CHEMICAL ENGINEERING TRANSACTIONS
VOL. 67, 2018
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Valerio Cozzani, Bruno Fabiano, Davide Manca

ISBN 978-88-95608-64-8; **ISSN** 2283-9216
DOI: 10.3303/CET1867018

Risk Assessment Method of Goaf Water Hazard in Coal Mine: Application of GIS-based AHP Vulnerability Index Method

Jian Zhao[a]*, Bin Peng[b], Yanhui Shen[a], Yonggang Wang [a]

[a]School of Optoelectronic Engineering, Zaozhuang University, Zaozhuang 277160, China PowerChina, Guizhou Electric Power Design & Research Institute Corporation Limited, Guiyang Guizhou 550023 China
[b]Administration of Work Safety of Shuicheng country, Shuicheng 553600, China
23498742@qq.com

To solve the difficulties with predicting and evaluating the goaf water hazard in coal mines, taking the goaf water hazard of one certain coal mine in Shuicheng County, Guizhou Province as the research object, the newly proposed GIS-based AHP vulnerability index method was applied in this paper, on the basis of the proposed master control index system of goaf water and the vulnerability index method. Through the detailed analysis of the geological condition, hydrogeological condition and goaf water hazards law of the mining area, the 12 main control factors affecting the goaf water hazards in the coal mines were determined. Then, the powerful data management and spatial analysis functions of GIS were applied to build the thematic maps and hierarchical graphs of the 12 main control factors for the goaf water hazards in coal mine. The AHP method was adopted to determine the weight contribution of each main control factor in forming goaf water hazards in coal mines. In this way, one GIS-based AHP vulnerability assessment model of goaf water in coal mine was constructed. Finally, according to the vulnerability index statistical chart of coal mine goaf water hazard obtained, the zoning threshold of goaf water hazard vulnerability was determined and analyzed, which was used to make zoning of the goaf water hazards and obtain the prediction map of coal mine water hazards, thus eventually achieving the zoning features of goaf water hazards in coal mines.

1. Introduction

In recent years, with the increase of coal mining depth, the increase in intensity, and the large-scale development of lower group coal in China, the geological conditions for mine exploitation have become increasingly complex and changeable (Arpan and Debashish, 2018; Nevaid et al., 2018; Wu et al., 2009). In some areas of small coal mines that are closed or stopped for a long time in the mining area, there have accumulated goaf water. Such water hazard is hidden and random, often causing the catastrophic consequences (Ding, 2013), as one of the major disasters affecting the coal mine production and construction. Due to the water hazards, the mines stop production, or there even occur to the accidents of submerging the mine from time to time, thus, the economic losses caused are enormous (Liu and Li, 1992; Chu, 1995; Ma and Meng, 2013). The goaf water hazards in coal mines have brought great challenges to the safe mining of coal resources.

As the mining goes on year by year, surface water has introduced into the goaf near the surface through cracks and subsidence areas, threatening the mine excavation area and the mining working face. The goaf water has caused certain impacts on the normal production and mining activities of coal mine. Traditional prediction method of goaf water hazards in coal mines cannot reflect well the goaf water hazard mechanism under the comprehensive influence of various control factors. Therefore, the new technology and new method should be adopted to study the vulnerability of goaf water hazards in coal mines, so as to achieve the source control of goaf water hazard factors in coal mines and advance prevention of accidents. It can effectively restrain the occurrence of major accidents in coal mines, which thus is of great significance for the sustainable development of China’s coal industry (Wu et al., 2007; Wu et al., 2007; Wu et al., 2007).

