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GULLY-SPECIFIC DEBRIS FLOW HAZARD ASSESSMENT IN CHINA

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ABSTRACT: Techniques of gully-specific debris flow hazard assessment developed in four periods since the end of the 1980s have been discussed in the present paper. The improvement for the empirical assessment method is the sectionalized function transformation for the factor value, rather than the classified logical transformation. The theoretical equation of the gully-specific debris flow hazard is expressed as the definite integral of an exponential function and its numerical solution is expressed by the Poisson Limit Equation. Current methods for assessment of debris flow hazard in China are still valid and practical. The further work should be put on the study of the reliability (or uncertainty) of the techniques. For the future, we should give a high priority to the relationship between debris flow magnitude and its frequency of occurrence, make more developments of prediction model on debris flow magnitude, so as to finally reach the goal of assessing the hazard of debris flow by theoretical model, and realize both actuality assessment and prediction appraisal of debris flow.

KEY WORDS: debris flow; hazard; gully-specific debris flow assessment; theoretical equation

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1 INTRODUCTION

Hazard, the short form of hazard degree, is a quantitative expression of an extreme event. Researches on landslide hazard assessment have had a history of nearly 40 years (JONES, 1992). The earliest research referring to debris flow hazard assessment might be " Study on judgment of outbreakability of debris flow" by ASHIDACH and others(1977). " Outbreakability "used in the above paper means only frequency of debris flow occurrence; it differs in some degree from" hazard "we use now, which comprises both debris flow magnitude and its frequency of occurrence. HOLLINGSWORTH and KOVACS (1981) put forward a frame for debris flow hazard assessment by using the method of point rating. They suggested that three variables of lithology, gradient and drainage density may be used, and separately divided into five grades: 0, 1, 2, 3, 4, and then sum the grades of the three variables to assess debris flow hazard. However, except division of drainage density, they did not give division precept for the other two variables. This might be the earliest one of the several studies concerning quantitative assessment on debris flow hazard in the United States. In China, TAN (1986) carried out a research related to debris flow severity. According to comments from TANG and TANG (1994), LIU (1988) published an earliest paper formally studying debris flow hazard in China, and since then research in this filed has lasted for more than ten years with the researches continuously deepened and new results coming out (YANG *et al.*, 1991; XU and YANG, 1993; LI, 1999). Until now, the basic principles and technical methods for hazard assessment of debris flow catchments have been primarily formed, and improved step by step in practice. The objective of this paper is to give an overview of the gully-specific debris flow hazard assessment in the past over ten years and the latest development, as well as proposes the perspective for future studies.

2 EARLIEST HAZARD ASSESSMENT OF GULLY-SPECIFIC DEBRIS FLOW

The earliest hazard assessment of gully-specific debris

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flow employs eight variables (LIU, 1988), including maximum volume of a debris flow deposit in the depositional area (magnitude) (M), frequency of debris flow occurrence (F), volume of unconsolidated materials in the catchment (W), maximum boulder diameter (BD), maximum debris flow density (RC), maximum rainfall within 12 hours in the catchment (RF), relief of the catchment (RE), and drainage basin area (A). The former 5 variables are internal factors affecting the hazard of debris flow; the latter 3 variables are environmental factors relevant to debris flow hazard. Use the maximum volume of a debris flow deposit in the depositional area as the leading factor, analyze the correlation between the leading factor and each of the other 7 factors, and work out the correlation between every two factors and the correlation sequence. Then based on the sequence, give each factor a corresponding weight. For simplification, we give a weight of 1 to the factor at the end of minimal correlation in the correlation sequence, and increase in arithmetical progression by the common difference of 1 toward the end of maximal correlation sequence. Therefore, the weights of these factors are in turn 1, 2, 3, 4, 5, 6, 7, and 8. The weight of the leading factor "maximum volume of a debris flow deposit in the depositional area" is 8, i. e., $M \rightarrow 8$, so weights of other factors are: $A \rightarrow 7$, $RC \rightarrow 6$, $RF \rightarrow 5$, $BD \rightarrow 4$, $RE \rightarrow 3$, $F \rightarrow 2$, $W \rightarrow 1$.

