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A Water-Inrush Risk Assessment Based on Geographic Information System/Analytic Hierarchy Process Analysis—Case Study of the Shanghaimiao Coal Mine, China

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Abstract Water inrush through a coal seam roof is one of the major threats to coal mining safety. Accurate prediction of the potential water flux is critical for both mining safety and mine operation. This study uses a quantitative approach to evaluate the risk of water inrush in a coal mining operation. This novel approach involves conducting a comprehensive analysis by utilizing the lithology and lithofacies change, tectonic field, groundwater chemical field, and a pumping test data set of the aquifers in a geographic information system (GIS) and analytic hierarchy process (AHP) process, which can be coupled with future numerical groundwater flow simulation. The test site is the No. 8 coal seam at the New Shanghai No. 1 Mine in Inner Mongolia, China. The results indicate that (1) the risk of water inrush is higher in the north section of the study area because of the abundance of well water in the roof aquifer, the maximum roof deformation, and the large thickness ratio between brittle and plastic rocks, and that (2) the safe area, lower safe area, transition area, lower danger area, and danger area account for, respectively, 26.39%, 6.28%, 56.84%, 9.32%, and 1.17% of the entire mine area, and the high-risk areas are mainly distributed in the northern region.
Keywords water-inrush,hydrogeology, roofing aquifer, mining safety, AHP

Introduction

Water inrush through a coal seam roof is one of the major threats to coal mining safety. Accurate prediction of the potential water flow is critical for both mining safety and mine operation. Numerous studies have investigated the water-inrush mechanism of the coal mine roof. (Chen et al. 2010) developed a physical model to simulate the roof water inrush for a gold mine in Shandong Province. However, their lack of a quantitative analysis may have caused deviation in the results. The recent development of geographic information systems (GIS) has stimulated various studies of the water inrush in coal seams. By coupling GIS and artificial neural networks (ANN), Wu et al. 2006 established a vulnerability forecasting model of the floor groundwater outburst. Dong et al. 2013 applied an analytic hierarchy process (AHP) with GIS in a groundwater risk assessment of the third aquifer in Tianjin City, China.

The objective of the present study is to develop a GIS- and AHP-based quantitative and comprehensive zoning scheme for water inrush in the roofing aquifer of the No.8 coal seam near the New Shanghai No.1 Mine in Inner Mongolia, China. Data sets on the lithology and lithofacies change, tectonic convergence, geological deformation characteristics, and pumping tests are used in this study.

Materials and methods

Study area

The New Shanghai No. 1 Mine, which is located in Etukeqian County of the Inner Mongolia Autonomous Region in China (fig.1), was established in 2008 by the Inner Mongolia

Shanghai Coal Mining Bureau. It has abundant high-quality coal resource reserves with low ash, low sulfur, low phosphorus, and a high heat capacity(Qin et al. 1999). Four water-inrush accidents with a flow rate of less than 20 m^3/h occurred in the course of mine construction.

The roof of the main coal seam, the No. 8 coal seam of the New Shanghai No. 1 Mine, consists mainly of mud rock and sandy mudstone, with parts of siltstone, post stone, and medium coarse sandstone.

