CHINESE GEOGRAPHICAL SCIENCE
Volume 10, Number 2, pp. 138 – 143, 2000
Science Press, Beijing, China

UNCERTAINTY ANALYSIS ON ZONATION MAPS OF DEBRIS FLOW HAZARD IN YUNNAN PROVINCE, CHINA

LIU Xi-lin

(Department of Urban and Environmental Sciences, Peking University, Beijing 100871, P. R. China; Institute of Mountain Hazards and Environment, the Chinese Academy of Sciences, Chengdu 610041, P. R. China)

ABSTRACT: Different researchers select different factors and use different methods to assess the regional hazard degrees of debris flow. Consequently, even for the same region, there are often different hazard zonation maps, and there must be some uncertainty in the zonations. Thus the certainty analysis of zonation maps becomes obviously important. For debris flow hazard, those zonation maps with a certainty analysis could provide most valuable information for land users, hazard managers and policy makers. By comparison of three researchers' findings in Yunnan Province, this paper shows that seven to nine influential factors are chosen for the zonation maps. Spatial density of debris flow ravines, regional average rock-weathering coefficient, yearly precipitation, days of ≥50 mm daily rainfall, and proportion of sloping land with slope ≥25° to the total land are the most acceptable factors. Mathematical methods of maximum-minimum values, upper-lower limit values and Fuzzy values are used to quantify the factors. Step-by-step methodology is commonly used for the zonation maps. Research results show that maximum uncertainty is 66.6% and minimum uncertainty is 35.7% in debris flow hazard maps of Zhaotong Prefecture and Yunnan Province. Therefore there is still much work for us to improve the zonation methodology.

KEY WORDS: debris flow; hazard zonation; uncertainty; zonation map

CLC number: P642.23   Document code: A   Article ID: 1002-0063(2000)02-0138-06

1 INTRODUCTION

Debris flow is one of the six primary natural hazards, which influences the development of national society and economy in China. Its severity is secondary to flood, draught, earthquake, typhoon, but stronger than biological hazards. More than 30 000 debris flow creeks are scattered in the whole mountainous area, and especially concentrated in southwest of China. Debris Flow Information System (DFIS) operated by the Institute of Mountain Hazards and Environment of the Chinese Academy of Sciences has already established a database and catalogue collected about 10 000 debris flow creeks.

Zonation map of debris flow hazard is the basic map for land-use planning and disaster mitigation, and also the useful tool for regional forecast and assessment. In Austria and Switzerland, the nationwide hazard zonation maps including debris flow was compiled by AULITZKY (1994) and LATELTIN ①. The distribution of debris flow disaster and its dangerous regionalization map in China (1:6 000 000) was completed by the Institute of Mountain Hazards and Environment (1992). However, the uncertainty of this kind of zonation maps has also aroused attention from many researchers (CARRARA *et al.*, 1992). In this paper, two cases are given to analyze the different zoning factors and methods resulting in different zonation maps

Received date: 1999-08-10
Foundation item: Supported by the Education Bureau of the Chinese Academy of Sciences.
Biography: LIU Xi-lin (1963 –), male, a native of Hunan Province, is a research professor. His research interests include debris flow assessment and geomorphology.

① LATELTIN O., 1998. Example of hazard assessment and land-use planning in Switzerland for snow avalanche, floods and landslides. WMO-Comprehensive Assessment of Risks from Natural Hazards.

even for the same objective. Thus after comparing them, the uncertainty of the zonation maps for each case is presented.

2 STUDY CASES

2.1 Yunnan Province

Yunnan is a frontier province of southwestern China, with an area of 394 139 km^2 and 1786 major debris flow ravines. It is one of the provinces suffering most seriously from debris flow hazards in China. In recent forty years, approximate 5000 people were killed by debris flows. The economic loss from debris flow disasters ranges yearly several to tens of million US dollars, which takes 2% – 10% of the total financial expense of the province.

2.1.1 LIU's hazard zonation

(1) Principles of the zonation

Four major principles are considered. They are similarity, integrity, factor synthesis and factor dominant (LIU, 1989). Similarity is the basic principle for all kinds of zonation. Only those areas being of similar characteristics may be zoned to an identical zone. Integrity refers to regional completeness, such as administrative districts or natural drainage area and geomorphic unit. For the sake of the completeness, the boundary of the assigned region is usually as the limit of the zones. Factor synthesis, in other words, is multiple-factor principle. Comprehensive analysis of factors influencing the regions should be considered. Factor dominant, i.e., primary factor, is a principle to decide the factor that has the greatest influence on the zonation.

