Assessment model of debris flow hazard along the Tianshan Highway

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Abstract

Debris Flow Hazard Assessment along the Tianshan Highway was carried out based on an established model. The assessment results indicated impacts of debris flow hazards to the highway and supplied a quantitative index with highway construction designs and protection in the debris flow affected area. The model formula can be shown as: $S=K_1K_2$; here S is highway debris flow hazard degree, K_1 is debris flow hazard degree ($0 \leq K_1 \leq 1$), K_2 is highway damage degree ($0 \leq K_2 \leq 1$). Index K_1 as well as K_2 are obtained with quantitative calculations respectively. This model has been verified based on research on highway debris flow in the Tianshan Mountain area of Xinjiang in China.
Keywords: highway, debris flow, hazard degree, assessment model.

1 The idea of highway debris flow hazard degree assessment model

The debris flow in the Chinese Xinjiang's Tianshan mountainous area is one kind of serious natural disaster, which can interrupt the transportation on road, destroy the highway facilities, even create serious traffic accidents frequently [1].

Current domestic and foreign debris flow risk factor assessment models only can appraise debris flow gully to the natural degree and are unable to evaluate the road safety rate. In order to appraise the debris flow effectively to the highway harm degree, meet quantitative factors [2] and instruct the highway design and maintenance, we set up the following highway debris flow hazard degree assessment model.

$$S=K_1K_2 \tag{1}$$

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where S= the highway debris flow hazard degree and K_1= the debris flow hazard degree and K_2 =the highway damage degree.

The model meaning is that debris flow hazard degree (K_1) multiplying the highway damage degree (K_2) equals the highway debris flow hazard degree, namely S ($0 \leq S \leq 1$).

2 The highway debris flow hazard degree (K1) of the Tianshan area

The debris flow hazard degree (K_1) refers to expert investigation method [3] and debris flow hazardous factor gray connection fundamental research [4], screens from more than 20 factors and determines 9 hazardous factors [4–6], i.e. G_{L1}, G_{L2}, G_{S1}, G_{S2}, G_{S3}, G_{S4}, G_{S5}, G_{S6}, G_{S7} (see Table 1) respectively.

Table 1: Weighted value and weighted rate of hazardous factor In K_1.

Hazardous factor	S_5	S_7	S_6	S_3	S_2	S_4	S_1	L_1	L_2
Weighted value	1	3	4	5	6	7	8	16	16
Weighted rate	0.0152	0.0455	0.0606	0.0758	0.0909	0.1061	0.1212	0.2424	0.2424

From this table, we see that 2 main hazardous factors (G_{L1}, G_{L2}) occupy 48.48% and 7 secondary hazardous factors account for 51.52%.

Thus there is the debris flow hazard degree formula:

$$K_1=0.2424G_{L1}+0.2424G_{L2}+0.1212G_{S1}+0.0909G_{S2}+0.0758G_{S3} +0.1061G_{S4}+0.0152G_{S5}+0.0606G_{S6}+0.0455G_{S7} \quad (2)$$

where K_1 is the debris flow hazard degree ($0 \leq K_1 \leq 1$), G_{L1} is the possible maximum debris flow evaluation per time, G_{L2} is the debris flow frequency evaluation, G_{S1} is the drainage area evaluation, G_{S2} is the main ditch length evaluation, G_{S3} is maximum relative height evaluation, G_{S4} is the basin cutting density evaluation, G_{S5} is the main ditch bed curving coefficient evaluation, G_{S6} is the silt military supplies segment size ratio evaluation and G_{S7} the water source military supplies quantity evaluation.

Table 2 shows the multiple coefficient of correlation evaluation standard.

3 The highway damage degree (K2) of the Tianshan debris flow area

In order to better limit debris flow to the harmful degree on highway, we ideally suppose the roadbed height for zero (crawling in the mud-rock flow area through the time) and do not suppose structures and arch of bridge. It is advantageous for getting the damage ratio.

Table 2: Tianshan highway debris flow hazardous factor rank and evaluation.

