Regional geo-environment assessment for mining area based on Monte Carlo simulation and its case study

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Abstract
Based on the system analysis on the structure and function of the mining environment social and economic system analysis, an indicator framework for geological environment assessment of single mine as constructed. With the involvement of combination weighting theory, Satty's Weighting method and Entropy Weight method was combined to compute the weight of each index. Furthermore, probability distribution function was employed to describe the probabilistic distribution characteristics of each index, and Monte Carlo method was used to propagate the influence of uncertainties of index on the regional geological quality of the environment. Ultimately, a MC-base method was constructed to evaluate the regional geological environment. The model was applied to assess the mine geological environment quality of two areas within the Ningxia Hui Autonomous. The results showed that: 1) the relative difference between the Monte Carlo-based method and the traditional method is 11%; being compared with traditional methods, the model can overcome the limit of measured data' discrete, and is able to fully characterize the regional geological environment quality; 2) Case studies show Zhongwei area's mine geological environment quality is worse than that of Guyuan area with more than 95% of the mine subject to serious or very serious damage level. It is therefore suggested that in making planning of environmental protection and mine geological environment restoration of, Zhongwei area should be paid more attention and placed in front of the sequence.
Key words: REGIONAL ENVIRONMENT ASSESSMENT; MONTE CARLO SIMULATION; GEO- ENVIRONMENT; PROBABILITY DISTTIBUTION FUNCTION

1. Introduction

With technological progress and social development, world population is growing rapidly, leading to a sharp increase in demand for mineral resources from human beings [1-3]. What follow is the atmosphere, soil, surface water and groundwater contamination and environment deterioration caused by the exploitation of mineral resources [4-7]. In the early 1970s, Western developed countries began to impose strict mine environmental protection and evaluation system [8-9]. With the holding of 15th UNEP Governing Council in 1989 and the promulgation of “United Nations' Declaration on Sustainable Development ", the developed countries pay more attention to environmental protection of mine. On the one hand, the government has increased and improved the legal system related to mine environment protection; on the other hand, mining companies in these countries have begun to implement margin system.

In China, the study on mine geology and its environmental impact assessment begins late. Since the 1990s, the environmental impact of mining is gradually realized, and "three wastes" emissions, environmental degradation caused by mining geological disasters and land resources destruction is emphasized. Since 2000, China Geological Survey began a nationwide environmental investigation and evaluation. In 2005, mine geological environment survey and evaluation of 31 provinces, autonomous regions and municipalities are completed, which provides basic information for the national geological environment planning and mine geological environment evaluation. On this basis, the domestic geological evaluation on mine environment moves into in-depth study stage, and various quantitative and semi-quantitative evaluation methods and models have been proposed and applied in large quantity. Chen Yuhua et al. build a quality evaluation index system of mine environment and an assessment analysis implementation scheme of mine environment based on GIS through a systematic investigation of mine environment. Yang Meizhong et al. apply fuzzy comprehensive evaluation method to conduct quantitative evaluation research on mine geological environment. Wang Haiqing et al. make a contrastive analysis of various evaluation methods of mine geological environment, including application grid method, vector polygon method, and buffer method and so on. Meng Qingkai et al. establish a fuzzy SODATA clustering algorithm, which provides a new research idea for mine geological environment evaluation.

The launch and wide application of above-mentioned research work have played an important role in the control and reduction of mining pollution and the protection of environment. However, the above environment evaluation of mine geological environment is limited to a single project level, so it can only approve or reject the specific mining projects, but cannot affect the overall decision-making and layout of the area, nor can guide the development of more macro policy or planning. Meanwhile, as it is confined to a single mining project, it cannot solve the numerous indirect, secondary cumulative effects generated during mining.[10] The fundamental way to solve these defects is to extend mine geological environment assessment from construction project level to the region, as well as government planning and policy levels, that is, to carry out regional environmental assessment of mine geology[11]. One idea of regional environmental assessment is to build a unified evaluation index system of mine geological environment, and then this index system can be applied to conduct quantitative evaluation on the mines within the study area one by one, so as to reveal the geological environment conditions of the research area to some extent. But on the one hand, when the samples are relatively less, due to the constraints of the discreteness of the measured data, the characterization of geological environment quality of the research area is relatively inadequate; on the other hand, when the data are relatively much, for example, the number of mines in certain areas are usually much up to several hundreds, the workload will undoubtedly be enormous if the data are evaluated one by one and analyzed statistically. Therefore, the coupling effects of uncertainties in the evaluation process may be the improvement direction of the quality assessment of regional mine geological environment.