Use the weight of factors as cardinal number and common difference, divide the range of factors into four classes, and then increase the score of each factor in arithmetical progression depending on the grade value of each factor. Finally, summarize all scores of the eight factors; the result is the hazard of the debris flow catchment (Table 1).

Table 1 Scheme for gully-specific debris flow hazard (LIU, 1988)

Factor and score	Symbol	Class 1	Class 2	Class 3	Class 4
Maximum volume of a debris flow deposit in the depositional area ($\times 10^3 m^3$)	M	≤1	2 - 9	10 - 99	≥100
Factor score		8	16	24	32
Volume of unconsolidated materials in the catchment ($\times 10^4 m^3$)	W	≤0.5	0.6 - 49	50 - 199	≥200
Factor score		1	2	3	4
Maximum boulder diameter (m)	BD	≤1	1.1 - 3.0	3.1 - 7.9	≥8
Factor score		4	8	12	16
Maximum debris flow density (t/m^3)	RC	≤1.5	1.6 - 1.9	2.0 - 2.2	≥2.3
Factor score		6	12	18	24
Maximum rainfall within 12 hours in the catchment (mm)	RF	≤25	26 - 49	50 - 99	≥100
Factor score		5	10	15	20
Relief of the catchment (km)	RE	≤0.5	0.6 - 1.0	1.1 - 2.9	≥3
Factor score		3	6	9	12
Frequency of debris flow occurrence (%)	F	≤10	11 - 49	50 - 99	≥100
Factor score		2	4	6	8
Drainage basin area (km^2)	A	≤0.5	0.6 - 10	11 - 34	≥35
Factor score		7	14	21	28
Score summation	S	36	72	108	144

As shown in Table 1, the hazard of gully-specific debris flow (H) is divided into five classes: $H = 36$, very low hazard; $36 < H < 72$, low hazard; $72 \leqslant H < 108$, moderate hazard; $108 \leqslant H < 144$, high hazard; $H = 144$, very high hazard.

Practical application of many years has shown that, this method has the following shortcomings: 1) internal factors of debris flow are difficult to obtain, so the operability of this method is reduced; 2) unable to put up the position of the frequency of debris flow occurrence as the leading factor; 3) values of hazard are not standardized, incompatible with the range of vulnerability and risk; 4) hazard classes are not convenient to be compared with those of other similar assessment methods (Table 2).

3 HAZARD ASSESSMENT OF GULLY-SPECIFIC DEBRIS FLOW IN THE EARLY 1990S

Totally 12 variables are selected for hazard assessment of gully-specific debris flow in this period (LIU *et al.*, 1993). They are: maximum volume of a debris flow deposit in the depositional area (magnitude) (L_1), frequency of debris flow occurrence (L_2), drainage basin

Table 2 Comparison of the hazard and severity of gully-specific debris flow

	Very low	Low	Moderate	High	Very high	Reference
Hazard	36	36 – 72	72 – 108	108 – 144	144	LIU, 1988
Severity	<33	33 – 63	63 – 87	> 87		TAN, 1986

area(S_1), length of the main channel (S_2), relief of the catchment(S_3), mean gradient of hillslopes in the source area of the catchment(S_5), drainage density of the catchment(S_6), sinuosity of the main channel bed (S_7), length proportion of the unstable channel to the whole (S_9), maximum rainfall within 24 hours (S_{10}), mean annual rainfall (S_{11}), population density (S_{14}). As leading factors, the L_1 and L_2 are internal factors influencing the hazard of debris flow; while being auxiliary factors, the other 10 are environmental factors relevant to debris flow hazard. The method to determine the weight of each factor is the same as that used before (LIU, 1988). The two leading factors are endowed with a same weight. Thus, weights of all factors are: $L_1 = L_2 \rightarrow 11$, $S_1 \rightarrow 10$, $S_6 \rightarrow 9$, $S_2 \rightarrow 8$, $S_3 \rightarrow 7$, $S_9 \rightarrow 6$, $S_{11} \rightarrow 5$, $S_5 \rightarrow 4$, $S_{10} \rightarrow 3$, $S_{14} \rightarrow 2$, $S_7 \rightarrow 1$.