(2) Factors of the zonation

From the background concerning debris flow genesis, more than twenty factors may be involved. However, we only choose those most significant ones, which satisfactorily contribute to the zonation. Thus we assign the spatial density of debris flow ravines as the primary factor, and analyze the correlation between the primary factor and the other factors. Therefore, based on the correlative coefficients, eight influential factors are selected. They are expressed with the following parameters (LIU, 1989): 1) Spatial density of debris flow ravines (ravines/1000 km^2). 2) Flood hazard occurrence frequency (number of actual floods/number of potential floods). Potential floods mean under a certain rainfall, the floods probably occur in a given area, which is defined by the local meteorological department and is different from place to place). 3) Regional average rock-weathering coefficient (coefficient of Cainozoic and Mesozoic rock gives 0.6; coefficient of Palaeozoic and Proterozoic rock gives 0.5). 4) Average variation coefficient of monthly precipitation (more than ten-year's mean). 5) Active fault density (km/1000 km^2). 6) Average annual days ≥25 mm daily rainfall (more than ten-year's mean). 7) Proportion of cultivated land with slope ≥25° to the total cultivated land (human activity index). 8) Proportion of sloping land with slope ≥25° to the total land.

(3) Methodology of the zonation

Step 1: To collect the eight parameters for each regional unit. Because the parameters contain both natural and social-economic aspects, for the reason of feasibility, we choose the administrative districts, such as county or township, as the regional unit.

Step 2: To transform the maximum value into 1 and the minimum value into 0 for each series of parameters so as to make the value range of the eight parameters be within 0 – 1.

Step 3: To give weights for each kind of parameters based on the analysis of "Grey System Theory" (LIU *et al.*, 1992a). The weights of the eight factors from (1) to (8) are respectively 0.33, 0.17, 0.14, 0.12, 0.10, 0.07, 0.05, 0.02.

Step 4: To sum the eight weighted transformed parameter values for each regional unit. That is the regional hazard degree of the unit (0≤Hazard degree ≤ 1).

Step 5: To grade the regional hazard degree into three or four grades depending on demand accuracy. Here four grades are adopted.

(4) Result of the zonation

Yunnan has 17 prefectures. We set the prefecture as the regional unit and keep the bounder of prefectures as the zone limit. Thus the zonation map of debris flow hazards in Yunnan Province has be obtained, which is zoned into three "Zone I", two "Zone II", one "Zone III" and two "Zone IV" (Fig. 1). Zone I (very high severity): hazard degree ranging 0.71 – 0.87, with an area of 46 131 km^2, taking 11.7% of the total. Zone II (high severity): hazard degree ranging 0.52 – 0.65, with an area of 139 521 km^2, taking 35.4% of the total. Zone III (medium severity): hazard degree ranging 0.33 – 0.48, with an area of 111 163 km^2, taking 28.2% of the total. Zone IV (light severity): hazard degree ranging 0.26 – 0.32, with the area of 97 324 km², taking 24.7% of the total.

