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Topographic Features of Debris Flow Gullies in Moxi Basin, Southwestern of China

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Abstract

Debris flows are the main geological hazards in the Moxi basin, which locate on the eastern slope of the M.T Minya Konka, Sichuan province, southwestern of China. The location of 49 debris flow gullies have been identified and mapped from the 1:50000 scale through the extensive field survey across the Moxi basin. The historical events data were collected from documents and visit to local residents, and were used as the basis for frequency analysis. Anymore, topographic features of debris flow gullies have been calculated using GIS software. The analysis showed that 73.5% of the debris flow gullies are not randomly distributed but concentrated directly adjacent to the western side of Moxi fault, and only 26.5% are located to the eastern side. The numbers, frequency, catchments area, gully length, gully slope ratio of these debris flow gullies in Moxi basin were affected by the glaciations and geological activity. The results show potential activity of debris flow in Moxi basin is strong, this research is essential to debris flow hazards mitigation.

Keywords

Debris Flow, Topographic Features, Moxi Basin

1. Introduction

Debris flows are one of the most important types of geological hazards in mountainous area, and caused great human and economic losses (Sergio, 2008). Two of the most dangerous aspects of debris flows are their rapid onset and the significant distances between where they initiate and where they may eventually cause damage (Santi, 2010). Worldwide, reports range up to nearly 1000 deaths per year due to landslides and debris flows (Dilley et al., 2005).

Affected by the geological, geo-morphological and climatic conditions of the mountainous environment, the debris flow has often been seen in southwestern of China. For the past few decades, the per capita wealth in mountain area has increased. At the same time, losses from debris flow are reported to have increased rather dramatically in southwestern China, There is obvious evidence that debris flows have changed substantially in rate of occurrence or magnitude, and effected the development of local economy.

Debris flow is a unique geomorphic process often can be seen in Moxi basin. Moxi basin locates on the eastern of the M.T Minya Konka, southwestern of China. The basin area is 904 km^2, and where distributing 49 de-

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bris flow gullies. The source of debris flow in Moxi basin is loose moraine from glacier erosion, the hydrodynamic force was supplied by rain storm, and the debris flow movement accompanied with high-frequency, high speed, long distance, large volume and severe hazard (Tie, 2011). Because of the rare human being activities in this basin in early periods, the hazards caused by this type of debris flow were not caused more care from local people and was not well documented. After the 20th century, because of the growing of population and accelerating activity caused by people, the hazards caused from debris flow were increasing obviously during the process of road, railway, power station and other infrastructures construction. On 11 August 2005, 4 gullies occurred debris flows in Moxi basin, debris flows damaged the houses, roads, power stations, and dammed the Dadu river for 20 min, more than 1200 persons have been tramped in Hailuogou scenic spot and caused more than 10 millions loss (Chen, 2006).

Much research about the glacier evolution has been carried out in Moxi Basin science 1936 (Heim, 1936), the earliest investigations of the debris flow processes in this area have been conducted at 1991 (Lv, 1991), and several researchers recognized that the occurrence of debris flow in this area is typical and provide some useful basic data. However, few efforts have been devoted to examine the debris flow mechanism, the gully evolution characters, the relationship between debris flow and glacier evolution. It is only recently, the debris flow hazards in Moxi Basin has affected to park visitors, personnel and infrastructure, especially the group debris flow occurred in 2005 has been recognized by government and researchers (Chen, 2006). Many medias have published accounts of debris flows that have trapped park visitors in Moxi Town , and in some cases have nearly led to damage of road, bridges, electricity stations, and including jam the Dadu river in July 1989, August 2005 (Chen, 2006; Ni, 2010).

A comprehensive survey has been carried out in Moxi basin from 2008 to 2010. Based on this survey, we call attention to debris flow morphological characteristics and distribution (Tie, 2011). Moxi basin was being taken as the research region, because severe debris flows widely occurred in the study area and have caused great economic losses.