2. Method and models

In the prevention planning process of a wide range of mine geological environment, because of the differences in vulnerability, sensitivity, ecological environment and interference level of geological environment in various regions, the differences in social and economic developmental level of different regions, the order of priority development or protection should be divided in accordance with the status quo of mine geological environment quality in various areas in the mine development and environmental protection planning process. The premise of the division is to establish a unified evaluation method of regional mine geological environment quality.

Through system analysis on the structure and function of "mine environment - social economy" complex environmental system, this study establishes a frame model of single mine geological environment quality evaluation indicators, and determines every index weight based on Satty's weight method and entropy weight method. The probability distribution characteristics of each indicator in the indicator system are described by applying probability distribution function (PDF) [12], the impact of the probability distribution characteristics of each indicator on regional geological environment is studied by using Monte Carlo method, and the regional geological environment evaluation method based on Monte Carlo method is ultimately built.

2.1 Evaluation index system construction of single mine geological environment

Assuming there are N mines in the research area, the geological environment quality of single mine can be evaluated by Formula (1).

$$EQ=\sum_{i=1}^{l} Q_i W_i \quad (1)$$

Where, EQ: comprehensive index of single mine geological environment quality; Q_i : score value of No. i evaluation indicator; W_i :corresponding weight of No. i evaluation indicator; i : number of indicators.

2.1.1. Screening of evaluation indicators

"Programming Specifications of Mine Geological Environment Protection and Recovery Scheme" is the basic source of indicators, literature review and expert consultation are applied, and combined with objective indicators screening methods (cluster analysis, canonical correlation, principal component analysis and factor analysis, etc.), a three-layer structure of 7 criteria and 21 indicators system is selected and established, which can be seen in Table 1.

2.1.2 Quantitative classification of indicators

Table 1 contains both quantitative indicators and qualitative indicators. For quantitative indicators, such as economic losses, casualties and wastewater emissions intensity, only the observed value is needed. For qualitative indicators, such as disaster type, production status, etc., relative comparison after the qualitative assignment based on the characteristics of each index is conducted to determine their relative degree.

The indicators after quantitative classification are conducted normalized and standardized treatment by using the Formula (2).

$$C_{ij}=B_{ij} / MaxB_{ij} \quad (2)$$

Where, i : criterion layer, j : No. j indicator of No. i criterion layer, $MaxB_{ij}$: the largest index value of criterion layer i .

2.1.3 Indicator Weight Calculation

Index weight calculation is the most important link in the quality evaluation of regional mine geological environment. Weight calculation methods generally include subjective weighting method, such as expert scoring method, sorting and Satty's weight method, and objective weighting method, such as entropy weight method, standard deviation method and CRITIC method. Objective weighting method has small workload, can effectively avoid bias caused by human factors, but cannot consider the relative importance of the indicator itself. The subjective weighting method can reasonably determine the index weights based on the actual situation, but is easily influenced by subjective factors of expert. Therefore, this paper uses a combination of objective and subjective weighting methods, combines Satty's weight method and entropy weight method, and integrates the advantages of objective and subjective weighting methods to calculate the index weight.

Table 1. Frame model of regional mine geological environment evaluation indicators

Objective Layer	Criteria	Indicators System	
Frame of Mine Geological Environment Evaluation Indicators	Topography and geology（B1)	Topography and geomorphology（X1)	
		The rate of vegetation coverage（X2)	
		The engineering geological conditions along the way（X3)	
	Geological disasters（B2)	Disaster type（X4)	
		Scale of the disaster（X5)	
		Casualties（X6)	
		Economic losses（X7)	
	Situation of mining (B3)	Scale of mine（X8)	
		Economic types（X9)	
		Recovery method（X10)	
		production status（X11)	
	Resource damage (B4)	The damage types of land occupations（X12)	
		The damage area of land occupation（X13)	
	Emission of pollutants (B5)	wastewater emissions intensity（X14)	
		Solid waste	Solid waste emissions intensity（Y1)

		emissions（X15）	Solid historical burden (Y2)
	The impact on surface water environment (B6)	The influence of water environment area（X16）	
		Drop of underground water level（X17）	
	The rate of environmental governance (B7)	The utilization rate of wastewater cycle（X18）	
		The treatment rate of wastewater（X19）	
		Annual comprehensive utilization rate of waste residue（X20）	

Details of Satty's weight method and entropy weight method can be found in the reference. The key question is how to achieve a combination weighting of the two methods.

n weight vectors calculated by using different weight calculation methods constitute a basic weight vector set $U\left|\{u_1,u_2,...,u_n\}\right.$, and a possible weight set is obtained through the arbitrary combination of n weight vectors.

$$U=\sum_{k=1}^{n}\alpha_k u_k^{\Gamma}\ (\alpha_k > 0) \qquad (3)$$

In the formula, u: a weight vector, α_k: weight coefficient.