Please cite this article as: Zhao J., Peng B., Shen Y., Wang Y., 2018, Risk assessment method of goaf water hazard in coal mine: application of gis-based ahp vulnerability index method, Chemical Engineering Transactions, 67, 103-108 DOI: 10.3303/CET1867018

2. Research area

The coal mine is located in Shuicheng County, Liupanshui City, Guizhou Province. The mine lies in the transitional zone between the eastern Yunnan Plateau and the central Guizhou Plateau. It has the landforms of structural erosion and denudation of the low-middle-mountain. The overall topography of the mining area is high in the South and East, low in the north and west. The highest point is at the top of the hill near the inflection point No. 10 on the southern boundary of the mining area, with an elevation of 1984.02m. The lowest point is in the north of the turning point 0 in the western part of the mining area, with an elevation of about 1750m, and the maximum relative height difference is 234m. Most of the rock mass is bare, and the topographic slope angle is 5°-30°, generally 12°-20°, with the mining area of 400,850 m^2. According to the weather observation data of the Shuicheng Weather Station, the average annual precipitation in this area is 1,223.6mm. The coal mine is located in the midstream of the east side of the Xiaohe River ramp in the Weining North West structural deformation zone from the Yangtze Platform to the North Guizhou Tailong to Liupanshui Fault Depression. The faults and folds are well developed in the area. The rock formation is monoclinic and the stratum trend is 145°-175°, tilt angle 36° to 43°, about 40°on average. The tectonic lines are generally distributed in the northeast direction. During the production process, it's found that there are two large faults and the small faults are more developed.

3. Geographic information system (GIS) and analytic hierarchy process (AHP)

Geographic Information System (GIS) has powerful spatial information processing and analysis function. It has the characteristics of processing spatial information with many influencing factors, inaccurate conditions, and huge information volume. In addition, the spatial composite superposition function of GIS is used to process the output, and the spatial distribution results of the goaf water hazard vulnerability in coal mine are given in the form of visual map (Chen, 1999). Analytic Hierarchy Process (AHP) has strong advantages in dealing with uncertainties and some subjective information. The goaf water hazards in coal mines are characterized by multiple control factors and uncertain conditions. The use of AHP can comprehensively analyze the factors that control the goaf water hazards, and then make a reasonable assessment of goaf water hazards in coal mines by combining the effects of various factors (Saaty, 1980).

4. Vulnerability index method for evaluating goaf water hazard in coal mine

4.1 Determining the weight of each evaluation factor based on AHP method

4.1.1 Set goals and evaluation factors

The general purpose for AHP is to make risk assessment of the goaf water hazard in coal mines. Taking the mechanism and influencing factors of the goaf water hazards into consideration, a total of 12 evaluation factors were selected, including A-goaf water, B-transmission fissure zone, C-average annual rainfall, and D-infiltration coefficient. E- topographic slope, F-aeration zone type, G-average permeability coefficient, H-old mine goaf, I-intersection of fault and its endpoint distribution, J-density of fault, K-index of fault scale, L-specific capacity respectively.

4.1.2 Construct judgment matrix

According to the index system, by using the scale method, expert consultation method, and questionnaire survey, eight experts in the field were selected to respectively rate the importance of the indicators, and then the rating results were further discussed and summarized internally, to obtain the two-by-two judgment matrix S.

MATLAB software was applied to calculate the largest eigenvalue of judgment matrix *S*, λ_{max}=11.7342, and eigenvector w={0.0846,0.0805,0.0782,0.1553,0.0477,0.0477,0.0885,0.0279,0.0885,0.0885,0.1649,0.0477}.

4.1.3 Consistency check

For the consistency check of the judgment matrix, the consistency index needs to be calculated.

$$CI = \frac{\lambda_{\max} - n}{n - 1} = \frac{11.7342 - 12}{12 - 1} = -0.0242$$

At n=13, the average random consistency index was obtained by looking up the table. Random consistency ratio:

$$CR = \frac{CI}{RI} = \frac{-0.0242}{1.54} = -0.0157 < 0.10$$

Therefore, it is believed that the soring results based on AHP have satisfactory consistency, that is, the allocation of weight coefficients is very reasonable. The weight coefficient values of all indicators are shown in Table 1.

