Evaluation of the Risk of Water Gushing Inrush in Aquifer of Coal Seam Roof Based on "Three Diagram Method" – a Case Study in Hu Jiahe Coal Mine, China

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Research

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Abstract

Coal seam roof inrush phenomenon is common in Jurassic coalfield in China. In order to evaluate accurately the risk of coal seam roof water inrush (CSRWI) it needs to analyze the degree of water rich degree and crack height of strata aquifer. Based on the combined weight-TOPSIS theory, this paper intends to adopt the 8 factors of aquifer thickness, lithological structure index, core adoption rate and permeability coefficient, and TDS from the three aspects of aquifer lithology, hydrology and hydrochemical characteristics. As an evaluation index of the water richness of the aquifer in the Luohe Formation, By using the method of GI method and independent weight method subjective and objective weights influencing aquifer water rich control factors are determined and then weights are coupled by differential maximization theory. Based on GIS spatial analysis technology, an evaluation model of aquifer water rich in coal seam roof aquifer was established and verified by field measured hydrological pore data. Through empirical value calculation of coal seam roof crack height and further refinement of hydraulic fracture zone spread across aquifer floor and combined with aquifer degree of water enrichment and roof cracking degree to carry out comprehensive evaluation of the risk of CSRWI. The most important factors affecting the degree of water enrichment of aquifers are lithological structure index and permeability coefficient, followed by TDS. Compared with water-rich index method, the water-rich degree of aquifer can be effectively determined based on combination weight and TOPSIS method. Moreover, subdivision of roof crack degree indicates that the development height of hydraulic fracture zone in research area is disturbed by aquifer actual disturbance; Risk assessment results indicate that high risk of water inrush lies in southwest side of research area and prevention should be strengthened when mining. This study provides a new idea for evaluating risk zoning of coal seam roof gushing (inrush) water in coal mines of Binchang.

1. Introduction

mine hydrogeological conditions become more complex along with increasing coal mining intensity and depth in recent years, Water problems occurred frequently threatening the safety of mining the coal seam (Meng 2011; Wu 2014; Dong 2020). Roof water hazard is one of the most important forms of water disaster in coal mines (Jin. 2017; Cui and Wu 2012). Therefore risk assessment of CSRWI can not only provide technical support for mine prevention and control water work but also has practical significance for coal safety mining (Wang. 2015).

When coal mining activity deepening, its influence scope gradually spread to overlying aquifer in coal seam; once water-flowing fracture zone breaks through impermeable layer causes roof aquifer and groundwater in overlying water collapse into underground mine causing roof flood accident (Gui. 2017), Water inrush from coal seam roof is a dynamic phenomenon controlled by multiple factors and complicated formation mechanism, Many scholars have done researches on mechanism of CSRWI (Xu et al. 2011; Xu et al. 2012; Yang et al. 2018),

In order to reveal the interaction between the main controlling factors, Wuqiang established a method to quantitatively solve the problem of WICSR which named “three-picture-double prediction method” based on the multiple geological information fusion technology of GIS(Wu et al. 2000; Wu et al. 2015; Wu et al. 2016). However this method usually uses AHP to determine the weight of main control factors whereas AHP relies mainly on subjective judgment of decision makers; factors selected are mainly based on aquifer properties such as thickness permeability coefficient etc. Methods such as gray correlation method, entropy weight method, extension evaluation method and fuzzy comprehensive analysis method were gradually applied to the risk assessment of CSRWI, which improved the accuracy and applicability of the method (Wang et al. 2012; Li 2015;
Moreover some scholars attempt to evaluate WICSR based on considering relevant characteristics of water-resisting layer (Wang et al. 2012; Liu 2015; Fang et al. 2016). Considering this, this paper tries to find an index which can characterize aquifer circulation condition from Cretaceous Luohe Aquiferous Group, By using the method of combing GI theory with independence right coefficient to select the weight of the main control factors, To establish a model for evaluating water quality of coal seam roof aquifer based on combination weight-TOPSIS method, and verify it through measured specific yield. Furthermore, the crack safety degree of coal seam roof strata is refined to indicate disturbance of overlying rock variation to aquifer during coal mining. Based for the WICSR that was evaluated by using cluster analysis method. In order to predict and prevent WICSR that provides certain reference value for coal mine which has lower hydrogeological investigation degree to appear flood accident during mining process afterward.

