Coal Mine Flood Risk Analysis based on Fuzzy Evaluation Method

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Abstract: Coal mine flood accident is one of the five major disasters in coal mine. It often causes catastrophic damage with high number of human injuries and deaths. The prevention and control of coal mine water hazards is an important task of coal mine safety management. This paper discusses the use of fuzzy evaluation method to identify the sources of danger of the flood accidents, and analyzes the flood accident risks according to the actual coal mine situations. The author hopes that this paper can play a guiding role in the prevention and control of the coal mine flood accidents.

1. Introduction
Water disaster is one of the five natural disasters in coal mine. The water burst has long been the prominent problem perplexing the coalmine production. In China, the coal seam occurrence modes and the coal mine hydrogeological conditions vary significantly. Many coal mines face the serious water hazards, and the coal seam mining process are threatened by various kind of water hazards. Therefore, the task of preventing and controlling water hazards in coal mines is arduous.

The fuzzy theory is mainly used to solve those problems which have no clear connotation and extension [1]. The causes of coal mine flood accidents are various, and the time when these causes will lead to flood accidents is always uncertain. Fuzzy theory has obvious advantages in solving this kind of uncertainty problem [2].

The fuzzy evaluation method firstly determines the set of evaluation factors, and assigns each factor a corresponding weight value to form the evaluation matrix, then constructs the system evaluation matrix by using the corresponding weight value and the evaluation matrix, finally calculates the system score and compares it with the security grade to come up with an assessment[3].

2. Determine the set of evaluation factors
To avoid and reduce any flood accidents, the root causes of the accidents must be fully understood and the counter-measures must be in place to prevent them from occurring. To prevent and eliminate coal mine flood accidents, first things first, one needs to identify the potential hazard source of flood. Identification of the hazard source mainly relies on expert consultation based on the geological conditions, the hydrogeological types, the waterproof coal pillar setting, mining situation, safety management status, previous accident information of a coal mine.

The risk sources of flood accidents depend on many qualitative variables. Based on past experience and expert consultation, the main factors leading to flood accidents are: complexity of the geological, hydrogeological conditions, insufficient drainage capacity of mines, human factors and improper safety management. With the fuzzy evaluation, the above factors are defined as the class 1
evaluation indexes, and represented by \( u_1, u_2, u_3 \) and \( u_4 \) respectively. Each index is further divided into several affecting factors, represented by \( u_{ij} \) \( (i=1,2,3,4; \ j=1,2,3,4) \), See Table 1.

**Table 1** Hazard source evaluation index of mine flood accident

| Evaluating Indicator \((u_i)\) | Influencing Factor; Influence Factor \((u_{ij})\) |
|-------------------------------|---------------------------------------------|
| Complexity of the geological and hydrogeological conditions \((u_1)\) | Extractive conductive aquifer \((u_{11})\) |
| | Excavating and conducting water in old kiln \((u_{12})\) |
| | Excavating and conducting surface water body \((u_{13})\) |
| | Fault water conductivity \((u_{14})\) |
| | Encounter with karst or Underground river \((u_{15})\) |
| Insufficient drainage capacity \((u_2)\) | Water tank design, maintenance defects \((u_{21})\) |
| | Pump selection, maintenance defect \((u_{22})\) |
| | Drainage pipe defect \((u_{23})\) |
| | Inaccurate water inflow prediction \((u_{24})\) |
| | Power shortage \((u_{25})\) |
| Human factor \((u_3)\) | Non-closed exploratory drilling \((u_{31})\) |
| | Improper retention of waterproof coal pillar \((u_{32})\) |
| | Incorrect Mining method \((u_{33})\) |
| | Illegal operations \((u_{34})\) |
| Safety mismanagement \((u_4)\) | Water detection/removal procedures not being carried out properly \((u_{41})\) |
| | Lack of Safety technology background \((u_{42})\) |
| | Insufficient safety training and education \((u_{43})\) |
| | Lack of emergency plan and its execution exercise \((u_{44})\) |

3. **Fuzzy Comprehensive Evaluation of the risk of Coal Mine Flood Accidents**

3.1 Establishment of the class 1 set of indexes for the flood accident risk assessment

This paper uses four evaluation indexes, as shown in Table 1.

\[ U = \{ u_1, u_2, u_3, u_4 \} \]