Table 1: Weight allocation of risk assessment index for goaf water hazards

Index	A	B	C	D	E	F	G
Weight	0.0846	0.0805	0.0782	0.1553	0.0477	0.0477	0.0885
Index	H	I	J	K	L		
Weight	0.0279	0.0885	0.0885	0.1649	0.0477		

4.2 Evaluation results and analysis

4.2.1 Hierarchical graph of goaf water hazard assessment index in coal mine

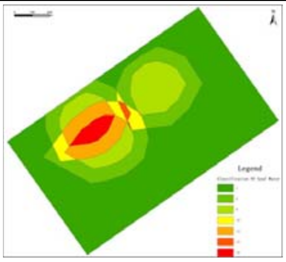
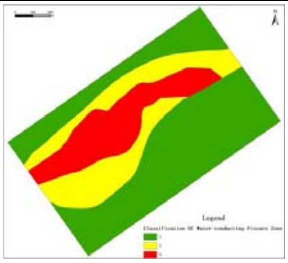
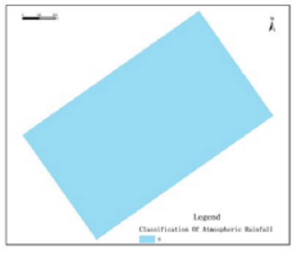
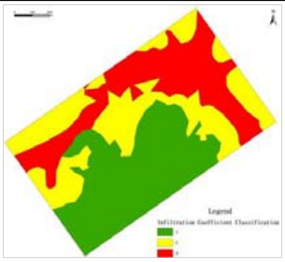
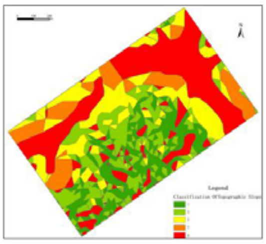
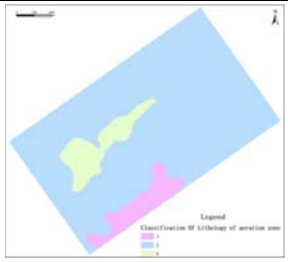
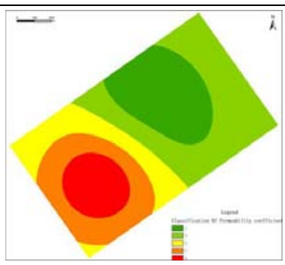
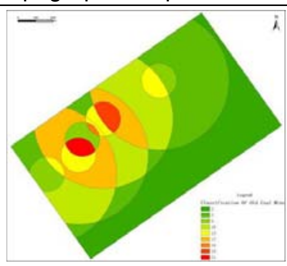
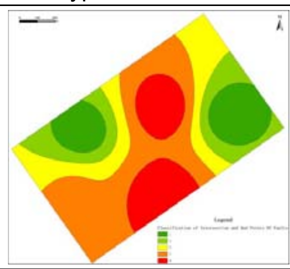
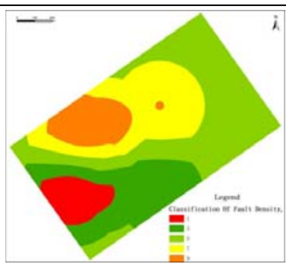
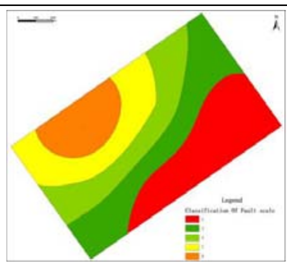
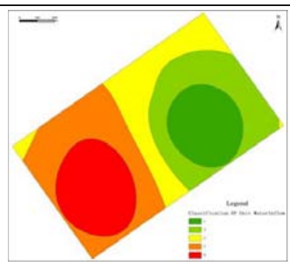
		
1. Hierarchical graphs of old mine goaf	2. Hierarchical graphs of transmission fissure zone	3. Hierarchical graphs of annual rainfall
		
4. Hierarchical graphs of infiltration coefficient	5. Hierarchical graphs of topographic slope	6. Hierarchical graphs of aeration zone type
		
7. Hierarchical graphs of average permeability coefficient	8. Hierarchical graphs of old mine goaf	9. Hierarchical graphs of the intersection of fault and its endpoint distribution
		
10. Hierarchical graphs of fault density	11. Hierarchical graphs of index of Fault scale	12. Hierarchical graphs of specific capacity

Figure 1: Hierarchical graphs of water hazard assessment factor in old mine goaf

In the GIS-based Hierarchical graphs of each evaluation indicator for coal mine goaf-water hazard (Fig.2), the red zone to dark green zone indicates the distribution of the quantified value from high to low. The higher the value, the greater the impact on the goaf water hazard of the coal mine. That is, the red zone has the greatest impact on the goaf water in coal mines, and the dark green zone has the smallest.

