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Research on risk assessment of debris flow in a mining area in western China based on the game theory empowering normal cloud theory

Risk assessment of debris flow is an uncertain problem involving randomness and fuzziness. The cloud model is used to distinguish for assessing the risk of debris flow scientifically and rationally. Firstly, the system standard of debris flow risk assessment is constructed; secondly, impact factor of each assessment system which belonging to cloud droplet of each risk level produced by normal cloud generator, the subjective weights and objective weights of the debris flow influence factors are coupled by using game theory, and consider the fuzziness of debris flow basic data, using the Monte Carlo modelling thought, and by generating large cloud droplets and statistics of the average value in a mini zone near the basic data for evaluating debris flow as the basic data belonging to some hierarchical average degree of certainty; finally, the proposed model is used for case research, and compared to several existing mature methods to prove the proposed model is feasible and reasonable.

Keywords: *Debris flow, risk assessment, cloud model, game theory, Monte Carlo modelling.*

1. Introduction

Debris flow is a common geological disaster in mountain areas of China. It has the characteristics of sudden eruption, rapid movement and short duration, etc. It seriously threatens the safety of life and property of the people in mountain areas [1]. The risk assessment of debris flow is the foundation of debris flow risk management and disaster management, and also is an important link of prevention and control in debris flow disaster. It is of great significance to protect people's life and property safety.

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With the introduction of some modern mathematical methods and cross disciplines, the study on risk assessment of debris flow has stepped into a interdisciplinarity. The neural network technology is applied to study on the risk area of debris flow by Zhang Chen etc. [2]; based on methods of information entropy and fuzzy mathematics to establish fuzzy evaluation model for risk assessment of debris flow by Ning Na etc. [3]; based on the analytic hierarchy process and the unknown measuring theory to establish hierarchical unknown measuring recognition model for risk assessment of debris flow by Liu Hai etc. [4], the catastrophe model is used to classify the risk of debris flow by An Yuhua etc[5]. These methods had achieved certain results, but they also need further improvement. For example, the neural network technology requires many prior samples, and network generalization performance is difficult to guarantee, which leads to miscarriage of justice in some cases; the subjective influence factors of fuzzy judgment are more; the determination of the confidence level in the unknown measure theory lacks certain criteria; the index order of mutation theory is too subjective. At the same time, the indexes of debris flow evaluation system are often random and fuzzy, these methods often only focus on one of the characteristics, which is not in line with the actual situation.

The normal cloud model is built on the basis of fuzzy mathematics and probability theory [6], often using numerical characteristics of expectation, entropy and hyper entropy features to qualitative mathematical concept, through the cloud generator implements the mutual exchange of qualitative concepts and quantitative values in the model to achieve perfect union of fuzziness and randomness. Obviously, the risk assessment of debris flow is also a problem of dealing with fuzziness and randomness. Therefore, the game theory empower to cloud model applied to risk assessment of debris flow in this paper. For determining the weight of debris flow impact factors, to compound the subjective weight of analytic hierarchy process and objective weight-value of entropy weight method by game theory combination method for getting synthetical weight of overall consideration subjectivity and objective ultimately. When calculate each index of evaluating debris flow relative to the certainty degree of each danger level, considering that fuzzy measurement indexes of debris flow gully is not calculated by substituting a specific quantity value into the model, but by means of the Monte Carlo modelling thought [7] get the certainty degree through the average value of a certain block. Finally, the feasibility and rationality of the proposed model is verified by comparing the engineering examples with the existing mature methods.

2. Establish risk assessment system of debris flow

The key of debris flow risk assessment is to select the appropriate index and establish the evaluation system. The topographic and geomorphic features, geological structure and formation lithology characteristics, population distribution of natural climatic region, etc of evaluating region are likely to affect the final results of the evaluation. For assessing and forecasting the risk of debris flow, it is necessary to extract specific risk factors from these influence characteristics. As for the debris flow gully, its lithology and structural characteristics itself have great complexity, and there are many specific factors that affect the risk of debris flow, there is an important significance to select specific factors, appropriate impact factor can reflect the dominant factors of debris flow damaging, which can take corresponding measures to control the factors, to minimize the losses caused by disasters. The debris flow basin area S1of surveying area, length of main gully bed S2 , maximum relative elevation difference of basin area S3, cutting density S4, bending coefficient S5 of main gully bed, sediment supply length ratio S6, 24h maximum precipitation S7, one of the largest debris flow out of the volume S8, frequency of occurrence S9 and population density in river basin S10 as a specific risk factors of debris flow evaluation. Among them, S1directly influences the regional sediment, and then affect the loose source reserves in the basin; S2 is bigger that more loose solid matter is accumulated along the way; S3directly affects the speed of the debris flow confluence; S4 is a comprehensive reflection of lithology and rock weathering degree and geological structure in the region; S5 is effect of discharge debris gullies; S6 characterizes the debris flow potential of provenance; S7 reflects the kinetic energy conditions of debris flow; S8 shows direct collapsing force of debris flow; S9 is a statistical magnitude on the debris flow; S10 is a comprehensive reflection of human activities triggered a factor of debris flow. According to the evaluation index system, the specific risk system is shown in Table 1. The risk of debris flow is divided into 4 grades, from grade I to grade IV, the risk degree is small, medium, large and great, and the dangerous degree of debris flow in the evaluation section is higher, that the issues that need special attention.

