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Study of the influence of karst water runoff on mining based on fuzzy mathematics

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Taking Fengfeng coal field as an example, the paper applies the fuzzy mathematics principle to the strength of karst runoff zone of Minmetals field partition. The frequency statistics method is adopted to define the membership degree, elevation, single well water inflow, karst rate, and hydration group classification. At the same time, considering the influence of the ionic concentration of karst water runoff intensity, the fuzzy comprehensive evaluation method is used for the calculation, and the results show that the strength of the karst runoff zone will affect the safety of mining. Karst water runoff intensity is proportional to the concentration of the ions. The relationship between runoff intensity and single well water inflow is most obvious. The biggest water inflow of the single well is in a strong runoff zone, and in a weak runoff zone it is very small, which provides decision basis for mine safety production planning. Minmetals is located in the Ordovician limestone strong runoff belt of Gushan east side, thus constituting a serious threat for deep coal seam mining. The research in this paper provides a theoretical basis for Minmetals deep seam mining from the weakest runoff.

Key words: Fuzzy mathematics, Karst water, Runoff belts, Mining.

INTRODUCTION

Fengfeng coal field is located at the border area of Shanxi, Hebei and Henan provinces. On the west side there is a mountain area, and on the east side sloping plains. The coal reserves are large, and it is a typical karst water filling deposit. Fengfeng mine field, which is within the scope of the formation of the Ordovician and Permian lime, is located in the runoff karst belt of Gushan east, and karst water is a serious threat to the safety mining of ore deposit. There is Ordovician limestone karst run-off zone (hereinafter referred to as the gray) and the big blue limestone also has the characteristics of runoff belt according to coal mining practice, but the Ordovician limestone runoff belt is much bigger than the large blue limestone runoff belt. On the other hand, there are strong and weak points of runoff, the strong belt is a great threat to safe mining. Therefore, the research on the strength of the runoff has a practical significance for the mining of the coal seam at a 100 m level below the horizontal [1,2].

Fuzzy mathematics (Fuzzy for short) is proposed by L.A. Zadeh in 1965 in the “Fuzzy sets”. With the development of computer science, it can solve many problems which cannot be solved by the “deterministic mathematics” and “random mathematics”. It has great advantages for description and handling of fuzzy events. Fuzzy comprehensive evaluation is a kind of method of comprehensive evaluation of phenomena which are influenced by various factors. In recent decades, fuzzy mathematics has been widely applied in many fields such as geology, environment, agriculture, medicine, meteorology, etc. [3]. Fuzzy mathematics is applied to the study of groundwater, mainly for the evaluation of groundwater quality [4-7] and of groundwater pollution [8-10] in two aspects. Fuzzy mathematics was applied to the research of groundwater runoff belt by Liu [11], Zhang [12], Liu [13], Tian [14], Xu [15], Zheng [16], Zhao [17]. In this paper, the fuzzy comprehensive evaluation method was used to study the strength of karst runoff zone, the “frequency statistics method” was used to determine the membership degree, and good results were achieved.

THEORY OF FUZZY COMPREHENSIVE JUDGMENT

Comprehensive Evaluation Principle

Given two finite fields [3]:

$$\mathbf{U} = \{u_1, u_2, \cdots\cdots, u_n\}$$

$$\mathbf{V} = \{v_1, v_2 \cdots\cdots, v_m\}$$

where U is a collection of factors of comprehensive evaluation, a total of N factors; V is a collection of reviews, a total of M levels.

Set the factor $\mathrm{R}_{\mathrm{i}} = (r_{i1}, \cdots, r_{ij}, \cdots, r_{im})$ is the single factor evaluation for i, which can be seen as a subset of the Fuzzy on the U, r_{ij} indicates the evaluation of the i factor for the degree of membership of j to v_j, thus the total evaluation matrix of n factors is obtained.