2. The Study Area

The hujiage mine field is located in the northwest of Xianyang, Shaanxi Province, the main mining coal seam is number 4, the mine field is divided into six areas, of which 401,402 is the first mining face, which is the key area of this study, with an area of about 12.86km$^2$ (Fig. 1). The study area is situated in the Longdong Loess Plateau, the terrain is low in the southwest and high in the northeast, and the Jinghe River runs through the mining area, dividing the well field into a geomorphological pattern alternating between the loess plateau and the river valley terraces. Most of the surface of the study area is covered by a very thick loess layer, and the bedrock is exposed only on both sides of the river valley (Liu. 2015). The mine field is less controlled by structural factors, and there is only an anticline or syncline developed near the east-west direction along the axis, and the dip angle of the two wings of the fold is generally 1-3 °.

The study area is located in the southern discharge area of the Cretaceous groundwater flow system Jinghe to Malian River secondary groundwater system in the Ordos Basin, which belongs to the plateau confined water basin (Mu. 2012). The runoff direction of the main aquifer in the mine field is controlled by topography and geomorphology, which flows from the higher terrain in the north to the south valley; the groundwater collects from the east, north and west to the lower reaches of the Malian River, and the water is abundant and discharged in the area of Tingkou outside the coal field in the form of spring (Fig. 2). The aquifer of the Cretaceous Luohe fgroup is the main water-filled aquifer in the coal field, which is widely distributed and extends far in the study area. mainly lateral recharge, which can be regarded as an unbounded confined aquifer. From the borehole data, it is known that the value of specific field is $0.02313\pm0.7484$L/s·m, the coefficient of permeability is $0.01237\sim0.23318$ m/d, and having aquifers of medium water-richness. The type of water quality is SO$_4$·Cl·Na, which belongs to brackish water.

3. Data Preparation

3.1 Factors of Aquifer water yield property

Aquifer water yield property (AWYP) characterizes the water output capacity of the aquifer (Li. 2018), This indicator is usually controlled by the water content of the aquifer itself and the water supply capacity of the aquifer. In a broad sense, the amount of groundwater given by the aquifer includes dynamic reserves and static reserves. Specifically, the water richness of the aquifer is not only closely related to the lithology, the thickness of
the aquifer, the degree of fracture development and the degree of structure of the rock; The circulation and recharge capacity of the aquifer also affects the water richness of the aquifer. The recharge, runoff, and discharge conditions of groundwater are mainly affected by the topography and the spatial location of the aquifer.

Generally, the specific field is used to evaluate the water richness of the aquifer, due to the low degree of hydrogeological survey of this study area, Based on the hydraulic characteristics of the aquifer itself and the recharge capacity of the aquifer in the study area, this paper selects relevant indicators, and uses the combined weighting-TOPSIS method to construct a water-rich evaluation model, and combined with the specific field data to compare and verify the model. Based on the research area data and previous relevant results, this study intends to consider the factors affecting the water richness of the aquifer from four aspects: the lithological structure, seepage characteristics and hydrochemical field of the aquifer, It is controlled by the thickness of the aquifer, lithology combination index, core monitor rate, permeability coefficient and TDS (Table 1), as follows:

### Table 1 Comprehensive evaluation index for water richness of aquifer

| Target layer                          | First level indicator                  | Secondary index                      |
|---------------------------------------|----------------------------------------|--------------------------------------|
| Water-rich evaluation system of Luohe formation aquifer | Characteristics of the rock            | Aquifer thickness                     |
|                                       |                                        | lithology combination index          |
|                                       |                                        | core monitor rate                     |
|                                       | Hydraulic characteristics              | coefficient of permeability          |
|                                       | Water hydration field                  | TDS                                  |

(1) **Aquifer thickness**

The sandstone aquifer of Luohe formation is the main water storage layer of mine water. Generally speaking, under the condition that other factors remain unchanged, the thicker the aquifer is, the larger the water storage space is, which can provide greater water permeability under the same hydraulic conditions. According to the data of the study area (Fig 3a), the thickness of Luohe formation is gradually increasing from south to north, reaching the maximum value of 366m in the northwest direction and the minimum value of 280m in the southeast direction.