3. Based on the game theory combination of empowering normal cloud theory

3.1 Cloud model theory

The cloud model theory is a theory of putting forward on the basis of fusing probability theory and fuzzy mathematics by Professor Deyi Li. Often using numerical characteristics of expectation, entropy and hyper entropy features to qualitative mathematical concept, through the cloud generator implements the mutual exchange of qualitative concepts and quantitative values in the model to achieve perfect union of fuzziness and randomness. Among them, the normal cloud model is the most basic and the most commonly used. It has been used in the stability evaluation of surrounding rock, rock burst intensity classification and ecological evaluation, the algorithm of normal cloud generator is [6]:

Step 1: To determine the relevant parameters, that is expectation Ex, entropy En, hyper entropy He, droplet number n;

Step 2: To generate En as expectation, He is normal random number y_i of corresponding standard deviation;

Step 3: In order to further generate Ex as expectation, y_i is the normal random number x_i of the standard deviation;

Step 4: Get certainty degree $u(x_i) = \exp\left(-\frac{(x_i - Ex)^2}{2y_i^2}\right)$;

Step 5: Calculation of n of cloud droplets and corresponding certainty degree $u(x_i)$.

3.2 Cloud model digital characteristics of debris flow evaluation factors

From the above, three key parameters (Ex, En, He) of the normal cloud algorithm need to be given in advance [9]. Combined with the literature, the digital characteristics of the debris flow evaluation factor can be given according to the following formula:

$$\begin{cases} Ex = \dfrac{C_{max} + C_{min}}{2} \\ En = \dfrac{C_{max} - C_{min}}{6} \\ He = k \end{cases} \quad \dots \quad (1)$$

Table 1: Debris flow risk grading standards

Grade	S1/ km^2	S2/ km	S3/ km	S4/ km. km^{-2}	S5	S6	S7/ mm	S8/ person. km^{-2}	S9 /10^4. m^3	S10 /%
I	<0.5	<1	<0.2	<5	<1.10	<0.1	<25	<50	<1	<10
II	(0.5, 10)	(1, 5)	(0.2, 0.5)	(5, 10)	(1.10, 1.25)	(0.1, 0.3)	(25, 50)	(50, 150)	(1, 10)	(10, 50)
III	(10, 35)	(5, 10)	(0.5, 1.0)	(10)~(20)	(1.25, 1.40)	(0.3, 0.6)	(50, 100)	(150, 250)	(10, 100)	(50, 100)
IV	> 35	> 10	> 1.0	> 20	> 1.40	> 0.6	> 100	> 250	> 100	> 100

In the formula, C_{max}, C_{min} are indicate the maximum and minimum values of a certain level respectively; for the single boundary variables, such as $[C_{min}, +\infty]$ and $[-\infty, C_{max}]$, can be determined according to boundary of the actual data, then enter the equation (1) to calculate; k is the constant, in applications, it is usually called 0.01. According to Table 1 grading standards, substitute into formula (1), and then through the positive normal cloud generator generates each debris flow risk assessment indexes belong to each level of the cloud as shown in Fig.1, produced a total of 300 droplets per level.

