

New Mine Geological Environment Impact Assessment Method

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Abstract: Building an assessment framework and corresponding index system applicable to geological environment impact assessment (GEIM) for new mines contributes to supervision and protection of the geological environment of mines. Taking GEIM of a limestone mine to be built in Chongzhou as a case, this study, by making use of analytic hierarchy process and subsequent transformation from qualitative to quantitative variables, established the quantitative assessment and the zoning assessment system in terms of the following four aspects, namely geological environment of the mine, geological disaster risks, the influence of mining on groundwater environment, and its impact on land and landscape resources. The current study employed multi-objective linear weighting function to form mathematical model and then worked out environmental quality scores and the zonations, which were expected to reflect the characteristics of the geological environment of the mine. Besides, the assessment results were analyzed so as to provide important reference for predictions on possible environmental impact brought by the mine and for comprehensive treatment of the geological environment.

Keywords: Environmental impact assessment; A new mine; Analytic Hierarchy Process; The multi-objective linear weighting function method

Introduction

Mine geological environment refers to a relatively independent environmental system formed by material exchange and energy transport between mineral deposit as well as its surrounding lithospheric surface (*i.e.*, rock, mineral, soil, groundwater, geological processes and geological phenomena) affected by the mining activities, and the atmosphere, water, and biosphere. The interaction of all mining practices such as mining, mineral separation and subsequent mineral processing with mine geological environment may lead to geological environmental damages such as slope instability and land occupation as well as water and soil pollution (M Monjezi, 2009).

Plenty of work has been done to identify geological hazards or the subsequent impacts on property and human safety resulting from mining

(LI Yan, 2005; MU Qi-chao, 2012; WEI Yi-qiang, 2010). However, due to the diverse and complex factors responsible for geological environment impacts of mining, there has been no widely accepted methodological strategy to integrate the plentiful information and multiple indices relating with the evaluation. The typical methods reported such as grey comprehensive evaluation by JIANG Fu-liang (2009) and fuzzy synthesis evaluation by YANG Mei-zhong (2006) dealt with the evaluation involving in expert personal judgment with vagueness and ambiguity to some extent. Therefore, the combination of analytic hierarchy process (AHP) and multi-objective linear weighting function (MOLF) in our study based on decisions of up to five experts were expected to lessen the flaws. Otherwise, specific considerations of assessment indices and forming structural framework for planning new mines are severely deficient according to our knowledge up to date, which are also covered in the current study.

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This study took a planning open pitting limestone mine as a case to conduct geological environmental impact assessment with proposed AHP and MOLF and the specific considerations for the planning new mine. Geological environment zonation for the mine was obtained to determine the impact levels and present relevant prevention schemes and suggestions in accordance with geological environmental conditions and environment impact levels of different zones.

Background of the Study Area

The research area is a limestone mine located in the Jiguan Mountain in Chongzhou, Sichuan, southwest of China. It is 104 km west of Chengdu city, covering an area of about 6.7 km² (Fig. 1). The Mining of limestone here is to supply cement materials demanding for the reconstruction of Wenchuan county after the 2008 Great Wenchuan Earthquake. The limestone deposit in the strata of median Permian system, and opencast mining was adopted as the main method. The limit angle of the side slope was set at 55°, and the yield was estimated at 200 Wt/a. This research was conducted based on the data collected by survey of mine geological and environmental conditions.

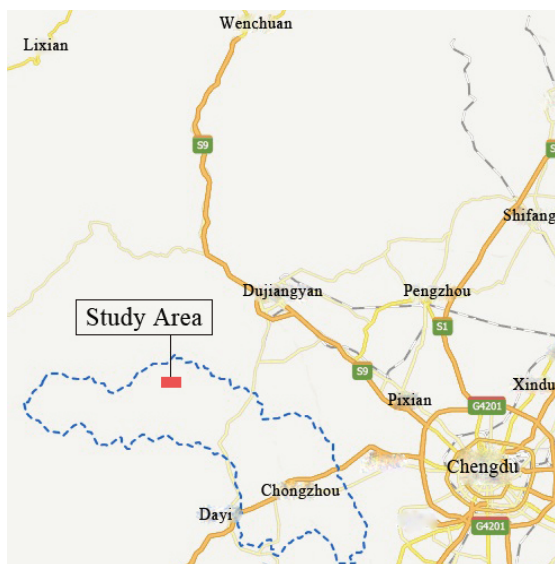


Fig. 1 Location of the study area

Methods for Geological Environment Impact Assessment of Mines

According to Requirements of Sichuan Geological Environment Impact Assessment

Technology of mine (for Trial Implementation) (2006), possible geological environment impact brought by a new mine can be summarized as follows.

