

# Application on Floor Water Inrush Evaluation Based on AHP Variation Coefficient Method with GIS

Weitao Liu · Qiang Li · Jiyuan Zhao

Received: 30 December 2017 / Accepted: 14 February 2018 / Published online: 20 February 2018  
© Springer International Publishing AG, part of Springer Nature 2018

**Abstract** The prediction and prevention of floor water inrush is directly related to the safety of the coal mine production. The previous evaluation method of floor water inrush was more one-sided and lacked main control factors related to mining conditions. In order to evaluate the floor water inrush more accurately, under the project background of geological data of Wanglou coal mine, stope width, mining depth, fault scale index, water pressure, water abundance and thickness of aquifer were selected as main controlling factors of floor water inrush. Combined with the subjective weight analytical hierarchy process and the objective weight variation coefficient method, the weight coefficients corresponding to the main controlling factors were obtained respectively. The thematic map of the risk assessment of coal seam floor water inrush was drawn by combining the constructed comprehensive weight vulnerability index model and geographic information system. The results show that: ① according to the actual geological data of mine, two fault related factors were removed. And stope width and mining depth were increased as the main controlling factors to evaluate floor water inrush. It is easier to compare and calculate the weight of evaluation factors. ② The constructed comprehensive weight vulnerability index model can comprehensively

evaluate the risk of floor water inrush. And the results of the evaluation are more accurate. ③ The related thematic maps can directly reflect the risk of floor water inrush, which is of guiding significance for the prediction and prevention of coal seam floor water inrush.

**Keywords** Analytical hierarchy process · Variation coefficient method · Vulnerability index · Risk of floor water inrush

## 1 Introduction

Floor water inrush is one of the important problems that perplex coal mine production, which not only cause casualties and economic losses but also has enormous impacts to the area's water resources and environment (Zhang et al. 1997). With the increase of mining depth, the distance between the coal seams and the Ordovician limestone strong aquifer is getting closer, and the water pressure and the risk of floor water inrush are also increasing. The complicated formation and coal mining under pressure also lead to the increasing risk of coal seam floor water inrush. The mechanisms underlying floor strata deformation and failure depth have been studied (Zhang and Liu 1990; Qian et al. 1996; Li 1999). And the floor failure characteristics have been researched (Sun et al. 2011; Sun 2014). In order to evaluate floor water inrush, the

---

W. Liu · Q. Li (✉) · J. Zhao  
Shandong University of Science and Technology,  
Qingdao 266590, Shandong, China  
e-mail: 279020677@qq.com

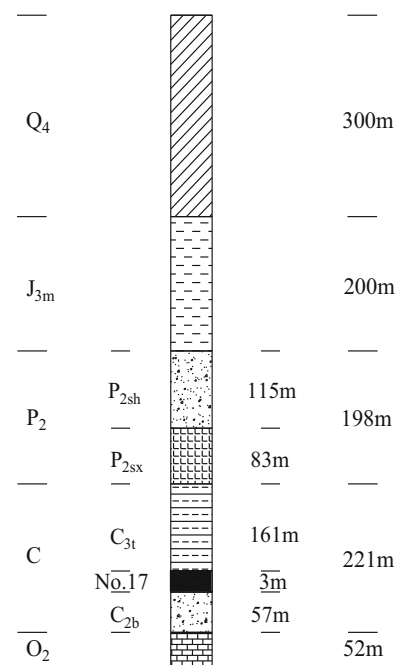
sensitivity of main factors controlling floor failure depth was also studied (Liu et al. 2015, 2017). With the deepening of the mechanism of floor water inrush, many evaluation methods used for analyzing coal seam floor water inrush include expert systems (Gao et al. 2009), artificial neural networks (Dong et al. 2012; Zeng et al. 2016), the water inrush coefficient method (Zhou et al. 2006), Analytical Hierarchy Process (Liu et al. 2000; Luo 2012), the vulnerability index method (Wu et al. 2006, 2009, 2015). Zhang et al. (2013) established a fisher discriminant analysis model of floor water inrush risk and accurately predicted the inrush risk of test samples using the distance discriminant method by previous water inrush data. Liu et al. (2014) used the extension theory to establish a matter element model based on the extension theory and analytical hierarchy process. Zhang et al. (2015) analyzed floor failure process and formation of water inrush channel under the coupling condition of stress field and seepage field. Ni and Luo (2000) put forward dominant surface water control mechanism and established the corresponding advantages and evaluation criteria. The preferred fault has obvious shielding effect, which is the main cause of the lagging water inrush.

The main controlling factors affecting floor water inrush have the characteristics of multilevel and multi index. At the same time, the influence of these factors on the floor water inrush is different. So it is necessary to determine the weight of the main factors. The accuracy of weight is directly related to the accuracy of the risk assessment of floor water inrush. The Previous method of calculating the weight of multi factor index was subjective or objective. These evaluation methods were more one-sided. Based on previous studies, the author combines AHP and variation coefficient method to construct comprehensive weight evaluation method from the perspective of subjective and objective. Combined with the comprehensive weight coefficient and GIS, the corresponding zoning map of the risk of floor water inrush can be drawn, which can intuitively reflect the risk degree of water inrush from the floor. In the process of coal mining, the floor water inrush can be prevented and treated in time, which is of great significance to the actual production.

