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The Application of Grey Matter Element Analysis in the Geological Hazard Risk Evaluation

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Abstract: The geological conditions in our country are complex, the geological environment is fragile, and the types of geological hazards are diverse, which has brought severe economic losses and casualties, and becomes an outstanding problem in the development of our society. In this paper, according to the common features of geological hazards, the risk evaluation system of geological hazards is constructed. The grey matter element analysis and grey theory are used to establish the risk evaluation model of geological hazards. The geological hazard risks are divided into 4 grey clustering. This method provides a professional, scientific and reasonable evaluation method for the geological hazard risks.

Keywords: *geological hazards; grey element; whitening value; risk; weight*

1. Introduction

Geological hazards are natural hazards of which the geological dynamic activity or geological environmental variation are as the main causes. Geological hazards are also a phenomenon or process that under the effect of earth's interior dynamic, external dynamic and man-made geological dynamic, the earth happens abnormal energy release, material movement, rock mass deformation and displacement and environmental variation, which harms human's lives, property, human life and economic activities, and destroys the resources and environment of human's existence and development. These geological hazards include earthquakes, volcanoes and geothermal hazards, collapse, landslide, debris flow, ground fissure , land subsidence, ground collapse, rockburst, adit water outburst, mud outburst , gas outburst , spontaneous combustion of coal seam, loess hydrocompaction, expansive soil , sand liquefaction, soil freezing and thawing, soil and water loss, land desertification and swamping, soil salinization, etc.

The geological conditions in China are very complicated. Mountain area is in the majority. The geological environment is fragile. There are many types of geological hazards. The influential areas are wide. The scales of geological hazards are large. Its characteristics are fast forming, high frequency, and long time. With the deepening of western development, the development and construction of land resources is advanced rapidly. The dual effects of nature and human beings exacerbated the occurrence of geological hazards in the western mountainous areas. Frequent geological hazards brought serious economic losses and casualties, which become a significant problem in economic development and sustainable development.

To evaluate the geological hazard risks, we could look for the rules and development stages of geological hazards, which could timely and accurately predict the harm degree and time of geological hazards. It could provide theoretical basis for the prediction and prevention of geological hazards. Using matter element analysis method and the grey theory to evaluate the geological hazard risks, a scientific and reasonable evaluation model is established.

2. The risk evaluation system of geological hazards

2.1 The selection principles of the main geological hazard factors

There are many different kinds of geological hazards in our country. In the selection process of the main influencing factors of geological hazards, we should fully consider the wholeness, locality, systematicness, scientificity, feasibility and measurement.

In the process of selecting risk evaluation system indexes of geological hazards, the following principles should be followed.

(1)The combination of comprehensiveness, systematicness and emphasis factors

In the selection process of risk evaluation factors of geological hazards, we should not only comprehensively consider various geological hazard influences, but also form a system. At the same time, according to the evaluated area, the local emphasis factors should be considered, achieving the combination of comprehensiveness, systematicness and emphasis factors.

(2)The combination of accuracy and fuzziness

The geological hazard evaluation should be based on a large amount of data as support. Therefore, the selected influencing factors should collect accurate data. At the same time, some factors just need to evaluate the general direction that means, achieving the combination of accuracy and fuzziness.

(3)The combination of diversity and changeability

China is a large country with big regional differences of natural geography and geological environment. The types of geological hazards and danger levels are also different. At the same time, the data under the same index of geological hazards of the same area may be also changing. Therefore, in the selection process of evaluation indexes, the diversity and changeability should be combined.

(4)The feasibility

The evaluation system of geological hazards must be operable, which could be able to be performed. Therefore, the evaluation factors should be simple, practical and scientific as far as possible.

2.2 The influence the main factors of geological hazards to the geological hazards

There are many factors which can lead to geological hazards. Geological conditions, topography, climate and vegetation, and human damage activities are the main factors. The specific influencing factors and second-level factors are shown in table 1.