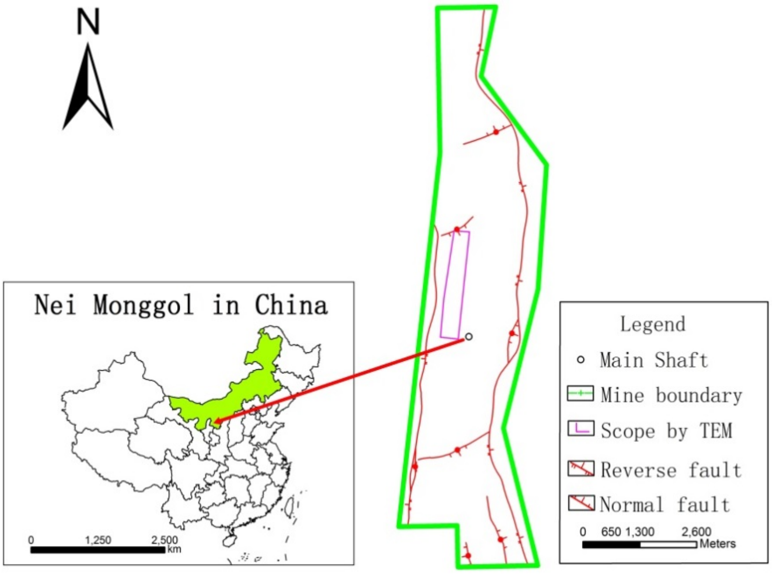

Fig. 1 *Location of the New Shanghai No. 1 Mine in Inner Mongolia, China.*

Hydrogeology in the New Shanghai No. 1 Mine, Inner Mongolia

The coal seam is located in the western Ordos Basin, which has strong and integrated rock strata. The two major sandstone aquifers from the Cenozoic Erathem are a Quaternary system and a bedrock fracture system with a general flow direction from northeast to southwest.

Main controlling factors of the roofing aquifer on the No. 8 coal seam

The roofing aquifer systems on top of the No. 8 coal seam are the Yanchangzu aquifer and the sandstone aquifer at the bottom of Zhiluozu strata. The No. 8 coal seam roof directly exposes the Yanchangzu aquifer, and groundwater can flow into the mine after the roof caves. In addition, there is a close relationship between the Yanchangzu aquifer and the bottom aquifer of the Zhiluozu strata, and groundwater may enter the mine in this way. The following geological controlling factors (Dong et al. 2007) were defined in this study, based on the characteristics of the roofing aquifers and the coal seam roof (fig.2).

Water-rich classifications for the roofing aquifer

Two classification systems are used for the roofing aquifer: characteristics of the lithology and lithofacies, and characteristics identified by pumping tests. Characteristics of the lithology and lithofacies are based on the thickness ratio between brittle rock and plastic rock and the thickness of the aquifer. The thickness ratio between brittle rock and plastic rock of the aquifer ranges from 4.3 to 13.31 m, and the thickness of the aquifer ranges from 23.82 to 127.85 m. Characteristics identified by pumping tests are the specific capacity, with values ranging from 0.0117 to 0.1234 L/s/m, and the average hydraulic conductivity (K), with values ranging from 0.0432 to 0.344 m/d.