- Mining activities may lead to geological disasters such as surface collapse, ground subsidence, ground fissure, mountain crack, collapse, landslide, and debris flow.
- Mining activities may result in changes in water resources and water environment, including the break of regional water balance, groundwater resource exhaustion, sea water intrusion, pit inrush, and water pollution.
- Mining activities may cause damage to land resources and soil environment, including changes in the present land use, soil and water loss, land desertification, soil pollution and so on.

GEIM especially emphasizes the forecast of geological environmental problems, namely potential geological disasters. Therefore, this study, in line with this unique feature, systematically and hierarchically analyzed the assessment, and highlighted the framework. The assessment was divided into three aspects, namely geological hazard assessment, groundwater environment impact assessment, land resources and geological relic impact assessment. Among them, geological hazard assessment was conducted through investigating the present situation of the mine, for instance, the present geological environmental conditions and the existing geological disasters. Groundwater environment impact assessment as well as land resources and geological relic impact assessment forecasted the potential impact in the future mining process in accordance with mining planning. Then, comprehensive zonation assessment for mine geological environment was conducted accordingly.

Based on the above considerations, the assessment procedures can be developed with four aspects as follows:

Index System of Geological Environment Impact Assessment of Mines. There are many complex factors influencing mine environmental geology (DENG An-yun, 2009). In line with different mine environmental geological backgrounds and mining processing ways, types, forms, quantity and seriousness of mine environmental geological problems can also be different. Based on the mine geological environment and the actual

situation of mining scheme, this study presented the following four factors influencing the mine environmental geology, namely mine geological environmental conditions, geological hazard, influence of mining on groundwater environment and its impact on land and landscape resources, these factors were taken as the basis of constructing the index system of geological environment impact assessment for mines. The final index system included three levels, four kinds of influencing factors and eleven assessment indexes. The assessment index system is shown in Fig. 2.

Weight Calculation. Analytic hierarchy process (LUO Bing-jia, 2013; HUANG Shuang-bing, 2012; QIAO Xu-jun, 2012) was used to determine the weight. Through systematic analysis, this method decomposed a complex problem into an orderly class hierarchy model (see Fig. 2), compared any two coherent factors of each class, judged and quantified the relative importance of various factors, so as to determine the weight of

assessment indexes (TANG Zhao-hui, 2012). In this study, five experts from Sichuan Geology and Mineral Exploitation Bureau and Chengdu University of Technology, who have been long engaged in geological disaster prevention and geological environmental protection, were invited to give quantitative assessment of mine geological environmental conditions and provide guidance for the assessment process. First, the five experts constructed a judgment matrix with 1-9 scaling method. The judgment matrix is shown below, and the table cells stand for the judgment of these five experts on the importance of factors. Feature vector w was obtained by sum-product method. In the weight consistency check, the index consistency ratio (CR) of these five experts was $(0.020, 0.079, 0.031, 0, 0)$, $(0.016, 0.003, 0.078, 0, 0)$, $(0.013, 0.033, 0.031, 0, 0)$, $(0.023, 0.033, 0.031, 0, 0)$ and $(0.045, 0.087, 0.078, 0, 0)$ respectively, with values all less than 0.1. Therefore, the consistency was believed to be good, and the results were acceptable.

