulate targeted control measures in this paper. This has positive effects on improving the water quality safety level, increasing water use efficiency, and reducing water system operation energy consumption etc. of the park (Huang and Zheng, 2018).

2. Analytic hierarchy process and the basic principles of membership determination

Analytic Hierarchy Process (AHP) is a systematic technique of the target (multi-indicator) and multi-scheme optimization decisions that decomposes complex goal into various levels of multiple targets, and calculate the single order (weight) and total order of each level by using the qualitative index fuzzy quantification method (Ma et al., 2018; Wu, 2006; Song and Yang, 2003; Saaty, 1978; Lan et al., 2006; Zhang, 2006; Jin et al., 2004; Lyu, 2002; Luo et al., 2008; Liu et al., 2008). The AHP is divided into four steps, namely, establishing a hierarchical structure model, constructing a comparation judgment matrix, calculating the maximum eigenvalue of the comparison judgment matrix and its corresponding eigenvector, hierarchical ordering and

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consistency test (Guo et al., 2008; Fan et al., 2012; Deng et al., 2017; Zhang et al., 2017; Zhang, 2012; Suresh and Mujumdar, 2004).

2.1 Establishing a hierarchical structure model

Through the survey of potential water pollution in mountain industrial parks, the water pollution risk assessment of industrial parks is divided into three layers: 1) goal layer (A layer), i.e., water pollution risk assessment of mountain industrial parks; 2) criterion layer (B layer), including the water pollution risks of the four subsystems in water supply, water use, drainage and flood control, and the water pollution risk level is determined by criterion layer; the impact mode needs to be reflected by the related specific factors, which is the intermediate link to solve the problem; 3) Decision layer (C layer); the criterion layer is sub-divided to 15 impact factors, and by analysing and solving these impact factors, the water pollution risk assessment of the mountain industrial park can be completed.

2.2 Constructing an indicator system

The four relatively independent subsystems that constitute the water system were used as the criterion layer (B layer) to construct the water pollution assessment indicator system of the mountain industrial park. Fig.1 shows the constructed water pollution risk assessment indicator system of the industrial park, including the decision-making indicators subordinated to each criterion layer.

Water Pollution Risk Assessment for Mountainous Area Industrial Zone														
Water pollution risk on water supply subsystem					Water pollution risk on water use subsystem				Water pollution risk on drainage subsystem			Water pollution risk on flood control subsystem		
Water resource chemical pollutions	Storage capacity of reservoir	Control and storage capacity of reservoir	Water transmission pipeline	Water supply method	Chemical residue in water use	Water use method	Water temperature control system	Maintenance structure	Drainage pipeline	Chemical residue in water drainage	Water discharge	Local rainfall	Flood control facility	Surface permeability

Figure 1: Water pollution risk assessment indicator system of the mountain industrial park

2.3 Fuzzy comprehensive evaluation principle

The basic path of water pollution risk assessment in mountain industrial parks based on fuzzy comprehensive evaluation is: comprehensively consider the influence degree of all factors and use AHP to determine the weight of each factor to distinguish its relative importance; then, calculate the possibility of each factor by constructing mathematical model, and take the one with high possibility as the final determined value per the difficulty level (Buckley and Chana, 1989).

The main steps of multi-level fuzzy comprehensive evaluation:

(1) Determine the evaluation indicators and relevant weights;

(2) Establish the evaluation result set V. This step has the same meaning as establishing the evaluation result set in the single-level fuzzy comprehensive evaluation, $V=\{v_1, v_2, \cdots\cdots, v_n\}$;

(3) Conduct a comprehensive evaluation of the primary indicators, that is, conduct comprehensive evaluation according to various factors in a certain category. It is assumed that the i-th (i=1,2⋯n) are comprehensively evaluated, the membership matrix of the kth (k=1, 2⋯m) factors in the evaluation result set is given as:

$$R_i = \begin{bmatrix} r_{i11} & r_{i12} & \dots r_{i1m} \\ r_{i21} & r_{i22} & \dots r_{i2m} \\ \dots & \dots & \dots & \dots \\ r_{in1} & r_{in2} & \dots r_{inm} \end{bmatrix}$$