2)optimizing the weight coefficient α_k of linear combination to minimize the deviation of u and each u_k (Formula 4) , to find the most satisfactory weight vector:

$$\min\left\|\sum_{j=1}^{n}\alpha_j\times u_j^{T}-u_i^{T}\right\|_2\ (i=1,2,...n) \qquad (4)$$

According to the differential nature of matrix, the optimal first derivative condition of Formula (4) is:

$$\sum_{j=1}^{n}\alpha_j\times u_j\times u_j^{T}=u_j\times u_i^{T} \qquad (5)$$

$(a_1, a_2, ..., a_n)$ is obtained according to Formula (5), and then normalization processing is carried out on it:

$$\alpha_k^{*}=\frac{\alpha_k}{\sum_{k=1}^{n}\alpha_k} \qquad (6)$$

The combination weight finally obtained is:

$$u^{*}=\sum_{k=1}^{n}\alpha_k^{*}\cdot u_k^{T} \qquad (7)$$

Index weight calculated by using Satty's weighting method and entropy weight method, and the combination weight value calculated through Formula 4-6 is shown in the table below.

2.2. Monte Carlo Simulation

Obviously, Formula 1 can also be used to evaluate the mine geological environment quality of a region. The key question is how to value the indicator xi in the formula. Assuming there are a total of N mines in the region, N Q1 values exist for the indicator xi, and conducting hypothesis testing and statistical analysis on N Q1 values can obtain probability distribution function of Q1 values. Similarly, conducting hypothesis testing and statistical analysis on other indicators x1, x2, x3... xn can obtain probability distribution function of other indicators.

Obviously, when every indicator represents in the form of probability distribution, the evaluation results, comprehensive index EQ, should obey a specific probability distribution. In this case, for Formula 1, the use of analytical method is difficult to obtain the probability distribution of EQ, but Monte Carlo simulation can solve this problem. Monte Carlo simulation is to generate a sample value of each indicator through direct or indirect sampling based on the PDF of index xi, and then this sample value is substituted into Formula 1 to obtain comprehensive index EQ. After repeated independent analog computations, a set of values $EQ_1, EQ_2,...EQ_n$, of comprehensive index EQ can be obtained. When the simulation times are enough, the cumulative probability distribution function $F(EQ)$ of Q can be obtained

Table 2. Index weights determined by satty's weighting method, entropy weight method and combination weight method

Index	SW method	EW method	CW method		Index	SW method	EW method	CW method

Landform	0.0508	0.0486	0.0502	Press accounts, the destruction of land types	0.0086	0.0115	0.0093
Rate of vegetation coverage	0.0177	0.0242	0.0193	Press accounts, the destruction of land area	0.0486	0.0582	0.0510
Geological engineering conditions of rock and soil	0.0256	0.0175	0.0236	Annual emissions of waste water	0.1064	0.1096	0.1072
Types of disaster	0.0703	0.0669	0.0694	Annual emissions of waste residue	0.0823	0.0765	0.0809
Scale of the disaster	0.0318	0.0352	0.0326	Accumulation of waste residue	0.0244	0.0344	0.0269
Casualties	0.2115	0.2032	0.2094	Influence of water environment area	0.0155	0.0141	0.0151
Economic loss	0.1019	0.0913	0.0992	Level of groundwater decline	0.0820	0.0897	0.0839
Scale of mine	0.0257	0.0456	0.0307	Utilization rate of wastewater cycle	0.0129	0.0083	0.0118
Economic type	0.0044	0.0037	0.0042	Treatment rate of wastewater	0.0131	0.0089	0.0121
Mining method	0.0340	0.0219	0.0310	Annual comprehensive utilization rate of waste residue	0.0214	0.0138	0.0195
Production status	0.0111	0.0169	0.0125				

Notes: Satty's Weighting method, Entropy Weight method and Combination Weight method are simply named as SW method, EW method and CW method, accordingly.