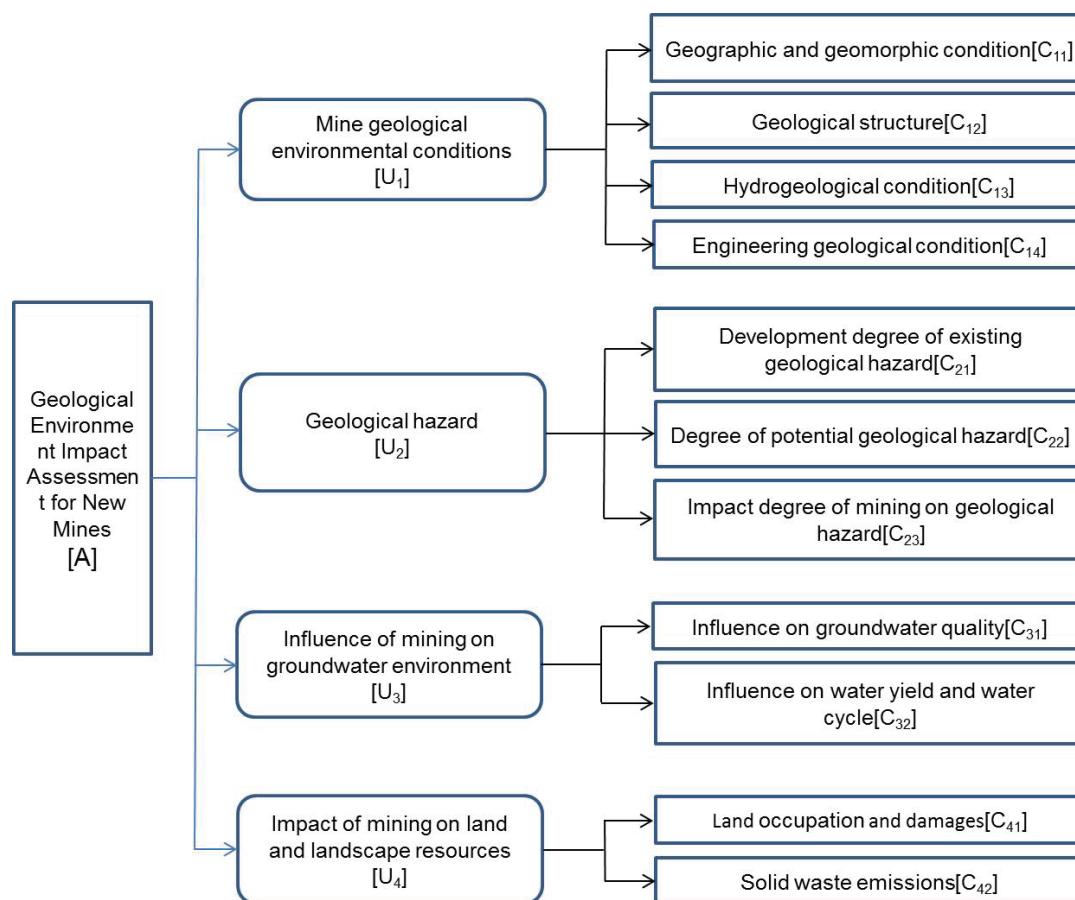


Fig. 2 Index system of GEIM

Table 1 Objective hierarchy judgment matrix and index weights

A	U ₁	U ₂	U ₃	U ₄	w	$\bar{w}$
U ₁	(1,1,1,1,1)	2,2,2,2,1/2	3,3,2,4,5	4,5,3,4,2	(0.45,0.47,0.43,0.47,0.31)	0.42
U ₂	1/2,1/2,1/2,1/2,2	(1,1,1,1,1)	(3,3,1,3,3)	(4,4,2,4,4)	(0.32,0.31,0.23,0.31,0.46)	0.32
U ₃	(1/3,1/3,1/2,1/4,1/5)	(1/3,1/3,1,1/3,1/3)	(1,1,1,1,1)	(1,2,1,2,1/2)	(0.12,0.14,0.19,0.13,0.09)	0.13
U ₄	(1/4,1/5,1/3,1/4,1/2)	(1/4,1/4,1/2,1/4,1/4)	(1,1/2,1,1/2,2)	(1,1,1,1,1)	(0.10,0.08,0.15,0.09,0.14)	0.11
U ₁	C ₁₁	C ₁₂	C ₁₃	C ₁₄	-	-
C ₁₁	(1,1,1,1,1)	(1/2,1/2,1/2,1,2)	(3,2,2,1,2)	(1/2,1/2,1/3,1/3,1/2)	(0.20,0.19,0.18,0.18,0.29)	0.20
C ₁₂	(2,2,2,1,1/2)	(1,1,1,1,1)	(2,3,2,2,2)	(2,1,1,1,1)	(0.37,0.35,0.32,0.28,0.24)	0.31
C ₁₃	(1/3,1/2,1/2,1,1/2)	(1/2,1/3,1/2,1/2,1/2)	(1,1,1,1,1)	(1/5,1/3,1/2,1/2,1)	(0.10,0.11,0.14,0.16,0.17)	0.13
C ₁₄	(2,2,3,3,2)	(1/2,1,1,1,1)	(5,3,2,2,1)	(1,1,1,1,1)	(0.32,0.35,0.36,0.37,0.29)	0.34
U ₂	C ₂₁	C ₂₂	C ₂₃	-	-	-
C ₂₁	(1,1,1,1,1)	(1/2,3,1/2,1,1)	(2,1/2,1/2,1/2,1/3)	-	(0.31,0.35,0.20,0.26,0.23)	0.24
C ₂₂	(2,1/3,2,1,1)	(1,1,1,1,1)	(2,1/2,1/2,1,1)	-	(0.49,0.17,0.31,0.33,0.32)	0.35
C ₂₃	(1/2,2,2,2,3)	(1/2,2,2,1,1)	(1,1,1,1,1)	-	(0.20,0.48,0.49,0.41,0.45)	0.39
U ₃	C ₃₁	C ₃₂	-	-	-	-
C ₃₁	(1,1,1,1,1)	(1,1/2,1/2,1/2,1)	-	-	(0.50,0.33,0.33,0.33,0.50)	0.45
C ₃₂	(1,2,2,2,1)	(1,1,1,1,1)	-	-	(0.50,0.67,0.67,0.67,0.50)	0.52
U ₄	C ₄₁	C ₄₂	-	-	-	-
C ₄₁	(1,1,1,1,1)	(1,1,1,1,1)	-	-	(0.50,0.50,0.50,0.50,0.50)	0.50
C ₄₂	(1,1,1,1,1)	(1,1,1,1,1)	-	-	(0.50,0.50,0.50,0.50,0.50)	0.50