Then, the fuzzy comprehensive evaluation set of the i-th factor is:

$$B_i = W_i \cdot R_i = (W_{i1} + W_{i2} \cdots W_{in}) \cdot \begin{pmatrix} r_{i11} & \cdots & r_{i1m} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{inm} \end{pmatrix} = b_{i1}, b_{i2}, \dots, b_{im}$$

where: i=1, 2...n, B_i is the operation result of each factor included in the i-th indicator of the B layer relative to its superior factor, b_i is that of each sub-factor in the i-th indicator of the B-layer relative to its weight, and R_i is the fuzzy evaluation matrix.
Comprehensive evaluation of level-2 factors were conducted.The evaluation matrix should be the lowest level fuzzy comprehensive evaluation matrix:
$B=W\cdot(B1B2\cdots Bn)^T=(w1w2\cdots wn)\cdot(B1B2\cdots Bn)^T$

3. Water pollution risk indicator weight and consistency test of industrial park

3.1 Constructing the judgment matrix

The AHP was used to calculate the weight value of the water pollution risk assessment indicators in the industrial park. After determining the indicator system, the judgment matrix was constructed using 1 to 9. The judgment matrix is a quantization matrix that characterizes the relative importance of the factor at this layer to a factor above. In the judgment matrix A, b_{ij} means the relative importance of b_i to b_j, generally taking 1, 2, ⋯, 9 and its reciprocal; at $b_{ij}=1$, the factor i and j are equally important; at $b_{ij}=3$, the factor i is slightly more important than j; so, at $b_{ij}=9$, the factor i is extremely important than j. The judgment matrix satisfies: $b_{ii}=1$, $b_{ij}=1/b_{ji}$ (Dudois and Prade, 1979).
When using 1 to 9 to construct the judgment matrix, the importance degree of the water pollution risk in the water supply system is 2/1 of that in the water system of the constructed judgment matrix, that is, the value of the element a_{12} in the matrix A is 2/1; also, the water pollution risk of the flood control system is more important than that of the water supply system, so its importance degree of the water pollution risk in the water supply system is 8/9 than that of the flood control system, that is, the value of a_{14} is 8/9. Similarly, by comparing the importance of other factors, the judgment matrix is constructed as:

$$A_1=\begin{bmatrix}\frac{1}{1} & \frac{2}{1} & \frac{8}{7} & \frac{8}{9}\\ \frac{1}{2} & \frac{1}{1} & \frac{4}{7} & \frac{4}{9}\\ \frac{7}{8} & \frac{7}{4} & \frac{1}{1} & \frac{7}{9}\\ \frac{9}{8} & \frac{9}{4} & \frac{9}{7} & \frac{1}{1}\end{bmatrix};\ B_1=\begin{bmatrix}\frac{1}{1} & \frac{3}{1} & \frac{3}{4} & \frac{1}{2} & \frac{1}{1}\\ \frac{1}{3} & \frac{1}{1} & \frac{1}{4} & \frac{1}{6} & \frac{1}{3}\\ \frac{4}{3} & \frac{4}{1} & \frac{1}{1} & \frac{2}{3} & \frac{4}{3}\\ \frac{6}{3} & \frac{6}{1} & \frac{3}{2} & \frac{1}{1} & \frac{6}{3}\\ \frac{3}{3} & \frac{3}{1} & \frac{3}{4} & \frac{1}{2} & \frac{1}{1}\end{bmatrix};\ B_2=\begin{bmatrix}\frac{1}{1} & \frac{8}{3} & \frac{8}{5} & \frac{8}{3}\\ \frac{3}{8} & \frac{1}{1} & \frac{3}{5} & \frac{1}{3}\\ \frac{5}{8} & \frac{5}{3} & \frac{1}{1} & \frac{5}{3}\\ \frac{3}{8} & \frac{1}{1} & \frac{3}{5} & \frac{1}{1}\end{bmatrix};\ B_3=\begin{bmatrix}\frac{1}{1} & \frac{7}{8} & \frac{7}{4}\\ \frac{8}{7} & \frac{1}{1} & \frac{8}{4}\\ \frac{4}{7} & \frac{1}{2} & \frac{1}{1}\end{bmatrix};\ B_4=\begin{bmatrix}\frac{1}{1} & \frac{3}{8} & \frac{3}{5}\\ \frac{8}{3} & \frac{1}{1} & \frac{8}{5}\\ \frac{4}{7} & \frac{1}{2} & \frac{1}{1}\end{bmatrix}$$