3.2 Establishment of the class 2 set of indexes \( U_{ij} \) for the flood accident risk assessment

\[ U_1 = \{ u_{11}, u_{12}, u_{13}, u_{14}, u_{15} \}; \quad U_2 = \{ u_{21}, u_{22}, u_{23}, u_{24}, u_{25} \}; \]
\[ U_3 = \{ u_{31}, u_{32}, u_{33}, u_{34} \}; \quad U_4 = \{ u_{41}, u_{42}, u_{43}, u_{44} \}; \]

3.3 Establishment of a set of evaluation marks

\[ V = \{ v_1, v_2, v_3, v_4, v_5 \} = \{ \text{Extremely high risk, High risk, Moderately high risk, Normal risk, No risk (safe)} \} \]

As an example, for a coal mine, the evaluation mark sets are defined as: \( V = \{ v_1, v_2, v_3, v_4, v_5 \} = \{ \text{Extremely high risk, High risk, Moderately high risk, Normal risk, No risk (safe)} \} \) with the corresponding vector defined as: \( C = \{ 95, 80, 65, 45, 30 \} \).

3.4 Determine the weight set \( A \)

Determine the fuzzy weight of the evaluation index:

\[ A = \{ a_1, a_2, a_3, a_4 \}. \]

Where \( a_i \) \( (i=1,2,3,4) \) is the weight for evaluation index \( u_i \) which are described before.
The fuzzy weight is usually determined by the so-called expert investigation approach, in which several experienced experts are asked to independently estimate the membership of the evaluation index $U_i$ to the flood accident risk of a coal mine based on its specific situation. Then the estimation results of different experts are averaged and normalized to obtain the weight set $A$.

For example: the flood accident risk assessment weight set $A$ for a coal mine is determined as $A = \{a_1, a_2, a_3, a_4\} = \{0.40, 0.15, 0.30, 0.15\}$

3.5 Conduct the single factor evaluation and establish the fuzzy relation matrix $R_i$ of index versus evaluation.

This approach is to invite a number of coal mine safety experts (such as: 10) to evaluate and score. For example, for index $u_2$ (insufficient drainage capacity), 10 experts are requested to estimate, based on the actual conditions of the mine, the weight of five secondary indexes, namely, Water tank design and maintenance defects, pump selection and maintenance defects, drainage pipeline defects, Inaccurate water inflow prediction, power shortage. The results are normalized and shown in Table 2.

| subject of entry | weight | Extremely high risk | High risk | Moderate risk | Normal risk | safe; No risk |
|------------------|--------|---------------------|-----------|---------------|-------------|--------------|
| Water tank design and maintenance defects (u21) | 0.25 | 0 person; short-cut process 0 | 1 person; short-cut process 0.1 | 3 person; short-cut process 0.3 | 6 person; short-cut process 0.6 | 0 person; short-cut process 0 |
| Water pump selection and repair defects (u22) | 0.30 | 0 person; short-cut process 0 | 4 person; short-cut process 0.4 | 4 person; short-cut process 0.4 | 2 person; short-cut process 0.2 | 0 person; short-cut process 0 |
| Drainage pipeline defect (u23) | 0.05 | 0 person; short-cut process 0 | 0 person; short-cut process 0 | 2 person; short-cut process 0.2 | 7 person; short-cut process 0.7 | 1 person; short-cut process 0.1 |
| Inaccurate water inflow prediction (u24) | 0.3 | 0 person; short-cut process 0 | 0 person; short-cut process 0 | 0 person; short-cut process 0 | 8 person; short-cut process 0.8 | 2 person; short-cut process 0.2 |
| Power shortage (u25) | 0.1 | 0 person; short-cut process 0 | 0 person; short-cut process 0 | 1 person; short-cut process 0.1 | 7 person; short-cut process 0.7 | 2 person; short-cut process 0.2 |

Based on the table 2, $R_2$ and $A_2$ is obtained as:

$$R_2 = \begin{bmatrix} 2.0 & 7.0 & 1.0 & 0.0 & 0.0 \\ 0.0 & 2.0 & 4.0 & 0.4 & 0.0 \\ 1.0 & 7.0 & 2.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.8 & 0.2 \\ 0.0 & 0.0 & 0.1 & 0.7 & 0.2 \end{bmatrix}$$

$$A_2 = (0.25, 0.3, 0.05, 0.3, 0.1)$$

Similarly, $R_1, R_3, R_4, R_5; A_1, A_3, A_4, A_5$ can be obtained by the same way described above.

