Application of RS and GIS in prediction of the debris flow

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Abstract

Prediction of debris flow properly is very important, and then the accurate investigation and analysis of the factors are the primary tasks. Applying the French SPOT5 remote sensing image (RS) which the analytic precision is 2.5m, geologic map and Geographic Information System (GIS) to analyze the rock character, the drainage area, the length, the slope of valley and the other factors of Xiabaitan groove which control the scale of the debris flow case and through the Global Positioning System (GPS) can ensure the veracity of the analysis during the field investigation. Through the field investigation about the debris flow fans and the others evidence of the debris flow analyzes the scale of the debris flow case. Through combining the analysis of the factors and the results of the field investigation, it is founded that the eruption ratio and the scale of Xiabaitan groove are very high.

Keywords: GIS system; RS technology prediction; Debris flow.

1. Introduction:

China is a mountainous country where has various geological disasters. Every year geological disasters resulted in a huge lost on people's lives and property. In recent years, geological disasters in China shows that the trend is becoming more frequent, especially due to global climate changing, acceleration of mountainous area's economic development and irrational exploitation of landslides which resulted in some debris flow (Kang et al.,2004). For example, there were 22758 geological disasters leading to 720 person deaths and missed in China during 2008, the economic loss amounted to 17.734 billion RMB. After Wenchuan earthquake, during repairing the highway to Wenchuan, nearly 200 people were dead and missing because of the debris flows. There were 49 deaths and 42 missing during the debris flows which happened in Kangding in Sichuan province, Miyi and Jinyang in July 2009.

Previously, debris flows has been considered as "acts of God" in human's mind until 1928. Since then, the scientific research on debris flows had never been stopped. The debris flow is a complex phenomenon of geological disasters. It is an admixture of water loose and solid erosion that occur in certain topographic conditions (Hungr, 2000). Due to lots of factors affecting debris flow, it is necessary to fully understand the mechanisms of debris flow and utilize the new technologies such as ERTS, GIS and Remote Sensing

Technologies to make it possible to perform a comprehensive and accurate computer simulation in order to develop a more effective disaster prevention and mitigation strategies to reduce unnecessary human casualties and property loss.

2. Characteristics and influencing factors of Xiabaitan groove::

In order to find out the characteristics and influencing factors of Xiabaitan groove, we use the French SPOT5 remote sensing image with the resolution of 2.5m and interpreted it (Figure 1). From Figure 1 we can see that the accumulated fan of Xiabaitan groove is just 730m away from proposed Wudongde dam, and the accumulated fan has squeezed the main river channel which leads to a certain offset. So the investigation and comprehensive study will be very important. Xiabaitan groove has several clear characteristics which are essential difference with the hill-shaped debris flow, the risk is becoming higher. Firstly, the drainage area which is about 3.1km^2 and the development water system of Xiabaitan are very favorable for aggregating rainfall during the short time (Liu et al., 1995). Secondly, the lithology of the Xiabaitan groove is complex and fractured which provides a large number of loose materials when the debris flow breakout (Yang, 2003; Cui et al., 1990). The hydrographic factor of Xiabaitan groove is also very favorable case to the breakout of the debris flow, the detailed data will be offered in the following paragraph.

