Weight calculation of risk factors for debris flow in earthquake zone based on combination weighting method

Guo Xiaoxiao^{1,a} Liu Wenbai^{1,b} Wang Yangcheng^{2,c}

¹ College of Marine Science and Engineering, Shanghai Maritime University, Shanghai 201306, China;

² College of Civil Engineering and Transportation Engineering, Hohai University, Nanjing , 210098, China;

^a 1171710705@qq.com, ^b liuwb8848@163.com, ^c wycwangyangcheng@163.com

Key words: debris flow in earthquake zone analytic hierarchy process gray relational degree method combination weighting method

Abstract. It is of great practical value to study the risk assessment of debris flow in the earthquake zone for ensuring people's safety and constructing key projects. Taking six debris flows in the earthquake area as examples, this paper calculates the weight of each Impact factor by using the analytic hierarchy process (namely subjective weighting method) and gray relational degree method (namely objective weighting method), then the weights of subjective and objective are calculated and dealt with using combination weighting, and the highest proportion of weight are annual rainfall and seismic intensity respectively.

Debris flow disaster has a serious impact on human life. Therefore, the research to debris flow disaster has important guiding significance for preventing and mitigating disaster [1]. Many scholars at home and abroad have also studied the risk assessment of debris flow [2,3]. At present, the objective weight assignment method and subjective weight assignment method are the most common methods of determining the dangerous weight of debris flow, but the combination weighting method which combines the two methods is very scarce. In this paper, we will take 6 debris flows in the earthquake area as the research object, conduct on-site geological survey, calculate the weight of each evaluation factor separately by using analytic hierarchy process and gray relational degree method, and calculate the combined weight.

The selection of impact factors of debris flow

Based on the obtained data of the study area, taking the characteristics of the study area in the earthquake area into consideration, the risk factors of the study area are determined as the nine factors, the debris flow scale, the watershed area and the occurrence frequency of the debris flow, the cutting density of watershed, maximum relative height difference of the watershed, annual rainfall, main channel length, population density and seismic intensity.

Impact factor weight of debris flow

the analytic hierarchy process

Establish a systematic hierarchy structure model

Taking the risk degree of debris flow in the earthquake area as the target level of the hierarchy structure, the four factors that can induce the occurrence of debris flow, source conditions, landforms, induced factors, and earthquake effects are used as the guideline layer of the hierarchy structure. The nine factors are selected as the index layer of the hierarchy structure.

Construct judgment matrix of pairwise comparison

The relative importance of each factor was quantified using the reciprocal scale method with a scale of 1 to 9 (Table 1) as a judgment dimension [4].

Through the questionnaire and expert opinion scoring, a comprehensive analysis of the risk factors of debris flow and their interaction effects, with reference to the judgment standards of each literature [5], determine the relative importance of each factor to give the scale value and to obtain the matrix A-Bi, Bi-Ci.

Table 1, scale method proposed by Satty

Relative degree of importance	definition
1	Equal importance
3	One element is slightly more important than the other
5	One element is obviously more important than the other
7	One element is more important than the other element
9	One element is extremely more important than the other
2,4,6,8	represent the compromise scale between the two standards
reciprocal	If the i and j factors determine the scale of a_{ij} , j and i are compared to determine the scale value of $1 / a_{ij}$

Single order of hierarchy and consistency test

Firstly calculate the eigenvalue of each judgment matrix, and then calculate the consistency index, which is calculated as follows:

$$CI = \frac{I_{\max} - n}{n - 1}. \quad (1)$$

Where n is the matrix order; $I_{\max}$ is the largest eigenvalue.

Table 2 is the mean random consistency index(RI).

Table 2, Random consistency index () value									
n	2	3	4	5	6	7	8	9	10
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.46	1.49

The criterion of random consistency ratio $CR = CI / RI$ is:

When $CR < 0.1$, Consistency of the matrix is good and reasonable;

When $CR = 0.1$, Consistency of the matrix is slightly reasonable;

When $CR > 0.1$, Does not meet the principle of consistency;

Overall ranking of hierarchy and consistency test

The total weight of the indicator level ω_i and it's formula is^[6]:

$$\omega_i = \sum_{j=1}^m b_j c_{ij} (i = 1, 2, \dots, n)$$

(2)

Where b_j is the weight of single rank order of second level indicators B_j ; c_{ij} is The single-ranked weights of hierarchy of the three-level indicators for the secondary indicators.