2. Study Site

2.1. Geology and Geomorphology

The study area is defined as the western slope of the M.T Minya Konka, which peak altitude is 7556 m. The basin area is 904 km^2, includes a series ravines and creeks that drain the range towards the Dadu river. These ravines are usually the paths of debris and flood originated in the higher areas of the drainage basins (Tie, 2011). The most important ravines are Yajiagenghe, Nanmenguangou, Yanzigou, Mozigou and Hailuogou (**Figure 1**). Yanzigougou and Nanmenguangou gullies are important landslide activity area, particularly debris and floods. Alluvial fan deposits located along the foot of the gully mouth show that the activity of moraine transports has been significant along the Pleistocene and Holocene.

The geology of the area is relatively homogeneous, mainly formed by quartzite, slate and schist, and the age of stratum including Devonian, Permian and Quaternary. Three types of main units of Quaternary deposits can be identified which formed in Pleistocene and Holocene in the area. The first type is glacier deposits formed by late Pleistocene to Holocene, mainly composed of moraine with boulder, coarse granularity mixes with silt, and exposed as a slope with a hard distincting structure. This type of mass mainly distributes in upstream of ravines and creeks, with the depth 10 m to 200 m. The second type is a sequence of late Pleistocene to early Holocene fluvoglacial deposits (outwash), mainly composed of sand and gravel, locate in the lower area and with the depth from 5 m to 120 m, which is important to the form of Moxi platform. The third type is a sequence of Holocene debris flow deposit, with the depth of 5m to 50 m, mainly composed of boulder, coarse granularity with clay and silt mixture, and has bad size classification character. Fluvoglacial deposits and debris flow deposits are deposit across each other on the lower area, over 10 - 150 m thick, mainly composed of boulder, coarse granularity with sand and gravel, and formed the Moxi platform, which is 120 m high, 10.7 km long and 1 - 2 km width.

The landform in Moxi basin was controlled by the geologic conformation, the Xianshuihe fault was cross the basin. Affected by the fault, take the Yajiageng gully as a borderline, the terrain on each sides show an obvious difference. On the eastern of Yajiageng gully prevailing a middle-mountain terrain, and the western of Yajiageng gully prevailing a high-mountain terrain.

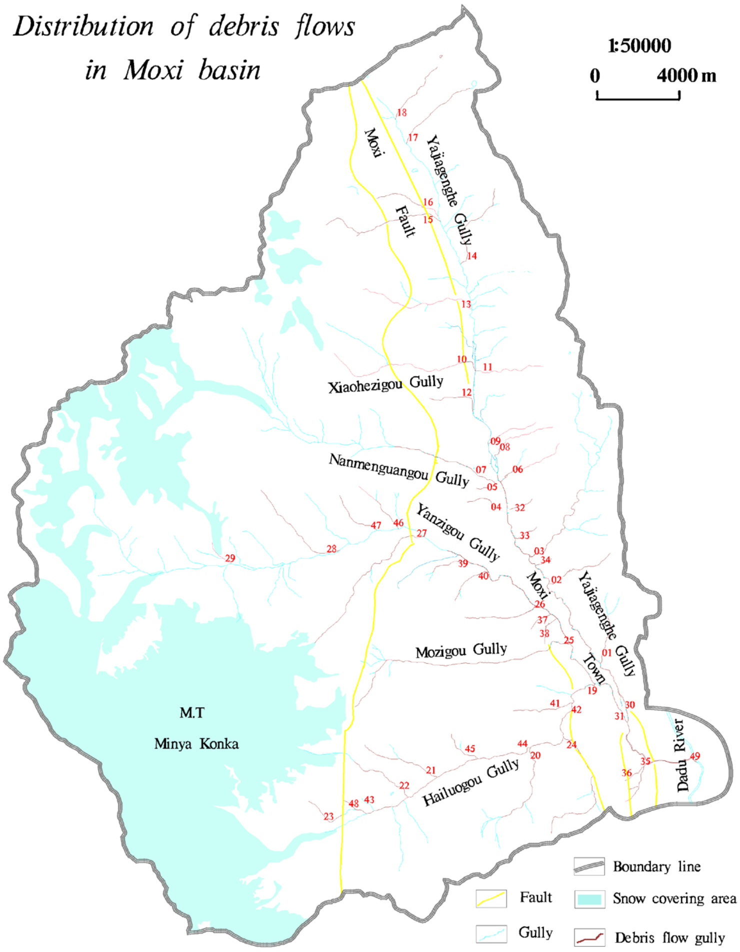

Figure 1. The distribution of debris flow gullies in Moxi basin.