Multiply the transformed value of each factor by each corresponding weight, and the product is the score of each factor. Then sum all scores of the 12 factors; the summation is the hazard of the gully-specific debris flow. The equation is shown as the following

$$\begin{aligned} H = {} & 0.14\, G_{L_1}\ 0.14\, G_{L_2} + 0.13\, G_{S_1} + 0.1\, G_{S_2} + \\ & 0.09\, G_{S_3} + 0.05\, G_{S_5} + 0.12\, G_{S_6} + 0.01\, G_{S_7} + \\ & 0.08\, G_{S_9} + 0.04\, G_{S_{10}} + 0.06\, G_{S_{11}} + 0.03\, G_{S_{14}} \end{aligned} \tag{1}$$

the symbols in equation (1) may be seen from Table 3. The value of each factor's weight means the weightiness, i. e., the corresponding proportion of the factor in hazard assessment.

This method for hazard assessment of gully-specific debris flow overcomes shortcomings of the previous. It furthermore has two remarkable merits: 1) use a mathematical equation to calculate the hazard of debris flow, and the hazard values are standardized within the range of 0 – 1 (0 – 100%); 2) instead of directly summing all factor's value (score) in former studies, this method

Table 3 Scheme of the variable classes and their transformed values for gully-specific debris flow hazard (LIU, 1993)

Factor and transformed value	Symbol	Class 1	Class 2	Class 3	Class 4
Maximum volume of a debris flow deposit in the depositional area($\times 10^4 m^3$)	L_1	<1	1 – 10	10 – 100	> 100
Transformed value	G_{L_1}	0	0. 3	0. 7	1
Frequency of debris flow occurrence(%)	L_2	<10	10 – 50	50 – 1070	> 100
Transformed value	G_{L_2}	0	0. 3	0. 7	1
Drainage basin area(km^2)	S_1	<0. 5	0. 5 – 10	10 – 35	> 35
Transformed value	G_{S_1}	0	0. 3	0. 7	1
Length of the main channel(km)	S_2	<1	1 – 5	5 – 10	> 10
Transformed value	G_{S_2}	0	0. 3	0. 7	1
Relief of the catchment(km)	S_3	<0. 2	0. 2 – 0. 5	0. 5 – 1	> 1
Transformed value	G_{S_3}	0	0. 3	0. 7	1
Mean gradient of hillslopes in the source area of the catchment(°)	S_5	<25	25 – 40	40 – 50	> 50
Transformed value	G_{S_5}	0	0. 3	0. 7	1
Drainage density(km/km^2)	S_6	<5	5 – 10	10 – 20	> 20
Transformed value	G_{S_6}	0	0. 3	0. 7	1
Sinuosity of the main channel bed	S_7	<1. 1	1. 1 – 1. 25	1. 25 – 1. 4	> 1. 4
Transformed value	G_{S_7}	0	0. 3	0. 7	1
Length proportion of the unstable channel to the whole	S_9	<0. 1	0. 1 – 0. 3	0. 3 – 0. 6	> 0. 6
Transformed value	G_{S_9}	0	0. 30	0. 7	1
Maximum rainfall within 24 hours(mm)	S_{10}	<25	25 – 502	50 – 10022	> 100
Transformed value	$G_{S_{10}}$	0	0. 3	0. 7	1
Mean annual rainfall(mm)	S_{11}	200 – 800	800 – 1000	1000 – 12002	> 1200 or <200
Transformed value	$G_{S_{11}}$	0	0. 3	0. 7	1
Population density (person/km^2)	S_{14}	<50	50 – 150	150 – 250	> 250
Transformed value	$G_{S_{14}}$	0	0. 3	0. 7	1

multiplies the transformed value of each factor by each weight as the factor′s score, and then sum the score of each factor.