If the comprehensive index is equal to EQ_B, EQ_E, EQ_G and EQ_W, it represents the geological environment quality of single mine is a very serious area, serious area, moderate area and lighter area 4 respectively, and according to Formula 2-4, the probability PB, PE, PG and PV of regional mine geological environment quality which is a very serious area, serious area, moderate area and lighter area 4 respectively are calculated according to Formula 2-4.

$$\begin{cases} PB = \mathrm{P}\left(\mathrm{EQ} \le \mathrm{EQ_B}\right) = \mathrm{F}\left(\mathrm{EQ_B}\right) \\ PE = \mathrm{P}\left(\mathrm{EQ_B} \le \mathrm{EQ} \le \mathrm{EQ_E}\right) = \mathrm{F}\left(\mathrm{EQ_B}\right) - \mathrm{F}\left(\mathrm{EQ_B}\right) \\ PG = \mathrm{P}\left(\mathrm{EQE} \le \mathrm{EQ} \le \mathrm{EQ_G}\right) = \mathrm{F}\left(\mathrm{EQ_G}\right) - \mathrm{F}\left(\mathrm{EQ_E}\right) \\ PW = \mathrm{P}\left(\mathrm{EQ_G} \le \mathrm{EQ} \le \mathrm{EQ_W}\right) = 1 - \mathrm{F}\left(\mathrm{EQ_V}\right) \end{cases} \quad (8)$$

Case study

Ningxia Hui Autonomous Region, referred to Ning for short, is one of China's five autonomous regions. Ningxia is one of the cradles of Chinese civilization, located in the "Silk Road", and is an important channel of east-west traffic trade historically. According to statistics, in the region there are 1370 various types of mining enterprises (Table 3), including 12 large mining companies, 32 medium-sized mining enterprises, and 1326 small-scale mining enterprises. Because of the rich mineral resources, collapse, landslides, mudslides and other geological disasters induced by various mining activities occur frequently, and meanwhile soil and water environmental degradation caused by wastewater and waste emissions is gradually intensified. To protect the recovery and treatment of Ningxia mine environment, the evaluation on the mine geological environment quality status of various regions in Ningxia is required to divide the order of priority development or protection, to provide scientific basis for mine development and environmental protection planning.