2.2. Climate

The climate in Moxi basin may be classified as continental-monsoon-platform climate, characterized by a cool summer season and a cold winter season. The climatic characteristics of this area are conditioned by two main atmospheric factors: the Southeastern monsoon and warm-humid current from Sichuan basin. The maximum annual precipitation is 897.8 mm at 1600 m location and 1941.5 mm at 3000 m location. The maximum precipitation in history year is 1113.6 mm at 1600 m location and 2160.00 mm at 3000 m location (**Table 1**).

May to September is the rainy season in Moxi basin, most of the rainstorms are occurred in these months, and these rainstorms always induce debris flow and landslides. The maximum monthly average precipitation occur in July, and The minimum monthly average precipitation occur in December and January (**Table 2**).

Affected by the topography, the change of temperature and precipitation along the vertical direction is obvious, the temperature is reducing with the increasing of altitude, and the precipitation is increasing with the increasing of altitude under the 3000 m, and is reducing with the increasing of altitude more than 3000 m. According to the long-term climate records on the altitude 1600 m show, there is a pronounced June to September seasonal peak in precipitation, account for more than 60 percent of the annual total falling. According to the observation data, the mean annual precipitation in study area was 865.0 mm, the highest monthly summer precipitation occurs during June is 300.5 mm. This climate condition is advantaged for debris flow occurrence.

2.3. The Loose Source of Debris Flow

There are 49 debris flow gullies distribute in Moxi basin. Most of the debris flows initiate at high elevation, ranging from 2000 to 4500 m. These loose sources are mainly supply from the moraine which distributed in

Table 1. The precipitation characters in Moxi basin (mm).

Number	Yearly maximum precipitation	Annual precipitation	Monthly maximum precipitation	Monthly average precipitation	Daily maximum precipitation	Daily average precipitation
01	2160	1941.5	438.5	161.8	91	5.3
02	1113.6	897.8	300.5	81.4	75.3	2.8

Notes: 01 is the weather station located in the elevation of 3000 m, 02 is the weather station located in the elevation of 1600 m.

Table 2. The monthly average precipitation in Moxi basin (mm).

precipitation station number	Jan	Feb	Mar	Apr	May	Jun
01	27.5	36.7	85.2	154.5	233.2	307.1
02	3.7	7.3	30.8	63.0	108.3	173.8
	Jul	Aug	Sep	Oct	Nov	Dec
01	320.4	296.3	235.9	158.1	61.5	25.2
02	194.8	173.3	130.3	59.8	16.7	3.2

Notes: 01 is the weather station located in the elevation of 3000 m, 02 is the weather station located in the elevation of 1600 m.

Moxi basin widely. Based on the field survey and statistic, the potential volume of unstable moraine which in Moxi Basin is 3012 × 104 m^3， and the volume of loose moraine which can become the resource of debris flow directly is 1247 × 104 m^3 (**Table 3**). The starting zones of debris flows correspond to the uppermost occurrence of loose moraine, often located at the front of glacier, upstream or middle stream of stream, time range from early Gongga Ice Age to Little Ice Age. These moraines consist of thick (50 - 300 m), wide distribution and instability. Under the erosion process, the moraine has been incised strongly, the erosion depths range from meters to decameters, with steep gully slope (40˚ - 80˚), volumes range from several thousand cubic meters to ten billion cubic meters. Otherwise, the loose material of landslide and rock-fall from steep rock efforts to the debris flow is obvious too.

According to the field survey and statistic, the loose source supplying process in Moxi basin including three main types, the first type is the moraine or colluvial deposit is initiated by collapses or landslides from channel bank. The second type is the loose source which deposited in channel bed is initiated by channel flow erosion. The third type is the loose source accumulated on the slope is initiated during slope flow process.