3.3 Weights definition of each influence factor in debris flow risk assessment

In the current method of weight determination, it can be roughly divided into two methods: the subjective weighting method and the objective weighting method. The commonly used methods are analytic hierarchy process, entropy weight method, projection pursuit method, grey relational method, etc. Because the weights calculated by different weights may be different, which leads to the final weights are determined by the lack of certain criteria, therefore, in practice, the combination weights are often used to determine the final weights. Here, the game theory is used to integrate the subjective weights obtained by analytic hierarchy process and the objective weights computed by the entropy weight method. The analytic hierarchy process is a widely used method of decision making method by constructing the two-two comparison matrix of each influence factor and then determining the weight by a certain method; entropy weight method is a method of weight determination developed by the theory of information entropy, and the main steps are as follows:

Step 1: According to the value r_{ij} of evaluation object, constructing judgment matrix R; in the formula, m shows the number of objects; n shows the number of evaluation indexes.

$$R = (r_{ij})_{m\times n} \quad (i = 1,2,...,n,\ j = 1,2,...,m) \qquad ... \qquad (2)$$

Step 2: Dimensionless processing to R; the judgment matrix is processed by column normalization, to get $R = (a_{ij})_{m\times n}$.

Step 3: To calculate the entropy of each evaluation index number:

$$H_i = -\frac{1}{\ln m}\sum_{j=1}^{m} f_{ij}\ln f_{ij} \qquad ... \qquad (3)$$

In the standard entropy method, the f_{ij} as per equation (6), when the value of f_{ij} is 0, equation (3) is not convergent and meaningless. So, here, it needs to improve the value of f_{ij}, improved expressions are presented in equation (5).

$$f_{ij} = a_{ij} \Big/ \sum_{j=1}^{m} a_{ij} \qquad ... \qquad (4)$$

$$f_{ij} = (1 + a_{ij}) \Big/ \sum_{j=1}^{m} (a_{ij} + 1) \qquad ... \qquad (5)$$

Step 4: According to equation (6) to determine the weight of each index.

$$w_i = (1 - H_i) \Big/ \left(n - \sum_{i=1}^{n} H_i \right) \qquad ... \qquad (6)$$

The weight vector is calculated by the analytic hierarchy process of $W_1 = \{w_{11}, w_{12}, ..., w_{1n}\}$; the weight vector is calculated by entropy method of $W_2 = \{w_{21}, w_{22}, ..., w_{2n}\}$. The combination weight vector is:

$$W = \sum_{k=1}^{2} \alpha_k \cdot W_k^T \qquad ... \qquad (7)$$

By using the game theory to optimize α_k in formula (2), to minimize the exiting deviation between possible weight vector W and each basic vector, and the game model is derived as follows:

$$\min \left\| \sum_{k=1}^{2} \alpha_k \cdot W_k^T - W_k \right\|_2 \quad (k = 1,2) \qquad ... \qquad (8)$$

According to the idea of matrix differential, the first derivative condition of formula (8) is translated into:

$$\begin{bmatrix} W_1.W_1^T & W_1.W_2^T \\ W_2.W_1^T & W_2.W_2^T \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix} = \begin{bmatrix} W_1.W_1^T \\ W_2.W_2^T \end{bmatrix} \qquad ... \qquad (9)$$

Through the calculation of the MATLAB software solution of 1 2 $[\alpha_1, \alpha_2]$. In general, the obtained combination coefficient α_k should be positive, due to the solution formula (4) always has negative value solution, so the normalized formula in reference [10,11], to ratiocinate α_k is:

$$\alpha_k^* = |\alpha_k| \Big/ \left| \sum_{k=1}^{L} \alpha_k \right| \qquad ... \qquad (10)$$

In the formula, L get 2; that the weight of each influence factor of final debris flow can obtained by formula (7).

3.4 Identification of risk grade about debris flow

The basic process of dividing the risk of debris flow by using the normal cloud model is: according to the method of section 2.2, each index of the debris flow is calculated to correspond to the digital eigenvalues of different grades, generate the corresponding cloud model according to the normal cloud algorithm, as shown in Fig.1, and through the method in 2.3 to determine the debris flow risk assessment indicators in each of the factors affecting the weight, for the certainty degree U of debris flow risk level assessment is :

$$U = \sum_{i=1}^{m} u w_i \qquad ... \qquad (11)$$

In the formula, u shows the corresponding certainty degree of assessment of cloud droplet (index); w_i is the corresponding weight of the index; according to the principle of maximum comprehensive certainty, finally determine the risk grade of evaluation debris flow. Among them, taking into account the fuzziness of debris flow evaluation index in calculating certainty degree, that is, the evaluation index itself is not completely defined, not in accordance with a precise value p to determine the degree of substitution solution, but by means of the Monte Carlo modelling thought by statistics the certainty average value of a confidence interval (p-Δp, p+Δp) nearby as a certainty degree $\bar{u} = \sum_{i=1}^{k} u_i / k$ of the index.