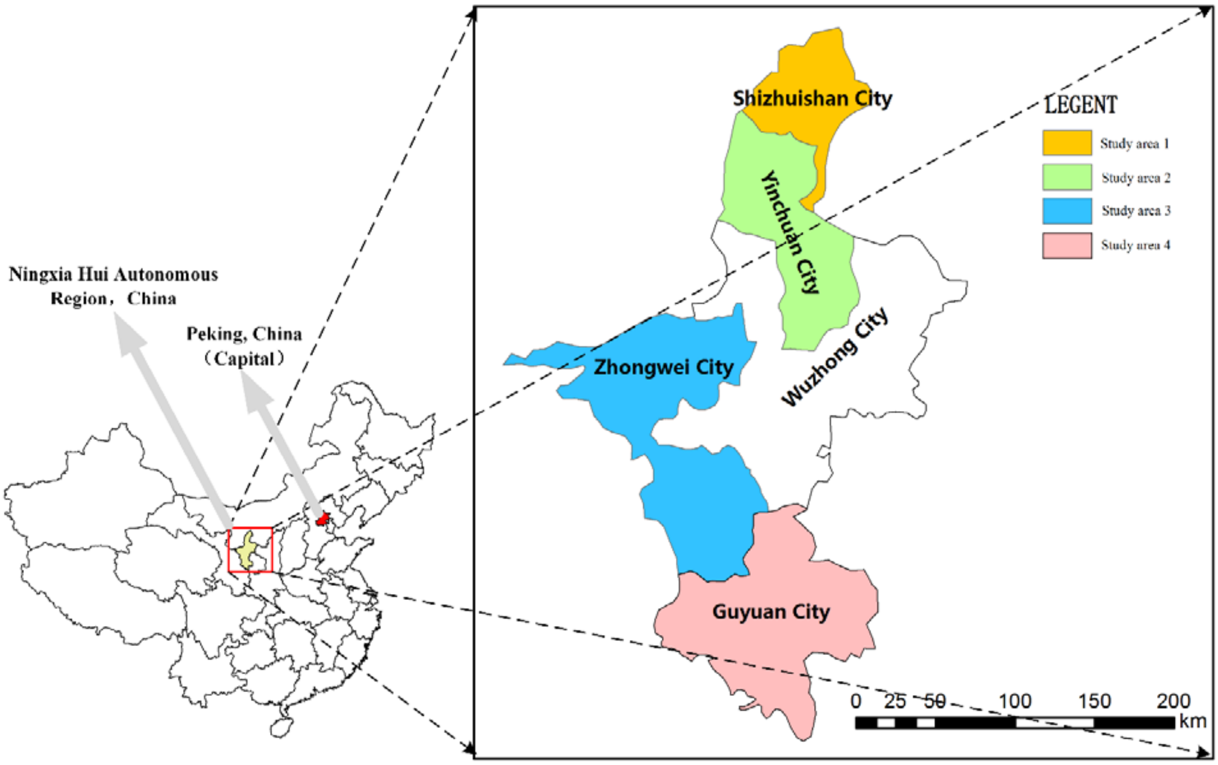


Figure1. Geographic Position of Research Area

This paper applies regional mine geological environment evaluation method based on Monte Carlo to conduct evaluation and comparison of the regional mine geological environment quality in Guyuan City, Zhongwei City, Shizuishan city and Yinchuan City of Ningxia, to provide decision support for regional mine development and environmental protection.

Table 3. Scores and description of qualitative indicators

Index	Score	Description
The type of surface topography	4	Rocky Mountains, undulating terrain, the relative elevation
	3	Hilly area, undulating terrain, relatively large height difference
	2	Aeolian sand, flat terrain, the relative difference is small
	1	Plain area, flat terrain, the relative difference is small
Geotechnical engineering geological conditions	3	The structure of wall rock of ore body is broken, the rock for the semi hard thin layer of loose rock, thick loose layer
	2	Deposits of surrounding rock for the semi hard lump of clastic rock, loose layer thinner
	1	Deposit rock for hard lump of thick layer of loose rock, thin layer
Number of disasters	5	>4
	4	4
	3	3
	2	2
	1	1
	0	No disaster
The scale of the disaster	3	Large
	2	Medium-sized
	1	Small
	0	No disaster

Mining scale	3	Large
	2	Medium-sized
	1	Small
The types of mining enterprises	3	Personal
	2	The collective
	1	State-owned
Mining method	3	Open-pit mining
	1	Underground mining
The present situation of mine production	3	Production
	2	In the construction
	1	Closed pit
Press accounts, the destruction of land types	4	Cultivated land
	3	Woodland
	2	Grassland
	1	Other

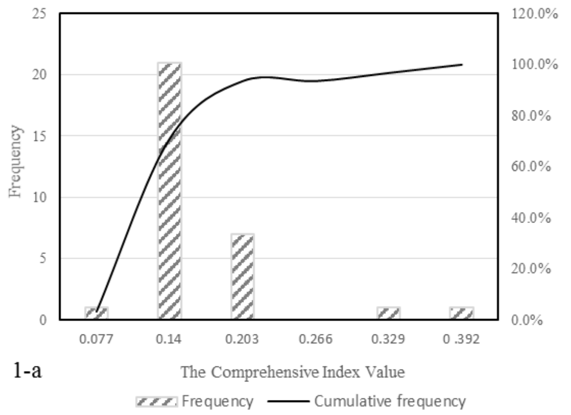
Table 4(a). Probability Distribution Type and Statistical Parameter Value of Index Value

Index	Guyuan City			Zhongwei City		
	Distribution type	mean value	Standard deviation	Distribution type	mean value	Standard deviation
The landform	Normal	0.83	0.15	Normal	0.91	0.20
The geological conditions of rock and soil engineering	Normal	0.82	0.30	Normal	0.39	0.12
The types of disaster	Secondary	0.04	0.16	Normal	0.15	0.17
The scale of the disaster	Normal	0.06	0.25	Normal	0.19	0.23
Casualties	Single	0.00	0.00	Secondary	0.03	0.18
Economic loss	Normal	0.00	0.02	Single	0.00	0.00
The scale of mine	Normal	0.34	0.06	Normal	0.34	0.06
Economic type	Normal	0.84	0.25	Normal	0.79	0.19
Mining method	Normal	0.38	0.17	Normal	0.71	0.34
Production status	Single	1.00	0.00	Normal	0.96	0.12
Press accounts, the destruction of land types	Normal	0.57	0.34	Normal	0.33	0.12
Press accounts, the destruction of land area	Normal	0.03	0.14	Normal	0.01	0.03
Annual emissions of waste water	Normal	0.00	0.01	Secondary	0.02	0.06
Annual emissions of waste residue	Single	0.00	0.00	Single	0.00	0.00
Accumulation of waste residue	Normal	0.00	0.01	Normal	0.01	0.02
The influence of water environment area	Normal	0.02	0.10	Normal	0.07	0.16
The level of the groundwater decline	Normal	0.03	0.14	Normal	0.23	0.26
The utilization rate of wastewater cycle	Normal	0.03	0.16	Normal	0.53	0.51
The treatment rate of wastewater	Normal	0.03	0.16	Normal	0.50	0.51
The annual comprehensive utilization rate of waste residue	Normal	0.33	0.47	Normal	0.85	0.31