(2) **Lithology combination index**

According to previous studies, there is a good correlation between the water richness of aquifer and the lithology and assemblage characteristics of its vertical water-bearing rock group (Hou. 2019). Brittle rock is changeable to produce fissures after high strength, so that its water conductivity is enhanced. However, plastic rock is mainly plastic deformation after stress, and its water storage and water conductivity are relatively weak. The index of lithologic structure index can express this relationship quantitatively. In view of the characteristics of the water-bearing medium in the study area, this paper intends to quantify the clastic rocks with different particle sizes (Table 2), and construct the lithologic structure index to evaluate the water-rich strength. The larger value of is,
the larger the particle size of the rock stratum. The larger the water storage space of the rock is, the larger the water storage space of the rock is.

\[ r = \frac{\sum h_i s_i}{\sum h_i} (i = 1, 2 \ldots , 6) \]

Among them, \( \sum h_i \) is lithologic thickness, m; \( s_i \) is structural coefficient, m

### Table 2 Rock structure coefficient table

| Rock grain size | Conglomerate | Coarse sandstone | Medium sandstone | Fine sandstone | Siltstone | Sandy mudstone | Mudstone |
|-----------------|--------------|------------------|------------------|---------------|-----------|---------------|---------|
| Structural coefficient | 1 | 0.8 | 0.6 | 0.4 | 0.3 | 0.2 | 0.1 |

On the whole, the lithologic structure index of the aquifer of Luohe formation is relatively larger in the east of the study area (Fig 3b) and smaller in the west, indicating that the water storage space of the strata in the study area is gradually increasing from west to east.

### (3) Core monitor rate

The sandstone aquifer of Luohe formation belongs to fracture confined aquifer, and the development degree of fracture is positively correlated with its water richness. The rock quality designation (RQD) is often used to identify the crushing degree of rock mass. RQD and core recovery rate are not the same concept. RQD is the comprehensive index to reflect the crushing degree of rock mass. Core recovery rate only reflects the quality of boreholes and is related to the crushing degree of rock strata and drilling technology. However, due to the limitation of RQD in practical application, core recovery rate is usually used as an index to characterize the integrity of rock mass (Li, 2019). It is generally believed that the lower the adoption rate is, the more broken the rock layer is, and the stronger the water conductivity is, on the contrary, it shows that the water conductivity is relatively weak. The core recovery rate of Luohe formation sandstone in each borehole is calculated by constructing lithologic recovery index.

\[ n = \frac{\sum h_i n_i}{\sum h_i} \]

On the whole, the core adoption rate of the sandstone aquifer of Luohe formation in the study area shows a trend of decreasing gradually from north to south (Fig 3c), and the water conductivity increases gradually accordingly.

### (4) Osmotic coefficient

The permeability of the rock layer also affects the water richness of the aquifer, and the permeability coefficient of the aquifer is a common comprehensive index to describe the permeability of the rock layer, which
characterizes the ability of the water body to flow through the medium. It is generally believed that the greater the permeability coefficient of the rock layer, the better its water richness. As can be seen from the above picture (Fig 3d), the regional permeability coefficient of the aquifer of Luohe formation in the southwest of the middle of the study area is relatively large, and then decreases to both sides, and its value is relatively small in the eastern part of the study area.

(5) Hydrochemical field

According to the theory of groundwater dynamics, the permeability coefficient of aquifer depends not only on the voids of rocks, but also on the physical properties of permeable liquids. In the past, scholars often ignore the influence of physical properties of water on permeability coefficient, but for underground rock mass, the salinity, water temperature and water pressure all affect the weight ratio and viscous dynamic coefficient of liquids. This paper intends to analyze the water permeability of aquifers from the point of view of the salinity of aquifers.

According to the theory of water quality concentration gradient field (You. 2019), in the area with small TDS, the groundwater recharge is sufficient, the runoff speed is faster, and the contact time with surrounding rock is shorter, but with the flow direction of groundwater, the hydraulic slope decreases gradually, the velocity slows down, the reaction time between groundwater and surrounding rock becomes longer, the TDS value increases gradually, and the TDS value tends to be stable in the discharge area. Due to the lack of salinity data in this mine field, and the numerical difference between salinity and TDS is only half of the bicarbonate content, the spatial distribution of TDS can be used to approximately represent the cycle characteristics of aquifers. Under the condition that other factors remain unchanged, the smaller the TDS concentration is, the stronger the hydraulic alternation capacity of the groundwater is, the larger the hydraulic slope is, and the stronger the recharge capacity is. Through the analysis of the existing data, it is found that the study area is located in the concentrated discharge section of the secondary groundwater system of Jinghe-Malian River, and the overall TDS varies widely. According to the study (Fig 3e), the TDS concentration in the study area increases gradually from south to north, and its value is the lowest in the southwest, indicating that the aquifer in this area has a strong ability to accept recharge, and the TDS concentration gradually increases to the northwest with the change of topography.