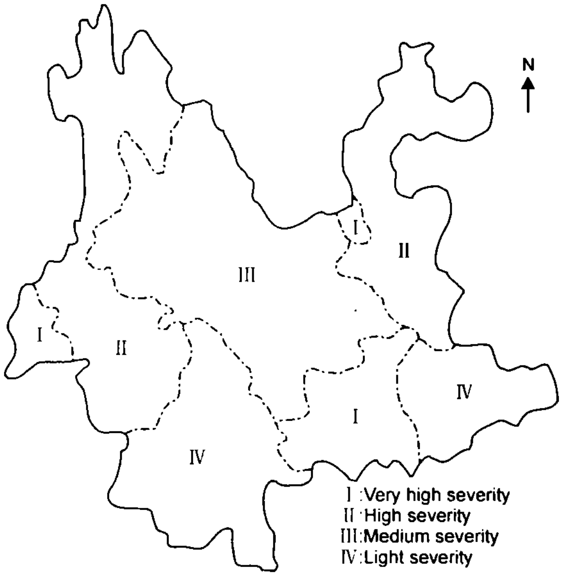

Fig. 1 Zonation sketch of debris flow hazard in Yunnan by LIU

2.1.2 ZHU and TANG's hazard zonation

(1) Factors of the zonation

Also eight parameters are considered by ZHU and TANG (1996). They are as follows: 1) Region relief (difference between the highest point elevation and the lowest point elevation in the unit). 2) Regional average rock-weathering coefficient (the same as LIU's). 3) Fault types (similar to LIU's). 4) Yearly precipitation and daily rainfall density (similar to LIU's). 5) Gully cutting density (total length of gully in the unit/total area of the unit). 6) Seismic intensity (EMS I – XII). 7) Rural population density and forest coverage (the rural population density index is a risk element but a influential factor on debris flow hazard, which seems not appropriate used here). 8) Spatial density of debris flow ravines (the same as LIU's).

(2) Methodology of the zonation

Step 1: To divide the province territory into 903 grids, with latitude rang of 10' and longitude range of 15' for each grid, and to gather the eight parameters for each grid.

Step 2: To sum the eight parameter values and divided by eight for each grid so as to get D, and to average all D to get a mean value X.

Step 3: To calculate the difference between the maximum and the minimum of the eight parameter values for each grid so as to get R and to average all R to get a mean value R'.

Step 4: To calculate the upper limit value $X + AR'$ and the lower limit value $X-AR'$ (X means the central line value; A is an empirical value; $0 < A < 1$; here A is assigned 0.5), and to grade the upper and lower limit values into three or four grades depending on the demand accuracy. Here four grades are adopted.

Step 5: To zone the hazard zonations using the graded grid limits given by step 4.

(3) Result of the zonation

The zonation map of debris flow hazards in Yunnan Province is shown in Fig. 2 (ZHU and TANG, 1996). Zone I (very high severity): the lower limit value > 2.8, with an area of 30 150 km², taking 7.42% of the total. Zone II (high severity): the limit values 2.4 – 2.8, with an area of 153 450 km², taking 37.76% of the total. Zone III (medium severity): the limit value 2.0 – 2.4, with an area of 182 250 km², taking 44.85% of the total. Zone IV (light severity): the upper limit values < 2.0, with an area of 40 500 km², taking 9.97% of the total.

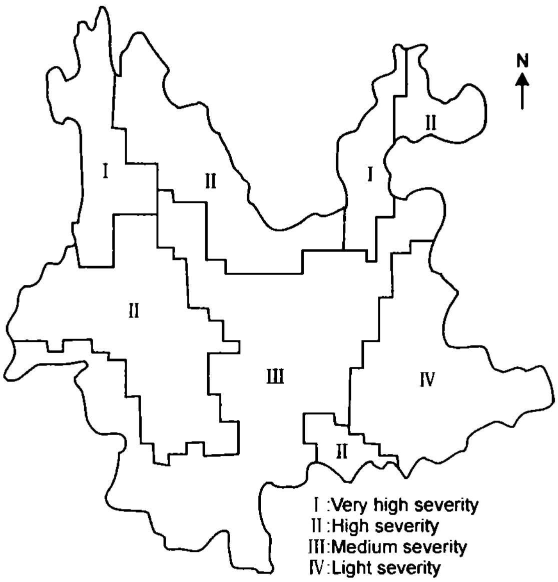

Fig. 2 Zonation sketch of debris flow hazard in Yunnan by ZHU and TANG(1996)

2.2 Zhaotong Prefecture

Zhaotong is a prefecture located in the northeast of Yunnan, with 11 counties and territorial area of 22 434 km². There are distributed 330 major debris flow creeks. Since 1980, debris flow hazards have been more active than before and debris flow disasters are hindering the social and economic developments in this district.

2. 2. 1 LIU' s hazard zonation

Principles, factors and methodology of the zonation are the same as the paragraph 2. 1. 1. Here three grades are adopted. The result of the hazard zonation is given in Fig. 3 (LIU, 1994).