3. Methods

Field survey is the important method which supports us to carry out the debris flow identify in Moxi basin. We made field survey in the study basin between 2008 and 2010. Survey typically involved determining the extent of the flows, interviewing local residents and a review of the literature to determine the timing of events, following the tracks of flows to the source in the basin to determine characteristics of flow initiation and flow initiation zones, sampling material from flow deposits and source areas, and geologic mapping of bedrock and colluviums. At the same time, the data of debris flow historical events get from the documents recordation and visit to local resident. Some features are referred to when identifying debris flows. Each debris flow must include source area, flow path, and deposits (debris flow fan)—that is, the source, transportation, and deposition zones can be identified by field survey. Since debris flow is a rapid, strong movement of debris materials along the flow path, the traces of canalized stream flow, sharp bank erosion, and uneven debris deposits show evidence of debris flow. Moreover, it is usually associated with landslides (Liu, 2008).

The general characteristics of these debris flow gullies are collected through Geographic Information System (GIS). Morphological characters of debris flow gullies analysis were using the relief map with the scale 1:50000 in Moxi basin. These data were used to identify and plot all visible debris flow landforms and snow covering area in preparation for analyzing their distribution using spatial analyst with GIS. All recognizable debris flows were mapped by purple line along its gully of each landform (**Figure 1**). Moreover, the integrity index and the incision index which can indicate the conflux hydrodynamics and evolution stage of debris flow gully have calculated.

Table 3. The characteristic of debris flow source (moraine) in Moxi basin.

Moraine location	Age	Code	Depth (m)	Condition	Location	Volume (10^4 m^3)
Along channel bank	Early Gongga ice age moraine	Q31gl	>200	Middle	Upper and middle reaches of Yajiageng gully	275
	Late Gongga ice age moraine	Q33gl	200 - 300	Unstable	Middle reaches of Yanzi, Nanmenguan, and Damugan gully	590
	Early Holocene Proluvial deposit	Q41df + pl	30 - 160	Stable	Moxi Mesa and the mouth of some gully	259
	Remnantdeluvium	Q43edl	1 - 3 m	Unstable	Except cliff	63
	Colluvium	Q43col + dl	>5 m	Unstable	Covered on channel bank and slope	67
Accumulating in channel bed	Latter Holocene moraine	Q43gl	5 - 20	Unstable	Upper and middle reaches of Yanzi, Nanmenguan, Mozi, Xiaonanmenguan gully	222
	Debris flow and flood deposit	Q43df + pl	5 - 150	Middle stable	Located in stream outlet area	1536

3.1. The Integrity Coefficient of Debris Flow Gullies

The integrity factor is a landform index which can the catchments condition and dynamic characteristics of debris flow gully, generally, the ration between debris flow gully length and width are more close to 1.0 or more than 1.0, the better drainage condition for flow conflux are, and this can be helpful for debris flow initiation (Yan, 2003). The integrity factor of gully can be calculated as:

$$\delta = A / L^2$$

where δ is integrity factor (non-dimensional), A is the catchments area of debris flow gully (km^2), L is the length of debris flow channel (km).

3.2. The Incision Index of Debris Flow Gully

The incision index which can indicate the evolution stage of debris flows gully. The lower the index value is, the more mature evolution the gully is, the debris flow active degree are lower, vice versa (Yan, 2003). The incision index (h') was defined as:

$$h' = h / L_p$$

where h' is the incise index (non-dimensional), h is the relative elevation difference of debris flow gully (m), L_p is the catchments perimeter of debris flow gully (m).

3.3. The Slope Ratio of Debris Flow Gully

The slope ratio of debris flow gully is an important coefficient of gully figuration, which reflects the potential energy when debris flow movement, such as the run-out distance, flow velocity and damage power of debris flow. The slope ratio in this paper (S) was calculated in this paper as:

$$S = H / L$$

where S is the slope ratio, its unit is ‰, H is the relative elevation difference of debris flow gully (m), and L is the length of debris flow gully.

4. Results

4.1. The Statistic Relationship of Debris Flow Gullies

Although there distributed more than 100 gullies in Moxi basin, only the gullies with obvious patterns of debris flow gully are identified as debris flow data. The gullies that are too vague to be identified are excluded from the database for this study. Based on these identify features, a total of 49 debris flow gullies were mapped on the map. Data of these 49 debris flow gullies we used in Moxi basin including catchments area, basin perimeter, channel slope, channel length, incision index, integrity coefficient and relative elevation difference etc.