3.2 Water-owing fracture zone height

The key point of the regional prediction of the cracking degree in coal seam mining is whether the WFFZ breaks through the overlying water-filled aquifer. According to rock physical mechanics test results show that coal seam number 4 is main coal seam in Hu Jiahe coal mine whose roof is dominated by mudstone siltstone fine sandstone and belongs to semi hard rock, At the same time, the roof strata of coal seam are relatively complete. Compressive strength of overburden rock in coal seam number 4 is 6.50-26.20MPa which belongs to weak stable rock group. WFFZ is calculated by using the following empirical formula.

\[ H_{ij} = \frac{100 \sum M}{0.25 \sum M + 6.88} \pm 11.49 \]
In this paper, the value obtained by the empirical formula is modified by using the data of WFFZ measured in the field. The average mining thickness of number 4 coal is 12m, mining width of the working face is 180m. Through the method of borehole color TV observation (Fig 4) and the analysis of the leakage of flushing fluid (Liu 2015) combined with numerical simulation, it is comprehensively determined that the coal seam mining thickness with 22.32 times the WFFZ is the best.

Using this ratio to correct the development height of the WFFZ, the analysis shows (Fig 5) that the WFFZ has connected the roof aquifer in the study area, and the development height of the WFFZ reaches the maximum on the southeast side of the study area. Its value is 251.21m, gradually decreasing from south to north, and its minimum value is 113.83m on the northeast side of the study area.

4. Methodology

(1) GI Method

GI is a subjective weighting method formed on the basis of the traditional analytic hierarchy process (Wang and Guo 2012). Compared with the AHP method, GI does not need to construct a matrix and test consistency, but only needs to subjectively rank the importance of the indicators, and then assign values according to the importance of the indicators.

(2) The independence weight coefficient method

The independence weight coefficient method is a method to obtain the objective weight by calculating the multiple correlation coefficient based on the theory of multiple regression analysis (He and Gao 2001). The larger the multiple correlation coefficient is, the stronger the collinear relationship between the index and other indicators is, which reflects that there is more repetitive information among the data, and the weight of the index is smaller. The independence weight coefficient method is suitable for the complex relationship between evaluation indexes, and the repetitive information between evaluation indexes can be reduced by using this method.

(3) Combinatorial weighting method based on grade difference maximization

Whether the combination of GI method and independent weight coefficient method is reasonable or not remains to be tested. In this paper, the following formula is used to analyze the correlation between the variables composed of subjective and objective weight values.

\[ p = 1 - \frac{6}{n(n^2-1)} \sum_{j=1}^{n} (w_j - \beta_j)^2 \]

The methods of combining and assigning weights generally include linear addition combination method, multiplication normalization method and so on. The weighted average of weights by addition combination method is not conducive to highlight the advantages and disadvantages of information, while the use of multiplication normalization method will lead to more obvious "multiplier effect". The combination weighting method based on grade difference maximization has great advantages in the combination of index weights (Li 2019), which is a combination weighting method with a single index as a combination unit. for the value of the
combination weight, it is not simply to directly add and multiply the subjective and objective weights, but to establish an optimization model to solve the combination weights according to the reasonable range of the subjective and objective weights. It takes into account the advantages of subjective and objective weighting methods.

(4) Combinatorial weighting method based on grade difference maximization

TOPSIS method is also called "sorting method of approximate ideal solution" (Liu 2006). This method is a commonly used intra-group comprehensive evaluation method in multi-criteria and multi-attribute decision-making criteria. Based on the normalized original data matrix, the evaluation object is sorted by the Euclidean distance from the positive ideal solution and the negative ideal solution respectively, the closer the evaluation object is to the positive ideal solution and away from the negative ideal solution is the optimal solution, and the quality of the index is evaluated accordingly; in this paper, the index weight is introduced into the TOPSIS method (Wang 2006), and finally the comprehensive evaluation is carried out by using the TOPSIS method through obtaining the index comprehensive weight in the grade difference maximization method.

5. Results And Verification

5.1 Zoning for evaluation of water richness of aquifers

Standardize the water-rich prediction index of the existing boreholes, and use Matlab to calculate the weight of the main control factors that affect water-rich (Table 3).