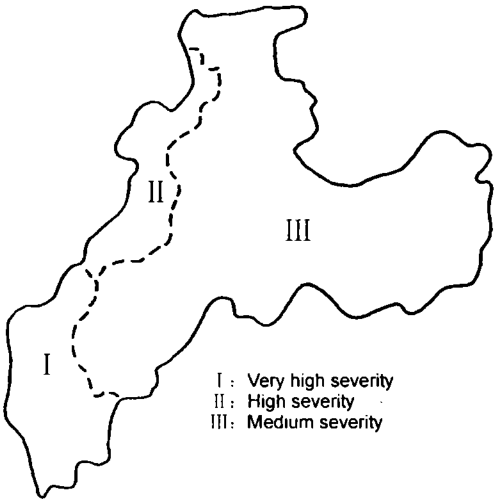

Fig. 3 Zonation sketch of debris flow hazard in Zhaotong Prefecture by LIU

Zone I (very high severity): hazard degree 0. 93, with an area of 3 196 km², taking 14. 25% of the total. Zone II (high severity): hazard degree 0. 72, with an area of 2770 km², taking 12. 35% of the total. Zone III (medium severity): hazard degree 0. 29 - 0. 43, with an area of 16 468 km², taking 73. 4% of the total.

As one can see in the zonation map of Yunnan Province, the Zhaotong Prefecture is zoned as Zone II (high severity). Furthermore, in Zhaotong Prefecture, it is zoned again into Zones I, II and III (from very high severity, high severity to medium severity) with the same method. Therefore, the zonation maps of debris flow hazard are relative severity maps and their values of hazard degree are not yet absolutely comparable now.

2. 2. 2 LIU and WANG' s hazard zonation

(1) Factors of the zonation

Totally nine factors are considered (LIU and WANG, 1995). 1) Region relief (the same as ZHU and TANG' s). 2) Gully cutting density (the same as ZHU and TANG' s). 3) Regional average rock - weathering coefficient (the same as LIU' s). 4) Reclaiming index (ratio of cultivated land to the total land). 5) Days of ≥50 mm daily rainfall (similar to LIU' s). 6) Seismic intensity (the same as ZHU and TANG' s, 1996). 7) Wasteland index (ratio of wasteland to the total land). 8) Average variation coefficient of monthly precipitation (the same as LIU's). 9) Proportion of sloping land with slope ≥25° to the total land (the same as LIU's).

(2) Methodology of the zonation

Step 1: To grade the factors into several grades depending on the demand accuracy. Here five grades are adopted.

Step 2: To determine the ranges of the standard normal distribution and probability corresponding with five grades.

Step 3: To give weights for the factors using the analysis of "Grey System Theory". The weights of nine factors from (1) to (9) are separately 0. 13, 0. 12, 0. 12, 0. 12, 0. 12, 0. 12, 0. 10, 0. 08, 0. 08.

Step 4: To delimit the hazard zones using the limit of the counties as regional unit by three grades of fuzzy values.

(3) Result of the zonation

The zonation map of debris flow hazards in Zhaotong is shown in Fig. 4 (LIU and WANG, 1995). Zone I (very high severity): with an area of 7 675 km², taking 34. 21% of the total. Zone II (high severity): with an area of 3 504 km², taking 15. 62% of the total. Zone III (medium severity): with an area of 11 233 km², taking 50. 07% of the total.

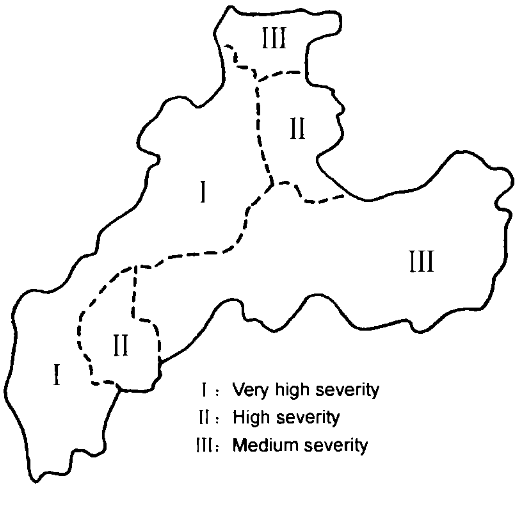

Fig. 4 Zonation sketch of debris flow hazard in Zhaotong Prefecture by LIU and WANG(1995)

3 DISCUSSIONS

The above three methods are all mathematical ways to zone debris flow hazards, so it is hard to say which is the most favorable although they have their interior advantages and disadvantages. Generally say, LIU's method is the earliest one and more popular one. ZHU and TANG follow the factor selection and LIU and WANG follow the factor weighting but the mathematical proceeds are different in spite of sharing the same zonation principles.