Table 4(b). Probability Distribution Type and Statistical Parameter Value of Index Value

Index	Shizuishan City	Yinchuan City

	Distribution type	mean value	Standard deviation	Distribution type	mean value	Standard deviation
The landform	Normal	0.89	0.26	Normal	0.69	0.39
The geological conditions of rock and soil engineering	Normal	0.39	0.13	Normal	0.46	0.16
The types of disaster	Secondary	0.19	0.19	Normal	0.01	0.03
The scale of the disaster	Normal	0.26	0.31	Normal	0.01	0.06
Casualties	Normal	0.05	0.21	Single	0.00	0.00
Economic loss	Normal	0.05	0.15	Single	0.00	0.00
The scale of mine	Normal	0.40	0.18	Single	0.33	0.00
Economic type	Normal	0.55	0.27	Normal	0.88	0.17
Mining method	Normal	0.86	0.28	Single	0.33	0.00
Production status	Normal	0.98	0.08	Normal	0.98	0.08
Press accounts, the destruction of land types	Normal	0.26	0.06	Normal	0.40	0.23
Press accounts, the destruction of land area	Normal	0.08	0.23	Normal	0.00	0.01
Annual emissions of waste water	Normal	0.06	0.22	Single	0.00	0.00
Annual emissions of waste residue	Normal	0.06	0.23	Single	0.00	0.00
Accumulation of waste residue	Normal	0.06	0.23	Single	0.00	0.00
The influence of water environment area	Normal	0.09	0.16	Single	0.00	0.00
The level of the groundwater decline	Normal	0.26	0.25	Single	0.00	0.00
The utilization rate of wastewater cycle	Normal	0.44	0.46	Single	0.00	0.00
The treatment rate of wastewater	Normal	0.43	0.47	Single	0.00	0.00
Annual comprehensive utilization rate of waste residue	Normal	0.33	0.47	Single	0.17	0.31



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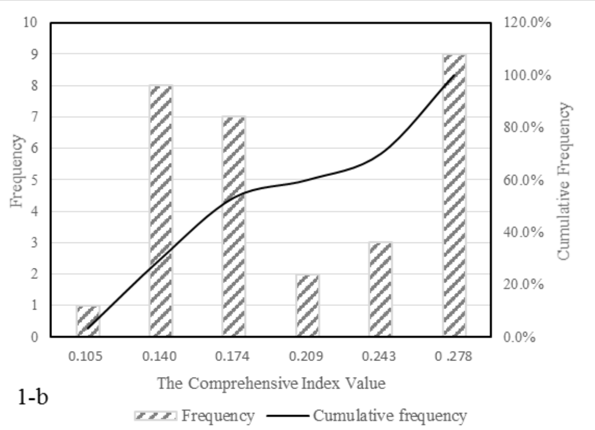

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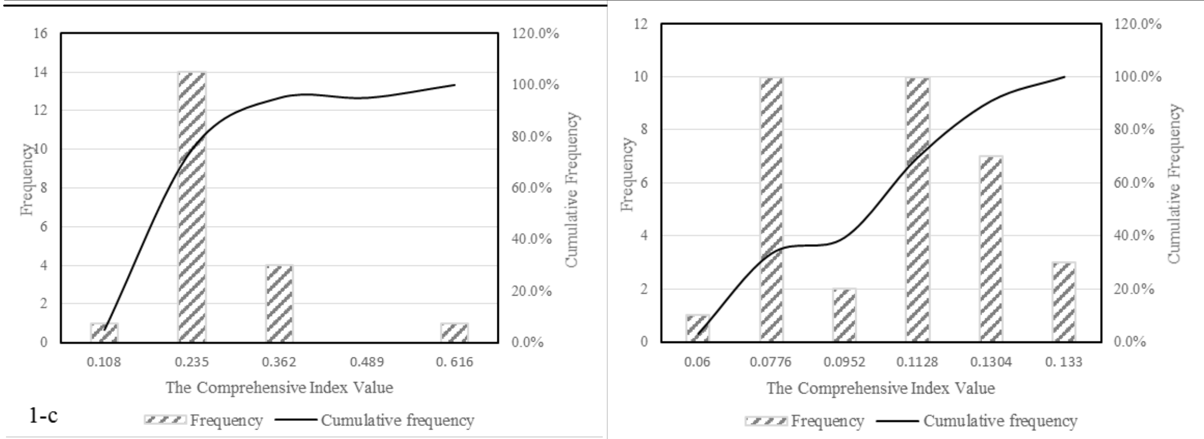

