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Water inrush evaluation of coal seam floor by integrating the water inrush coefficient and the information of water abundance

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ABSTRACT

The method of singular coefficient of water inrush to achieve safety mining has limitation and one sidedness. Aiming at the problem above, large amounts of data about water inrush were collected. Then the data, including the maximum water inrush, water inrush coefficient and water abundance in aquifers of working face, were processed by the statistical analysis. The analysis results indicate that both water inrush coefficient and water abundance in aquifers should be taken into consideration when evaluating the danger of water inrush from coal seam floor. The prediction model of safe-mining evaluation grade was built by using the support vector machine, and the result shows that this model has high classification accuracy. A feasible classification system of water-inrush safety evaluation can be got by using the data visualization method which makes the implicit support vector machine models explicit.

1. Introduction

The hydrogeological condition of coal mine in China is very complex. Most of North China coal fields are under the threat of water inrush from the Ordovician limestone confined aquifer. It has been long that hydrogeologists use water inrush coefficient (*Ts*) as important indicator of risk evaluation of water-inrush from coal floor [1]. Practice has shown that, when mining shallow coal seams, using water inrush coefficient to assess the risk of floor inrush is generally realistic. But with the increase of mining depth, Ordovician limestone water pressure gradually increases, and *Ts* in the deep coal seam mining face often far outweighs the upper limit value of safety mining in the provision of "coal mine water prevention and control". In this case, the deep coal seam cannot be mined according to the provision. But production has proved that: as long as Ordovician limestone water abundance is not better, even water inrush coefficient is larger than the prescribed upper limit value, working face is still able to achieve safe mining [2–8].

Many scholars pay close attention to this problem and results in many conclusions. Shi put forward a method by which we can use probability index of water-inrush to forecast floor water inrush; Wu presented a new approach to evaluate the problem, which is called vulnerability index; Shi et al. used data fusion theory to solve this problem; Yin et al. established a prediction model based on GIS; and Yu et al. applied four-zone theory in water-inrush evaluation [4,9–16]. The analytical approach about water-inrush-factor was adopted by Sun to assess the risk of floor water-inrush. The achievements mentioned above have important theoretical significance in safety production of mine. However, restricted by technical conditions and geological conditions in practical production, it is a hard work to accurately get all necessary hydrogeological information. So these applications are limited under some conditions.

Based on water inrush coefficient (*Ts*) and units-inflow (*q*), the safe-mining evaluation model was established and a convenient evaluation method was given for secure production provided.

2. Data analysis

After a long period of collection, the integrated data of 49 working faces were got, including water inrush coefficient (*Ts*), water abundance indicators of Ordovician limestone aquifer (units-inflow *q*) and maximum water-inrush value (*Q*) from Huafeng Mine, Suncun Mine, Xiezhuang Mine, Huaibei Zhuzhuang Mine, Zibo Longquan Mine, Kailuan Linxi Mine, Pingdingshan Mine and so on, as shown in Table 1.

Some water inrush coefficients which are larger than 0.1 MPa/m, even 0.15 MPa/m beyond the upper safe-mining limit value prescribed in the 'the preventing and managing requirement of

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Table 1
Comprehensive data of water inrush from coal seam floor.