The eight factors for the hazard zonation proposed by LIU (1989) emphasize hazard actuality instead of hazard causation because the primary factor — spatial density of debris flow ravines is given the biggest weight. Among the eight factors selected by ZHU and TANG (1996), four of which are the same as or similar to LIU's (1989). However, neither hazard actuality nor hazard causation are emphasized because there are no weights given. Four of the nine factors presented by LIU and WANG (1995) are also the same as or similar to LIU's (1989), and three of which are used by ZHU and TANG (1996). On the contrary, LIU and WANG's (1995) emphasis is on hazard causation, rather than hazard actuality because there is no index of debris flow actuality chosen.

Superposition of Fig. 1 and Fig. 2 has created Fig. 5.

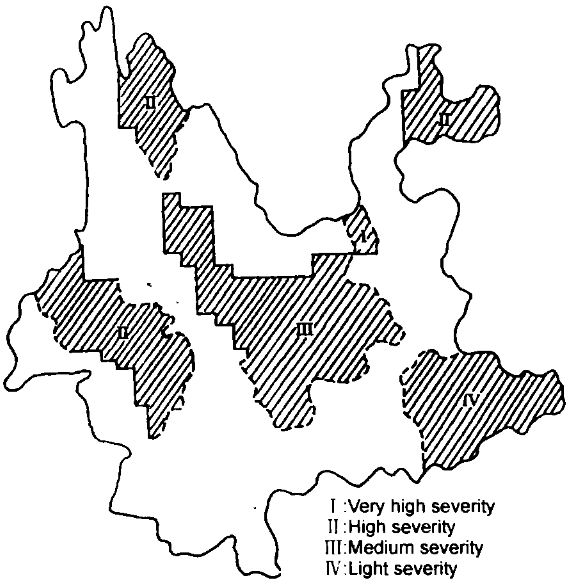

Fig. 5 Overlapped zonation sketch of debris flow hazard in Yunnan

The overlap data of LIU *et al.* (1992b) and ZHU and TANG (1996) are shown in Table 1. It is difficult to say the overlap areas are reliable areas, but at least we can say these areas are of more certainty for the zonation results of debris flow hazard than other areas. The overlap area in Yunnan is 33.4% of the total.

Table 1 Overlap data of different zones of debris flow hazard in Yunnan

	I	II	III	IV	Total
Area(km²)	1 260	57 600	45 900	27 000	131 760
Percent(%)	0.3	14.6	11.6	6.9	33.4

Fig. 6 is an observed debris flow density in Yunnan Province achieved by field investigation and aerial photograph interpretation.

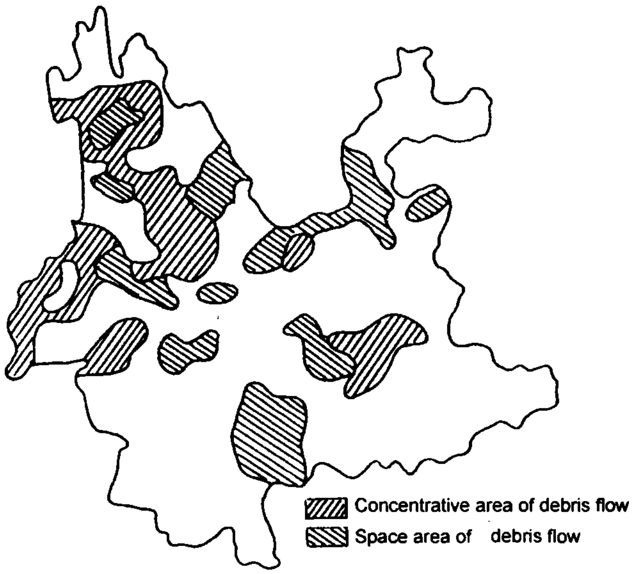

Fig. 6 Observed debris flow density in Yunnan

The overlap data of LIU (1994) and LIU and WANG (1995) are shown in Table 2. The overlap area in Zhaotong is 64.3% of the total.

Table 2 Overlap data of different zones of debris flow hazard in Zhaotong

	I	II	III	Total
Area (km²)	3 196	0	11 233	14 429
Percent (%)	14.2	0	50.1	64.3

Compared with all these zonation maps, there is no surprise at us that a specific point in this zonation map belongs to Zone I but in that zonation map it may belong to Zone II, especially in those places nearby the boundaries. We understand this phenomenon is resulted from the difference of the factors, weights and steps by different researchers because there has not been a general cognized methodology for debris flow hazard zonation up till now.