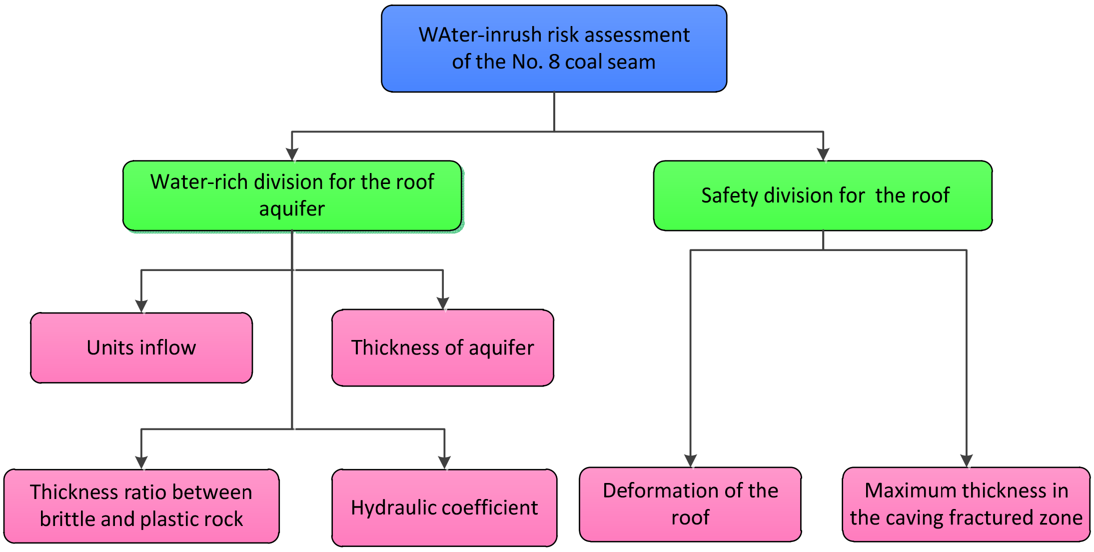

Fig. 2 *The main controlling factors constituting the hierarchical graph.*

Safety classifications for the roof

Two classification systems are used to determine the safety of the roof: the deformation of the roof and the maximum thickness in the caving fractured zone. The overlying rock of the No. 8 coal seam roof is soft and medium soft rock. We simulated the maximum thickness in the caving fractured zone by using the Flac3D modeling code, optimized the results using the empirical formulae, and then calculated the deformation of the roof by using existing methods(Su 2005, Wang 2005).

Table 1 *Weight of each controlling factor by the analytic hierarchy process*

Controlling factor	Weight
Specific capacity	0.3138
Thickness of the aquifer	0.2099
Thickness ratio between brittle and plastic rocks	0.0857
Hydraulic conductivity	0.0573
Deformation of the roof	0.2222
Maximum thickness in the caving fractured zone	0.1111

Notes: A consistency check resulted a consistency ratio (CR) of 0.040, which indicates the matrix has a reasonable consistency because the CR is less than 0.10

A quantitative and comprehensive zoning scheme of water inrush was developed according to the following steps:

Step1: Establish an index system to reflect the condition of the water-inrush risk. In this study, the evaluation index system, presented as a water-inrush risk model, established six factors from the two classification systems: water-rich classifications for the roofing aquifer and the safety classifications (fig.2).

Step2: Determine the weight of each controlling factor by the AHP. Recently, numerous researchers have developed various approaches to determine the weight of the AHP mode. In this study, the AHP weights were determined by a multi-criteria system (table 1). Based on the experts' judgment, each controlling factor was divided into five grades, and the corresponding score for each grade ranged from 0 to 100, in intervals of 20.

These grades of water-inrush risk assessment are as follows: safe area, less safe area, transition area, less danger area, and danger area.

Step3: A raster overlay algorithm was applied to determine the comprehensive zoning scheme for each controlling factor in the study area(fig.3). The raster map for each controlling factor was multiplied by the corresponding weight determined by the AHP. The raster maps for all six controlling factors were integrated into one assessment layer by summing the weighted grade in each raster, which is the comprehensive zoning scheme of the water-inrush risk assessment of the No. 8 coal seam roof.