Table 3 The weight value of each main controlling factor based on the maximization of combined weight-grade difference

| Main controlling factor          | Aquifer thickness | Lithologic association index | Core adoption rate | Permeability coefficient | TDS  |
|---------------------------------|------------------|------------------------------|--------------------|--------------------------|------|
| GI                              | 0.1163           | 0.2920                       | 0.2232             | 0.1860                   | 0.1825|
| Independence coefficient        | 0.1897           | 0.2360                       | 0.1643             | 0.2240                   | 0.1860|
| Combinatorial weighting         | 0.1504           | 0.2658                       | 0.1770             | 0.2265                   | 0.1865|

In the “Detailed Rules for Coal Mine Water Prevention and Control”, the specific capacity of boreholes is used to evaluate and classify the water-abundance of aquifers. Because the specific capacity of hydrological boreholes in the study area should be classified as medium water-rich according to the detailed rules, there is no strong water-rich area in the study area, and the maximum water gushing capacity of pumping test is only 0.43 L/s · m. In order to improve the efficiency of coal mine water control, cluster analysis is used to further subdivide the classification method (Table 4).

Table 4 The classification table of aquifer rich water level

| Main controlling factor          | Aquifer thickness | Lithologic association index | Core adoption rate | Permeability coefficient | TDS  |
|---------------------------------|------------------|------------------------------|--------------------|--------------------------|------|
| GI                              | 0.1163           | 0.2920                       | 0.2232             | 0.1860                   | 0.1825|
| Independence coefficient        | 0.1897           | 0.2360                       | 0.1643             | 0.2240                   | 0.1860|
| Combinatorial weighting         | 0.1504           | 0.2658                       | 0.1770             | 0.2265                   | 0.1865|
Water-rich evaluation partition needs to classify index according to comprehensive index of water rich in different regions usually using natural discontinuous method. The author thinks that natural discontinuous method depends only on sample itself breakpoints and uses the theory of collection classes to classify data. Meanwhile it remains to be discussed whether natural discontinuous method is adopted for water-rich classification of different regions. Based on GIS spatial analysis this paper attempts to construct a water rich model based on combination weighting TOPSIS method:Clustering analysis was used to classify the closeness degree between indexes and divided aquifer water-rich into four grades (Table 5) drawing zoning map of aquifer water-rich grade (Fig 6).

**Table 5 Water-rich Prediction partitioning based on combination weighting-TOPSIS method**

| Relative rank of water rich | Predictive subarea | Water-rich properties of pore holes |
|----------------------------|--------------------|-----------------------------------|
|                            |                   | Weak | Quite middle | Middle | Good | Better |

**Fig. 6 Zoning map of water-rich degree of aquifer in Luohe formation**

Among the prediction zones for aquifer enrichment and represent the middle water-rich regions. Comparing the water-rich prediction partition result obtained by water-rich index method and combined weighting-TOPSIS method compared with measured water-rich grade of borehole drilling hole, it is found that the water-rich classification determined by combination weighting-TOPSIS method agrees well with water-rich grade of borehole (Table 6). Meanwhile compared with thematic maps the core rate and TDS are smaller in regions with larger permeability coefficient indicating that fractures in aquifer are relatively developed and storage space is larger. Strata can give more groundwater under gravity release underwater. However, the permeability coefficient and lithologic composition index value of the region is relatively small indicating that plastic rocks are relatively larger and permeability of aquifer is weaker than that in the aquifer.

**Table 6 Comparison of Prediction results of Aquifer water-rich**
### Numbering of boreholes

| Borehole | Specific Capacity | Water-rich Index Method | Combinatorial Weighting-TOPSIS Method |
|----------|-------------------|-------------------------|--------------------------------------|
| 2-4      | 0.2929            | П                       | П                                    |
| B2       | 0.0451            | І                       | І                                    |
| T1       | 0.2771            | П                       | П                                    |
| T2       | 0.1803            | П                       | П                                    |
| T4       | 0.2855            | І                       | П                                    |
| T6       | 0.3803            | П                       | Ш                                    |
| T9       | 0.4066            | Ш                       | Ш                                    |
| T5       | 0.4364            | Ш                       | Ш                                    |
| B4       | 0.1558            | П                       | П                                    |

#### 5.2 Prediction of the safety of coal roof cracking

The development height of WFFZ is calculated by using empirical formula, and the thickness of sandstone aquifer in Luohe formation is broken through the development height of hydraulic fracture zone, which means that the main aquifer degree disturbed by hydraulic fracture zone is represented. According to the measured data of T5 and T6 holes measured on site, this paper gives a partition diagram of roof crack safety, and finds that the whole area is in danger zone of roof cracking.