4.2.2 Goaf-water hazard risk assessment model in coal mine

The coal mine goaf-water hazard risk assessment model is actually a mathematical model that shows the effect of various evaluation indicators on the goaf water hazards. The calculated values obtained from this model can reflect the hazard level of coal mine goaf-water at certain geographical location.

the goaf-water hazard risk assessment model in Dongfeng Coal Mine is:

$$VI = \sum_{K=1}^{n} W_K \cdot f_k(x,y) = 0.0846\, f_B(x,y) + 0.0805\, f_C(x,y) + 0.0782 f_D(x,y) + 0.1553 f_E(x,y) + 0.0477 f_F(x,y) + 0.0477\, f_G(x,y) + 0.0885 f_H(x,y) + 0.0279 f_I(x,y) + 0.0885 f_J(x,y) + 0.0885\, f_K(x,y) + 0.1649\, f_L(x,y) + 0.0477\, f_M(x,y) + 0.0458\, f_N(x,y)$$

4.2.3 Determine the zoning threshold

Based on the model calculations above, the formula was input into the ARCGIS attribute database, to obtain the vulnerability index (VI) of the research area. The greater the VI, the higher the possibility of the goaf water hazard in coal mines. Using the statistics function of GIS, the statistical chart of coal mines goaf-water VI (Fig.2) was obtained, with a maximum of 3.829, a minimum of 9.152, an average of 3.21479, and a standard deviation of 1.055197, which further determines the zoning threshold 4.3, 5.7, 6.8, 7.7.

According to the VI zoning threshold, the research area was divided into five zones: $VI > 7.7$ means higher-risk zone; $6.8 < VI \le 7.7$ is the high-risk zone; $5.7 < VI \le 6.8$ is medium-risk zone; $4.3 < VI \le 5.7$ is low-risk zone; $VI \le 4.3$ is the lower-risk zone.

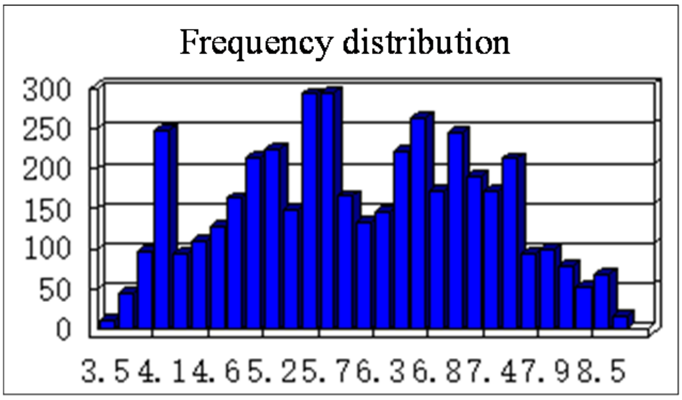


Figure 2: Statistical chart of vulnerability index

4.2.4 Coal mine goaf-water hazard risk assessment division and features

(1) Coal mine goaf-water hazard risk assessment division

Using the GIS spatial analysis function, according to the zoning threshold, the goaf-water hazards in coal mines were divided into five zones: low-risk zone, lower-risk danger zone, medium-risk zone, high-risk zone and higher-risk zone, so as to obtain the zoning map of goaf-water hazard prediction in coal mine (Fig.3).

(2) Zoning characteristics of goaf-water hazards in coal mines

The total area of coal mine is 400,850m^2. The main sources of coal mine goaf water are atmospheric precipitation and the impact of small rivers.

