Debris-flows scale predictions based on basin spatial parameters calculated from Remote Sensing images in Wenchuan earthquake area

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Abstract. Debris flow is a common hazard in the Wenchuan earthquake area. Collapse and Landslide Regions (CLR), caused by earthquakes, could be located from Remote Sensing images. CLR are the direct material source regions for debris flow. The Spatial Distribution of Collapse and Landslide Regions (SDCLR) strongly impact debris-flow formation. In order to depict SDCLR, we referred to Strahler's Hypsometric analysis method and developed 3 functional models to depict SDCLR quantitatively. These models mainly depict SDCLR relative to altitude, basin mouth and main gullies of debris flow. We used the integral of functions as the spatial parameters of SDCLR and these parameters were employed during the process of debris-flows scale predictions. Grouping-occurring debris-flows triggered by the rainstorm, which occurred on September 24th, 2008 in Beichuan County, Sichuan province China, were selected to build the empirical equations for debris-flows scale predictions. Given the existing data, only debris-flows runout zone parameters (Max. runout distance L and Lateral width B) were estimated in this paper. The results indicate that the predicted results were more accurate when the spatial parameters were used. Accordingly, we suggest spatial parameters of SDCLR should be considered in the process of debris-flows scale prediction and proposed several strategies to prevent debris flow in the future.

1. Introduction

Debris flows occur when masses of unconsolidated sediment, agitated and saturated with water, surge down slopes in response to gravitational attraction [1]. They occur typically in steep torrent channels in catchments with steep slopes and abundant sedimentary debris. The formation of debris flows requires the following conditions: (1) a torrent catchment, (2) abundant supply of loose debris, (3) a source of abundant moisture. Debris flows are caused by the combination of those conditions. The spatial distribution of those factors effect debris-flows formation greatly.

To perform a hazard assessment and eventually to design protective measures against debris flows, it is necessary to estimate the parameters of debris-flows scale. Existing empirical models base either

on physically measured characteristic of catchment or on a statistical analysis [2]. Most empirical models only refer to spatial distribution of debris-flows catchment conditions and little models involve spatial distribution parameters. The aim of this paper was to: (1) develop models to depict spatial distribution of debris-flows catchment conditions, (2) introduce spatial distribution parameters into debris-flows scale predictions. Group-occurring debris-flows triggered by the September 24th, 2008 rainstorm in Beichuan County were selected to build empirical equations. Out of the limitation of existing data, only debris-flows runout zone parameters (Max. runout distance L and Lateral width B) were estimated in this paper.

2. Material And Methodology

The Wenchuan earthquake-hit regions mainly distribute in the Longmenshan Mountain and hill area of the Sichuan Basin edge, which are mountain canyon regions [3]. After Wenchuan earthquake, debris-flows gullies came into the active period. Debris-flows catchment conditions were changed by the strong surface disturbance and large-scale destructive vegetation [4].

2.1. Study area and Data

The intense rainfall, which happened on September 24th, 2008, initiated widespread debris flows in Beichuan County, the epicenter of the Wenchuan Earthquake (Fig.1). Extraordinary abundant of loose solid materials and local short-time heavy rainfall by the extreme climate were the basic reasons of the debris flow occurrence [5]. CLR were the main material source area for this event. We used Remote Sensing image of ALOS AVNIR-2, 04/06/2008(Fig.2) to locate CLR. The images have four spectral bands with a spatial resolution of 10 meters. But the result would have been better if high resolution images were used [6].
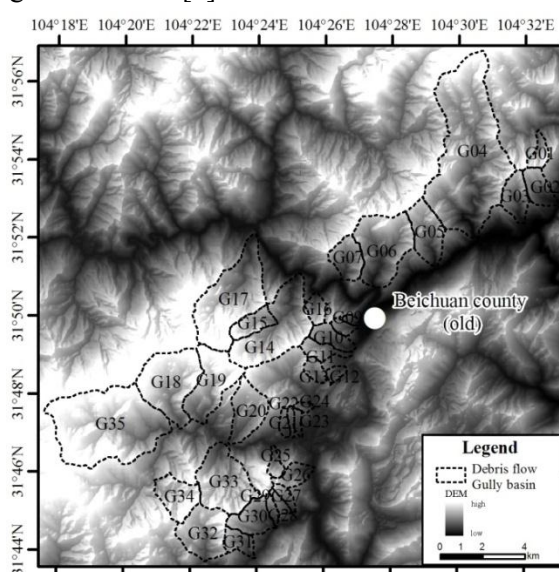
Figure 1. The studied area.
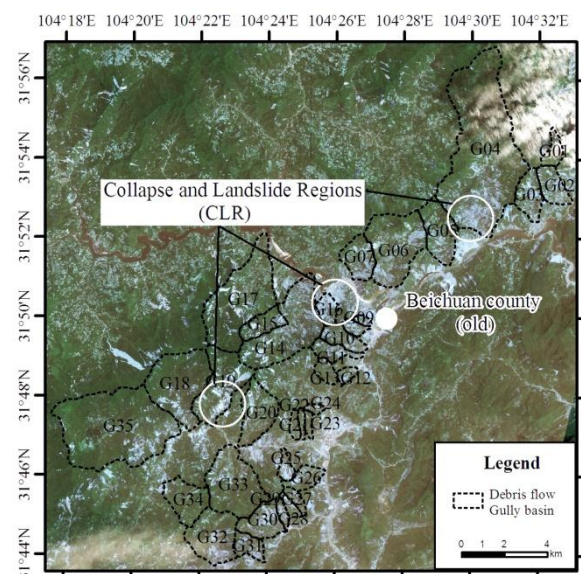
Figure 2. Remote Sensing images of studied area