## 2 Geological Conditions and Hydrogeological Conditions

The strata in the Wanglou mine, from new to old, are the: Quaternary Holocene ( $Q_4$ ), Mengyin formation of the upper Jurassic ( $J_{3m}$ ), Shihezi Formation of the upper Permian ( $P_{2sh}$ ), Shanxi formation of the lower Permian ( $P_{2sx}$ ), Taiyuan formation of the upper Carboniferous ( $C_{3t}$ ), Benxi formation of the middle Carboniferous ( $C_{2b}$ ) and Middle Ordovician. The main coal-bearing strata of the area are the upper Carboniferous ( $C_{3t}$ ), Taiyuan formation (Fig. 1). The main minable seam is No. 17 coal seam which has a thickness ranging from 0.8 to 3.5 m, and averaging 3 m. In the course of seismic data interpretation, no anomalous response to the collapse column was found, which confirms the undeveloped collapse column.

The major aquifers of the area are: Quaternary pore aquifer, Upper Jurassic gravel fissure aquifer, Shanxi formation sandstone fissure aquifer, Taiyuan formation limestone karst fissure aquifer, Benxi extremely weak aquifer and Ordovician limestone aquifer. The Ordovician limestone aquifer is located under Carboniferous and Permian. Drill hole exposing thickness greater than 50 m. According to the drilling pumping test, The Ordovician limestone aquifer is buried in the



**Fig. 1** The schematic geological profile

depth of – 900 m. The water level elevation is 30.78 m and the unit inflow are 1.68–0.20 L/(s m).

### 3 Construction of AHP<sub>VC</sub> Comprehensive Weight Model

Geographic information system can transport, process and store spatial geographic information, and then draw the related thematic map. AHP<sub>VC</sub> was used to evaluate the influence factors of floor water inrush from the subjective and objective points of view. The weight value of each influence factor was calculated. And then, the spatial superposition analysis was used to obtain the related evaluation map with GIS. Analytical hierarchy process is a decision analysis method which combines the qualitative and quantitative analysis of multi-objective complex problems. This method can combine qualitative analysis with quantitative analysis, and judges the relative weight with the experience of decision makers from the subjective point of view. Each standard weight of each decision plan can be given reasonably, and the order of a plan can be also obtained by weight. Analytical hierarchy process can be more effectively applied to those problems which are difficult to be solved by quantitative methods. Variation coefficient method is a kind of objective weight method through calculating the weight of the information contained in the index directly. The variation coefficient is also known as the “standard difference”, which is another statistic to measure the variation of the observed values in the data. If the unit of measure is the same as the average, it can be compared directly with the standard deviation. If the unit of measure is different from the average, the ratio of standard deviation to average (relative value) should be used for comparison instead of the standard deviation.

#### 3.1 Determination of Main Controlling Factors

According to the research of three dimensional seismic exploration and drilling data, the main factors that control the water inrush hazard analysis of the Ordovician limestone aquifer of No. 17 seam include:

1. *Fault scale index* The fault scale index reflects the effect of different scale faults on the water inrush sensitivity of the floor system. The more

developed the fault is, the greater the possibility of floor water inrush is. The fault scale index is defined by:

$$F = \frac{\sum_{i=1}^n l_i h_i}{S_i}, i = 1, 2, \dots, n \quad (1)$$

where  $F$  is fault scale index;  $h_i$  is throw of the  $i$  th fault, m;  $l_i$  is strike length of the  $i$  th fault in the subarea, m;  $n$  is the number of fault in the subarea; and  $S_i$  is the area of subarea, m<sup>2</sup>. The fault scale index can be divided by the following method. Wanglou mine field was divided into several unit grids of size 500 × 500. According to the formula (1) in the paper, the strike lengths of all faults in the unit grid were counted to calculate the fault scale index. And then, the value of fault scale index was given to the center point of the corresponding unit grid.

2. *Coal seam mining depth* The coal seam mining depth is closely related to mine pressure. With the increases of mining depth, the pressure of mine increases. The probability of coal seam floor water inrush also increases.
3. *Stope width* The stope width is considered as a standard to measure the size of mining space. With the increases of the mining space, the pressure of the two wall of the working face also increases. At the same time, the more serious the deformation and destruction of the floor are, the greater the probability of water inrush is.
4. *Equivalent thickness of the water-resisting layer and water pressure* The water pressure of confined water is a prerequisite for floor water inrush. Under the water pressure action, water-resisting layer will be constantly eroded and scoured to form a large number of fissures, and the integrity of the water-resisting layer will be destroyed. The aquifers can inhibit the floor water inrush. And the thickness and lithologic combination are the standard to measure the capacity of the aquifers. The water inrush coefficient was defined by:

$$T = \frac{P}{M} \quad (2)$$

where  $T$  is water inrush coefficient, MPa/m;  $P$  is water pressure, MPa;  $M$  is the thickness of the water-resisting layer, m.