Meanwhile, this method has also disadvantages: 1) Too many environmental factors result in complicated appraisal. 2) A few environmental factors have repeated physical meanings. For example, relief of the catchment and mean gradient of hillslopes in the source area both are topographic factors and represent the potential energy of debris flow provided by the drainage area; maximum rainfall within 24 hours and mean annual rainfall both are meteorological factors and represent the kinetic energy of debris flow provided by the external environment. 3) The weight of “maximum volume of a debris flow deposit in the depositional area” and the weight of “frequency of debris flow occurrence” are not great enough to embody the leading position of these two factors in debris flow hazard assessment.

4 HAZARD ASSESSMENT OF GULLY-SPECIFIC DEBRIS FLOW IN THE MID 1990S

In this period, the improved method for hazard assessment of gully-specific debris flow totally employs 10 factors(LIU and TANG, 1995). Mean gradient of hillslopes in the source area and mean annual rainfall are taken away. Leading factors are still maximum volume of a debris flow deposit in the depositional area (magnitude) and frequency of debris flow occurrence, and other 8 factors are the same with those used in the early 1990s. The same method (LIU *et al.*, 1993) is used to reallocate the weight coefficient of each factor. Prominences are given to “maximum volume of a debris flow deposit in the depositional area” and “frequency of debris flow occurrence”; their weights are twice the maximal weight of auxiliary factors (Table 4).

Table 4 Weight of the variable for gully-specific debris flow hazard

	L_1	L_2	S_1	S_6	S_2	S_3	S_9	S_{10}	S_{14}	S_7
Weight	16	16	8	7	6	5	4	3	2	1
Weight coefficient	0.24	0.24	0.12	0.1	0.09	0.07	0.06	0.04	0.03	0.01

The equation to calculate the hazard of gully-specific debris flow is

$$H = 0.24\,G_{L_1} + 0.24\,G_{L_2} + 0.12\,G_{S_1} + 0.09\,G_{S_2} + 0.07\,G_{S_3} + 0.1\,G_{S_6} + 0.01\,G_{S_7} + 0.06\,G_{S_9} + 0.04\,G_{S_{10}} + 0.03\,G_{S_{14}} \qquad (2)$$

where the symbols are the same as those used in equation(1). The variable classes and their transformed values may be seen in Table 5.

Besides conquering shortcomings of the method used in the early 1990s, this method has also the following improvements: 1) to avoid error due to great interval between transformed values, 6 in stead of 4 classes are used to divide variable for improving sensitivity of variation of the variable values; 2) upper and lower limits of most variables are adjusted, except those ranges of L_1 and S_9 keep unchanged, ranges of L_2, S_1, S_2, S_3, S_6, S_7, S_{10}, S_{14} are widened in accordance with factual situations; 3) boundaries of each class are clearly defined; brackets“( )” mean that the value in them is not included in the class. Therefore, changeability of the variable′s value due to unclear boundary is avoided.

5 LATEST HAZARD ASSESSMENT OF GULLY-SPECIFIC DEBRIS FLOW

The latest study of hazard assessment of gully-specific debris flow was published in English in Proceedings of International Symposium of Interpraevent (LIU, 1996). The method was applied by BECHT and RIEGER (1997) in Germany. This improved hazard assessment method adopts seven factors. Besides the two leading factors of magnitude(M) and frequency of occurrence (F), other auxiliary environmental factors are further reduced to five. They are: drainage basin area(S_1), length of the main channel (S_2), relief of the catchment (S_3), drainage density(S_6), length proportion of unstable channel to the whole(S_9). These five auxiliary factors can be obtained relatively precisely from the topographic map of debris flow catchments. The method to select auxiliary factors is: use double-series correlation analysis to analyze the correlation between each of the 14 candidate factors and debris flow magnitude and its frequency of occurrence, judge whether an auxiliary factor is closely related to the leading factors depending on the mean value of the two correlation values with the magnitude and the frequency, and finally decide to accept or reject it.