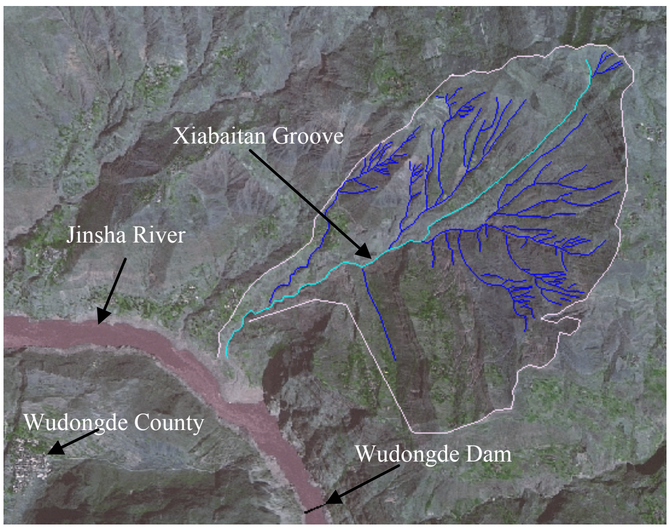

Figure1 Aerial photo of Xiabaitan groove

3. The eruption mechanism of valley shaped debris flow:

3.1 Natural and Geographic conditions:

3.1.1 Topographic Conditions:

Topographic condition is one of the most important factors in the development of debris flow. The topographical conditions of valley-shaped debris flow determine the eruption probability and the scale of debris flow from various aspects. For example, in the area of the catchment, the shape of the groove and the difference of elevation between the source area and accumulated area determine the energy of the debris flow. The drainage area of Xiabaitan groove is 3.1 km^2 and the water system is very developed which makes sure aggregate enough water during the short time in order to express the terrain of Xiabaitan groove in detail; we cover the remote sensing image with the contour lines. The contour lines of the elevation were obtained automatically. Each contour line has 10m difference in elevation, in order to show convenience, the figure which the each contour line has 50m difference in elevation is given (Figure 2). The elevation of the highest and lowest is 2.09km and 0.83km, the difference in elevation of the drainage area reach 1.26km. Thus, as one of the necessary factors, the big difference make the debris flow have very huge gravitational potential energy which could change into kinetic energy that human beings is very difficult to prevent (Wang et al., 2003).

Figure 2 Contour line map

In addition to the drainage catchment and the difference of elevation, the shape and the slope of the groove are also very important during the evaluation process of the debris flow (Bernander, 2000). For example, the shape of Xiabaitan groove is like the letter “V” and the slope is near vertical (Figures 3&4). The vertical slope will be helpful to gather the solid materials in the bottom and the shape of Xiabaitan will be helpful to gather the precipitation in a narrow valley so that the flood has the energy strong enough to carry the solids with fluids forming a debris flow (Tang, et al., 1994; Picareli, et al., 2008). The comprehensive and accurate topographical conditions are shown in the following Table1.

Figure 3 Shape of the groove

Figure 4 The vertical slope

Table 1
Topographical condition of Xiabaitan

Position	H*max*	H*min*	Length	B*d*[*1]	Gradient	S*d*[*3]	Degree of slope	T*d*[*2]
	m	m	m	km/km^2	%	km^2	°	
E:102° 37.441 N: 26° 20.716′	2090	835.4	3100	7.63	40.7	3.1	33	1.12

*1. It expresses the length of channel per km^2.
2. It expresses the curvature of main groove.
3. It expresses the drainage area.

3.1.2 Climate:

The rainy season and dry season of Xiabaitan groove are highly concentrated. The average annual rainfall in Xiabaitan area is about 1060mm, rainfall concentrated in the May to October, over the years the average monthly rainfall is 173mm ~ 229mm, the specific indicators of rainfall intensity (Table 2). Not only the hydrographic factor but also the temperature impacts the debris flow (Liu et. al., 1998; Tang et. al., 2002). The Annual maximum temperature of Xiabaitan groove is about 35ºC, the minimum temperature is about -6ºC, the maximum relative difference of temperature is about 41ºC and the maximum relative temperature is about 77.7ºC. The large difference of temperature during a year and the relatively high maximum temperatures circumstances is conducive to the physical weathering of rock which resulted in the landslides and avalanches of the two sides of the main valley in rainy season, and offered large amount of loose solids to the debris flows (Ren, et al., 2008).

Table 2
Quantity of rainfall

rainfall[*]	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
$H_{1/6}$/mm	10.1	10.1	14.1	15	13.3	12.6	13.7	18.1	21.7	13.7	12.5	15.6
H_1/mm	30.3	34.2	27.7	29	35.7	30.9	31.6	77.2	44.6	31.1	32.2	34.7
H_6/mm	53.5	51.9	32.3	59.7	77.1	64	86.6	98.7	78.8	58.3	66.2	60.3
H_{12}/mm	53.6	76.5	44.6	69.2	77.1	65	90.4	98.7	80.7	70	67.1	61.5
H_{24}/mm	56.9	81.4	56.6	89.4	80.3	84.5	90.4	100.1	80.7	70.2	67.1	66.2

*The rainfall per hour.

3.1.3 Vegetation:

The vegetation in watershed area also affects the probability and intensity of the breakout of the debris flow. The vegetation of Xiabaitan groove is very poor where overall coverage is about 20%. The area near the village is woody plants coverage and the other area is just covered with the herbaceous plants or even mostly bare rock. As usual, the poor vegetation is not conducive to water and soil conservation, then it is advantageous to the breakout of the debris flow and leads to large-scale viscous mud flows or debris flows during the rainstorm. However, through the survey in recent years we found that the impact of vegetation on debris flow is very limited. For example, the debris flow erupted in Sichuan, in July 2006, even though the rate of vegetation coverage is 80% and the forest coverage rate exceed 50% (Shi, et al., 2008; Wu, et al., 1990).