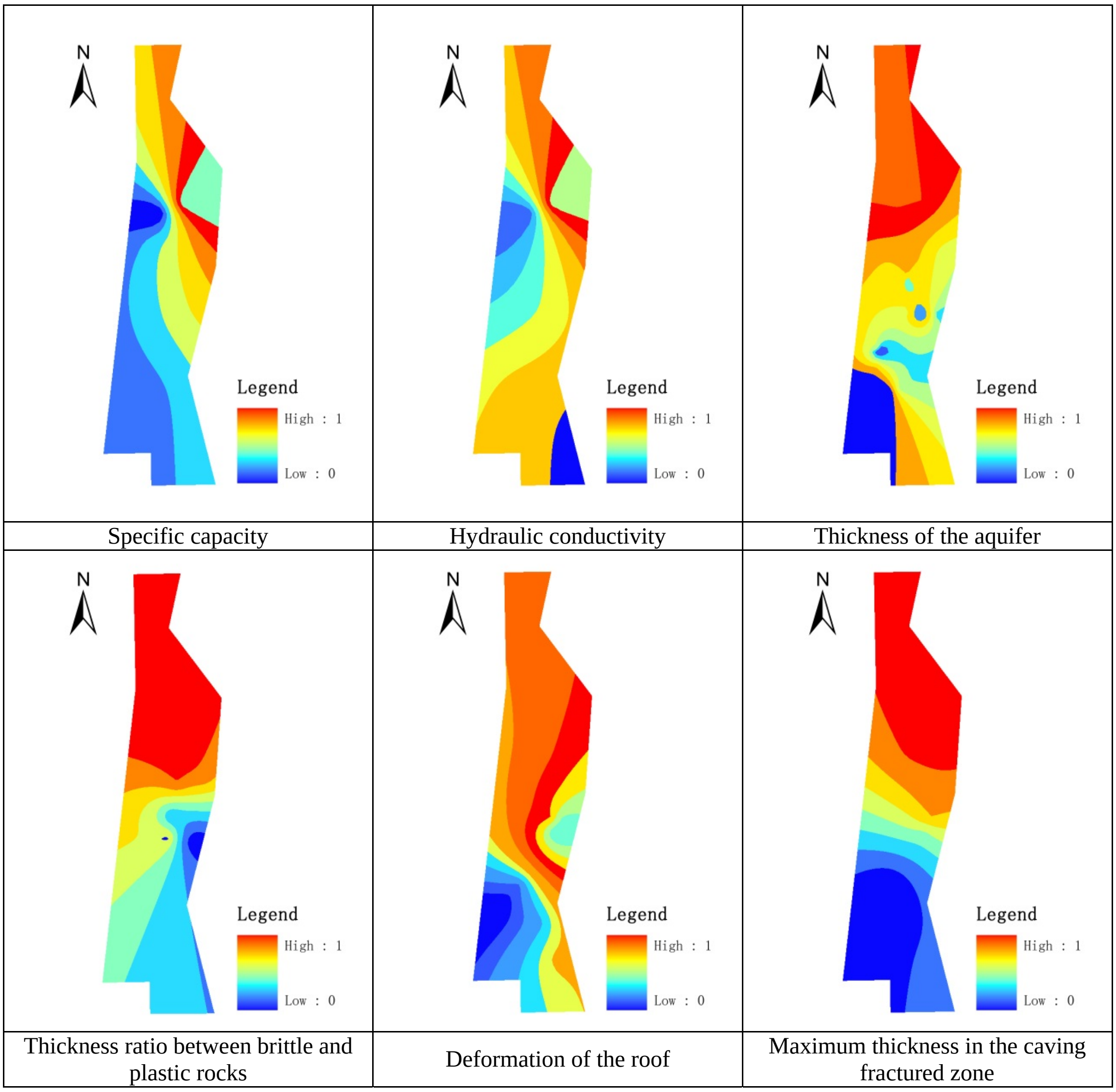

Fig. 3. *Maps of each controlling factor with standardization values between 0 (blue) and 1 (red) before being multiplied by*

Results and discussion

The specific capacity, thickness of the aquifer, thickness ratio between brittle and plastic rocks, hydraulic conductivity, deformation of the roof, and maximum thickness in the caving fractured zone are mapped in fig.3. Data sets of the deformation of the roof and the maximum thickness in the caving fractured zone were calculated by building a Flac3D model. Fig. 4 shows the comprehensive zoning scheme of water-inrush risk assessment of the No. 8 coal seam roof.

The less danger area and the danger area are approximately 10.49% of the entire study site (table 2). Generally, these areas have an abundance of well water in the roof aquifer, maximum deformation of the roof, and a greater thickness ratio between brittle and plastic rocks, which may increase the risk of water inrush.

Table 2. *Size of the area with different risk grades*

Risk grade	Area (km^2)	Percentage
Safe area	7.02	26.39
Less safe area	1.67	6.28
Transition area	15.12	56.84
Less danger area	2.48	9.32
Danger area	0.31	1.17