4. Hazard assessment of debris flow in a mining area in western China

4.1 Risk assessment based on the game theory empower normal cloud theory

In order to test the feasibility and rationality of the model, a number of debris flows of the mine in the western China are carried out the verification of this case [8]. The county where the mine belongs to is located in the western part of China, latitude and longitude 102.5°-103.0°E, 28.6°-29.3°N, mainly steep mountainous, 650m above sea level, the county elevation of 1070m. The region has proven 29 kinds of metal and nonmetallic ore, including lead, zinc, copper, iron ore and other minerals. Which lead-zinc reserves of 1.5 million tonnes (280 grams per tonne of average silver), the annual output of Sichuan province, according to the first, accounting for 10% of China, is the famous lead and zinc town. Due to the lack of understanding of the importance of mountain environment and forest ecosystems, the natural environment and ecological balance have been damaged to a certain extent. So the

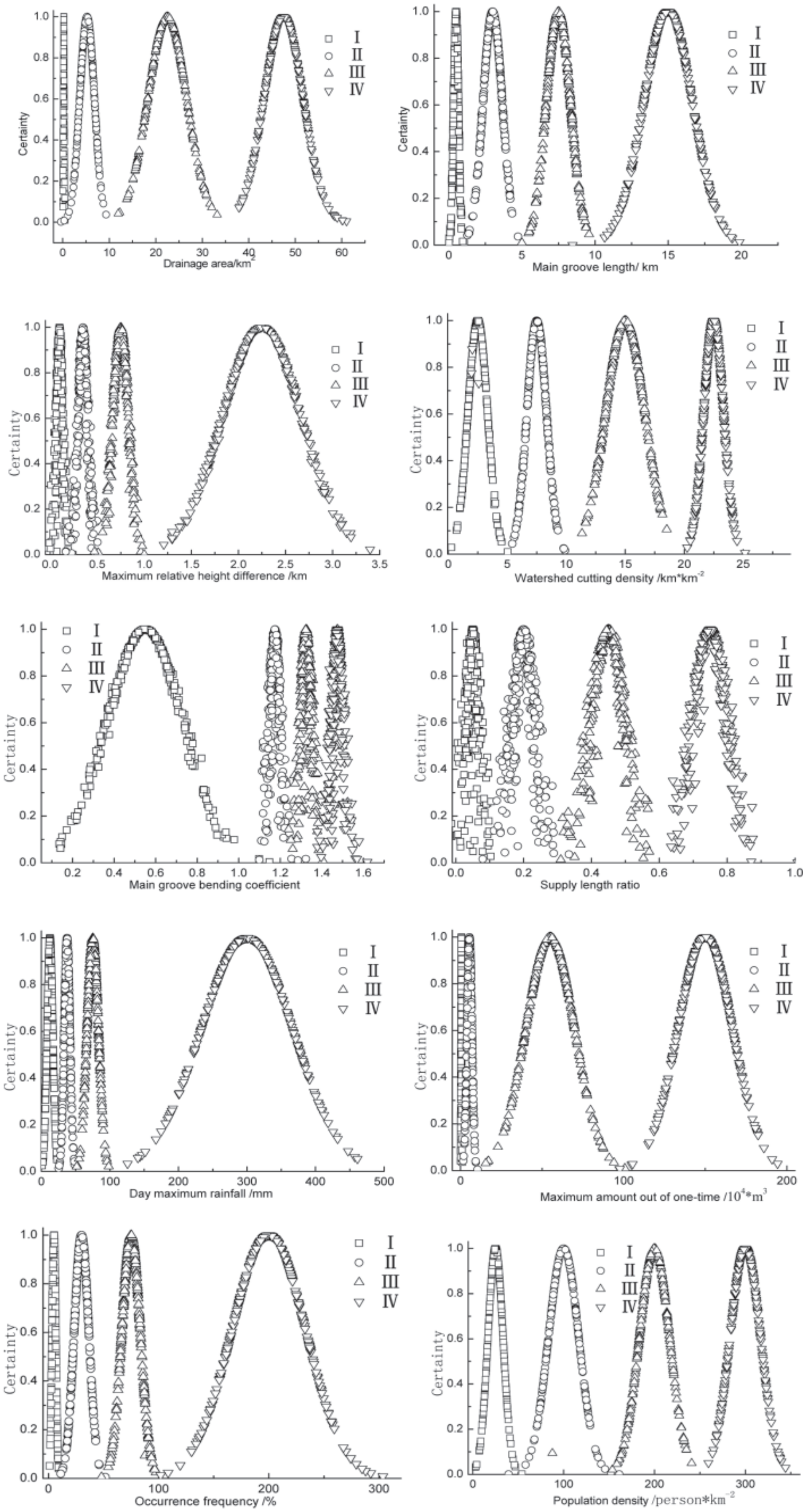

Fig.1 Each influencing factor risk class cloud model of debris flow

TABLE 2: ASSESSMENT RESULTS OF DEBRIS FLOW RISK

Number	Final degree of certainty				Assessment results				
	I	II	III	IV	This model	Extension model	Unknown measure theory	Fractal dimension theory	Set pair analysis theory
1	0.0000	0.0000	0.0067	0.4700	IV	IV	IV	IV	IV
2	0.0000	0.0127	0.0664	0.2295	IV	IV	IV	IV	IV
3	0.0000	0.1792	0.0925	0.0467	II	II	II	III	III
4	0.0009	0.2274	0.1350	0.0702	II	III	II	III	III
5	0.0007	0.1838	0.2516	0.0212	III	II	II	III	III
6	0.0000	0.0000	0.1672	0.3875	IV	IV	IV	IV	IV
7	0.0000	0.0599	0.2555	0.0320	III	III	III	IV	III
8	0.0000	0.3249	0.0390	0.1586	II	II	II	III	III

mountain geological disasters are serious, and debris flow is in the first place. The debris flow in the area to be evaluated is located in the vicinity of the village of Eidai, about 5km north of the county. It is a part of the Daidu River tributary of the Niri River and belongs to the part of the county's Eidai lead-zinc mine. It is a mine mainly composed of artificial mining slag debris flow gully, ditch about 3430m, the relative