5. *Water abundance of the Ordovician limestone aquifer* The water abundance of karst aquifers

directly affects the degree of water inrush and the degree of threat to the mine. According to a large amount of measured data, the water abundance and development degree of karst aquifers are closely related to the coal seam floor water inrush. The better the water abundance of the karst aquifers is, the greater floor water inrush is. The unit inflow of drill holes are usually measured the water abundance of aquifers.

### 3.2 Building Analytical Hierarchy Process Model

#### 3.2.1 Design of Analytic Hierarchy Process

According to the influencing factors of floor water inrush, the studied problems were divided into 3 hierarchies. The risk assessment of the Ordovician water inrush was the final problem to be solved, so it was regarded as the target layer of the Analytical Hierarchy Process model (A hierarchy). Geological structure, hydrogeological conditions and mining conditions include sub factors that affect the floor water inrush, which are the intermediate links that affect the floor water inrush. Therefore, these three factors are considered as the criterion hierarchy (B hierarchy). The sensitive factors that affect the floor water inrush form the decision layer of the model (C hierarchy). The factors that make decisions at the C hierarchy will ultimately solve the target problem (A hierarchy). The Analytical Hierarchy Process model is shown as Fig. 2.

#### 3.2.2 Constructing Judgment Matrix

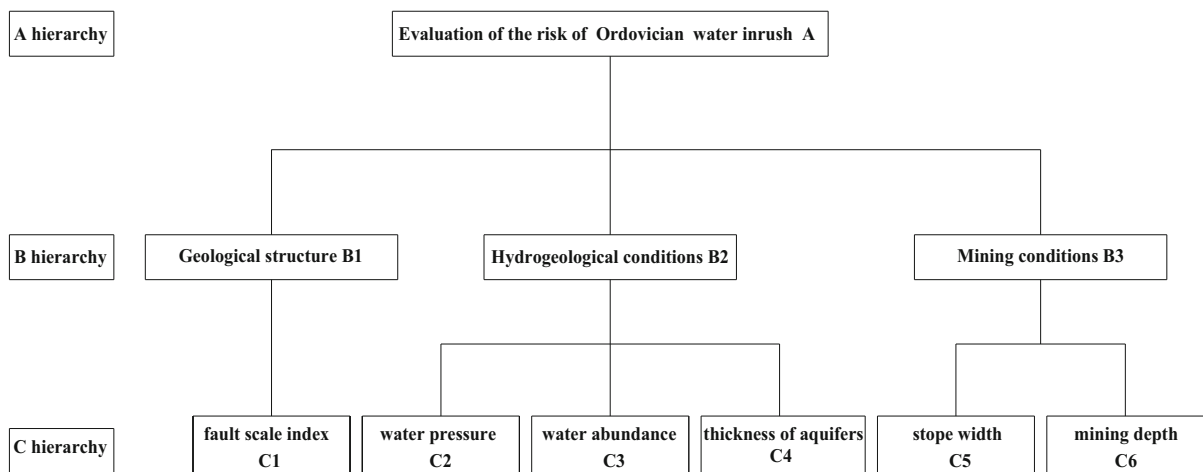
Expert scoring method is used to compare various influencing factors of floor water inrush, obtain the relative importance of various influencing factors, quantification score to various influencing factors. These data are statistically, collated, summed up and analyzed to form the desired set of evaluation. Tables 1, 2, 3 is a judgment matrix for the analysis of No. 17 coal seam floor water inrush.

Three judgment matrices are consistent, and the weight of each factor  $C_i$  for the target hierarchy was calculated (Table 4).

#### 3.3 Variation Coefficient

According to three-dimensional geological exploration and drilling hole monitoring point data, detailed geological data of seven drilling holes monitoring points in the mining area can be obtained. Fault scale index, coal seam mining depth, stope width, equivalent thickness of the water-resisting layer, water pressure of the Ordovician limestone aquifer, water abundance of the Ordovician limestone aquifer are shown in Table 5.