These debris flows greatly impacted the community of the Beichuan County (Tab.1) and caused 42 fatalities, damaging many roads and other infrastructures. These damages were caused by both the rainfall and earthquake. Therefore, it is meaningful to elucidate the characters of debris flows formation and their movement processes in the highly seismic intensity areas [7].

Table 1. Data set of debris-flows in Beichuan County, 2008.09.24

Gully name (Code)	Basin Area, A (km^2)	Relative Altitude, H (km)	Sediment Volume, V_L(10^{6}m^3)	S	Parameters of SDCLR			Max.runout distance, L (km)	Lateral width, B (km)
					D	M	G		
Tongbao(G01)	1.06	0.88	1.24	0.563	-	-	-	0.19	0.22
Yunlicun(G02)	1.94	1.1	4.46	0.462	0.391	0.539	0.662	0.24	0.23
Huangjiaba(G03)	2.41	1.14	6.47	0.475	0.430	0.526	0.744	0.38	0.31
Xiaonan(G04)	0.69	0.66	0.65	0.57	0.305	0.643	0.730	0.11	0.11
Hualin(G05)	3.52	1.18	4.85	0.511	0.413	0.592	0.594	0.25	0.46
Dongxi(G06)	7.49	1.16	12.05	0.491	0.385	0.487	0.654	0.24	0.38
Loufangping(G07)	2.49	1.02	5.14	0.548	0.487	0.527	0.631	0.23	0.22
Xinjiecun(G08)	0.29	0.69	0.3	0.472	0.419	0.641	0.667	0.18	0.12
Shenjia(G09)	0.83	0.85	3.17	0.52	0.482	0.475	0.703	0.35	0.26
Sujia(G10)	1.52	1	3.32	0.453	0.412	0.528	0.734	0.19	0.13
Weijia(G11)	1.36	1.12	5.1	0.504	0.351	0.521	0.759	0.32	0.15
Shiyicun(G12)	0.27	0.7	0.13	0.369	0.356	0.522	0.753	0.21	0.16
Caoshan(G13)	10.15	1.47	17.6	0.453	0.421	0.486	0.711	0.49	0.46
Caoshangou(G14)	1.81	1.06	3.16	0.466	0.398	0.529	0.743	0.13	0.24
Dashuicun(G15)	1.12	0.93	2.99	0.538	0.497	0.570	0.617	0.14	0.35
Shilong(G16)	9.91	1.54	8.72	0.493	0.445	0.492	0.683	0.35	0.31
Qingjiecun(G17)	0.57	0.82	2.11	0.514	0.514	0.488	0.673	0.25	0.27
Pashancun(G18)	7.6	1.24	10.21	0.542	0.393	0.586	0.674	0.43	0.38
Guanmenzi(G19)	5.5	1.5	10.01	0.513	0.425	0.560	0.773	0.44	0.33
Daancun(G20)	3.67	1.3	7.21	0.381	0.388	0.407	0.722	0.21	0.23
Xujiacun(G21)	0.6	0.58	0.09	0.427	0.362	0.587	0.644	0.21	0.19
Liulincun(G22)	0.45	0.56	0.62	0.502	0.435	0.524	0.760	0.16	0.2
W.Liulincun(G23)	0.46	0.6	0.15	0.416	0.263	0.676	0.786	0.27	0.26
Yingding(G24)	0.32	0.54	0.96	0.449	0.350	0.598	0.774	0.2	0.18
Guoniucun(G25)	0.81	0.84	2.88	0.529	0.490	0.376	0.700	0.18	0.30
Shiyan(G26)	1.07	0.88	1.87	0.48	0.435	0.546	0.724	0.24	0.22
Chafang1(G27)	0.64	0.9	1.44	0.507	0.329	0.698	0.781	0.11	0.15
Chafang2(G28)	0.59	0.94	0.9	0.447	0.463	0.501	0.776	0.13	0.15
Datiancun1(G29)	0.55	0.92	1.39	0.454	0.367	0.554	0.764	0.11	0.12
Datiancun2(G30)	2.56	1.02	6.35	0.505	0.426	0.518	0.640	0.25	0.21
Wuxingcun(G31)	1.47	0.98	3.96	0.446	0.405	0.509	0.709	0.21	0.29
Fanzaocun(G32)	4.69	0.92	6.69	0.599	0.483	0.575	0.820	0.37	0.34
Tianbacun(G33)	6.29	0.82	3.03	0.542	0.454	0.592	0.659	0.31	0.25
Nanxingcun(G34)	3.11	0.56	2.09	0.543	0.407	0.535	0.705	0.32	0.37
Qiaoluocun(G34)	0.73	0.7	1.42	0.506	0.459	0.501	0.660	0.11	0.13