Figure 2. Cumulative Probability Distribution of the Comprehensive Indexes of Guyuan City (1-a), Zhongwei City (1-b), Shizuishan (1-c) and Yinchuan City (1-d) Mine Geological Environment Quality

3.1. Data Sources and Statistical Analysis

Index value data come from the survey results literature, including survey data of Guyuan City (31 mines), Zhongwei City (30 mines), Shizuishan City (20 mines) and Yinchuan City (34 mines). The probability distribution type and statistical parameters of each index are determined by hypothesis testing method, and it is shown in Table 4.

3.2. Results and Discussion

The probability distribution of index values in the table are substituted into Formula (1), cumulative probability distribution $F1(EQ)$, $F2(EQ)$, $F3(EQ)$ and $F4(EQ)$ of the comprehensive indexes of Guyuan City, Zhongwei City, Shizuishan City and Yinchuan City mine geological environment quality are obtained by Monte Carlo simulated calculation, and it is shown in Figure 2.

3.2.1. Model Validation

References divide the geological environment quality of single mine as very serious area, serious area, moderate area and lighter area 4, and the corresponding index is F≥0.2, 0.2 <F≤0.11, 0.11 <F≤0.06 , F <0.06. And probability of mine geological environment quality exceeding is calculated according to Formula (8).

At the same time to verify the validity of the model, the model simulation results are compared with the evaluation results of the literature, which can be seen in Table 4. It can be seen from Table 4 that this model's evaluation results on Guyuan City, Zhongwei City and Yinchuan City are basically same with the evaluation results of literature 1, and the maximum error is only 10.1 %. There are some errors in the evaluation results of Shizuishan City. In the model evaluation results, very serious damage and serious damage probability of Shizuishan City are 60% and 25% respectively, while the very serious damage and serious damage probability of Shizuishan City calculated according to literature 1 are 50% and 45%, and the maximum error is up to 44.4%. This is due to the statistics of each index of Shizuishan City are relatively less (20 mines), which are far less than the mine numbers of Guyuan City, Zhongwei City and Yinchuan City (30, 31 and 34 mines), and the accuracy of Monte Carlo method is significantly related to the number of samples. When the samples are sufficient enough, the regional mine geological environment quality evaluation method based on Monte Carlo method which is built in this paper can accurately evaluate regional mine geological environment quality.

Table 5. Evaluation results of regional mine geological environment quality (%)

	The evaluation results of this model					The evaluation results of literature 1			
	G City	Z City	S City	Y City		G City	Z City	S City	Y City
the probability of extremely serious	5	42	60	0	The proportion of extremely serious damage	7	43	50	0

damage									
the probability of serious damage	59	53	25	36	The proportion of serious damage	61	50	45	33
the probability of moderate damage	36	5	5	61	The proportion of moderate damage	32	7	5	66
the probability of minor damage	0	0	1	3	The proportion of minor damage	0	0	0	1

Notes: the Guyuan City, Zhongwei City, Shizuishan City and Yinchuan City are simply named as G,Z,S and Y City.

3.2.2. Comparison of Mine Environmental Quality in Different Regions

As can be seen from Table 5, except Yinchuan City, mine geological environment quality of Guyuan City, Zhongwei City and Shizuishan City all have probability of extremely serious damage, and the probability of extremely serious damage in Zhongwei City and Shizuishan City even reach 42% and 60%. Besides, according to Table 4, the quality of Guyuan mine geological environment is mainly "serious damage"（59%）, accompanying part of "moderate damage"（36%）. Condition of Zhongwei City is mainly "extremely serious damage"（42%） and "serious damage"（53%）. Condition of Shizuishan is mainly "very serious damage"（60%） and part of "serious damage"（25%）. Condition of Yinchuan City is mainly "serious medium damage"（61%）, part of "serious damage" （36%）and a few "minor damage"（3%）. Overall, Yinchuan mine geological environment quality is the best, Guyuan City is the second, Zhongwei City is the third, and Shizuishan mine geological environment quality is the worst.