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$$\mathbf{R}=\begin{pmatrix} \mathrm{R}_1 \\ \vdots \\ \mathrm{R}_i \\ \vdots \\ \mathrm{R}_n \end{pmatrix}=\begin{pmatrix} r_{11} & \cdots & r_{1j} & \cdots & r_{1m} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ r_{i1} & \cdots & r_{ij} & \cdots & r_{im} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ r_{n1} & \cdots & r_{nj} & \cdots & r_{nm} \end{pmatrix} \quad (1)$$

In the process of evaluation, because of the different proportion of each factor, the method of statistical test or expert evaluation can be used to establish the weight distribution between the factors, denoted by:

$$\mathbf{A}=\left(a_1,a_2,\cdots\cdots,a_n\right) \quad (2)$$

where $a_i \in [0,1]$, i=1,2,……,n and $\sum_{i=1}^{n} a_i = 1$,
A is the right coefficient row vector. In the assessment of groundwater pollution, the formula for weight calculation is:

$$a_i=\frac{c_i}{c_{0i}} \quad (3)$$

where: a_i is the weight; c_i are the measured values of the i pollutant; c_{oi} is the concentration allowable value of the i kind of water for a certain purpose.
If the standard value of a single factor is divided into several grades, for example, three grades, c_{oi} represents the average of the three levels:
c_{oi} =(first-class water standard + second-class water standard + third-class water standard)/3.
Fuzzy mathematical operations only allow the weights to be taken in the [0,1] interval, so the weight value of each factor must be normalized and the normalized formula is:

$$a_i=\frac{\dfrac{c_i}{c_{0i}}}{\sum \dfrac{c_i}{c_{0i}}} \qquad \left(\sum_{i=1}^{n} a_i = 1\right) \quad (4)$$

The model of comprehensive evaluation can be obtained by using the compound operation of the fuzzy matrix:

$$B=A\circ R \quad (5)$$

that is,

$$\left(b_1,b_2,\cdots,b_j,\cdots,b_m\right)=\left(a_1,a_2,\cdots\cdots,a_n\right)\circ \begin{pmatrix} r_{11} & \cdots & r_{1j} & \cdots & r_{1m} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ r_{i1} & \cdots & r_{ij} & \cdots & r_{im} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ r_{n1} & \cdots & r_{nj} & \cdots & r_{nm} \end{pmatrix} \quad (6)$$

In the formula: $B=A\circ R$ is the fuzzy transformation of U→V; R is the fuzzy transformation matrix; ∘ is multiplication of fuzzy matrix, setting ∘ =M(∧, ∨), $b_j=\vee_{i=1}^{n}(a_i \wedge r_{ij})$ (j =1,2,……,m), ∧ represents small, ∨ represents large, namely, when a matrix operation is performed , weight coefficient of each element of the row vector A is multiplied by the corresponding element of R column vector, taking the minimum value of the two elements.
For b_j (j=1,2,……,m) , according to the principle of maximum membership degree, taking $b_k=\max_j\left\{b_1,\cdots,b_j,\cdots,b_m\right\}$, so v_k which is the corresponding comment of b_k is the conclusion of the comprehensive evaluation.

Determination of membership degree

In fuzzy mathematics, the fuzzy boundaries of things are etched by the degree of membership. There are two methods for determining the degree of membership, one is the membership function method, and the other one is the frequency statistics method.

Membership function method

In most of the literature, the membership function is used to determine the membership degree r_{ij} , such as groundwater quality evaluation, groundwater pollution assessment and so on.

Frequency statistics method

According to the actual observation data, making the scatter diagram, the membership degree is equal to the number of samples s_j divided through the total number of s_n in a certain range of samples:

$$r_{ij}=\frac{s_j}{s_n} \quad (7)$$

Frequency statistics method is applied to the case of a large number of samples, such as the higher degree of hydrogeological exploration in the mining area, especially some of the old mining sites with rich observation data and exploration holes.

KARST RUN-OFF ZONE PARTITION

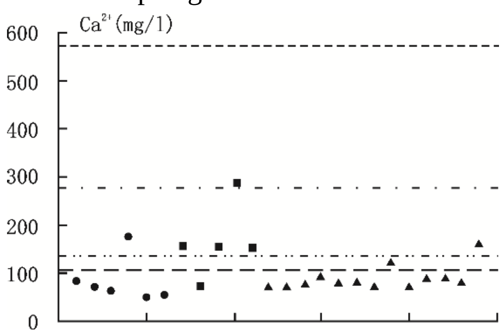
This paper applies the fuzzy comprehensive evaluation method to distinguish the strength of karst runoff zone of Minmetals field partition, providing decision basis for a mining plan. The membership degree is determined by the frequency statistics method, and the results are obtained by the composite operation of the fuzzy matrix.