height difference of about 1525m. Ditch high slope steep, due to perennial exploitation of lead and zinc mine, ditch within the accumulation of slag has nearly 1.258 million m³, while the ditch within the local slope rock piles development, in the ditch to form a large number of loose material. If the ditch outbreak debris flow, the attachment line safe operation will be seriously threaten. So, it is necessary to assess the risk of debris flow. The objective weight obtained by entropy weight method:

W_2 = [0.1096 0.0889 0.0993 0.1037 0.1059 0.1143 0.0654 0.1156 0.1389 0.0582]

The analytic hierarchy process quoted the results by works cited [4]:

W_1 = [0.1585 0.0741 0.0538 0.1236 0.0364 0.0417 0.0358 0.2356 0.2199 0.0206]

In equation (11) of W_1 and W_2, to obtain the combination coefficient, at last, the comprehensive weights of each influence factor are obtained by calculating the average certainty of each influence factor (each level set 1000 cloud droplets, the average value of 95% confidence interval of each measured target as an average degree of certainty by statistics):

W = [0.1494 0.0769 0.0623 0.1199 0.0493 0.0552 0.0413 0.2133 0.2048 0.0276]

Through the formula (11) to obtain the comprehensive degree of certainty, finally, the risk grade of debris flow is determined according to the principle of maximum integration. Table 2 presents calculation and evaluation results of the method in this paper, and it is compared to extension model [8,12], unknown measure theory [4], fractal dimension method [13] and set pair analysis method [14].

4.2 DISCUSSION

As shown in Table 2, for the evaluation of the typical debris flow gully mentioned above, the conflict between the model and the existing method is mainly in No. 5 of debris flow gully. In order to compare the differences of several different methods, from the intuitive statistics, each index of No.5 falls into number of different intervals: the number of indicators falling into rank II is 4; the number of indicators falling into rank III is 3; the number of indicators falling into rank IV is 3 (Fig.2); subjectively, there is a tendency to attribute number 5 to grade III. This shows that the model is