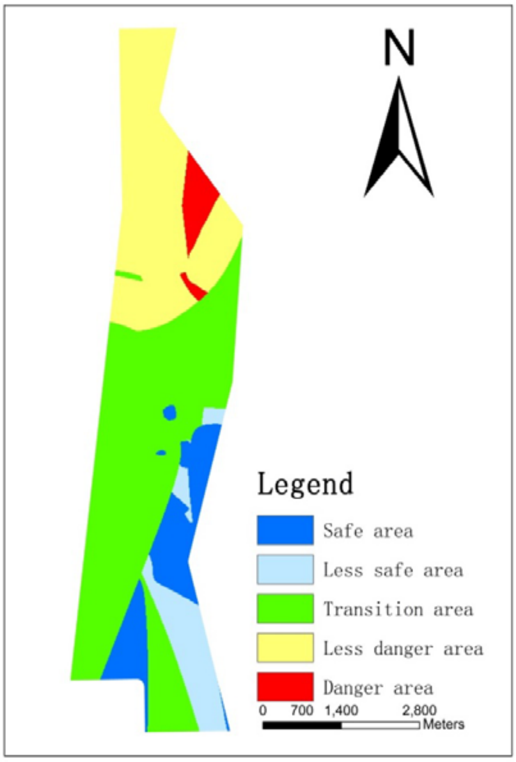

Fig. 4 *Comprehensive zoning scheme for the water-inrush risk assessment of the No. 8 coal seam roof*

Conclusions

In this study, the comprehensive zoning scheme for the water-inrush risk assessment of the No.8 coal seam roof near the New Shanghai No.1 Mine in Inner Mongolia was developed by using GIS and AHP. The following main conclusions were reached:

In general, the abundance of well water in the roof aquifer, maximum roof deformation, and large thickness ratio between brittle and plastic rocks increase the possibility of water inrush in the northern section of the study area.

The safe area, less safe area, transition area, less danger area, and danger area make up, respectively, approximately 26.39%, 6.28%, 56.84%, 9.32%, and 1.17% of the study area. The high-risk areas are distributed mainly in the northern region.

References

Berry PM, Dawson TP, Harrison PA, Pearson R, Butt N (2003) The sensitivity and vulnerability of terrestrial habitats and species in Britain and Ireland to climate change. Journal for Nature Conservation 11(1):15-23

Chen H, Li X, Liu A, Peng S, He X (2010) Physical simulation modeling of roof water inrush in underwater mining. Journal of China University of Mining and Technology 39(6): 854-859

Dong D, Sun W, Zhu Z, Xi S, Lin G (2013) Groundwater risk assessment of the third aquifer in Tianjin City, China. Water resources management 27(8): 3179-3190

Dong D, Wu Q, Zhang R, Song Y, Chen S, Li P, Liu S, Lv Z, Huang S(2007) Environmental characteristics of groundwater: an application of PCA to water chemistry analysis in Yulin. Journal of China University of Mining and Technology 17(1): 73-77

Hu G, Jin Z (2006) Research on distribution laws of abutment pressure in large mining height workface by FLAC3D simulation . Shanxi Coal 26(2):10-12

Luan Y, Li J, Ban X, Sang C, Zhang C, Ma D(2010) Observational research on the height of water flowing fractured zone in repeated mining of short-distance coal seams. Journal of Mining & Safety Engineering 1: 029

Qin J, Zhang Y(1999) Application of cortemporary statistical information analysis method in safety engineering: the principle of AHP. Safety and Environmental Protection Research Institute (5): 44-48

Su B (2005) Study on the apical plate of the water-inrush mechanism and the technique of prevention and harnessing in Huafeng Coal Mine. Shandong University of Science and Technology: Qingdao

Wang X (2005) Probe in mechanism of roof water burst in mines. Shandong University of Science and Technology: Qingdao

Wu Q, Pang W, Dai Y, Yu J (2006) Vulnerability forecasting model based on coupling technique of GIS and ANN in floor groundwater bursting. Journal of China Coal Society 31(3): 314-319

Wu Q, Xie S, Pei Z, Ma J (2007) A new practical methodology of the coal floor water bursting evaluating III: the application of ANN vulnerable index method based on GIS. Journal of China Coal Society 32(12): 1301-1306

Zheng J(2009) On selection for loading station location of railway in New Shanghai No. 1 Coal Mine. Shanxi Architecture 35(31): 31-32