No.	Mine name	Place	Water source	Q_g	Q (m^3/h)	Ts (MPa/m)	q (L/s·m)
1	Huafeng Mine	−90 level in No. 2 mine	Xu limestone	3	3480.0	0.1378	1.858
2	Huafeng Mine	The western of wellhole −50 level of No. 1 mine	Xu limestone	1	630.0	0.1608	0.0355
3	Huafeng Mine	−90 level in No. 2 mine	Xu limestone	3	7860.0	0.1190	3.5637
4	Suncun Mine	The downhill of No 4 coalseam in No 4 west mining area	First limestone	1	1460.0	0.0584	0.3964
5	Xiezhuang Mine	No. 31104E working face	Forth limestone	2	1660.2	0.1010	0.5009
6	Xiezhuang Mine	No. 31102E working face	Forth limestone	2	1680.0	0.0985	0.5008
7	Xiezhuang Mine	No. 31111E working face	Forth limestone	1	180.0	0.1195	0.0002
8	Xiezhuang Mine	No. 31108W working face	Forth limestone	1	67.8	0.1331	0.0001
9	Liangzhuang	The western main roadway of −110 level	Xu limestone	1	120.0	0.0480	0.0001
10	Liangzhuang	No. 51302 working face	Ordovician limestone	2	1920.0	0.1090	1.5662
11	Taoyang Mine in Feicheng	No. 9901 working face	Xu limestone	1	1083.0	0.0453	0.0480
12	Taoyang Mine in Feicheng	No. 9507 working face	Xu limestone	1	1394.0	0.0120	0.0480
13	Dafeng Mine in Feicheng	No. 9204 working face	Xu limestone	2	1628.0	0.1878	0.1280
14	Dafeng Mine in Feicheng	No. 10204 working face	Xu limestone	2	2035.0	0.1060	1.6195
15	Yangzhuang Mine in Feicheng	Return airway in No. 9101 working face	Xu limestone	3	5237.0	0.0790	2.7072
16	Baizhuang Mine in Feicheng	No. 8402 working face	Fifth limestone	1	198.0	0.0772	0.0192
17	Baizhuang Mine in Feicheng	No. 8603 working face	Fifth limestone	1	80.0	0.0548	0.0092
18	Baizhuang Mine in Feicheng	No. 8404 working face	Fifth limestone	1	60.0	0.0782	0.0092
19	Baizhuang Mine in Feicheng	No. 10404 working face	Fifth limestone	1	142.0	0.1311	0.0096
20	Baizhuang Mine in Feicheng	No. 9601 working face	Ordovician limestone	1	505.0	0.0644	0.0525
21	Baizhuang Mine in Feicheng	No. 9603 working face	Ordovician limestone	1	187.0	0.0693	0.0125
22	Baizhuang Mine in Feicheng	No. 9401 Inner working face	Ordovician limestone	1	743.0	0.0876	0.0725
23	Baizhuang Mine in Feicheng	No. 9401 working face	Fifth limestone	1	164.0	0.1137	0.0096
24	Baizhuang Mine in Feicheng	No. 10603 working face	Ordovician limestone	1	58.0	0.0819	0.0025
25	Baizhuang Mine in Feicheng	No. 10405 working face	Fifth limestone	1	49.0	0.0743	0.0092
26	Baizhuang Mine in Feicheng	No. 10409 working face	Fifth limestone	1	32.0	0.0647	0.0092
27	Baizhuang Mine in Feicheng	No. 10601 working face	Fifth limestone	1	59.0	0.0783	0.0092
28	Dafeng Mine in Feicheng	No. 10313 working face	Forth, Ordovician limestone	1	85.0	0.1700	0.0013
29	Yangzhuang Mine in Feicheng	No. 10706 working face	Forth, Ordovician limestone	1	50.0	0.1500	0.0013
30	Chazhuang Mine in Feicheng	No. 91002 working face	Forth, Ordovician limestone	1	65.0	0.1600	0.0013
31	Guozhuang Mine in Feicheng	No. N7107 working face	Forth limestone	1	125.0	0.0310	0.0625
32	Guozhuang Mine in Feicheng	No. N7109 working face	Forth limestone	1	114.0	0.0480	0.0625
33	Pandong Wall in Panxi Mine	No. 106 working face	Ordovician limestone	3	10640.0	0.0789	4.1781
34	Xiazhuang Mine in Zibo	No. 1007 working face in No. 100 mining area	Ordovician limestone	3	4006.0	0.1000	2.5072
35	Longquan Mine in Zibo	No. 149 working face in No. 1030 dip district	Ordovician limestone	2	1512.0	0.1616	0.4654
36	Zhaili Mine in Zibo	No. 102 working face in −185 level	Ordovician limestone	1	420.0	0.0277	0.0500
37	Shuangshan Mine in Zibo	The gate road of No. 4 eastern mining area in −160 level	Ordovician limestone	3	4200.0	0.0845	2.4677
38	Panxi Mine	No. 4191 working face	Ordovician limestone	1	192.0	0.0730	0.0101
39	Panxi Mine	No. 4192E working face	Ordovician limestone	1	240.0	0.0720	0.0201
40	Panxi Mine	No. 4193E working face	Ordovician limestone	1	330.0	0.0730	0.0301
41	Panxi Mine	No. 4192W working face	Ordovician limestone	1	240.0	0.0600	0.02001
42	Panxi Mine	No. 4193W working face	Ordovician limestone	1	600.0	0.0800	0.0601
43	Panxi Mine	No. 4194W working face	Ordovician limestone	1	180.0	0.0770	0.0101
44	Panxi Mine	No. 5191 working face	Ordovician limestone	1	70.0	0.0830	0.0001
45	Panxi Mine	No. 5192 working face	Ordovician limestone	1	250.0	0.0970	0.0201
46	Panxi Mine	No. 4195W working face	Ordovician limestone	1	740.0	0.0880	0.1736
47	Panxi Mine	No. 4196W working face	Ordovician limestone	1	326.0	0.0680	0.0301
48	Huafeng Mine	−90 level of No. 16 coal seam	Xu, Ordovician limestone	3	3498.0	0.1044	2.3048
49	Yangzhuang Mine in Huaibei	No. II617 working face	Limestone of Taiyuan Formation	2	2953.0	0.0960	1.7066