In order to eliminate the influence of different dimensions in the data of main controlling factors in Table 5, the data must be normalized. Because the larger the data of fault scale index, water pressure, water abundance, thickness of aquifers, stope width and coal seam mining depth is, the easier the floor water inrush occurs. So formula (3) is used to



**Fig. 2** AHP model design

**Table 1** Judgment matrix  $A-B_i$  ( $i = 1-3$ )

A	B <sub>1</sub>	B <sub>2</sub>	B <sub>3</sub>	$w'(A/B_i)$
B <sub>1</sub>	1	1/3	1/2	0.1507
B <sub>2</sub>	3	1	3	0.5753
B <sub>3</sub>	2	1/3	1	0.2740

$\lambda_{max}$  is 3.05362;  $CI$  is 0.02681;  $RI$  is 0.58;  $CR$  is 0.04622

**Table 2** Judgment matrix  $B_2-C_i$  ( $i = 1-3$ )

B <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>4</sub>	$w'(B/C_i)$
C <sub>2</sub>	1	2	1	0.4211
C <sub>3</sub>	1/2	1	1	0.2632
C <sub>4</sub>	1	1	1	0.3157

$\lambda_{max}$  is 3.05362;  $CI$  is 0.02681;  $RI$  is 0.58;  $CR$  is 0.04622

**Table 3** Judgment matrix  $B_2-C_i$  ( $i = 1-3$ )

B <sub>2</sub>	C <sub>5</sub>	C <sub>6</sub>	$w'(B/C_i)$
C <sub>5</sub>	1	3	0.75
C <sub>6</sub>	1/3	1	0.25

$\lambda_{max}$  is 2.0;  $CI$  is 0;  $RI$  is 0;  $CR$  is non-existent

**Table 4** The weight for each index of the total target

A/C <sub>i</sub>	B <sub>1</sub> /0.1507	B <sub>2</sub> /0.5753	B <sub>3</sub> /0.2740	$w'(A/C_i)$
C <sub>1</sub>	1			0.1507
C <sub>2</sub>		0.4211		0.2423
C <sub>3</sub>		0.2632		0.1514
C <sub>4</sub>		0.3157		0.1816
C <sub>5</sub>			0.75	0.2055
C <sub>6</sub>			0.25	0.0685

normalize data of various factors. On the contrary, the greater the thickness of the aquifer is, the more difficult floor water inrush occurs. So formula (4) is used to normalize the data of thickness of the aquifers.

$$X_i = \frac{x_i - x_{min}}{x_{max} - x_{min}} \tag{3}$$

$$X_i = \frac{x_{max} - x_i}{x_{max} - x_{min}} \tag{4}$$

The normalized value of each main controlling factor can be obtained from Table 6.

Variation coefficient calculating adopts the following formula:

$$v_i = \frac{\sigma_i}{\bar{x}_i}, i = 1, 2, \dots, n \tag{5}$$

where  $v_i$  is variation coefficient;  $\sigma_i$  is standard deviation;  $\bar{x}_i$  is average.

Weight calculating adopts the following formula:

$$w''_i = \frac{v_i}{\sum_{i=1}^n v_i} \tag{6}$$

where  $w''_i$  is weight;  $v_i$  is variation coefficient;  $n$  is number of main controlling factors.

Based on the principle of variation coefficient, the data can be calculated by formula (5) and formula (6) to normalize. The weight of each main controlling factor in floor water inrush can be obtained from Table 7.

### 3.4 Construction of Comprehensive Weight Model

Main controlling factors can be comprehensive weighted by the subjective method of AHP and the projective method of VC. The comprehensive weight model of weight coefficient obtained by AHP<sub>VC</sub> can be constructed by combining the subjective and objective weight coefficient of the main controlling factors obtained. The risk of floor water inrush can be evaluated more scientific and accurate from the perspective of subjective and objective. Model calculating adopts the following formula:

$$w_i = \alpha w'_i + (1 - \alpha) w''_i \tag{7}$$

where  $\alpha$  is preference coefficient, this paper takes 0.5;  $w'_i$  is weight coefficient obtained by analytic hierarchy process;  $w''_i$  is the weight coefficient obtained by the method of variation coefficient.

The comprehensive weight of each main controlling factor in floor water inrush can be obtained from Table 8.

**Table 5** Quantification of main control factors

Drilling hole	Fault scale index	Water pressure (MPa)	Water abundance [L/(m s)]	Thickness of aquifers (m)	Stope width (m)	Coal seam mining depth (m)
24-1	0.0279	9.9173	1.35	57.41	469.21	– 903.54
D15-1	0.0135	6.9600	1.03	51.13	437.82	– 614.09
12-4	0.0279	9.2455	1.33	65.68	263.64	– 828.09
D19-2	0.0649	5.8842	0.95	54.71	665.10	– 502.93
D29	0.0420	6.0577	0.90	58.15	647.62	– 516.84
D27	0.0172	4.7589	0.60	53.01	400.25	– 392.10
D29-1	0.1095	4.9097	0.55	67.96	320.11	– 392.23

**Table 6** Normalized value for each index

Drilling hole	Fault scale index ( $X_1$ )	Water pressure ( $X_2$ )	Water abundance ( $X_3$ )	Thickness of aquifers ( $X_4$ )	Stope width ( $X_5$ )	Coal seam mining depth ( $X_6$ )
24-1	0.1500	1	1	0.6269	0.5121	1
D15-1	0	0.4267	0.6000	1	0.4399	0.4340
12-4	0.1500	0.8698	0.9750	0.1355	0	0.8525
D19-2	0.5354	0.2181	0.5000	0.7712	1	0.2694
D29	0.2969	0.2518	0.4375	0.5829	0.9565	0.2439
D27	0.0385	0	0.0625	0.8883	0.3397	0
D29-1	1	0.0292	0	0	0.1407	0.0002