3.2 Consistency test of single hierarchical ranking

The element a_{ij} of A in the judgment matrix can be estimated using the knowledge and experience of the evaluator. Since the evaluator's judgment is estimated, it cannot ensure every factor of the comparison judgment matrix to satisfy:

$a_{ij}=a_{ij}\cdot a_{ij}$, CI=(λmax-n)/(n-1)

Therefore, before making decisions by the estimated judgment matrix, the consistency test must be performed by calculating the consistency index and the consistency ratio. The consistency ratio is given as:

CR=CI/RI

RI is a random index. Satty constructs the most inconsistency case, that is, the factor in different n comparison matrices are assigned with 1/9, 1/7, ..., 1, ..., 7, 9 by means of random access, and 100-500 words are used for different n, to calculate the consistency, and then the average. It's denoted as random index, as shown in Table 1.

Table 1: Random index RI value

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
RI	0	0	0.51	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

If the consistency ratio CR < 0.10, it is considered that the consistency in the comparison judgment matrix is acceptable, and the weight vector W is also acceptable.
The maximum eigenvalue λmax of each judgment matrix and its corresponding eigenvector W_i (i=1, 2, …, 5) were calculated by Maple, and the feature matrix vector was normalized to W_i. For matrix A, λmax=4.015, W_1=(0.280 0.161 0.245 0.315); for Matrix B_1, λmax=5.000, W_2=(0.176 0.059 0.235 0.354 0.177); for matrix B_2, λmax=4.062, W_3=(0.417 0.165 0.261 0.157); for matrix B_3. λmax=3.000, W_4 =(0.368 0.421 0.211); for matrix

B_4, λmax=3.000, W_5=(0.188 0.500 0.313); then the consistency test was performed using the CR method. The matrix A was tested to obtain: λmax=4.015, CI=0.0049, and CR<0.10.
Therefore, Matrix A has a satisfactory consistency. Similarly, the matrices B_1, B_2, B_3, and B_4 also has satisfactory consistency.

3.3 Total hierarchical ranking

The total hierarchical ranking means the ordering of the relative importance of the indicator layer to the goal layer, that is, the weight value of the water pollution risk in the mountain industrial park. It's calculated by probability multiplication. The weight of the total hierarchical ranking indicator is the product of the weight value for the C layer indicator and the weight value of the corresponding upper layer B indicator, and the sum of the total ranking weight values is 1.
Through calculation, the absolute weights of the 15 indicators in the C layer are shown in Table 2.

Table 2: Water pollution risk weight of industrial park

Goal layer A	Criterion layer B	Indicator layer C	Comprehensive weight A=(B×C)
Water pollution risk assessment of mountain industrial park	Water pollution risk of water supply system B_1(0.280)	Water source chemical pollution C_1(0.176)	0.049
		Reservoir storage capacity C_2(0.059)	0.017
		Pump power supply safety C_3(0.0.235)	0.066
		Water pipeline system C_4(0.354)	0.099
		Water supply method C_5(0.177)	0.050
	Water pollution risk of water system B_2(0.161)	Water chemical residue C_6(0.417)	0.067
		Water use mode C_7(0.165)	0.027
		Water temperature control system C_8(0.261)	0.042
		Maintenance structure C_9(0.157)	0.025
	Water pollution risk of drainage system B_3(0.245)	Drainage pipe network C_{10}(0.368)	0.090
		Drainage chemical residue C_{11}(0.421)	0.101
		Water discharge C_{12}(0.211)	0.052
	Water pollution risk of flood control system B_4(0.315)	Local precipitation C_{13}(0.188)	0.059
		Flood control facility C_{14}(0.500)	0.158
		Ground water seepage capacity C_{15}(0.313)	0.099