mine water', but the maximum water inrush values are little (Table 1). For instance, the maximum water-inrush value is just 180 m^3/h, while the value of water inrush coefficient reaches 0.119 MPa/m.

Instead, we will draw a contrary conclusion from line 33 and line 37 in Table 1. In the record, the maximum water inrush value of No. 106 working face of Pandong well in Panxi mine and the gate road of No. 4 eastern mining area of Shuangshan mine in Zibo respectively are 10640 and 4200 m^3/h, but the water inrush coefficients are only 0.0789 and 0.08446 MPa/m. As a result, it is inappropriate to make use of water inrush coefficient alone to evaluate the risk of water inrush from coal seam floor.

To further analyze the relationship among maximum water inrush value (Q), water inrush coefficient (Ts) and units-inflow (q), we took advantage of 3D visualization software to draw a three dimensional stereogram, as shown in Fig. 1.

Water inrush coefficients of 17 samples are greater than or equal to 0.1 MPa/m (Fig. 1). There are 11 sets of data that are ranged from 0.1 to 0.15 MPa/m, and the maximum water-inrush value among these 11 groups reach 7860 m^3/h when its units-inflow is 3.5637 L/s·m. Particularly, the maximum water inrush values of the 6 groups which water inrush coefficient exceeded 0.15 MPa/m are all less than 2000 m^3/h. Nevertheless, the maximum water inrush value among the records is 10,640 m^3/h while the value of water inrush coefficient is less than 0.1 MPa/m.

Pearson correlation coefficient was used to confirm the relationship among the maximum water inrush value (Q), water inrush coefficient (Ts) and units-inflow (q). Correlation is a stochastic relation [17]. That is, when one or several variables are confirmed, the corresponding variables vary via some dependence relationship within a certain scope though it is impossible to obtain totally.

Now suppose that there are n sets of observed estimation data like (x_i, y_i), $i = 1, 2, \ldots, n$. Then estimated formula of Pearson correlation coefficient between X and Y is shown as Eq. (1).

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{(x_i - \bar{x})^2}\sqrt{(y_i - \bar{y})^2}} \tag{1}$$