Table 1: *The main influence each factor to the geological hazards*

main factors	Second-level factors	Influence on geological hazards
Geological conditions A	rock mass structure	The more broken the rock is, the more incomplete the structure is, the more easily the geological hazards occur. Contrarily, the harder the rock is, the less the geological hazards are.
	fracture distribution	When fracture distribution density≤0.05, the possibility of geological hazards is small. The bigger the density is; the more easily geological hazards occur.
	earthquake intensity	When earthquake intensity≤5, the possibility of geological hazards is small. When earthquake intensity≥8,it could achieve high-risk level.
Topography B	hillside slope	When hillside slope≤15,the possibility of geological hazards is small. When hillside slope≥25, it could achieve high-risk level.
	relative altitude error	When relative altitude error≤100, the possibility of geological hazards is small. When relative altitude error ≥500,it could achieve high-risk level.
	geomorphic types	Plateau mountainous topography is easy to cause geological hazards. Low mountain and plain topography is not easy to cause geological hazards.
Climate and vegetation C	Climate type	The storm climate is easy to cause geological hazards.
	vegetation coverage	The larger the vegetation coverage is, the smaller the possibility of geological hazards is.
	average annual rainfall	The greater the average annual rainfall is; the more easily geological hazards occur.
Human damage activities D	cutting slope	Random cutting slope, the inclined-slope is easy to cause the geological hazards.
	deforestation	Deforestation, lower vegetation coverage is easy to cause the geological hazards.
	quarry blasting	Quarry blasting is easy to cause the geological hazards
	non-standard mining	Non-standard mining is easy to cause the geological hazards.
	reservoir and channel leakage	Reservoir and channel leakage is also easy to cause the geological hazards.

3. Grey matter element analysis method

Matter element analysis method is a kind of evaluating method of solving contradiction problems. This method uses the correlation function to analyze the questions, transferring incompatible problems into compatible problems, suitable for solving the fuzzy problems. And the grey theory is also solving fuzzy, unclear social problems with incomplete information. It is a new attempt combining the grey theory with matter element analysis method to evaluate geological hazard risks.

3.1 Determine the grey number whitening value

Here we adopt grey element expression, that is, using the ordered triple of object, object characteristics, and grey number whitening value to describe objects, written as $\tilde{\otimes}R$,and N indicates the object, c indicates object characteristics, $\tilde{\otimes}$ indicates the grey number whitening value corresponding to object characteristics c , therefore, grey element expression could be written as:

$$\tilde{\otimes}R = \begin{bmatrix} & N \\ c & \tilde{\otimes} \end{bmatrix}.$$

The geological hazard risks are evaluated in this paper. N , indicates the happening of the geological hazards, and c indicates the main influencing factors of geological hazards.

3.1.1 Determine the level of grey clustering

According to the analysis of the main factors of geological hazards, referring to a large number of literature and material, combined with the geological experts' opinion, the geological hazard risks are divided into four levels, that is, very big, big, general, small. The specific details are shown in table 2.

Table 2: *The level classification table of geological hazards (10 points system is used*

geological hazard risk levels	Scale (no unit)
very big	8~10
big	6~8
general	4~6
small	1~4

3.1.2 Determine the whitenization weight function

There are three kinds of expressions of the whitenization weight function, that is:

1. The upper grey number is $\otimes \in [0, d_1, +\infty)$, and its whitenization weight function is as follows:

$$f_1(d_{ji}) = \begin{cases} \dfrac{d_{ji}}{d_1}, & d_{ji} \in [0, d_1] \\ 1, & d_{ji} \in [d_1, +\infty) \\ 0, & d_{ji} \notin [0, +\infty) \end{cases} \quad (1)$$

2. The middle grey number is $\otimes \in [0, d_1, 2d_1]$, and its whitenization weight function is as follows:

$$f_2(d_{ji}) = \begin{cases} \dfrac{d_{ji}}{d_1}, & d_{ji} \in [0, d_1] \\ 2 - \dfrac{d_{ji}}{d_1}, & d_{ji} \in [d_1, 2d_1] \\ 0, & d_{ji} \notin [0, 2d_1] \end{cases} \quad (2)$$

3. The lower grey number is $\otimes \in [0, d_1, d_2]$, and its whitenization weight function is as follows:

$$f_3(d_{ji}) = \begin{cases} 1, & d_{ji} \in [0, d_1] \\ \dfrac{d_2 - d_{ji}}{d_2 - d_1}, & d_{ji} \in [d_1, d_2] \\ 0, & d_{ji} \notin [0, d_2] \end{cases} \quad (3)$$

The selection of d_1, d_2 in formula (1) (2) (3) is usually carried on according to the related standards or the previous experience, or could be valued according to the minimum, average, maximum of the sample matrix to determine the threshold value of lower limit, middle and upper limit.