Since the judgment of these experts was subject to subjectivity, the geometric method (LI Lu, 2009) of group decision-making was adopted to normalize the weight values, and the formula is as follows:

$$\bar{w} = \left(\prod_{k=1}^K w_i^k \right)^{\frac{1}{K}} \quad \forall k=1,2,3,4,5 \quad (1)$$

In the equation (1), $\bar{w}$ stands for the geometric average of the weight values, K stands for the number of experts, w_i^k stands for the number i index weight decided by the number k expert. The optimal weight obtained is shown in Table 1.

Quantification of Assessment Indexes. The limestone mine in Tujia Mountain in Chongzhou is a new mine and all the assessment indexes are qualitative. Therefore, quantification of indexes was decided according to the experience of the experts who have been engaged in the work related to mine geological environment and geological hazard (WANG Liang-jian, 2001). Each index was divided into three levels, namely Condition Poor, Medium and Good, and the coefficient of each level is 1, 0.5, 0.1 respectively. A expert group of five people gave scores according to the contents of the assessment indexes. Then the average of each level's coefficients graded by all the experts was calculated, and this average was thus believed

to be the score value of the qualitative index. The contents and coefficients of each level of assessment indexes are shown in Table 2.

Geological environment assessment indexes and quantitative rating scale of the limestone mine in Tujia Mountain in Chongzhou are shown in Table 2.

Mathematical Model. The complexity of the comprehensive assessment index system requires an integrated assessment method (LI Yan, 2005) supported by complicated and systematic theories. In this study, multi-objective linear weighting function (ZHAO Ying-xue, 2012) was employed to establish a mathematical model of mine environmental quality impact index.

$$= \sum_{i=1}^n (\sum_{j=1}^n i_{ij} \bullet w_{ij}) \bullet W_i, \quad \forall n=1,2,3,4 \quad (2)$$

In the equation (2), R is the overall score of geological environment quality, namely score of

the mine geological environment quality. A_i is the score of a certain qualitative index. w_{ij} is the weight value of the index level, and W_i is the weight value of the constraint level.

With the weights decided above, the mathematical model of mine environmental quality impact index was used to calculate the overall scores, which were taken as the reference to determine the assessment zonations. The mine geological environment was divided into four zonations, namely zonations of good, average, relatively poor, and poor geological environment quality. The assessment zonations were decided according to the following standards: for the zonation of good environment quality, $R < 0.3$; for the average, $0.3 < R < 0.5$; for the zonation of relatively poor environment quality, $0.5 < R < 0.7$; for the zonation of poor environment quality, $R \geq 0.7$.