Note: the debris-flows hazards data come mainly from reference papers [8].

2.2. Methodology

2.2.1. Quantitative geomorphological conditions. A.N Strahler (1952) used the integral of the percentage hypsometric curve (area-altitude curve), which relates the horizontal cross-sectional area of a drainage basin to the relative elevation above basin mouth, to analyse the morphometric of basins quantitatively [9].

$$y = f(x) \tag{1}$$

$$S = \int_0^1 f(x)\,dx \tag{2}$$

$$x = \frac{a}{A} \qquad y = \frac{h}{H}$$

Where: y is the ratio of the height of contour above base (h) to the total height of basin (H), x is the ratio of the area between the contour and the upper perimeter (a) to the total drainage basin area (A), S is the integral of the percentage hypsometric curve (area-altitude curve).

2.2.2. Quantitative spatial distribution models. Researchers mainly focus on the spatial distribution of loose sediment relative to basin elevation, main gully and basin mouth during debris-flows scale prediction. So, we built spatial analysis models to depict the spatial distribution of mainly available loose sediment.

$$t = f(x_t) \tag{3}$$

$$T = \int_0^1 f(x_t)\, dx_t \tag{4}$$

$$x_t = \frac{s}{A_s} \qquad t = \frac{h_s}{H_s}$$

Where: t is the ratio of the height of loose sediment region above base (h_s) to the total height of loose sediment region (H_s), x_t is the ratio of area between the contour and the upper perimeter loose sediment region area (s) to the total loose sediment distribute area (A_s), T is the integral of the loose sediment region area-altitude curve.

$$m = f(x_m) \tag{5}$$

$$M = \int_0^1 f(x_m)\, dx_m \tag{6}$$

$$x_m = \frac{s_1}{A_s} \qquad m = \frac{d_1}{D_m}$$

Where: m is the ratio of the distance of loose sediment region from gully-mouth (d_1) to the total (Max) distance from gully-mouth (D_m), x_m is the ratio of the area between the loose sediment region area (s_1) in the range of d_1 to A_s, M is the integral of the loose sediment region area-gully mouth distance curve.

$$g = f(x_g) \tag{7}$$

$$G = \int_0^1 f(x_g)\, dx_g \tag{8}$$

$$x_g = \frac{s_2}{A_s} \qquad g = \frac{d_2}{D_g}$$

Where: g is the ratio of the distance of the loose sediment region from gully (d_2) to the total (Max) distance of the basin from gully (D_g), x_g is the ratio of the area between the loose sediment region area (s_2) in the range of d_2 to A_s, G is the integral of the loose sediment region area-gully distance curve.

2.2.3. Development of debris-flow scale predictions model. Debris flows correspond with the elevation and micro-landform [10].The foremost feature of the debris-flows basin is the extraordinary abundant of loose solid materials in Wenchuan earthquake area, whose mainly available or direct source material were from CLR. The Spatial Distribution of Collapse and Landslide Regions (SDCLR) strongly affect the debris-flows formation. Therefore, its scale predictions should not only use the morphometric characteristics of catchment but also refer to the spatial distribution conditions of CLR. We used integral of functions as the spatial parameters and tried to add the parameters for debris-flows scale predictions. Grouping-occurring debris-flows triggered by the September 24th, 2008 rainstorm in Beichuan County (Tab.1) were selected to build the empirical equations for predictions. Limited by the existing data, we were only able estimate debris-flows runout zone parameters (Max. runout

distance L and Lateral width B) in this paper. The models were evaluated by performing regressions of the data in Tab.1.

$$L_f = 0.086 V_L{}^{\alpha(T,M,G)} + 0.114 A^{\beta(S,T,M,G)} H^{\gamma(S,T,M,G)} - 0.059 \quad (R^2=0.784) \tag{9}$$

$$B_f = 0.067 V_L{}^{\alpha(T,M,G)} + 0.062 A^{\beta(S,T,M,G)} H^{\gamma(S,T,M,G)} + 0.031 \quad (R^2=0.731) \tag{10}$$

$$\alpha(T,M,G) = T(M+G)$$

$$\beta(S,T,M,G) = \frac{S^2}{e^{T(M+G)}}$$

$$\gamma(S,T,M,G) = \frac{S}{e^{T+M+G}}$$

Where: L_f is the predicted maximum runout distance (km), B_f is the predicted maximum width (km).