hazardous factor rank	(1)	(2)	(3)	(4)	(5)	(6)	Unit
L_1	≤0.1	(0.1)~1	(1)~10	(10)~50	(50)~(100)	≥100	10^4m^3
G_{L_1}	0.0	0.2	0.4	0.6	0.8	1.0	
L_2	≤5	(5)~10	(10)~20	(20)~50	(50)~(100)	≥100	%
G_{L_2}	0.0	0.2	0.4	0.6	0.8	1.0	
s_1	≤0.1	(0.1)~1	(1)~5	(5)~10	(10)~ (30)	(30)~(50)	Km^2
Gs_1	0.0	0.2	0.4	0.6	0.8	1.0	
s_2	≤0.1	(0.1)~1	(1)~2	(2)~5	(5)~ (10)	≥10	Km
Gs_2	0.0	0.2	0.4	0.6	0.8	1.0	
s_3	≤0.1	(0.1)~0.5	(0.5)~0.7	(0.7)~1.0	(1.0)~(1.5)	≥1.5	Km
Gs_3	0.0	0.2	0.4	0.6	0.8	1.0	
S_4	≤0.1	(0.1)~1	(1)~5	(5)~10	(10)~ (20)	≥20	Km/km^2
Gs_4	0.0	0.2	0.4	0.6	0.8	1.0	
S_5	≤1.1	(1.1)~1.2	(1.2)~1.3	(1.3)~1.4	(1.4)~(1.5)	≥1.5	Non-unit parameter
Gs_5	0.0	0.2	0.4	0.6	0.8	1.0	
S_6	≤0.1	(0.1)~0.2	(0.2)~0.3	(0.3)~0.4	(0.4)~(0.6)	≥0.6	Non-unit parameter
Gs_6	0.0	0.2	0.4	0.6	0.8	1.0	
S_7	≤0.1	(0.1)~1	(1)~10	(10)~50	(50)~(100)	≥100	m^3/s
Gs_7	0.0	0.2	0.4	0.6	0.8	1.0	

Under the above supposed conditions, there are two factors deciding K_2: the debris flow harm highway length (L_S) and the average debris flow covered in silt pavement thickness (h_S). According to the Tianshan highway scene investigation materials and all previous years observed statistical analysis, we discovered the above two may be the good assessment for debris flow damage on the highway. According to expert investigation method [3] findings, we establish debris flow highway damage degree model formula as follows:

$$K_2=0.5G_{L_S}+0.5G_{h_S} \quad (3)$$

where K_2 is the debris flow hazard degree ($0 \le K_2 \le 1$), G_{L_S} is the debris flow harm highway length evaluation, G_{h_S} is the average debris flow covered in silt pavement thickness evaluation. The multiple coefficient of correlation evaluation standard sees Table 3 and Table 4.

This means tends to the compromise and the error relatively small. It is suitable to calculate the Tianshan debris flow area' s highway damage. Whether it can be applied to other highway debris flow area, it still needs to demonstrate.

Table 3: Graduation of Ls.

Ls (m)	0~ 10	10~ 20	20~ 30	30~ 50	50~ 100	100~ 200	200~ 300	300~ 400	400~ 500	≥ 500
G_{Ls}	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0

Table 4: Graduation of hs.

hs (m)	0~ 0.2	0.2~ 0.5	0.5~ 1.0	1.0~ 1.5	1.5~ 2.0	2.0~ 3.0	3.0~ 4.0	4.0~ 5.0	5.0~ 8.0	≥8.0
G_{hs}	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0

4 The application of highway debris flow hazard degree assessment model

Table 5 shows the results of Tianshan highway typical debris flow hazard degree assessment through the application of the above model.

We may see from Table 5 that the examination in 11 highway debris flow gully has 10 determination results to be reliable while 1 somewhat low, but the total highway debris flow risk factor determination result has 90.9% reliability.

At the same time, we carried on the risk factor computation and the normalization in 89 typical Tianshan highway debris flow processes [7] (selecting the biggest of all predicted values as denominator and recording as 1, other computed results are divided by this maximum value). The analysis result sees Figure 1.

Compared to the result and the thorough investigation from the chart, we discovered the model computation rate of accuracy is 89.5%, which explained that the method suits in the quantitative assessment of highway debris flow harm degree in this area.

Based on the foundation, Table 6 shows the formulation Tianshan highway debris flow hazard degree assessment rank and preventing and controlling countermeasures [8].

5 Conclusions and suggestions

Through the above research, we obtain the conclusions as follows:

1) Tianshan highway debris flow hazard degree assessment model is suitable for this area debris flow to the road harm degree quantitative graduation assessment.

2) Through organic synthesis of the debris flow hazard degree (K_1) and the highway damage degree (K_2), the debris flow natural characteristic and its harm function can be a whole. It may reflect objectively the harmed and threat degree of the debris flow area on the highway.

Table 5: Tianshan highway typical debris flow gully hazard degree and determination.