3.1.3 Determine the grey evaluation coefficients

Using the expert evaluation method to evaluate geological hazard risks, we could get D_{ji} , $D_{ji}^{(A)}$ indicates the evaluation matrix the evaluation experts i give to the j th second-level factors of certain geological hazard factor A .

Integrated $D_{ji}^{(A)}$ and $f_k(d_{ji})$ we could get the grey evaluation coefficient of certain second-level factor j to the main factor of geological hazard risks A which belong to k th grey clustering as follows:

$$\tilde{\otimes}_{ji}^{(A)} = \sum_{i=1}^{n} f_k(d_{ji}) \quad (4)$$

3.2 The grey matter elements of each main factor

$\tilde{\otimes}_{ji}$ $(j = 1, 2, \cdots, m; i = 1, 2, \cdots, n)$ is the corresponding grey number whitening value of n main factors of geological hazards under j th evaluation level, therefore we could get n -dimension grey element of j th evaluation level.

$$\tilde{\otimes}R_{jn} = \begin{bmatrix} & M_j \\ c_1 & \tilde{\otimes}_{j1} \\ c_2 & \tilde{\otimes}_{j2} \\ \vdots & \vdots \\ c_n & \tilde{\otimes}_{jn} \end{bmatrix},$$

M_j indicates the j th evaluation level, c_j indicates the main factor of i th geological hazard under j th evaluation level, $\tilde{\otimes}_{ji}$ $(j = 1, 2, \cdots, m; i = 1, 2, \cdots, n)$ indicates the corresponding grey number whitening value.

Here, for the convenience of calculation and analysis, gather the n -dimension grey element of m evaluation levels, write n -dimension composite grey element of m evaluation levels, use $\tilde{\otimes}R_{mn}$ to express:

$$\tilde{\otimes}R_{mn} = \begin{bmatrix} & M_1 & M_2 & \cdots & M_m \\ c_1 & \tilde{\otimes}_{11} & \tilde{\otimes}_{21} & \cdots & \tilde{\otimes}_{m1} \\ c_2 & \tilde{\otimes}_{12} & \tilde{\otimes}_{22} & \cdots & \tilde{\otimes}_{m2} \\ \vdots & \vdots & \vdots & & \vdots \\ c_n & \tilde{\otimes}_{1n} & \tilde{\otimes}_{2n} & \cdots & \tilde{\otimes}_{mn} \end{bmatrix}$$

m, indicates the number of evaluation level, n indicates the number of the main factors of geological hazards.

3.3 The relative optimization principle is used to construct n-dimension grey element of the ideal risk set

Find out the optimal value from m evaluation levels; make up an ideal risk set so as to construct the n-dimension grey element of the ideal risk set.

$$\tilde{\otimes}R_0 = \begin{bmatrix} & M_0 \\ c_1 & \tilde{\otimes}_{01} \\ c_2 & \tilde{\otimes}_{02} \\ \vdots & \vdots \\ c_n & \tilde{\otimes}_{0n} \end{bmatrix}.$$

Normally, the optimal value is determined according to the minimum value, the medium value and the maximum value of grey number whitening value of each main factor, namely, there are 3 types:

(1)The smaller the optimal type:

$\tilde{\otimes}R_{0i} = \tilde{\otimes}R_{1i} \wedge \tilde{\otimes}R_{2i} \wedge \cdots \wedge \tilde{\otimes}R_{mi}$;

(2)The moderate type:

$\tilde{\otimes}R_{0i} = u_{ji}$;

(3)The bigger the optimal type:

$\tilde{\otimes}R_{0i} = \tilde{\otimes}R_{1i} \vee \tilde{\otimes}R_{2i} \vee \cdots \vee \tilde{\otimes}R_{mi}$,

And $i = 1,2,\cdots,n$, $\wedge$ is min- operation, $\vee$ is max-operation.