After calculation, we can get the weight of indicators at all levels shown in Table 3

Table 3, indicators at all levels of weight

Target level	Guidelines layer (weight)	Indicator layer (weight)
Danger degree A	$w_{b1} = 0.136$	$w_{c1} = 0.1020$
		$w_{c2} = 0.0340$
		$w_{c3} = 0.0098$
	$w_{b2} = 0.115$	$w_{c4} = 0.0177$
		$w_{c5} = 0.0277$
		$w_{c6} = 0.0596$
	$w_{b3} = 0.468$	$w_{c7} = 0.3774$
		$w_{c8} = 0.0936$
		$w_{c9} = 0.2800$
	$w_{b4} = 0.280$	

gray relational degree method

According to relative theory^[7], Correlation analysis and calculation steps are as follows:

(1) The composition associated series, which is $X = \{X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9\} = \{\text{debris flow scale, debris flow occurrence frequency, watershed area, maximum relative elevation difference of watershed, density of watershed, main channel length, annual rainfall, population density, seismic intensity}\}$

(2) Data averaging and dimensionless processing

$$X'_i = X_i(k) / \frac{1}{6} \sum_{k=1}^6 X_i(k). \quad (3)$$

(3) Absolute difference sequence

$$\Delta_{ij}(k) = |X'_i(k) - X'_j(k)|. \quad (4)$$

(4) correlation coefficient

$$X_{ij} = \frac{\Delta_{\min} + r\Delta_{\max}}{|X'_i(k) - X'_j(k)| + r\Delta_{\max}}. \quad (5)$$

where, r is resolution factor, Generally take $r = 0.5$.

(5) Correlation

$$\gamma_{ij} = \frac{1}{n} \sum_{k=1}^m \xi(k). \quad (6)$$

(6) Factor weight

$$w_i = \bar{v}_i / \sum_{i=1}^9 \bar{v}_i . \quad (7)$$

According to the above steps, X_1 - X_9 are sequentially selected as the reference sequence for analyzing and calculating the matrix of correlation degree, and then the average value of each row is obtained. According to the formula 7, the weight values of each evaluation factor are shown in Table 4.

Table 4,Weight values for the factors

Weights	ω_1	ω_2	ω_3	ω_4	ω_5	ω_6	ω_7	ω_8	ω_9
Value	0.1137	0.1144	0.1132	0.1065	0.1086	0.1122	0.1109	0.1139	0.1067

Combination weighting approach

The weight vector generated by subjective weight determination is recorded as $W' = (w'_1, w'_2, \dots, w'_n)$, The weight vector generated by objective weight determination is recorded as $W'' = (w''_1, w''_2, \dots, w''_n)$. The importance of W' and W'' is represented by α and β , which combines the two vectors:

$$W = \alpha W' + \beta W'' . \quad (8)$$

Undetermined coefficient α and β are important parameters to determine the combination weight, you can set α and β to meet the unit constraints:

$$(\alpha^2 + \beta^2 = 1, \alpha > 0, \beta > 0) . \quad (9)$$

According to the weight rule of Multiple Attribute Decision Analysis, the target value of each evaluation object can be obtained:

$$d_i = \sum_{j=1}^n b_{ij} W_j = \sum_{j=1}^n b_{ij} (\alpha W'_j + \beta W''_j) . \quad (10)$$

In formula (10), b_{ij} is the value of the evaluation object. In general, The weight should make the sum of the Evaluating Value of the solution as large as possible, so that the following multi-objective optimization mathematical model is constructed as:

$$\max D = (d_1, d_2, \dots, d_m); \text{ s. t. } \alpha^2 + \beta^2 = 1; \alpha > 0, \beta > 0. \quad (11)$$