Serial number	The name of debris flow gully	The Computed result of highway debris flow hazard degree	Debris flow harm scene investigation results on present situation and active tendency	Determination result
1	N10	S=0.340	It is covered with mud and silt by 1.0 meter on the highway and harmed the highway section by 50 meters. The harm is small and the debris flow gully is in the development period, but the frequency is high.	Reliable
2	N14	S=0.537	It is covered with mud and silt by 1.5 meters on the highway and harmed the highway section 450 meters. The harm is highly serious and the debris flow gully is in the development period, but the frequency is high.	Reliable
3	N20	S=0.904	It is covered with mud and silt by 20 meters on the highway and harmed the highway section 550 meters, the harm is extremely serious and the debris flow gully is in the development period, but the frequency is low.	Small deviation
4	N31	S=0.966	It is covered with mud and silt by 15 meters on the highway and harmed the highway section 400 meters, the harm is extremely serious and the debris flow gully is in the development period, but the frequency is low.	Reliable
5	N32	S=0.431	It is covered with mud and silt by 2.2 meters on the highway and harmed the highway section 120 meters, the harm is moderate serious and the debris flow gully is in the development period, but the frequency is high.	Reliable

Table 5: Continued.

6	N47	S=0.507	It is covered with mud and silt by 1.5 meters on the highway and harmed the highway section 300 meters, the harm is highly serious and the debris flow gully is in the development period, but the frequency is high.	Reliable
7	N49	S=0.555	It is covered with mud and silt by 2.0 meters on the highway and harmed the highway section 350 meters, the harm is highly serious and the debris flow gully is in the development period, but the frequency is high.	Reliable
8	N61	S=0.353	It is covered with mud and silt by 1.2 meters on the highway and harmed the highway section 150 meters, the harm is serious and the debris flow gully is in the development period, but the frequency is high.	Reliable
9	N63	S=0.495	It is covered with mud and silt by 1.4 meters on the highway and harmed the highway section 350 meters, the harm is moderate serious and the debris flow gully is in the development period, but the frequency is high.	Reliable
10	N81	S=0.410	It is covered with mud and silt by 1.5 meters on the highway and harmed the highway section 180 meters, the harm is moderate serious and the debris flow gully is in the development period, but the frequency is high.	Reliable
11	N87	S=0.236	It is covered with mud and silt by 0.8 meters on the highway and harmed the highway section 20 meters, the harm is small and the debris flow gully is in the development period, but the frequency is high.	Reliable

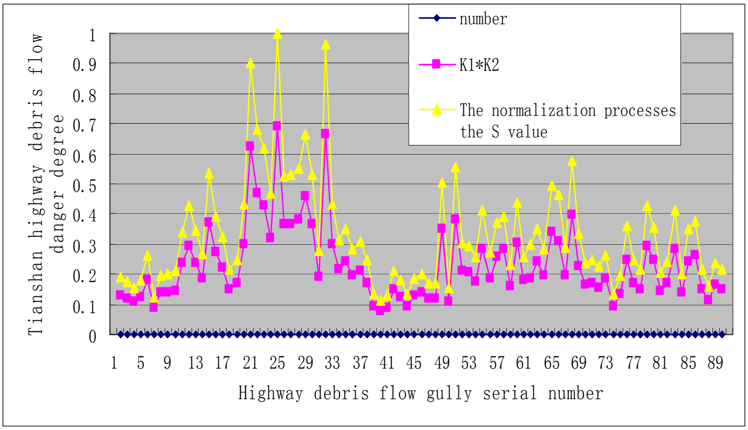

Figure 1: Tianshan highway debris flow hazard degree assessment results.

Table 6: Tianshan highway debris flow hazard degree graduation standard and prevention and control measures.

Highway debris flow hazard degree	Risk assessment	Preventing and controlling principles	Preventing and controlling countermeasures	Engineering design target
≥0.80	Extreme hazard.	Guarding primarily, governing secondly.	Circles prevention. If it is unable to circle prevention, we take the early warning measures. When it is necessary, biology and construction measures can be used together.	100 year once
0.50-0.80	Highly danger hazardous.	Guarding and governing together	Soft measure: prediction and forecast; Hard measure: biology and construction measures can be used together.	50 year once
0.25-0.50	Moderate hazard.	Governing primarily, guarding secondly.	Biology and construction measures can be used together, when it is necessary, monitoring system can be set up.	20 year once
≤0.25	Mild hazard.	Guarding primarily, governing secondly.	Enhance the conservation of water and soil and protect ecological environment.	10 year once

3) This model and the correlation graduation assessment system may be worked as the security margin of safety design research foundation on other debris flow area highway, rail and so on.

At the same time, we also proposed suggestions as follows:

1) To K_1 and K_2 in various factors quantitative graduation, we should consider different debris flow characteristics and carry on through the adjustment.

2) We should optimize the highway damage degree (K_2) formula further and let it be more reasonable.

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