The method to determine the weight and weight coefficient of each factor is the same as that used by LIU and TANG (1995). The results are shown in Table 6.

The new equation for calculating the hazard of gully-specific debris flow is as the following:

Table 5 Scheme of the variable classes and their transformed values for gully-specific debris flow hazard (LIU and TANG, 1995)

Factor and transformed value	Symbol	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Maximum volume of a debris flow deposit in the depositional area ($\times 10^4 m^3$)	L_1	≤1	(1) – 5	(5) – 10	(10) – 50	(50) – (100)	≥100
Transformed value	G_{L_1}	0	0.2	0.4	0.6	0.8	1
Frequency of debris flow occurrence (%)	L_2	≤5	(5) – 10	(10) – 20	(20) – 50	(50) – (100)	≥100
Transformed value	G_{L_2}	0	0.2	0.4	0.6	0.8	1
Drainage basin area (km^2)	S_1	≤0.5	(0.5) – 1	(1) – 2	(2) – 5	(5) – (10)	≥10
Transformed value	G_{S_1}	0	0.2	0.4	0.6	0.8	1
Length of the main change (km)	S_2	≥50, ≤0.5	(0.5) – 2	(2) – 5	(5) – 10	(10) – 30	(30) – (50)
Transformed value	G_{S_2}	0	0.2	0.4	0.6	0.8	1
Relief of the catchment (km)	S_3	≤0.2	(0.2) – 0.5	(0.5) – 0.7	(0.7) – 1.0	(1.0) – (1.5)	≥1.5
Transformed value	G_{S_3}	0	0.2	0.4	0.6	0.8	1
Drainage density (km/km^2)	S_6	≤2	(2) – 5	(5) – 10	(10) – 15	(15) – (20)	≥20
Transformed value	G_{S_6}	0	0.2	0.4	0.6	0.8	1
Sinuosity of the main channel bed	S_7	≤1.1	(1.1) – 1.2	(1.2) – 1.3	(1.3) – 1.4	(1.4) – (1.5)	≥1.5
Transformed value	G_{S_7}	0	0.2	0.4	0.6	0.8	1
Length proportion of the unstable channel to the whole	S_9	≤0.1	(0.1) – 0.2	(0.2) – 0.3	(0.3) – 0.4	(0.4) – (0.6)	≥0.6
Transformed value	G_{S_9}	0	0.2	0.4	0.6	0.8	1
Maximum rainfall within 24 hours (mm)	S_{10}	≤50	(50) – 75	(75) – 100	(100) – 125	(125) – (150)	≥150
Transformed value	$G_{S_{10}}$	0	0.2	0.4	0.6	0.8	1
Population density (person/ km^2)	S_{14}	≤20	(20) – 50	(50) – 100	(100) – 150	(150) – (200)	≥200
Transformed value	$G_{S_{14}}$	0	0.2	0.4	0.6	0.8	1

Table 6 Weight of variable for gully-specific debris flow hazard

	M	F	S_1	S_6	S_2	S_3	S_9
Weight	10	10	5	4	3	2	1
Weight coefficient	0.29	0.29	0.14	0.11	0.09	0.06	0.03

$$H = 0.29M + 0.29F + 0.14S_1 + 0.09S_2 + 0.06S_3 + 0.11S_6 + 0.03S_9 \qquad (3)$$

where M, F, S_1, S_2, S_3, S_6, and S_9 are separately the transformed value of m, f, s_1, s_2, s_3, s_6, and s_9.