**Table 7** The weight of the main controlling affecting factors in floor water inrush

Influencing factor	Weight ( $w_i''$ )
Fault scale index ( $w_1''$ )	0.2140
Water pressure ( $w_2''$ )	0.1856
Water abundance ( $w_3''$ )	0.1449
Thickness of aquifer ( $w_4''$ )	0.1232
Stope width ( $w_5''$ )	0.1477
Coal seam mining depth ( $w_6''$ )	0.1846

**Table 8** Comprehensive weight for each index

Influencing factor	Comprehensive weight ( $w_i$ )
Fault scale index ( $w_1$ )	0.1824
Water pressure ( $w_2$ )	0.2140
Water abundance ( $w_3$ )	0.1482
Thickness of aquifer ( $w_4$ )	0.1524
Stope width ( $w_5$ )	0.1766
Coal seam mining depth ( $w_6$ )	0.1266

### 3.5 Comprehensive Weight Vulnerability Index Model

The vulnerability model of floor water inrush is actually a combination of the established mathematical model and the main controlling factors influencing the coal seam floor water inrush in the actual geographical location. With the effect of the two aspects, the risk of coal seam floor water inrush can be

reflected in a certain geographic location. Therefore, the comprehensive weight coal seam floor water inrush vulnerability index model can be constructed by combining the initial model of vulnerability index and AHP<sub>VC</sub> comprehensive weight. Model calculating adopts the following formula:

$$VI = \sum_{i=1}^n w_i X_i \quad (8)$$

where  $VI$  is vulnerability index;  $w_i$  is factor comprehensive weight;  $X_i$  is normalized value.

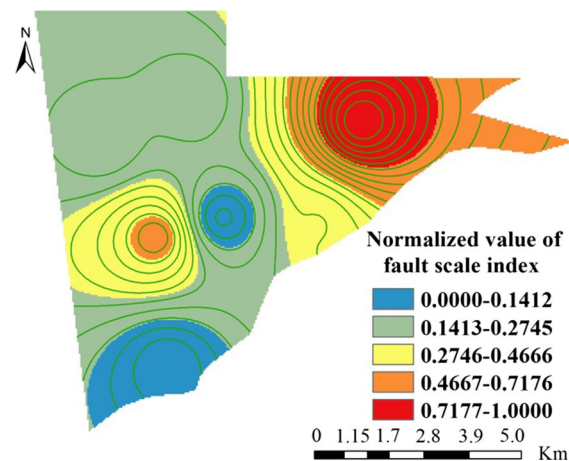
#### 4 Risk Analysis of Coal Seam Floor Water Inrush

##### 4.1 Drawing Normalization Thematic Map and Water Inrush Risk Zoning Map

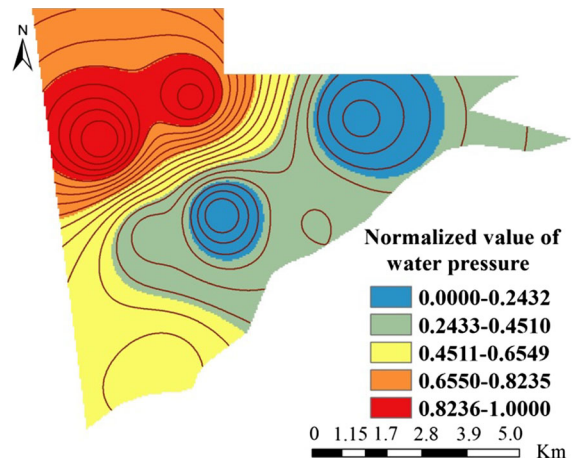
The normalized values of the main controlling factors are input into the spatial geographic information system. Each factor database is established, and the input data is interpolated and analyzed. Normalized thematic maps of all the influencing factors are shown as Figs. 3, 4, 5, 6, 7, 8. And the risk of water inrush zoning map is shown as Fig. 9. In order to test the accuracy of the water inrush prediction model, the prediction results were compared with the prediction results of the water inrush coefficient. Risk assessment zoning map of water inrush coefficient was shown as Fig. 10.

Five risk levels were used to define the vulnerability of the various No. 17 coal seam areas above the Ordovician limestone aquifer based on the  $VI$  calculated above. The threshold levels selected were 0.32, 0.42, 0.50, and 0.58; the larger values indicate a greater likelihood of water inrush. Word descriptors are noted below.