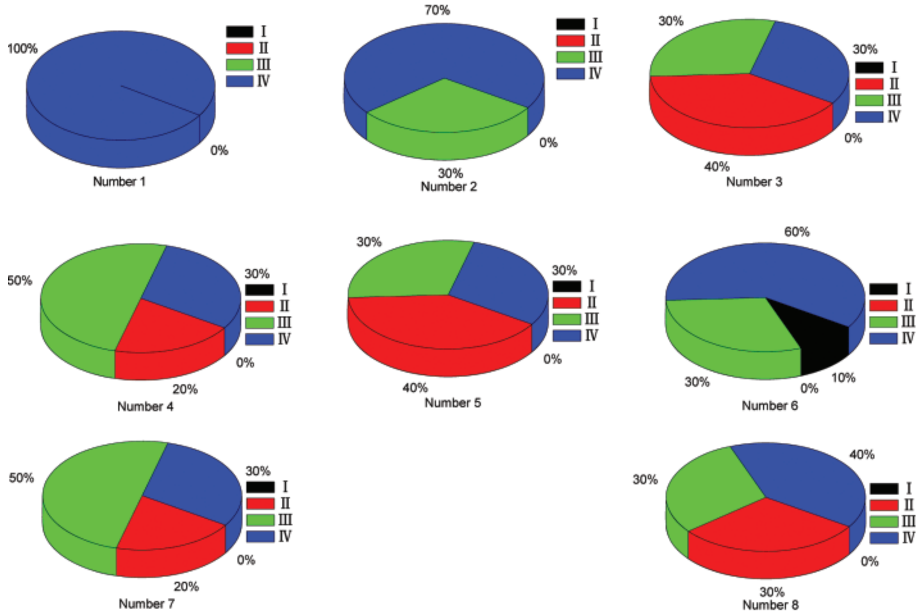

Fig.2 Each factor index charts of to be assessed debris flow ditches

reasonable; the deviation of number 4 is mainly due to the weight setting of this paper. Overall, the conclusions obtained in this paper are in agreement with other methods, easy to implement and have certain practicability. In the process of determining weights, apply the idea of game theory to fuse the subjective and objective weights. In the literature [15], the cloud model is adopted to study the debris flow evaluation, but the determination of the weight is lack of certain scientific basis; in this model, considering the fuzziness of measuring debris flow gully index, it is not calculated by substituting a specific quantity value into the model, But by means of the Monte Carlo modelling thought get the certainty degree through the average value of a certain block. By contrast, the obtained theory and model are more applicable to the risk assessment of debris flow.

It is necessary to explain that the evaluation results obtained by different models may have some deviations, but this method cannot be judged to be unreasonable. Because there are many factors that influence the final evaluation result of the model. For model of this article, the final evaluation results are influenced by the weight of each index, the parameters of the cloud model and boundary. The influence of the weights on the evaluation results can be directly reflected from the formula (11); the main parameters of the cloud model is the number of cloud droplets n and confidence interval, in a general way, the result of assessment is more authentic by multiplying the number of cloud droplets; the confidence interval is usually 95%. At the same time, the boundary setting is also a key factor affecting the final evaluation result of the model, and the boundary of the missing data is usually determined according to the boundary of the actual data. How to set model parameters better will be the focus of the next research.

5. Conclusion

(1) The randomness and fuzziness of each index factor in debris flow evaluation are suitable to evaluate the debris flow risk by cloud model. Each index parameter is not only supported by a large number of measured data, but also can deal with fuzzy with the help of number of cloud droplets, can be expected to obtain high reliability.

(2) In order to improve the human influence and computational distortion of the subjective and objective weights obtained by analytic hierarchy process and entropy weight theory, by using game theory thought, are to synthesize the subjective weights of analytic hierarchy process and the objective weights of entropy weight method linearly.

(3) When the game theory combination empower normal cloud model of comments raised in risk of debris flow is calculates the certainty of each index of evaluation debris flow gully, considering that fuzzy measurement indexes of debris flow gully is not calculated by substituting a specific quantity value into the model, but by means of the Monte Carlo modelling thought get the certainty degree through the average value of a certain block for risk assessment. Through an engineering example and compared to the existing mature methods, it shows that the model can evaluate the risk of debris flow effectively. The method is feasible, the conclusion is credible and has certain application value.

Acknowledgements

The study is supported by the Changjiang River Scientific Research Institute of Changjiang Water Resources Commission open research program (Grant No. ckwv2016393/KY), the Open Foundation of Jiangxi Engineering Research Center of Water Engineering Safety and Resources Efficient Utilization (Grant No. OF201605), Scientific and Technological Research Program of Chongqing Municipal Education Commission (Grant No. KJ1601005), Municipal Science and Technology Program of Wan-zhou district, Chongqing (Grant No.201503053), Science and Technology Talent Special Fund Project of Wan-zhou District, Chongqing (Grant No.2016027) •C Field Grade Major Breeding Program of Chongqing Three Gorges University (Grant No.15ZP04) and Disaster Prevention, Disaster Mitigation and Safety of Engineering Structure in Three Gorges Reservoir Area Innovation Team.

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