Superposition of Fig. 3 and Fig. 4 has created Fig. 7.

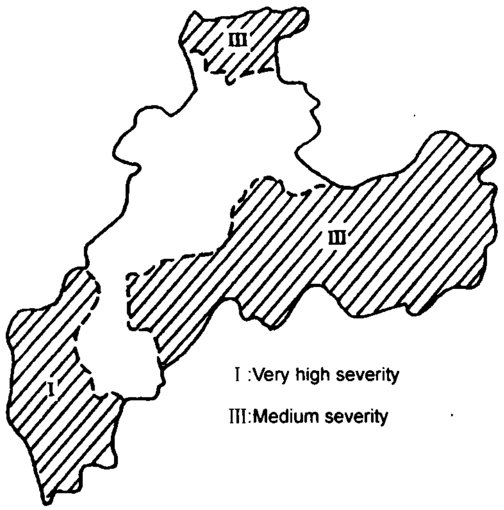

Fig. 7 Overlapped zonation sketch of debris flow hazard in Zhaotong

4 COMMENTS

The latitude-longitude grid as the regional unit has the advantage of more precision, but the disadvantage of difficulty to acquire the factor data in a given grid. The administrative district as the regional unit has the advantage of feasible operation, but disadvantage of less accuracy.

It is imperative to use the generalized factors (parameters) for the zonation of debris flow hazard although researchers may use different mathematical tools. Thus the difference among the results could be minimized.

It is necessary to give a certainty analysis on each kind of the zonation map of debris flow hazard by comparison of the former studies if one does this work in the same area. Thus authorities and local institutions may better utilize the information.

For Yunnan Province, the certainty of the current provided two versions of zonation maps on debris flow hazard is 33.4%. For Zhaotong Prefecture, the certainty of the current provided two versions of zonation maps on debris flow hazard is 64.3%.

All the mentioned hazard zones (grades) in this paper are relative in the given areas. There is not yet absolutely comparable zonation grades on debris flow hazard. That is why Zhaotong Prefecture in Yunnan Province is graded into Zone II, while within Zhaotong Prefecture, there may again be Zones I, II and III.

ACKNOWLEDGMENTS

This paper is the diploma thesis of the postgraduate studies on "Analysis and Management of Geological Risks" of the University of Geneva, Switzerland during April 27th to June 17th, 1998. Many thanks go to Drs. A. Petrascheck and Ch. Bonnard to review the manuscript.

REFERENCES

AULITZKY H, 1994. Hazard mapping and zoning in Austria: methods and legal implications[J] . *Mountain Research and Development*, 14 (4): 307 - 313.

CARRARA A, CARDINALI M, GUZZETTI F, 1992. Uncertainty in assessing landslide hazard and risk[J]. *ITC Journal*, (2): 172 - 183.

LIU Li, WANG Si-ge, 1995. Fuzzy comprehensive evaluation on land slide and debris flow risk degree in Zhaotong, Yunnan[J] . *Mountain Research*, 13(4): 261 - 266. (in Chinese)

LIU Xi-lin, 1989. Discussion on debris-flow outbreakability zoning[J] . *Journal of Catastrophology*, (4): 3 - 9. (in Chinese)

LIU Xi-lin, 1994. Disasters and regional risks of debris flow in Zhaotong Prefecture, Yunnan Province, China[J] . *Chinese Geographical Science*, 4(4): 371 - 382.

LIU Xi-lin, WANG Si-ge, ZHANG Xin-bao, 1992a. Influence of geologic factors on landslide in Zhaotong, Yunnan Province, China[J] . *Environmental Geology and Water Sciences*, 19(1): 17-20.

LIU Xi-lin, ZHANG Song-lin, TANG Chuan, 1992b. A method to determine the relative distributive density of debris flow[J] . *Journal of Soil and Water Conservation*, 6(1): 57 - 62. (in Chinese)

TANG Bang-xing, LIU Xi-lin, LIU Su-qing, 1992. Discussion on the risk regionalization of debris flow[A]. In: LI C. (Editor-in-chief). *Mountain Hazards and Environment in China*[M]. Chengdu: Chengdu Map Press, 13 - 20.

ZHU Jing and TANG Chuan, 1996. A study on the risk regionalization of debris flow hazards in Yunnan[J] . *The Chinese Journal of Geological Hazard and Control*, 7(2): 86 - 93. (in Chinese)