1) The area of higher-risk zone is 21,225m^2, accounting for 5.29% of the total area. In terms of regional characteristics, it's mainly distributed in the northwestern part of the coal mine. There are 2 goaf waters in this area at large volume. The old mine goafs are concentrated at gentle topographic slope. The infiltration coefficient is large, and it's easy to supply water for the goaf. The density of faults exposed by mining is large, the rock in the fault zone is broken, with large specific capacity, and there is a high possibility of water-guiding fissures penetrating.

2) The area of high-risk zone is 116,556m^2, accounting for 29.08% of the total area. In terms of the regional characteristics, it's mainly located in the northwest and northeast of coal mines, and within the influence range of goaf water. The old mine goaf is concentrated, at the relatively gentle topographic slope. The infiltration

coefficient is relatively large, and it's easy to form water hazards. The exposed geological faults are relatively developed, and the lithology of the fault zone is relatively broken, at the large specific capacity.

3) The area of medium-risk zone is 134,005m^2, accounting for 33.43% of the total area. In terms of its regional characteristics, it's mainly distributed in the southwestern part and the northeastern part of the coal mine. This area is located at the edge of two goaf waters and within the influence scope of one goaf-water site. It remains in the medium range in the aspects such as topographic slope, the possibility of penetrating water-guiding fissures, the development of geological structures, and specific capacity.

4) The area of lower-risk zone is 103,079m^2, accounting for 25.72% of the total area. In terms of its regional characteristics, it's mainly distributed in the south eastern part and the north eastern part of the coal mine. It is located at the edge of the mining area, outside the influence scope of goaf water, with only one small part in the old mine goaf at the edge zone of geological structure. There is small specific capacity, and less possibility of penetrating the transmission fissure zone.

5) The area of the low-risk area is 25,985 m^2, accounting for 6.480% of the total area. In terms of its regional characteristics, it's mainly distributed in the south eastern part of the coal mine. Without being affected by the goaf waters that have been detected and the old mine goaf, the geological structure is not developed, the lithology of coal mine roof is mainly mudstone with strong water-blocking ability, and the influence of transmission fissure zone is small. However, due to the fact that this area is in the affected zone of surface water, it is still necessary to strengthen the hydrogeological investigation, and waterproof measures must be taken to make water prevention and control according to the *Coal Mine Safety Regulations*, *Provisions of Coal Mine Water Prevention and Control*, and *Guizhou Coal Mine Water Harm Prevention Regulations* etc.