3.4 The correlation analysis

3.4.1 The data processing

Use the transformation method of interval data processing to carry on the dimensionless processing to the original data. There are three kinds of concrete forms:

(1)The smaller the optimal type:

$$\tilde{\otimes}'_{ji} = \frac{\max\tilde{\otimes}_{ji} - \tilde{\otimes}_{ji}}{\max\tilde{\otimes}_{ji} - \min\tilde{\otimes}_{ji}};$$

(2)The moderate type:

$$\tilde{\otimes}'_{ji} = \frac{\min(\tilde{\otimes}_{ji} - u_{ji})}{\max(\tilde{\otimes}_{ji} - u_{ji})};$$

(3)The bigger the optimal type:

$$\tilde{\otimes}'_{ji} = \frac{\tilde{\otimes}_{ji} - \min\tilde{\otimes}_{ji}}{\max\tilde{\otimes}_{ji} - \min\tilde{\otimes}_{ji}},$$

And $j = 1,2,\cdots,m$, $i = 1,2,\cdots,n$.

3.4.2 The correlation analysis

According to the structured n- dimension correlation coefficient of m evaluation levels, the composite grey element $\tilde{\otimes}R_\xi$ is as follows:

$$\tilde{\otimes}R_\xi = \begin{bmatrix} & M_1 & M_2 & \cdots & M_m \\ c_1 & \tilde{\otimes}\xi_{11} & \tilde{\otimes}\xi_{21} & \cdots & \tilde{\otimes}\xi_{m1} \\ c_2 & \tilde{\otimes}\xi_{12} & \tilde{\otimes}\xi_{22} & \cdots & \tilde{\otimes}\xi_{m2} \\ \vdots & \vdots & \vdots & & \vdots \\ c_n & \tilde{\otimes}\xi_{1n} & \tilde{\otimes}\xi_{2n} & \cdots & \tilde{\otimes}\xi_{mn} \end{bmatrix},$$

$\tilde{\otimes}R_\xi$ indicates the correlation coefficient whitening value of i th geological hazard main factor under the j th evaluation level after the standardization transformation,

$j = 1,2,\cdots,m; i = 1,2,\cdots,n$,and:

$$\tilde{\otimes}\xi_{ji} = \frac{\Delta\min + \rho\Delta\max}{\Delta_{ji} + \rho\Delta\max} \tag{5}$$

The Δ_{ji} in formula (5) is the absolute value of grey element whitening value after the i th geological hazard main factor under the j th evaluation level is carried on the data standardization and ideal risk set data standardization, that is, $\Delta_{ji} = \left|\tilde{\otimes}'_{0i} - \tilde{\otimes}'_{ji}\right|$, $\Delta\max$ indicates the maximum value of absolute error Δ_{ji}, $\Delta\min$ indicates the minimum value of absolute error Δ_{ji}, ρ indicates the resolution coefficient, normally, $\Delta\min = 0$, $\rho = 0.5$.

3.4.3 Calculate the correlation:

Use the analytic hierarchy process (AHP) to determine each evaluation index weight of geological hazard risk ω_k, ω_{kn}, and ω_k indicates the weight of the main factors, ω_{kn} indicates the weight of n th second-level index under k th main factor.

Carry on the weighted calculation to each risk factor of geological hazards, and we could get:

$$\tilde{\otimes}A_k = \omega_k \cdot \tilde{\otimes}R_\xi \tag{6}$$

$\tilde{\otimes}A_k$, indicates the overall grey correlation degree the major factors of geological hazards to risk level k.

Finally, according to the maximum membership degree principle, the risk level of geological hazards could be determined.