Table 2 Mine geological environment assessment indexes and quantitative rating standards

Constraint levels	Weight	Index levels	Weight	Condition levels		
				Poor 1	Medium(0.5)	Good(0.1)
Mine geological environment conditions	0.42	Geographic and geomorphic condition	0.2	complex terrain, medium deep cut	Average terrain, medium cut	Simple terrain, shallow cut or hilly
		Geological structure	0.31	Well developed structure, active neotectonics, unstable surrounding rocks, and complex lithology	Averagely developed structure, stable surrounding rocks, and single lithology	Simple structure, basically no active faults, stable surrounding rocks, and single lithology
		Hydrogeological condition	0.13	Ore deposit lower than erosion basis, good water yield, good supply but poor discharge, complex hydrogeological boundary	Ore deposit lower than erosion basis, good water yield, good supply but average discharge, complex boundary	Ore deposit higher than erosion basis, poor water yield, poor supply but good discharge, single hydrogeological boundary
		Engineering geological condition	0.34	Soft rocks, well developed fracture, low mechanical strength	Thick-layer solid rocks, medium developed fracture, medium mechanical strength	Bulk thick-layer solid rocks, Non-developed fracture, high mechanical

Table 2 Continued

Constraint levels	Weight	Index levels	Weight	Condition levels		
				Poor	1	Medium(0.5)
Geological hazard	0.32	Development degree of existing geological hazard	0.24	Multiple geological hazard, great scale, bedding slope, low rock mass strength or with soft rock strata, unscientific exploitation, close to the hidden danger	Single geological hazard, medium scale, reverse or wide-angle oblique crossing slope, medium rock mass strength, scientific exploitation, relatively far from the hidden danger	Single geological hazard, small scale, reverse slope, high rock mass strength, scientific exploitation, far from the hidden danger
		Degree of potential geological hazard	0.35			
		Impact degree of mining on geological hazard	0.39			
Influence of mining on groundwater environment	0.13	Influence on groundwater quality	0.45	Hydrochemical change, change in regional water balance	Change in hydrochemical indicator content, some groundwater regime is changed	No change in hydrochemical indicator content, no obvious change in groundwater regime
		Influence on water yield and water cycle	0.52			
Impact of mining on land and landscape resources	0.11	Land occupation and damages	0.5	Wide land occupation, serious deterioration, solid waste emissions affect the environment	Medium land occupation and deterioration solid waste emissions affect the environment	Slight land occupation and deterioration, solid waste emissions slightly affect the environment
		solid waste emissions	0.5			

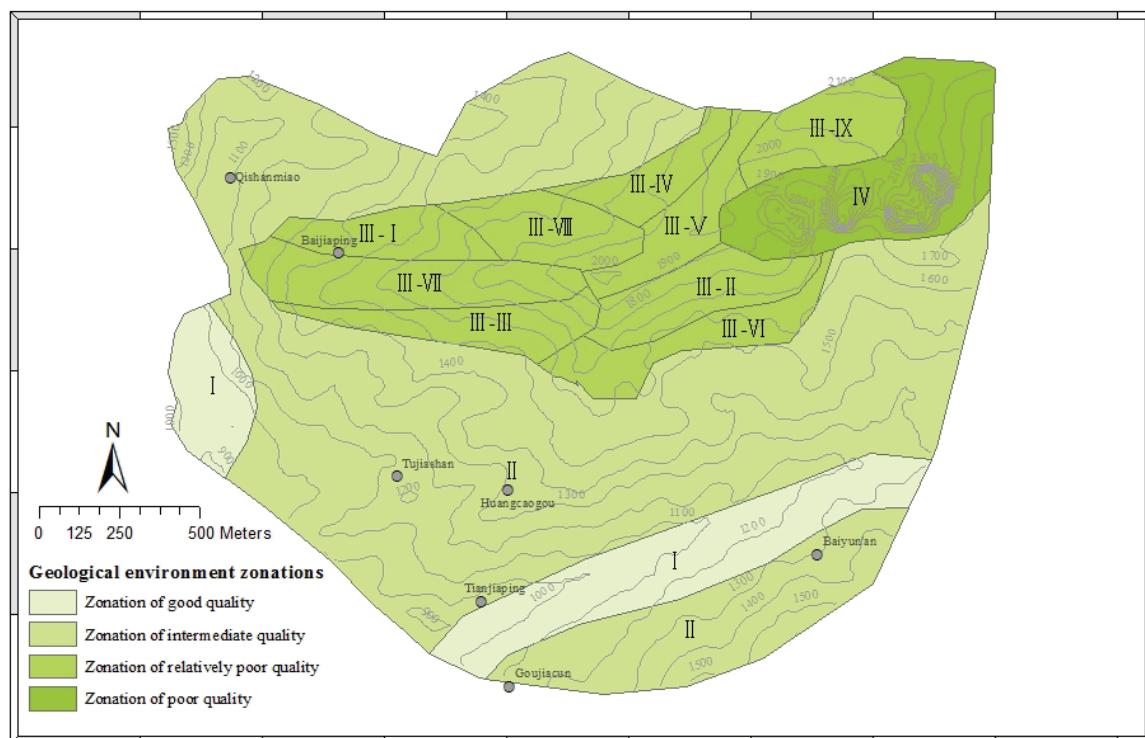
**Fig. 3** Geological environment zonations for Jiguan Mountain, Chongzhou