3.2 Geological conditions:

3.2.1 Geological structure:

The geological condition of Xiabaitan is very bad. There are two regional faults developed in this area, and they are Qingcaoping fault and Malutang fault. As the impact of the faults, the steep slopes of the groove and the rock properties, there are seven types of the loose solids which the main causes are different from each other (please refer to Figure 6). Those loose solids become the main source for the debris flow. The complex geological conditions and rock conditions lead to landslide and slump-phenomenon which are the main sources of the debris flow. For example, the breakout of the debris flow in the Oregon Coast Range is landslide triggered (Pierson, 1977; Frattini, et al., 2004).

3.2.2 Rock character:

The rock characteristic of Xiabaitan groove is very complicated and advantageous to the breakout of the debris flow. Xiabaitan is exposured Cretaceous Xiaoba group quartz-sandstone, siltstone bedded with mudstone, Xincun and Guangou group sandstone, mudstone and marlstone and Longjie group half-diagenesis silt (Figure 5). Especially, because of the sandstone of the Xincun group and the Guangou group with the mudstone of Longjie group which is weathered very serious formed a unique phenomenon “soft rock bedded with hard rock” and “hard rock bedded with soft rock” which formed the “soil column” and the “stone cap” which is conducive to form a large number of loose solid substances to the debris flow (Figure 6).

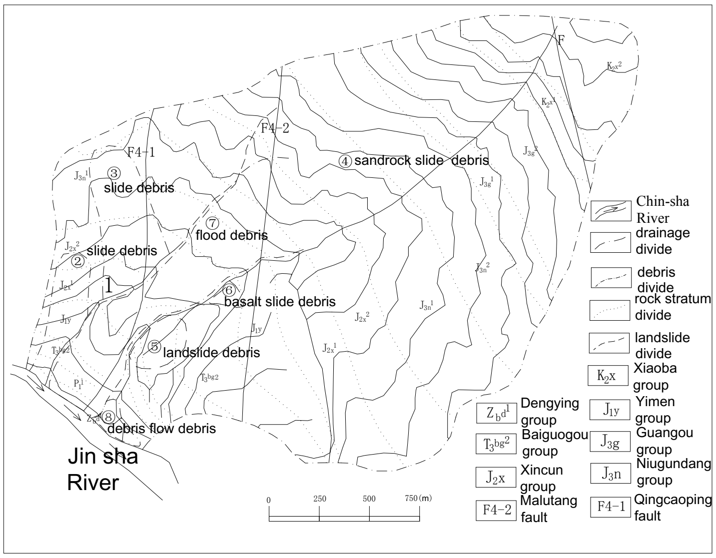

Figure 5 simple geological map

Figure 6 soil column

3.3 Accumulated Characteristic:

The accumulated characteristic of Xiabaitan is formed by at least two processes of debris flows (Figure 7). The deposit thickness exposed is 3.2 meters which formed by the first debris flow. There are many coarse granules in the first-phase deposit and the maximum particle diameter achieved 1.2 meters. It can be judged that the kinetic energy is very large. The thickness of second deposit is 2.8 meters which is formed by the next debris flow. The coarse granules' content is obviously reduced than the first-phase deposit and the maximum particle diameter is just 0.25 meters. By the thickness and maximum grain size it can be judged that the kinetic energy of the next debris flow is a little feebleness than the last phase. In order to compare the two deposits we did the particle analysis and accepted the kurtosis to indicate the size distribution (Figure 8).

Figure 7 Accumulative formation photo

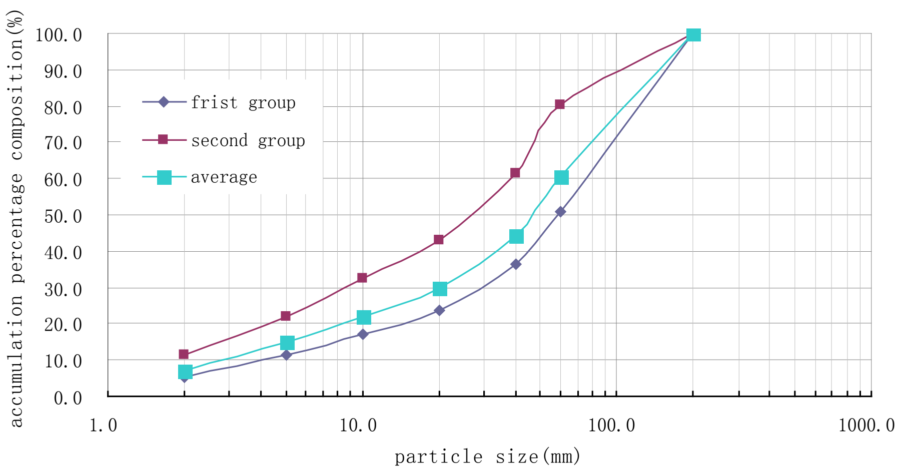

Figure 8 size distribution cure

4. Comprehensive evaluation:

Based on field survey and remote sensing image, the characteristic area of Xiabaitan groove could be accurately divided and the features of it can be seen in figure 9.