4. The simulation calculation of a certain city's geological hazard risk

Referring to table 2 and the formula(1)(2)(3), the 4 grey clustering function formulas of a certain city's geological hazard risks are determined as follows:

$$f_1(d) = \begin{cases} \frac{d}{8}, & 0 \le d \le 8 \\ 1, & d > 8 \\ 0, & d < 0 \end{cases},$$

$$f_2(d)=\begin{cases}\frac{d}{8}, & 0\le d\le 8\\ 2-\frac{d}{8}, & 8<d\le 16\\ 0, & d>16, d<0\end{cases},$$

$$f_3(d)=\begin{cases}\frac{d}{6}, & 0\le d\le 6\\ 2-\frac{d}{6}, & 6<d\le 12\\ 0, & d>12, d<0\end{cases},$$

$$f_4(d)=\begin{cases}1, & 0\le d\le 4\\ 2-\frac{d}{4}, & 4<d\le 8\\ 0, & d>8, d<0\end{cases},$$

Four geological experts are hired to score certain city's geological hazard risks according to risk factors. The results are shown in table 3.

Table 3: *The scores the experts give to a certain city's geological hazard risks*

Second-level factors	Expert 1	Expert 2	Expert 3	Expert 4
rock mass structure	4.3	5.8	5.5	6.8
fracture distribution	8.2	7.8	8.3	7.5
earthquake intensity	8.1	8.5	8.8	7.6
hillside slope	3.5	5.2	4.3	3.0
relative altitude error	4.2	3.8	3.6	4.5
geomorphic type	3.8	4.3	4.8	3.2
climate type	4.5	5.6	4.8	6.0
vegetation coverage	4.0	3.2	4.1	3.9
average annual rainfall	5.1	6.2	6.8	4.2
cutting slope	6.2	5.4	4.2	4.8
deforestation	4.3	4.8	3.8	4.2
quarry blasting	5.2	5.5	4.8	3.8
non-standard mining	6.6	5.6	5.2	4.4
reservoir and channel leakage	5.8	6.8	7.8	5.4

Therefore,

$$D^{(A)}=\begin{pmatrix}4.3 & 5.8 & 5.5 & 6.8\\ 8.2 & 7.8 & 8.3 & 7.5\\ 8.1 & 8.5 & 8.8 & 7.6\end{pmatrix},$$

$$D^{(B)}=\begin{pmatrix}3.5 & 5.2 & 4.3 & 3.0\\ 4.2 & 3.8 & 3.6 & 4.5\\ 3.8 & 4.3 & 4.8 & 3.2\end{pmatrix},$$

$$D^{(C)}=\begin{pmatrix}4.5 & 5.6 & 4.8 & 6.0\\ 4.0 & 3.2 & 4.1 & 3.9\\ 5.1 & 6.2 & 6.8 & 4.2\end{pmatrix},$$

$$D^{(D)}=\begin{pmatrix}6.2 & 5.4 & 4.2 & 4.8\\ 4.3 & 4.8 & 3.8 & 4.2\\ 5.2 & 5.5 & 4.8 & 3.8\\ 6.6 & 5.6 & 5.2 & 4.4\\ 5.8 & 6.8 & 7.8 & 5.4\end{pmatrix},$$

By the formula (4) and $D^{(A)}$ to calculate separately the 4 grey clustering's evaluation coefficients of the first second-level factor of the main factor, A namely:

$$\tilde{\otimes}_{111}=\sum_{l=1}^{4}f_1(d_{1l})=f_1(4.3)+f_1(5.8)+f_1(5.5)+f_1(6.8)=2.8$$

$$\tilde{\otimes}_{211}=\sum_{l=1}^{4}f_2(d_{1l})=f_2(4.3)+f_2(5.8)+f_2(5.5)+f_2(6.8)=2.8$$

$$\tilde{\otimes}_{311}=\sum_{l=1}^{4}f_3(d_{1l})=f_3(4.3)+f_3(5.8)+f_3(5.5)+f_3(6.8)=3.5$$

$$\tilde{\otimes}_{411}=\sum_{l=1}^{4}f_4(d_{1l})=f_4(4.3)+f_4(5.8)+f_4(5.5)+f_4(6.8)=2.4$$