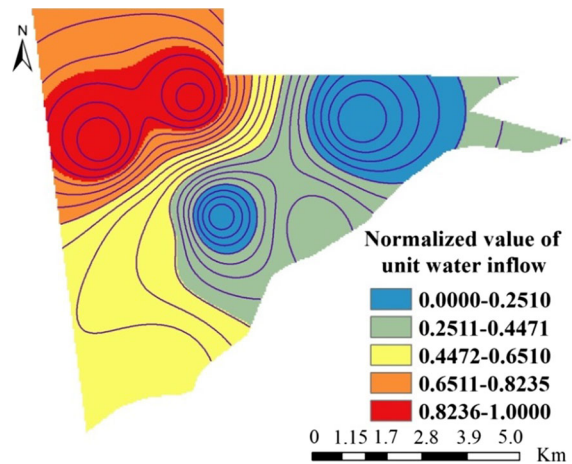
Dangerous area: ( $VI > 0.58$ ); Relatively dangerous area: moderate likelihood of floor water inrush ( $0.50 < VI \leq 0.58$ ); Transitional area: low likelihood



**Fig. 3** Thematic map of normalization of fault scale index



**Fig. 4** Thematic map of normalization of water pressure of Ordovician aquifer

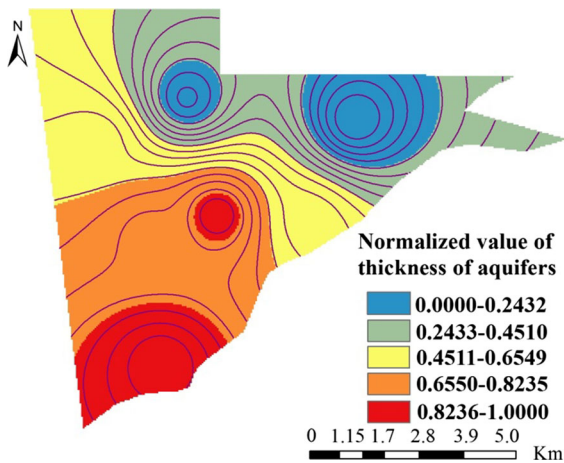


**Fig. 5** Thematic map of normalization of water abundance of Ordovician aquifer

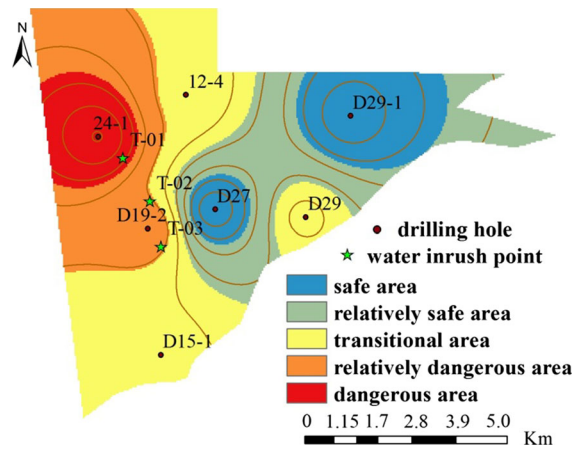
of floor water inrush ( $0.42 < VI \leq 0.50$ ); Relatively safe area: ( $0.32 < VI \leq 0.42$ ); Safe area: ( $VI \leq 0.32$ ).

##### 4.2 Identification and Test of Model

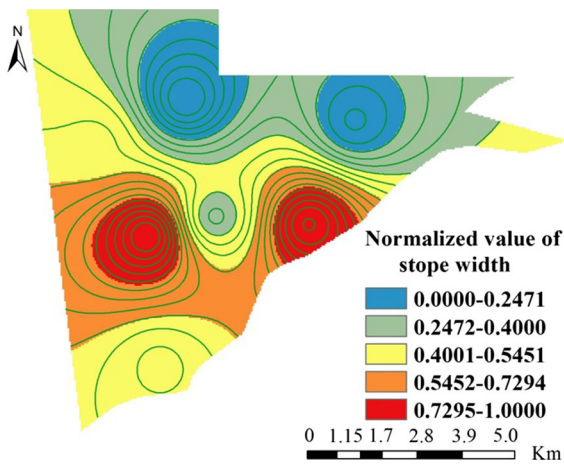
When the location of the water inrush point is more than 90% in the dangerous or relatively dangerous area, the result of water inrush prediction model is more satisfactory. From water inrush risk zoning map (Fig. 9), three water inrush points are in a dangerous or relatively dangerous area. T-01 is in the dangerous area. T-02 and T-03 are in the relatively dangerous area. The fitting effect can be considered better, which is approximately 100%.