The latest improvement changes the value transformation of factors from classified logical transformation to sectionalized function transformation (Table 7). Therefore, the transformed value of each factor within its own range varies continuously from 0 to 1, avoiding skip alteration of the transformed value at the junction of two classes.

6 THEORETICAL MODEL OF GULLY-SPECIFIC DEBRIS FLOW HAZARD

For many years of studies on the hazard of debris flow, we have come to know the importance of the magnitude and its frequency of occurrence in debris flow hazard assessment. OHMORI and HIRANO (1988) expressed the impact of a geomorphic event as the product of the magnitude and its frequency of occurrence of the geomorphic event. This viewpoint enlightened us for the development of the theory of debris flow hazard. Debris

Table 7 Sectionalized transformation function of gully-specific debris flow hazard

Transformed value (0 – 1)	Transformation function ($m, f, s_1, s_2, s_3, s_6, s_9$ are original values)
M	$M = 0$ if $m \leqslant 1$ $M = \log m/3$ if $1 < m \leqslant 1000$ $M = 1$ if $m > 1000$
F	$F = 0$ if $f \leqslant 1$ $F = \log f/2$ if $1 < f \leqslant 100$ $F = 1$ if $f > 100$
S_1	$S_1 = 0.2458 s_1^{0.3495}$ if $0 \leqslant s_1 \leqslant 50$ $S_1 = 1$ if $s_1 > 50$
S_2	$S_2 = 0.2903 s_2^{0.5372}$ if $0 \leqslant s_2 \leqslant 10$ $S_2 = 1$ if $s_2 > 10$
S_3	$S_3 = 2s_3/3$ if $0 \leqslant s_3 \leqslant 1.5$ $S_3 = 1$ if $s_3 > 1.5$
S_6	$S_6 = 0.05 s_6$ if $0 \leqslant s_6 \leqslant 20$ $S_6 = 1$ if $s_6 > 20$
S_9	$S_9 = s_9/60$ if $0 \leqslant s_9 \leqslant 60$ $S_9 = 1$ if $s_9 > 60$

flow is a type of extreme event that belongs to geomorphic hazard. Although OHMORI and HIRANO (1988) have not made further explanation on the impact of geomorphic event, they have made us find out a new way of thought: debris flow magnitude and its frequency of occurrence are the two essential variables of debris flow hazard, and the theoretical expression of debris flow hazard can be established based on this concept. For example, rock avalanche and dispersion on steep slope in mountainous area both are gravitational geomorphic events. Their magnitude both can be expressed in "cubic meter", and frequency of occurrence in "time/year". Given the same environmental conditions, rock avalanche has a larger magnitude but a lower frequency, while dispersion has a smaller magnitude but a higher frequency. If we only use magnitude to represent hazard, then the hazard of rock avalanche will be always larger than that of dispersion, because the magnitude of rock avalanche is always larger than that of dispersion. On the contrary, if we only use frequency of occurrence to express hazard, then the hazard of rock avalanche will be always smaller than that of dispersion, because frequency of occurrence of rock avalanche is always lower than that of dispersion. This inconsistent conclusion suggests that it is unreasonable to use only a single variable as magnitude or frequency of occurrence to express hazard.

We can also use an example to explain the reason why hazard is expressed in multiplication rather than summation of debris flow magnitude and its frequency of occurrence. Assume the frequency of occurrence (or probability) of a large scale of debris flow in a place is zero (or nearly zero, i. e., it occurs once within several thousand or tens of thousand years). If we add the magnitude and its frequency of occurrence, we will get a great value, which indicates that the hazard of debris flow in this place is very high, but it is not the case. However if we use multiplication of the magnitude and its frequency of occurrence, this problem will be removed. Therefore, debris flows with small magnitude and high frequency, medium magnitude and medium frequency or large magnitude and low frequency may have the same hazardousness.