4. Establishment and verification of fuzzy relations

4.1 Membership determination

Qualitative indicators refer to indicators that cannot be determined by quantitative numbers and can only be explained by words. In this study, the risk level was described qualitatively in different grades of "low, general, high, and very high". Percentage statistics method can be used by directly counting the evaluation results of the evaluated objects in percentage and taking the results as the membership degree of this indicators (Song and Yang, 2003; Saaty, 1978). For the water pollution risk assessment in mountain industrial parks, 10 experts were invited to conduct grade evaluation, where eight experts thought that the system is perfect with low risk, and the calculated membership degree is 0.8; 2 experts believed that the risk level of this system is general, and the degree of membership is 0.2; no experts believed that the system has high or very high risk, and its corresponding membership degree is 0. Finally, the fuzzy evaluation matrix of water risk in mountain industrial park is summarized as [0.8 0.2 0 0].

4.2 Establishing a fuzzy relation matrix

According to the risk value evaluation results of various risk indicators above, combined with the experts' evaluation results for these risks, the fuzzy relation matrix R was obtained, as shown in Table 3.

Table 3: Water pollution risk judgment matrix of mountain industrial park R

Evaluation factor layer	Low risk	General risk	High risk	Very high risk
Water source chemical pollution	0.8	0.2	0	0
Reservoir storage capacity	0.6	0.1	0.3	0
Pump power supply safety	0.3	0.7	0	0
Water pipeline system	0.2	0.6	0.2	0
Water supply method	0.1	0.3	0.5	0.1
Water chemical residue	0.9	0.1	0	0
Water use mode	0.5	0.2	0.3	0
Water temperature control system	0.7	0.3	0	0
Maintenance structure	1	0	0	0
Drainage pipe network	0.7	0.2	0.1	0
Drainage chemical residue	0.3	0.3	0.3	0.1
Water discharge	0.5	0.4	0.1	0
Local precipitation	0.2	0.6	0.1	0.1
Flood control facility	0.3	0.4	0.2	0.1
Ground seepage capacity	0.1	0.2	0.5	0.2

4.3 Evaluation results

Finally, the fuzzy comprehensive evaluation results are obtained as follows:
B=A×R={0.467 0.284 0.185 0.042}

Table 4: Level-2 evaluation results

Water pollution risk assessment level	Low risk	General risk	High risk	Very high risk
Evaluation results	0.467	0.284	0.185	0.042

5. Conclusions

Safety prevention and control of water pollution is the basic condition and important way for the healthy development of mountain industrial parks and the steady increase of local residents' income. The fuzzy AHP combined with expert judgement was applied to evaluate the water pollution risk of mountain industrial parks. The results show that the potential water pollution risk faced by the park is low, but the flood control facilities, chemical pollution, ground seepage capacity, and water pipeline system in 15 evaluation indicators still have unsafe effects, especially the pollution of various chemicals. Chemical fertilizer pollution around the water source, various chemical agent residues added in the water purification process, and various chemical residues mixed in the drainage etc. all pose certain risk to the safety of water sources, the quality of water supply and the water environment of the park, which requires strict control.

According to the above evaluation results, firstly, it is recommended that relevant departments should strictly control the dumping of chemical wastes around mountain industrial parks and chemical agents with small potential risks should be selected for water treatment. Secondly, clean production should be implemented in the park to avoid mixing various chemical residues into the drainage, and further contaminate the receiving water body; Finally, the safety design coefficient of the flood control, permeation enhancing and water pipeline system in the park should be moderately improved, and routine maintenance and overhaul should be carried out for the constructed and operated system, so as to exert its due effect.

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