In the same way, we could get the 4 grey clustering evaluation coefficient of the second and third second-level factor of the main factor A as follows:

$$\tilde{\otimes}_{112}=3.9,\tilde{\otimes}_{212}=3.9,\tilde{\otimes}_{312}=2.7,\tilde{\otimes}_{412}=0.2;$$

$$\tilde{\otimes}_{113}=4.0,\tilde{\otimes}_{213}=3.8,\tilde{\otimes}_{313}=2.5,\tilde{\otimes}_{413}=0.1.$$

Therefore, the grey evaluation coefficient matrix $\tilde{\otimes}R$ of the main factor A could be obtained, namely:

$$\tilde{\otimes}R_A=\begin{pmatrix}2.8 & 2.8 & 3.5 & 2.4\\ 3.9 & 3.9 & 2.7 & 0.2\\ 4.0 & 3.8 & 2.5 & 0.1\end{pmatrix}.$$

Using the bigger the optimal principle, the optimal solution of main factor A could be determined as follows:

$$\tilde{\otimes}R_0^{(A)}=\begin{bmatrix} & M_0\\ c_1 & 3.5\\ c_2 & 3.9\\ c_3 & 4.0\end{bmatrix}.$$

Using the bigger the optimal criterion to carry on the standardized processing to $\tilde{\otimes}R_A$, the formula (5) is used to calculate the correlation grey matter element of the main factor A, which is obtained as follows:

$$\tilde{\otimes}R_{\xi}^{(A)}=\begin{pmatrix}0.44 & 0.44 & 1 & 0.33\\ 1 & 1 & 0.61 & 0.33\\ 1 & 0.99 & 0.57 & 0.33\end{pmatrix}.$$

The risk evaluation index weights of geological hazards could be calculated using the analytic hierarchy process (AHP). The results are shown in table 4.

Table 4: *The risk evaluation index weights of geological hazards calculated by AHP*

Main factors	weight	Second-level factors	weight
Geological conditions A	0.32	rock mass structure	0.14
		fracture distribution	0.62
		earthquake intensity	0.24
Topography B	0.18	hillside slope	0.70
		relative altitude error	0.21
		geomorphic type	0.09
Climate and vegetation C	0.21	climate type	0.14
		vegetation coverage	0.62

		average annual rainfall	0.24
Human damage activities D	0.29	cutting slope	0.27
		deforestation	0.17
		quarry blasting	0.16
		non-standard mining	0.23
		reservoir and channel leakage	0.17

So we could get:

$\omega = (0.32, 0.18, 0.21, 0.29)$,

$\omega_A = (0.14, 0.62, 0.24)$,

$\omega_B = (0.70, 0.21, 0.09)$,

$\omega_C = (0.14, 0.62, 0.24)$,

$\omega_D = (0.27, 0.17, 0.16, 0.23, 0.17)$.

According to the formula (6) to calculate:

$$\tilde{\otimes}A = (0.14, 0.62, 0.24)\begin{pmatrix} 0.44 & 0.44 & 1 & 0.33 \\ 1 & 1 & 0.61 & 0.33 \\ 1 & 0.99 & 0.57 & 0.33 \end{pmatrix} = (0.92, 0.92, 0.66, 0.33)$$

The same we could get:

$\tilde{\otimes}B = (0.34, 0.34, 0.46, 1)$

$\tilde{\otimes}C = (0.36, 0.36, 0.63, 0.75)$

$\tilde{\otimes}D = (0.42, 0.42, 0.92, 0.55)$.

Finally, we could get the overall correlation coefficient of this city's geological hazards as follows:

$\tilde{\otimes}B = (0.55, 0.55, 0.69, 0.60)$,

According to the maximum membership degree principle, this city's geological hazard risk level could be judged as general risk.

5. Conclusions

In recent years, along with the random mining of human beings, the vegetation coverage becomes small, geological hazards occurred sometimes, which becomes a serious threat to people's daily lives. And geological hazard risks are becoming serious. To evaluate the occurrence of geological hazards is beneficial to accurately predict the possibility of geological hazards, timely prevent and reduce people's losses and reduce the casualties, formulate the corresponding prevention measures and timely deal with the disaster situation. In the process of geological hazard risk evaluation, matter element analysis method provides a professional, scientific and reasonable evaluation method, which could provide theoretical basis for the study of geological hazard risks.

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