We can get

$$\bar{\alpha}^* = \frac{\sum_{i=1}^m \sum_{j=1}^n b_{ij} W'_j}{\sum_{i=1}^m \sum_{j=1}^n b_{ij} (\alpha W'_j + \beta W''_j)}; \bar{\beta}^* = \frac{\sum_{i=1}^m \sum_{j=1}^n b_{ij} W''_j}{\sum_{i=1}^m \sum_{j=1}^n b_{ij} (\alpha W'_j + \beta W''_j)} . \quad (12)$$

In formula (12), $\bar{\alpha}^*, \bar{\beta}^*$ are the subjective weight and objective weight coefficients of the combination weighting, According to the table 3 and 4, obtain $\bar{\alpha}^* = 0.535, \bar{\beta}^* = 0.465$, combination weight $W = 0.535\bar{\alpha}^* + 0.465\bar{\beta}^*$, the target value of the comprehensive assessment of each programs are:

$$\bar{d}_i = \sum_{j=1}^n b_{ij} (\bar{\alpha}^* W'_j + \bar{\beta}^* W''_j) \quad (i = 1, 2, \dots, m) . \quad (13)$$

Table5 is the weighting coefficient of evaluation factor:

Table 5, Weighting coefficient of evaluation factor

Evaluation factor	Analytic hierarchy process (AHP)	Gray correlation method	Combination weights
Debris flow scale	0.1020	0.1137	0.1075
Debris flow frequency	0.0340	0.1144	0.0714
Drainage area	0.0098	0.1132	0.0579
Relative maximum Height difference of The drainage	0.0177	0.1065	0.0590
Cutting density of the Drainage	0.0277	0.1086	0.0653
Main channel length	0.0596	0.1122	0.0841
Annual rainfall	0.3774	0.1109	0.2535
Population density	0.0936	0.1139	0.1030
Seismic intensity	0.2800	0.1067	0.1994

Among the evaluation factors, the weight coefficients of seismic intensity and annual rainfall are the largest, and the values are 0.1994 and 0.2535, respectively. The role of rainfall and earthquakes are fully considered in this calculation method, which is closer to the actual situation of debris flow in the earthquake area.

Conclusion

This article draws the following main conclusions:

- (1) In this paper, combination weighting method combine analytic hierarchy process with gray correlation degree method.
- (2) The weight of the debris flow evaluation factor for the earthquake zone was calculated by using a combination weighting method. The highest weight values are annual rainfall and seismic intensity, and the values are 0.2535 and 0.1994, respectively.

Acknowledgements

This work was financially supported by the Shanghai Natural Science Foundation (0666666), Innovation Program of Shanghai Municipal Education Commission (060000) and Shanghai Leading Academic Discipline Project of Shanghai Municipal Education Commission (0555555).

Reference

- [1] Wei Fangqiang, Xie Hong, Zhong Dunlun, etc. Debris flow and its disaster mitigation in the construction of mountain towns in western China[J]. The Chinese Journal of Geological Hazard and Control, 2002, 04: 25-30+54.
- [2] Tan Bingyan. Quantitative Comprehensive Evaluation of the Degree of Debris Flow Gully [J]. Bulletin of Soil and Water Conservation, 1986, 02: 74-82.
- [3] Wei Binbin, Zhao Qihua, Grey Correlation Method Based Hazard Assessment of Debris Flow in Quake-Hit Area-Taking Debris Flows in Beichuan as an Example, 2013, 21(04): 525-533.
- [4] Xia Tian. Systematic Study on the Risk Assessment of Debris Flow in Earthquake Areas and Its Early Warning and Disaster Reduction [D]. Chengdu University Of Technology, 2013.
- [5] Deng Zhihui, Xie Mowen, Yin Yanli, etc. The Study on Debris Flow Hazard Assessment of

Reservoir Area on the Basis of AHP [J]. *Science & Technology Vision*, 2014, 33: 188-189+229.

[6] Dang Hongshe, Xie Chen, Wang Li. Evaluation of Debris Flow Risk Based on Analytic Hierarchy Process and Primary Component Analysis [J]. *Beijing: Mathematics in Practice and Theory*, 2015, 07: 176-183.

[7] Deng J. *The course of grey system theory*. Wuhan: Huazhong University of Science and Technology Press, 1998.