To make actuality assessment, the hazard of debris flow can be expressed as the product of debris flow magnitude and its frequency of occurrence, while making prediction appraisal, it can be expressed as the product of the magnitude and its probability of occurrence. Nevertheless, it is not easy to obtain the probability of debris flow occurrence. Comparatively, it is easier to use the past frequency as the future probability. According to TOBIN and MONTZ (1997), it is also feasible to deduce the probability from the observed frequency. JACKSON(1987) considered that, we can estimate a mean interval of debris flow based on the occurrence times within a historical period, and thereby work out the frequency of debris flow occurrence. Generally, frequency of debris flows is expressed by "time/year" or "time/100 years". This expression can be gained by simple value transformation. Therefore, the hazard of debris flow may be theoretically expressed as:

$$\text{Hazard}(H) = \text{Magnitude}(M) \times \text{Frequency}(F) \quad (4)$$

A number of studies suggest that, magnitude of geological and geomorphic hazards has a negative nonlinear relationship with frequency of occurrence (WOLMAN and MILLER, 1960; PACHECO *et al.*, 1992; STEIJN, 1996; HUNGR *et al.*, 1999). Assume the relationship between debris flow magnitude and its frequency of occurrence can be expressed by the following exponential function (LIU *et al.*, 2002):

$$F(M) = ae^{-bM} \quad (b > 0) \quad (5)$$

where $F(M)$ is the frequency of occurrence (%) when the magnitude is M; M is the magnitude of debris flow (expressed in cubic volume of a debris flow deposit with unit of 10^3m^3); a and b are undetermined coefficients.

From equation (4) and equation (5), it can be deduced that the hazard of debris flow is the definite integral area under the curve $M-F(M)$:

$$H = \int_0^M F(M)\,\mathrm{d}M \quad (6)$$

$$H = \int_0^M ae^{-bM}\,\mathrm{d}M \quad (b > 0) \quad (7)$$

To make the range of the hazard of debris flow vary within 0 – 1 or 0 – 100%, given $a = b$, then

$$H = \int_0^M ae^{-aM}\,\mathrm{d}M \quad (a > 0) \quad (8)$$

solution of the equation (8) is the following Poisson Limit Equation:

$$H = 1 - e^{-aM} \quad (a > 0) \quad (9)$$

where H is hazard of debris flow (0 – 1 or 0 – 100%); M is magnitude of debris flow ($\times 10^3\text{m}^3$, when $M \to \infty$, $H = 1$); a is the undetermined coefficient which is determined by the relationship of debris flow magnitude and its frequency of occurrence.

Theoretically, the hazard of debris flow can be precisely expressed as the definite integral area under the magnitude-frequency curve, i. e., the solution of equation (9). Although the theoretical equation cannot be directly applied in practice at present, it is undoubtedly an important direction that we should take much effort to study in the future. At the same time, it suggests that

Multiple Factor Composite Assessment Model (MFCAM) for debris flow hazard currently used in China still has their practicality and applicability.

7 SUMMARY

Assessment of debris flow hazard is an appraisal of the capability of debris flow to cause disasters. Current methods for assessment of debris flow hazard in China are still valid and practical. The further work should be put on the study of the reliability (or uncertainty) of the techniques, so as to provide users with more accurate assessing results. By analyzing reliability of each factor, we can improve the precision of input variable data. By comparing different methods, we can improve the degree of belief of the assessing results. Moreover, in-situ judgment by experts is also an effective way to verify or modify the assessment models. This paper has developed a theoretical solution of an exponential relationship between debris flow magnitude and its frequency of occurrence, but it is not the sole solution of the theoretical model. For the future, we should give a high priority to the relationship between debris flow magnitude and its frequency of occurrence, make more developments of prediction model on debris flow magnitude, so as to finally reach the goal of assessing the hazard of debris flow by theoretical model, and realize both actuality assessment and prediction appraisal of debris flow.

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