According to existing data, there are large thickness mudstone sand mudstone or siltstone in 80 ~ 100 m layer above Luohe formation. Due to plastic rock stress failure fracture, therefore, roof cracking safety can be divided into risk zone and serious danger zone according to roof crack height. Partition threshold value is defined as 0 m and 80 m, the height of roof cracking in the study area generally ranges from 4.58 - 172.33 m (Fig 7), with an average of 105.54 m. At the same time, most of the research areas are in serious hazard zones, but only small areas of risk fissure are found in southwest and northeast areas of research area.

#### 5.3 Comprehensive Evaluation Zoning of water bursting risk in Coal seam Roof Aquifer

The occurrence of mine roof water hazard depends on water rich intensity of aquifer within the range of fracture zone development range of water inrush fracture zone disturbed aquifer with large distance and relatively strong water rich degree zone whose risk probability of inrush water or water gushing is relatively high. Through spatial analysis function of GIS, the degree of water rich degree and crack safety degree of aquifer are evaluated according to different grades. Then GIS grid calculator is used to stack. Using the following partition criterion, CSRWI is divided into 5 regions.
As can be seen from the above picture, most of the southwest of the study area belongs to the area with greater risk of roof water gushing (inrush). The range of water diversion fracture zone and the bottom boundary of aquifer in this area is large, and the water-rich is relatively strong, which has a great influence on the safe production of the mine. It has been verified in the middle of the actual mining process in the first plate area. The scope of the relative risk area in the study area is larger; the small area in the middle of the coal mine is a relatively safe area, the degree of water richness is small, and the threat to the safety of mine production is small. The moderate risk areas are alternately distributed in the above areas (Fig. 8).

### 6. Discussion

In the study of water-rich zoning prediction of coal seam roof aquifer, it is found that coefficient of permeability and lithological association index are relatively complex coefficient, indicating that these indexes are correlated with other indexes, which accords with the degree of formation of aquifer itself. Moreover, consideration should be given to the amount of water available under gravity release underwater. Compared with water-rich index method, the accuracy of aquifer water-rich partition prediction obtained by combining weight-TOPSIS method is higher because this method doesn't depend on group idea at algorithm level. Meanwhile TOPSIS method considers the distance between evaluation factor and optimal worst solution, while natural discontinuous method is reasonable for different regions. This method provides a new idea for application of water-rich evaluation model in coal mine with lower hydrogeological investigation degree.

In coal seam roof cracking safety evaluation, previous researches indicate that roof is fractured risk zone in the study zone, but through analyzing relevant data, there is a layer of sandstone and mudstone intersecting along aquifer bottom, which can slow down disturbance failure degree of hydraulic fracture zone.

### 7. Conclusion

Luohe formation sandstone aquifer is main aquifer in mine. Water rich in space is widely developed. Considering geological and hydrogeological data of mining area comprehensively considering five factors including lithologic association index aquifer thickness and core taking rate besides including permeability coefficient and TDS etc. Furthermore, combining with the principle of differential maximization, subjective and objective weights of main control factors determined separately by means of GI method and independence weight method are combined respectively.
According to TOPSIS method combined with specification partition threshold was determined and compared with unit water inflow data obtained by drilling hole drilling method proved that this method has better effect.

Because the fracture zone of water guide zone has broken down the bottom boundary of Luohe formation aquifer fracture zone is divided into risk zone and serious danger zone which can be used to determine the distance between coal mining disturbed aquifer more accurately instead of the safety zoning map of collapse zone in traditional method.

By adding aquifer rich water partition diagram and roof crack safety zoning diagram to generate water inrush risk zoning diagram of coal seam roof aquifer it is found that water rich in aquifer of Luohe formation in research area increases gradually from southwest to northeast.

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Figures
Figure 1

Location of the study area and topography and geomorphology Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

The division map of groundwater system (adapted from Mu) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of
Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

**Figure 3**

Contour map of each main control factor
Figure 4

(a) Variation map of buried depth of water level

(b) Color TV observation map of borehole

Measured partial map of WFFZ
Figure 5

Contour map of the height of the WFFZ
Figure 6

Zoning map of water-rich degree of aquifer in Luohe formation
Figure 7

Zoning diagram of crack degree of coal seam roof
Figure 8

Zoning map of water inrush from coal roof