The fuzzy evaluation vector $B_i$ of each evaluation index can be calculated by using the fuzzy hierarchical comprehensive evaluation model, $B_i = A_i \times R_i$.

The fuzzy evaluation $B_2$ of insufficient drainage capacity is calculated as shown below:
B₂ = A₂ × R₂ = \begin{bmatrix}
0 & 0.1 & 0.3 & 0.6 & 0 \\
0 & 0.4 & 0.4 & 0.2 & 0 \\
0 & 0 & 0.2 & 0.7 & 0.1 \\
0 & 0 & 0 & 0.8 & 0.2 \\
0 & 0 & 0.1 & 0.7 & 0.2 \\
\end{bmatrix} \times \begin{bmatrix}
0.25 & 0.3 & 0.05 & 0.3 & 0.1 \\
0.3 & 0.4 & 0.05 & 0.4 & 0.2 \\
0.5 & 0.4 & 0.5 & 0.1 & 0.1 \\
0.6 & 0.9 & 0.6 & 0.3 & 0.2 \\
0.7 & 0.7 & 0.6 & 0.7 & 0.2 \\
\end{bmatrix} = \begin{bmatrix}
0 & 0.145 & 0.215 & 0.555 & 0.085 \\
\end{bmatrix}

It can be seen from the fuzzy evaluation vector that the component corresponding to the membership of the "Normal risk" has the largest value 0.555. According to the maximum membership principle, the insufficient drainage capacity should be classified as "Normal risk".

Another example. For a coal mine, 18 influencing factors for the same four indexes (complexity of geological and hydrogeological conditions, insufficient drainage capacity, human factors and safety mismanagement) have been evaluated, scored and normalized respectively by the experts. The fuzzy relation matrix for mine flood comprehensive evaluation is obtained as below:

R = \begin{bmatrix}
0.126 & 0.243 & 0.517 & 0.114 & 0 \\
0 & 0.145 & 0.215 & 0.555 & 0.085 \\
0 & 0.156 & 0.384 & 0.460 & 0 \\
0 & 0.085 & 0.273 & 0.568 & 0.074 \\
\end{bmatrix}

3.6 Overall assessment

The comprehensive evaluation of mine flood risk can be obtained by using the fuzzy hierarchical comprehensive evaluation model (B = A × R).

B = A × R = (0.40, 0.15, 0.30, 0.15) × \begin{bmatrix}
0.126 & 0.243 & 0.517 & 0.114 & 0 \\
0 & 0.145 & 0.215 & 0.555 & 0.085 \\
0 & 0.156 & 0.384 & 0.460 & 0 \\
0 & 0.085 & 0.273 & 0.568 & 0.074 \\
\end{bmatrix} = (0.050, 0.179, 0.395, 0.352, 0.024)

It can be seen from the fuzzy evaluation vector that the component corresponding to the membership of the "Moderately high risk" has the largest value 0.395. According to the maximum membership principle, the mine flood accident of this coal mine should be classified as "Medium risk".

With the rating level of the evaluation system defined as

V = \{extremely high, high, moderate, normal, safe\},

and the corresponding vector C = \{95, 80, 65, 45, 30\}, the comprehensive score is obtained as follows:

W = B × C^T = 0.050 × 95 + 0.179 × 80 + 0.395 × 65 + 0.352 × 45 + 0.024 × 30 = 61.31

According to the experts’ evaluation score, the fuzzy comprehensive evaluation shows that the flood accident risk of this coal mine is medium. Aiming at the identified hidden causes of the accidents, the coal mine needs to take proper correct action, and to come up with the risk prevention and control measures.

4. Conclusion

The coal mine water hazard accident seriously affects the coal mine safety production, and the water disaster prevention and cure is the important task of the coal mine safety management. The risk analysis, based on the classification of a mine’s hydrogeological types and taking into account the actual mine conditions, is of great significance for prevention and cure of the coal mine water hazards. This paper discusses the application of fuzzy evaluation method in mine flood accident risk analysis. Hopefully it can be useful for mine water hazards prevention and control. However, since the fuzzy single factor evaluation and comprehensive evaluation of this method depends on expert investigation
to essentially obtain the membership, in practical applications selecting the appropriate values usually has to rely on expert experience. Therefore, the expert’s experience has great impact on the evaluation result quality. In order to obtain a water hazard fuzzy evaluation assessment which reflects the actual situation of the coal mine, selecting right experts to do the job is a must.

References
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