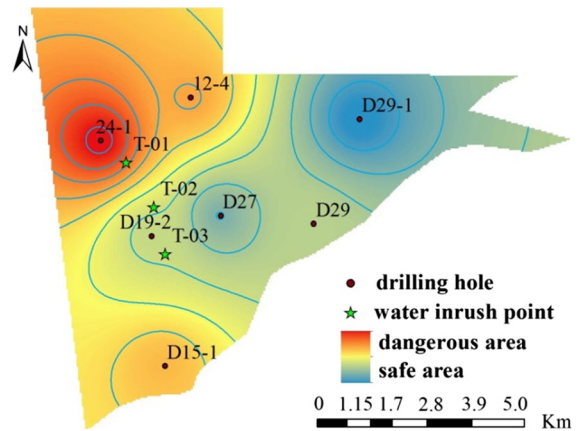
**Fig. 6** Thematic map of normalization of thickness of aquifers



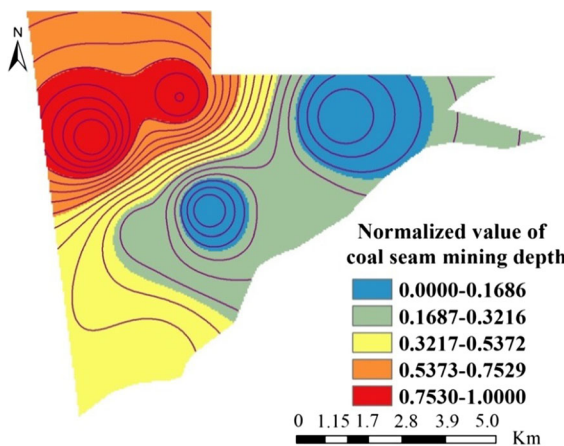
**Fig. 9** Zoning map of risk assessment of coal seam floor



**Fig. 7** Thematic map of normalization of stope width



**Fig. 10** Risk assessment zoning map of water inrush coefficient



**Fig. 8** Thematic map of normalization of coal seam mining depth

### 4.3 Results Analysis

From the fault scale index normalized thematic map (Fig. 3), the normalized value is large in the eastern part. The main reason is that many large faults are distributed in this area. For a single factor, the probability of water inrush is relatively high in the eastern part of the mining area. Figures 4, 5, 8 are the normalized thematic map of water pressure, water abundance and stope width. From their corresponding thematic maps, the distribution of their normalized values is similar. The normalized value is large in the northwest part, mainly because the coal mining depth is deep. The water pressure is large, the water abundance is strong and the mine pressure is great with Ordovician limestone aquifer closing. For a



single factor, the probability of water inrush is high in the northwest part of the mining area. From the normalized thematic map of the thickness of aquifer (Fig. 6), the normalized value is large in the south and small in the northeastern. For a single factor, the probability of water inrush is low in the south and high in northeastern. From the stope width normalized thematic map (Fig. 7), the normalized value is higher in the middle of mining area. The main reason is that this regional coal resource storage is rich. So the mining area is large, and the stope width is also large. For a single factor, the probability of water inrush is relatively high in the middle of the study area.

From the zoning map of risk assessment of floor water inrush (Fig. 9), the dangerous area is mainly distributed in the northwest part of the mining area and the fold axis affected zone and its surrounding area. The main reason is that mining depth is deep, water pressure is relatively large and water abundance is strong in the northwest part of the mining area. However, the equivalent thickness of the water-resisting layer that inhibits the water inrush is relatively small, and water inrush is easy to occur. When mining the coal seam in this area, the prevention and control measures for water inrush should be made in detail. The relatively dangerous areas are mainly distributed in the western and northwestern areas of the mining area. Mining depth is relatively deep, water abundance is relatively strong, stope width and water pressure are medium, and floor thickness of aquifer is relatively weak in these areas. When mining these areas, some measures should be taken to prevent and control water inrush, such as floor grouting reinforcement or reasonable planning of stope width, etc. The transitional area is mainly located in the middle part of the mining area and small part is located in the southeast part. Although water pressure and water abundance are better, the thickness of aquifer is thicker, and the water inrush may occur. The monitoring should be strengthened during the mining. Safe area and relatively safe area are mainly distributed in the middle east of mining area, because coal seam mining depth is shallow, stope width is small, water pressure and water abundance are weak. Water inrush will not occur during mining.

The water inrush coefficient can be calculated through the actual drilling data of the mine. When water inrush coefficient  $> 0.1$  Mpa/m, the probability of water inrush is larger. So the region of the water

inrush coefficient  $> 0.1$  Mpa/m is regard as dangerous area. When water inrush coefficient  $< 0.1$  Mpa/m, the probability of water inrush is smaller. So the region of the water inrush coefficient  $< 0.1$  Mpa/m is regard as safe area. From risk assessment zoning map of water inrush coefficient (Fig. 10), the water inrush point T-01 is in the dangerous area. And the water inrush points T-02 and T-03 are in safe area. The fitting effect can be considered relatively poor. Compared with the water inrush coefficient method, the comprehensive weight water inrush model can evaluate water inrush risk by combining various influence factors of floor water inrush. The evaluation is more comprehensive and the prediction result is more accurate than the water inrush coefficient.