Determination of evaluation factors

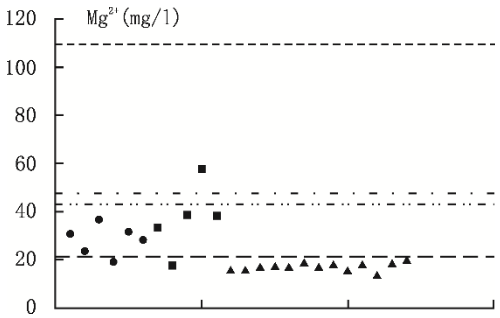
There are many factors that affect the strength of the karst runoff zone, such as elevation, water outflow from a single well, karst rate and water chemical group classification. According to the measuring point of the actual data of Minmetals , the paper chooses the karst groundwater's five factors C_a^{2+}, M_g^{2+}, SO_4^{2-}, HCO_3^- and single well water gushing amount as the evaluation factors. The concentration of each ion in the groundwater of different runoff intensity is also different, the average runoff intensity is small, and the runoff is weak, the concentration is large. The relationship between the single well water flow and the strength of the runoff is most obvious, single well water outflow of the strong runoff zone drilling is very large, and weak runoff with single well water inflow is very small.

Determination of evaluation set

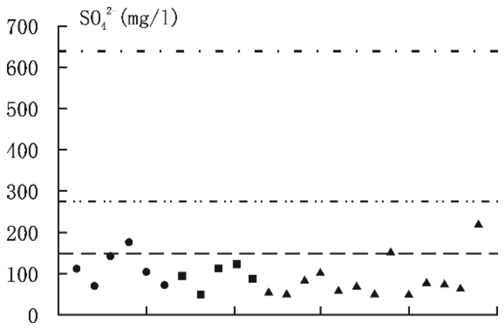
The paper takes the data of Minmetals mining field drilling for samples, a total of 24 samples in three areas, 13 samples of Daqing limestone, 5 samples of the central area of Ordovician limestone, 6 samples of the east wing area of Daqing. Factor set U＝（ C_a^{2+}， M_g^{2+}， SO_4^{2-}， HCO_3^-， water inflow of single well q） , comments collection is V=(strong, medium, weak, extremely weak), each factor on the four grade evaluation of the partition is shown in Table 1. According to the actual observation data of each well, the observation data of the well bore are determined in the planar rectangular coordinate system (Figure 1), the sample is the horizontal axis, the factor value is the vertical axis. The ratio of the number of samples and the total number of samples in this interval determines the membership degree of a certain factor to a comment (interval), that is, the use of frequency statistics method determines the membership degree.



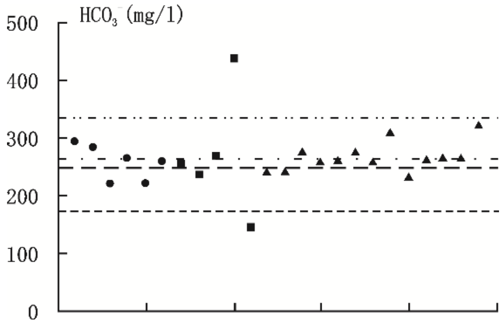
a. Corresponding diagram of the sample points and C_a^{2+}



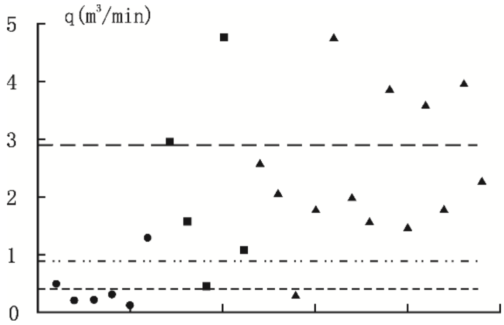
b. Corresponding diagram of the sample points and M_g^{2+}



c. Corresponding diagram of the sample points and SO_4^{2-}



d. Corresponding diagram of the sample points and HCO_3^-



e. Corresponding diagram of the sample points and the single well of the water inflow