Table 3 Comprehensive zonation assessment of mine geological environment impact and forecast results of environmental impact rating

Assessment zonation	zonation code	zonation area km ²	Period of impact	Major geological environmental characters	Forecast of geological environmental impact rating
zonation of good quality		0.67	During mining activity	Slight impact on groundwater environment	Slight
zonation of intermediate quality		3.92	During mining activity	Slight geological hazard	Slight
zonation of relatively poor quality	-	1.59	During mining separation and excavation	Vulnerable to geological hazard, medium geological hazard degree, medium impact on water and land resources	Slight
	-				Medium
	-				Medium
	-				Slight
	-		From mine construction to close		Slight
	-		During mining separation and excavation		Slight
	-		During mining separation and excavation		Slight
	-		From later period of mining to the formation of slope		Medium
	-		The later period of mining		Medium
	-		During mining activity		Slight
zonation of poor quality		0.49	During mining activity	Serious geological hazard	Slight

Results and Discussion

According to the results of the mine geological environment quality assessment, which was supported by the assessment theoretical framework and the method mentioned above, the limestone mine in Tujia Mountain in Chongzhou was divided into four environment zonations (Fig. 3). Among them, the zonation of intermediate geological environment quality covered the largest area, accounting for 58.51% of the total assessment scope. The zonation of good geological environment quality came next, accounting for 10.00% of the total assessment scope. The zonation of poor geological environment quality took up 7.31% of the assessment scope. The mine construction land mainly covered the zonations of average and relatively poor geological environment quality, and the zonation of relatively poor geological

environment quality took up 23.73% of the assessment scope.

In terms of geological environment zonations, specific analyses were employed to mitigate potential side impacts, given the potential suffering objective, possible damage extent, difficulties in environmental restoration and the mining plan.

For zonations of good and average geological environment quality, namely zonations I and II, there was slight geological hazard, and the mining activities had little impact on the groundwater environment in these areas. After mining practices, there will be a big platform in zonation II, which can be used for land reclamation, so as to fully make use of the land. Generally, mining activities bring slight influence on the land occupied and only cause slight land damage. And they produce no threats to the houses scattered in the area. Therefore, it is concluded that mining operations only have a slight impact on the geological

environment in zonations I and II. The zonation of relatively poor geological environment was also where geological hazard occurred most frequently during the mining process. But the scale of geological hazard was small, with slight to medium risks, and it had a slight to medium impact on water and soil resources as well as the environment. During the later period of mining, high and steep slopes will appear in sub-zonations III-VIII, where rock joints and fissures are well developed. Since there will appear bedding slopes at the eastern boundary of the mining area and this part meets the fault slope in a small angle, there will be a risk of collapse. So the geological environment impact is medium. If collapse or debris flow happens in the sub-zonations III-II, III-III during the mining process, the gully water will be influenced, which can affect the drinking water of some villagers downstream. Sub-zonation III-V was the mine storage area, which occupied a small amount of agricultural land, and had slight occupancy of land resources and cause minor damage. Therefore, the geological environment impact of mining activities in the area can be summarized as that the impacts in sub-zonations III-II, III-III, III-VIII are medium, and in the rest zonations are slight. The zonation of poor geological environment was the landslide accumulation area, which had high risks of geological hazard. However, it is far away from the mining area, so the mining practices will neither cause damages to the geological environment in this area, nor produce direct influence on the water resources and the ecological environment. So the geological environment of this zonation is only slightly affected.

Conclusions

This study divided the comprehensive zonation assessment of mine geological environment impact into four sub-assessment groups, covering mine geological environmental conditions, geological hazard, influence of mining on groundwater environment and its impact on land and landscape resources. On this basis, an assessment index system was established, and quantitative rating calculation was conducted during the qualitative assessment of mine geological environment quality,

thus fully manifesting the importance of GEIM for forecasting geological environment problems, and highlighting the status of geological environment impact assessment. The systematic and hierarchical analyses of the assessment helped to decompose assessment factors step by step, so as to form a hierarchical structure corresponding to the analytic hierarchy process. It is thus believed to be of great significance to the geological environment impact assessment for mines.

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