The above data show Zhongwei mine geological environment quality is the worst, thus Zhongwei City should be placed in the front of sequence in conducting the planning of relative environmental protection and mine geological environment restoration.

4. Conclusion

This paper discusses the comprehensive evaluation of regional mine geological environment, and constructs frame model of single mine geological environment quality evaluation indicators through conducting system analysis on the structure and function "mine environment - social economy" complex environmental system. Based on this, combination of subjective and objective weighting methods is applied to determine the weight of each index. By using the probability distribution characteristics of each index in description index system of probability distribution function, and applying Monte Carlo method to study the impact of probability distribution characteristics of each index on regional geological environment quality, a regional geological environment evaluation method based on Monte Carlo method is ultimately built. The model is applied to evaluate the mine geological environment quality of Guyuan City and Zhongwei City in Ningxia Hui Autonomous Region, and the results show that:

1) When the mine samples used for statistical are abundant, the relative difference between regional mine geological environment quality evaluation method based on Monte Carlo method and conventional method is 11%, thus having a higher degree of accuracy; Compared with traditional methods, model constructed in this paper can overcome the constraints of the discreteness of measured data, to fully characterize the regional geological environment quality;

2) The evaluation results show that the quality of Guyuan mine geological environment is mainly "serious damage"（59%）, accompanying part of "moderate damage"（36%）. Condition of Zhongwei City is mainly "extremely serious damage" （42%）and "serious damage"（53%）. Condition of Shizuishan is mainly "very serious damage"（60%） and part of "serious damage"（25%）. Condition of Yinchuan City is mainly "serious medium damage"（61%）, part of "serious damage" （36%）and a few "minor damage"（3%）.

3) In general, Yinchuan mine geological environment quality is the best, Guyuan City is the second, Zhongwei City is the third, and Shizuishan mine geological environment quality is the worst, therefore, Zhongwei City should be placed in the front of sequence in conducting the planning of relative environmental protection and mine geological environment restoration.

References

1. Gavin M.M. (2014) The future of Yellowcake: A Global Assessment of

Uranium Resources and Mining. *Science of The Total Environment*, 472(15), p.p.590-607.
2. Northey S., Mudd G.M., Weng Z. (2014) Modelling Future Copper Ore Grade Decline Based on a Detailed Assessment of Copper Resources and Mining. *Resources, Conservation and Recycling*, 83, p.p. 190-201.
3. J.S. Laura, J.B. Damian, S. Britaldo. (2014) Global demand for steel drives extensive land-use change in Brazil's Iron Quadrangle. *Global Environmental Change*, 26, p.p. 63-72, 2014.
4. Lu J.X., Anna L. (2014) Historicizing Sustainable Livelihoods: A Pathways Approach to Lead Mining in Rural Central China, *World Development*, 62, p p.189-200.
5. Nishant K.S., Lal C.R., Masto R.E.(2014) Reclamation of Overburden and Lowland in Coal Mining Area with Fly Ash and Selective Plantation: A sustainable Ecological Approach, *Ecological Engineering*, 71(9), p.p. 479-489
6. Gould W.D., Morgan K., Bidyut R. (2012) A Critical Review on Destruction of Thiocyanate in Mining Effluents, *Minerals Engineering*, 34(7), p p.38-47.
7. Adrián S, Clara V, Santiago A. (2013) The Public Good Dilemma of a Non-renewable Common Resource: A Look at the Facts of Artisanal Gold Mining, *Resources Policy*, 38(2), p p.224-332
8. Kang L.X. (1997) Different Roof Behavior under Different upper Mining Boundary Condition in Datong, *Journal of Coal Science and Engineering*, 3(2), p p.36-40.
9. Robert N.S. (2003) *Experience with Market-Based Environmental Policy Instruments, Handbook of Environmental Economics*, Resources for the Future:Washington,D.C..
10. Bodle W.W, Schora F.C. (1979) Coal Gasification Technology Overview, *Advances in Coal Utilization Technology Symposium*, p p.790-807.
11. Kirchner M, Schmid E.(2013) Integrated Regional Impact Assessment of Agricultural Trade and Domestic Environmental Policies, *Land Use Policy*, 35(11), p p.359-387.
12. Hannes J.K, Sandra U, Johannes S, et al.(2013) Regional Impact Assessment of Land Use Scenarios in Developing Countries Using the FoPIA Approach: Findings from Five Case Studies”, *Journal of Environmental Management*, 127(Supplement), p p.S56-S64.