Firstly, the eruption ratio is very high. The terrain condition, geological condition and the climate condition of Xiabaitan groove are very favorable for the debris flow and combine to the quantitative condition which is compiled by the state codes and the standard of DZ/T 0220-2006 that is formulated by the Ministry of Land and Resources of PRC (PRC,

2006) (Table 3). By the quantitative result which shows debris flow-prone degrees 43 minutes, we can see that Xiabaitan groove are vulnerable to breakouts of torrential valley-shaped debris flow.

Secondly, large scale and large energy; through the investigation and the geological map, it is analyzed that the direct and indirect solid resource is $830.3\times10^4 m^3$. During the analysis about velocity of debris flow and the flux of debris flow we choose the equation which is recommended by the state standard of DZ/T 0220-2006.

$$V_c = K \cdot H_c^{2/3} I_c^{1/5} \quad (1)$$

Where *Vc* = velocity of debris flow; *K*= coefficient of velocity; *Hc*=average depth of debris flow and *Ic*=hydraulic gradient.

$$Q_c = V_c \cdot F_c \quad (2)$$

$$Fc = (d + d + 2H \times \cot\theta) \times H / 2 \quad (3)$$

where *Qc*= flux of debris flow; *Fc* =cross-sectional area; *d* =mean width and θ =ratio of slope.

Combined the data of the investigation, the velocity of debris flow is 13.3m/s and the flux of debris flow reaches 67.62 m^3/s. The analysis explained that the quantity of the solid resource and the velocity of debris flow are enough to form the oversized scale debris flow. In theory, Xiabaitan could break out that scale debris flow, and actually in the investigation it is found that the thickness of accumulated fan actually reached 3.2 meters and the maximum particle diameter achieved 0.8 meters (please refer to Fig. 8 & 9). So both theory and facts make sure that Xiabaitan could and actually broken out that scale debris flow and will break out again if the factors become mature.

Thirdly, the outbreak frequency is very high which is proved by the findings of the "mud marks" and the "mud ball" it (Fig. 10) (Hu, 2001; Zhong, et al., 1994).

Figure10 Mud ball photo

Table 3
Evaluation criterion of breakout

Influencing factor	Evaluation criterion							
	Data	N	Data	N	Data	N	Data	N
Watershed area/km^2	>6	8	4-6	6	2-4	4	<2	1
Tap drain gradient/%	>40	8	30-40	6	15-30	4	<15	1
Hygrometric/$(H_{24})_{cp}$	>80	8	65-80	6	50-65	4	<50	1
Degree of slope/°	>60	6	45-60	4	30-45	2	<30	1
Rock character	Soft rock	6	Interbedded rock	4	Uncompleted Hard rock	2	Completed hard rock	1
Discrete material by person/$*10^3m^3$	>10	4	5-10	3	1-5	2	<1	1
Geological structure	Fault crush belt	4	Mid fault	3	Small fault	2	No fault	1
Maximum temperature difference of ground/°	>70	4	55-70	3	40-55	2	<40	1
Percentage of vegetation/%	<10	4	10-30	3	30-60	2	>60	1

* 39-52 high risk area，26-39 mid risk area，13-26 low risk area，<13 safe risk area, N=scores of factor

5. Conclusions:

Xiabaitan groove is only 300 meters away from Wudongde Dam which is very important to be investigated. During the investigation the engineers found three major problems. First, the acquisition of the measurement of site data is difficult or impossible, so we should integrate ERTS, GIS and Remote Sensing technologies to evaluating site characteristics. This is very helpful for us to monitor and manage the entire system. Second, the debris flow is controlled by many factors. For one same debris flow groove, it would never breakout the same rank damage. Third, every debris flow has its core factor(s), but we should not ignore the minor factors.

The accurate researches and evaluations on debris flow disaster risk ,the endanger scope and the extent of damage have extremely important practical significance .It has laid a solid foundation for the understanding of disasters, develop prevention policy, prevention and treatment of regional planning, implementing prevention and treatment various measures .

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