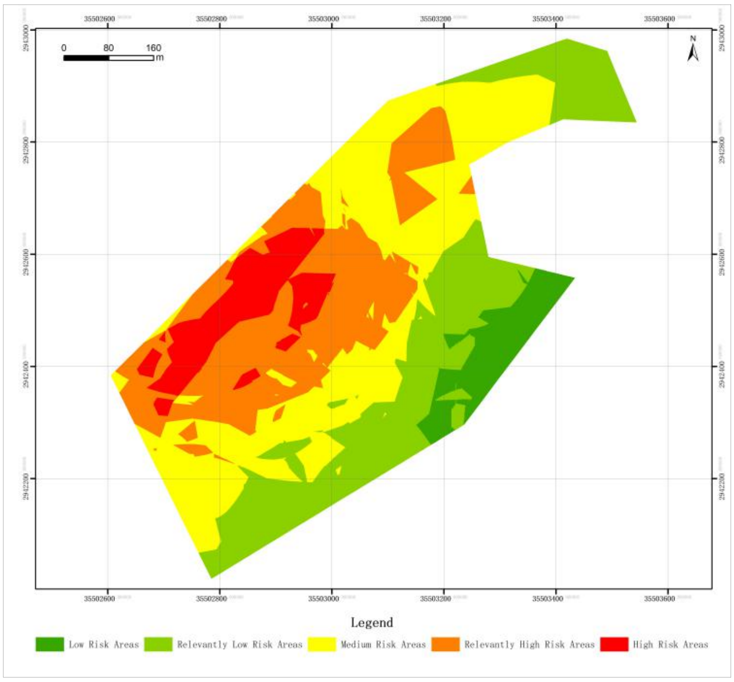


Figure 3: Partition map of water disaster forecast in old mine goaf

5. Conclusions and suggestions

Based on previous research on the influencing factors of coal mines' old air and water damage, and drawing on expert guidance, combined with the actual conditions of the mining area, the 12 major factors were taken as the main influencing factors on the coal mine goaf-water hazards, including goaf water, transmission fissure zone, multi-year average rainfall, infiltration coefficient, topographic slope, aeration zone type, average permeability coefficient, old mine goaf, intersection of fault and its endpoint distribution, density of fault, index of fault scale, and specific capacity. Their combined action affects the evolution process of goaf water hazards in coal mines.

According to the main control factor system for the goaf-water hazards in coal mines, the evaluation weight, evaluation model, and zoning thresholds of each factor were determined to ensure the accuracy of data overlay and the rationality of the evaluation model. GIS's powerful data analysis, processing, and display capability were applied to build the thematic map of each main control factor.

Through the GIS-based AHP Vulnerability Index Evaluation Model, the risk division and characteristics of coal mine goaf-water hazard were made, namely, low-risk zone, lower-risk zone, medium-risk zone, high-risk zone and higher-risk zone. Thus, the zoning chart for the prediction of the goaf-water hazards in coal mine was obtained.

This paper only discusses the GIS-based AHP vulnerability index method. In reality, there are other similar methods that are combined with GIS to form a set of complete evaluation system for coal mine goaf-water vulnerability index method.

Reference

Arpan H., Debashish C., 2018, Wireless relay placement optimization in underground room and pillar mines, Mathematical Modelling of Engineering Problems, 5(2), 67-75, DOI: 10.18280/mmep.050203

Chen S.P., 1999, Introduction of geographic information system, Beijing: Science press.

Chu S.L., 1995, Application of Mine Geophysical Prospecting, Beijing: Coal Industry Press.

Ding L., 2013, Early Warning System for Coal Mine Water Hazards Based on GIS, Mining Safety & Environmental Protection, 40(2), 46-51, DOI: 10.3969/j.issn.1008-4495.2013.02.015

Liu T.F., Li Z.P., 1992, Mine Geophysical Prospecting, Beijing: China Coal Industry Press.

Ma Y.J., Meng M., 2013, The application of TEM in detecting water hazards in coal mines, China New Technologies and New Products, 12, 63, DOI: 10.3969/j.issn.1673-9957.2013.12.123

Nevaid D., Krishna R., Chanda M.W., 2018, Design and dimensioning of sublevel stoping for extraction of thin ore (< 12 m) at very deep level: a case study of konkola copper mines (kcm), Zambia, Mathematical Modelling of Engineering Problems, 5(1),27-32, DOI: 10.18280/mmep.050104

Saaty T.L., 1980, The analytic hierarchy process, New York M cG raw-Hill.

Wu Q., Wang J.H., Liu D.H., Cui F.P., Liu S.Q., 2009, A new practical methodology of the coal floor water bursting evaluating □: the application of AHP vulnerable index method based on GIS, Journalof China Coal Society, 34(2), 233-238.

Wu Q., Xie S.H., Pei Z.I., 2007, A new practical methodology of the coal floor water bursting evaluating □: the application of ANN vulnerable index method based on GIS, Journal of ChinaCoal Society, 32(12), 1301-1306, DOI: 10.3321/j.issn:0253-9993.2007.12.014

Wu Q., Zhang Z.L., Ma J.F., 2007, A new practical methodology of the coal floor water bursting evaluating I-the master controlling index system construction, Journal of China Coal Society, 32(1), 42-47, DOI: 10.3321/j.issn:0253-9993.2007.01.009

Wu Q., Zhang Z.L., Zhang S.Y., Ma J.F., 2007, A new practical methodology of the coal floor water bursting evaluating II: the vulnerable index method, Journal of China Coal Society, 2007, 32(11), 1121-1126.