## 5 Conclusions

- (1) Geological and hydrogeological conditions were characterized in Wanglou mine. The fault scale index, the coal seam mining depth, the stope width, the water abundance of the Ordovician limestone aquifer, the equivalent thickness of the water-resisting layer and the water pressure of the Ordovician limestone aquifer were the six major controlling factors of the floor water inrush. Two fault related factors were removed and two factors associated with mining conditions were increased, which is more conducive to the comparison of various factors and the division of levels and easier to calculate.
- (2) The shortcoming of AHP is that the subjectivity is too strong. The shortcoming of VC is that the weight is not in conformity with the reality. The comprehensive weight method was applied to the evaluation of water inrush, which not only overcomes the shortcoming of subjective weighting method, but also avoids the shortcoming of the objective weighting method. The evaluation method is more comprehensive and the evaluation results are more accurate and practical.
- (3) Combining the analytical hierarchy process and the variation coefficient method, the comprehensive weighting method was established, and the comprehensive weight coefficient of the

main control factors was determined. The constructed weight vulnerability index model and GIS were combined to obtain the risk zoning map of floor water inrush and evaluate the risk of floor water inrush, which provides some guidance for prevention and treatment of floor water inrush.

**Acknowledgements** This work was financially supported by the National Natural science Foundation of China (Grant 51274135) and Graduate student science and technology innovation Project of Shandong University of Science and Technology (SDKDYC180101).

## References

- Dong DL, Sun WJ, Zhu ZC et al (2012) Water-inrush assessment of coal 12 floor using a GIS-based bayesian network for Fangezhuang coal mine with collapse column. *J Chin Coal Soc* 37(6):999–1004
- Gao YF, Zhang YQ, Zhang HM et al (2009) Expert system and application study on risk assessment of floor water inrush. *Chin J Rock Mech and Eng* 28(2):253–258
- Li BY (1999) “Down Three Zones” in the prediction of water inrush from coalbed floor aquifer-theory, development and application. *J Shandong I Min Tech* 18(4):11–18
- Liu WT, Zhang WQ, Li JX (2000) Safety evaluation of floor water inrush by analytical hierarchy process and fuzzy evaluation. *J Chin Coal Soc* 25(3):278–282
- Liu WT, Liu YJ, Shen JJ (2014) Safety evaluation of floor water inrush in deep mining based on fuzzy matter element theory. *J Shandong Univ Sci Technol* 33(3):25–31
- Liu WT, Liu SL, Ji BJ (2015) Sensitivity analysis of control ling factors on failure depth of floor based on orthogonal experiment. *J Chin Coal Soc* 40(9):1995–2001
- Liu W, Mu DR, Xie XX et al (2017) Sensitivity analysis of the main factors controlling floor failure depth and a risk evaluation of floor water inrush for an inclined coal seam. *Miner Water Environ* 4:1–13
- Luo C (2012) The water inrush evaluation based on AHP vulnerability index method in Liyazhuang mining area. *Coal Geol Explor* 40(5):47–50
- Ni HG, Luo GY (2000) Study on mechanism of preferred plane of water hazard in coal mine. *J Chin Coal Soc* 25(5):518–521
- Qian MG, Miao XX, Xu JL (1996) Theoretical study of key stratum in ground control. *J Chin Coal Soc* 21(3):225–230
- Sun J (2014) Failure characteristics of floor “three-zone” along the inclined direction of coal seam. *J Min Saf Eng* 31(1):115–121
- Sun J, Wang LG, Tang FR et al (2011) Microseismic monitoring failure characteristics of inclined coal seam floor. *Rock Soil Mech* 32(5):1589–1595
- Wu Q, Pang W, Dai YC et al (2006) Vulnerability forecasting model based on coupling technique of GIS and ANN in floor ground water bursting. *J Chin Coal Soc* 31(3):314–319
- Wu Q, Wang JH, Liu DH et al (2009) A new practical methodology of the coal floor water bursting evaluating IV: the application of AHP vulnerable index method based on GIS. *J Chin Coal Soc* 34(2):233–238
- Wu Q, Liu YZ, Zhou WF et al (2015) Evaluation of water inrush vulnerability from aquifers overlying coal seams in the Menkeqing Coal Mine, China. *Miner Water Environ* 34(3):258–269
- Zeng YF, Liu SQ, Zhang W et al (2016) Application of artificial neural network technology to predicting small faults and folds in coal seams, China. *Miner Water Environ* 2(2):175–181
- Zhang JC, Liu TQ (1990) On depth of fissured zone in seam floor resulted from coal extraction and its distribution characteristics. *J Chin Coal Soc* 15(2):46–55
- Zhang JC, Zhang YZ, Liu TQ (1997) Seepage of rock mass and coal floor water bursting. Geological Press, Beijing
- Zhang WQ, Zhang GP, Li W et al (2013) A model of Fisher’s discriminant analysis for evaluating water inrush risk from coal seam floor. *J Chin Coal Soc* 38(10):1831–1836
- Zhang SC, Guo WJ, Sun WB et al (2015) Formation and evolution process of floor water inrush channel under high water pressure. *J Shandong Univ Sci Technol* 34(2):25–29
- Zhou XL, Yang GY, Zheng SS (2006) Influencing factors on water burst in the roof of no. 3 seam in the Dongtan coal mine. *J Min Saf Eng* 23(3):281–288