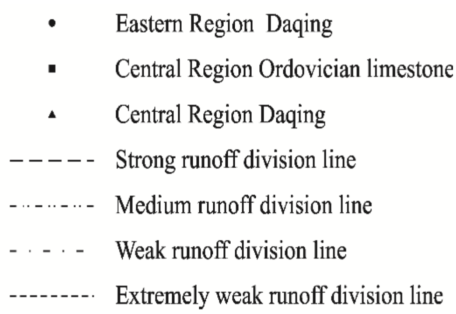


Fig. 1 Scatter diagram of each factor

The fuzzy evaluation matrix R（Table 1）can be obtained by the scatter diagram.The activity of SOD, H+-K+ATPase of mitochondia and the MDA level was measured according to the respective kit instruction.

Table 1. Fuzzy evaluation matrix R

	Central Daqing limestone				Central area of Ordovician limestone				East wing area of Daqing limestone			
R_1	0.846	0.077	0.077	0	0.2	0	0.6	0.2	0.833	0.167	0	0
R_2	1	0	0	0	0.2	0.6	0	0.2	0.167	0.833	0	0
R_3	0.846	0.154	0	0	1	0	0	0	0.833	0.167	0	0
R_4	0.231	0.615	0.154	0	0.2	0.4	0.2	0.2	0.333	0.5	0.167	0
R_5	0.308	0.615	0	0.077	0.6	0.2	0.2	0	0	0.167	0.167	0.666

Determination of weight

In the limestone region, the content of M_g^{2+} is very small, so its weight should be set smaller. The effects of the three factors of C_a^{2+} 、 SO_4^{2-} and HCO_3^- in the karst runoff zone are almost the same, so they have equal weights. The water inflow of the single well q has the most obvious effect on the strength of the karst runoff, and its weight is also the largest, so the determined weight A = (0.17，0.09，0.17，0.17，0.4).

Comprehensive evaluation

The fuzzy output B of central Daqing limestone is:

$$\mathbf{B} = \mathbf{A} \circ \mathbf{R} = (0.17, 0.09, 0.17, 0.17, 0.4) \text{ x}$$

$$\begin{pmatrix} 0.846 & 0.077 & 0.077 & 0 \\ 1 & 0 & 0 & 0 \\ 0.846 & 0.154 & 0 & 0 \\ 0.231 & 0.615 & 0.154 & 0 \\ 0.308 & 0.615 & 0 & 0.077 \end{pmatrix}$$

$b_1=(0.17\wedge0.846)\vee(0.09\wedge1)\vee(0.17\wedge0.846)\vee(0.17\wedge0.231)\vee(0.4\wedge0.308)=0.308$

In the same way: $b_2=0.4$，$b_3=0.154$，$b_4=0.077$

Therefore: B＝(0.308，0.4，0.154，0.077)

From the above results we can see that the membership degree of b_2 is the biggest, therefore, we can judge the central Daqing limestone as a moderate runoff zone. In the same way:

Fuzzy output of the central Ordovician limestone B＝(0.4，0.2，0.2，0.17), so it is a strong runoff zone;

Fuzzy output of the Daqing east wing area B＝(0.17，0.17，0.167，0.4), so it belongs to a very weak runoff zone.

From the above evaluation results, the central and east wing area belong to two different runoff zones, central Daqing limestone is a moderate runoff zone (compared with Ordovician limestone), the east wing area Daqing limestone is a very weak runoff zone and the central region of the Ordovician limestone is a strong runoff zone.

CONCLUSIONS

Through the above analysis and calculations, it is shown that the east wing area of Daqing limestone is an extremely weak runoff zone; the central area of the Ordovician limestone is a strong runoff zone, the central Daqing limestone is a medium runoff area (compared with the Ordovician limestone). These results are in line with the actual situation of the mine drilling, and the vast majority of holes is consistent with the results according to the minmetal actual observation data. Minmetals is located in the Ordovician limestone strong runoff belt of Gushan east side, the Daqing limestone moderate runoff belt is added to the central area, forming two sets of runoff belt systems, which is a strong runoff zone, posing a serious threat to the mining of deep coal seams. East wing area is extremely weak, which is favorable for the exploitation of mines, so the exploitation of the deep coal seam can be started from the east wing area.

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