3. Results

3.1. Analysis of spatial distribution models and parameters
We took Yingxiu town located in Wenchuan County, Sichuan province, China to test the models and quantitative parameters, as this area has a lot of collapses and landslides caused by earthquake.

Five debris-flows gullies were selected as examples. We used Remote Sensing image of SPOT and calculated the parameters (T, G,M) of SDCLR. The results were shown in following table (Tab.2).

Table 2. Data set of debris flow catchment basin for testing spatial distribution models

Gully name	Catchment area, A (km^2)	Relative Altitude,H (km)	Sediment Volume, $V_L(10^6 m^3)$	S	Parameters of SDCLR		
					T	G	M
Hongchun	5.50	1.26	3.84	0.486	0.480	0.529	0.289
Mozi	5.33	1.60	6.22	0.519	0.415	0.430	0.325
Shaofang	0.71	1.04	3.08	0.481	0.413	0.389	0.316
Xiaojia	0.49	1.07	0.49	0.432	0.413	0.432	0.295
Wangyimiao	0.47	1.00	0.73	0.392	0.467	0.486	0.266

The results showed that the parameters of the models reflected the differences between different areas when their physically measured characteristics of catchment were similar. For example, Xiaojia gully and Wangyimiao gully were very similar in catchment areas, relative altitudes and sediment volumes. But their spatial parameters (S, T, G, M) were different. Hongchun gully and Shaofan gully had different catchment area parameters, but their spatial parameters (S, T, M) are similar except G.

According to the results, the models could preliminarily depict SDCLR relative to altitude, basin mouth and main gullies, and the integral of functions could be used as the spatial parameters.

3.2. Analysis of the improved debris-flow runout zones models
Debris flows triggered by the August 14, 2010 rainstorm occurred in these five debris-flows gullies. The improved models in this paper were used to estimate the debris-flows runout zone parameters (Max. runout distance L and Lateral width B). The detailed results were as following table (Tab.3).

Table 3. Data set of debris flow hazards for testing debris-flow runout zones models

Gully name	Debris flow event date	Max.runout distance, L (km)	Lateral width, B (km)	L_f (km)		B_f (km)	
				value	Error (%)	value	Error (%)
Hongchun	14/08/2010	0.39	0.35	0.241	-38.2	0.188	-46.3
Mozi	14/08/2010	0.23	0.27	0.264	15.0	0.198	-26.7
Shaofang	14/08/2010	0.17	0.18	0.168	-0.9	0.154	-14.3
Xiaojia	14/08/2010	0.17	0.26	0.115	-32.5	0.114	-56.0
Wangyimiao	14/08/2010	0.22	0.21	0.123	-44.1	0.120	-42.6

This table showed that the estimated results from the improved models were not very accurate, especially the results for Hongchun gully, Xiaojia gully and wangyimiao gully. We considered two reasons for these results: 1) the models were empirical models and had some limitation, mainly because we built models using the Beichuan '9.24' debris-flows data; 2) There were some exceptional cases in this debris flow event. The main factors include extraordinary abundant loose solid materials and local short-time heavy rainfall. If only data from this five debris flows had been used, accurate values would have been obtained [11].

In summary, Debris-flows scale predictions should not only use the most important morphometric characteristics of catchment but also refer to the spatial distribution conditions of debris flow basin.

4. Conclusion

Empirical relationships of debris-flows can provide rough approximation and acceptable prediction of scale parameters. Present equations that based either on physically measured characteristic of catchment or on statistical analysis mostly have limitations in practice. These models only use limited spatial distribution of debris-flows catchment conditions and little models involve spatial distribution parameters. While in fact debris flows are controlled by the spatial interaction of different factors.

Spatial distribution models and parameters can depict spatial distribution of debris-flows catchment conditions qualitatively in this paper. The models may have some problems; however, this is searching for methods of studying spatial distribution of debris-flows catchment conditions qualitatively, especially in Wenchuan earthquake area. We proposed the spatial parameters of SDCLR should be introduced in the process of debris-flows scale predictions and the influence of rainfall conditions must be considered in the future.

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