Because of the distribution of glaciers in Moxi basin, the erosion caused by the glacier movement and flow was intense. Deep incision and continue rise of M.T Minyakongka cause the debris flow gully steep. Based on the statistic of 49 debris flow gully slopes in Moxi basin, 70% gully slopes are more than 400‰, 28% are more than 600‰，and only 0.9% gully slopes are less than 200%. Anymore, the gully slope has clear relationship with the area and length of debris flow gullies. There is a negative relationship between debris flow gully slope and catchments area. The less catchments area, the steeper gully slope, this phenomenon is obvious when the gully areas are less than 20 km^2, but it is not clear when the gully area is more than 20 km^2. At the same time, the negative relationship between gully slope and gully length is obvious too, the more length the gully, the less slope is, and this phenomenon is clear when the gully length is less than 7 km, but this relationship is not existing when the gully length is more than 10 km.

4.2. Historical Events Data

Because of the high altitude, cold climate and mountainous condition, the historical human activity in Moxi basin was few, the historical event documents of debris flow in Moxi basin were only a little. Anymore, the well growth vegetation in this area covers the debris flow trace and deposit, it is difficult for us to identify the past activity of debris flow. So, the historical events of most of the debris flow gullies were based on the members from local residents. Only the large-scale debris flow or group gullies outburst debris flow event has been recorded because those debris flow processes have caused casualties and loss. During the past one hundred years there documented 6 times of large-scale and group debris flow events in Moxi basin.

Based on debris flow historical events date from documents and local residents, we classify the debris flow into high-frequency (H), middle frequency (M) and low-frequency (L) according to the occurrence period. The occurrence probability of debris flow in the period which is more than 20 years is low-frequency debris flow gully, 5 - 20 years are middle frequency debris flow gully, and less than 5 years is high-frequency debris flow gully. Based on the class, there are 9 gullies are high-frequency debris flow and its ratio is 18% to total, 30 gullies are middle frequency debris flow and its ratio is 61% to total, 10 gullies are low-frequency debris flow and its ratio is 21% to total.

5. Discussions

5.1. Debris Flow Distribution and Geological Activity

The debris flow numbers, distribution, magnitude and frequency in the Moxi Basin are controlled by the geologic activity and glacial erosion processes. Affected by this, the debris flows in this basin are turbulent and complex, the dynamic process often goes with the combination of other mass-wasting processes such as the water movement from glacier melt and the flood process from rainfall, this integrative effect often remove or mask the landforms created by debris flows, and formed complex deposit landform, such as the Moxi platform, which is formed by fluvioglacial deposit and debris flow deposit. The statistic data shows that the spatial distribution of debris flows within the Moxi basin did not appear to be completely random, nor did it appear to be controlled by lithology. However, there did appear to be a zonal regular and adjacent to the western side of Moxi fault, which are the southern extending parts of Xianshuihe fault. From the **Figure 1** we can see, that most of the debris flow gullies are spread along the right side (western), and few debris flow gullies are scattered along the left side (eastern) of the Moxi fault. The debris flow gullies on the right side are 36, the 73.5% of total debris flow gullies in Moxi basin, and the debris flow gullies on the left side is 13, the 26.5% of total, the distribution characteristic of debris flow gully can be seen from **Table 4**.

5.2. Debris Flow-Frequency and Topographic Parameters

The historical frequency of debris flow is important for us to predicting hazards. Based on the statistics results of scale-frequency and occur date of debris flow in Moxi basin, a quasi-period in debris flow occurrence date, the quasi-period of debris flow in Moxi basin is 10 - 15 years. Meanwhile, during the quasi-period period, there is a high-frequency debris flow stage which usually continues for 2 - 3 years.

The evolution of debris flow was affected by the configuration of debris flow gully and the frequency of debris flow. So, the relationship between the frequency and topographic features of debris flow gullies can help us to understand the mechanism of debris flow in Moxi basin. **Table 5** shows that most of the high-frequency debris flow gullies in Moxi basin are small catchment area, shorter gully length and steep gully slopes, vice versa. Based on the statistics, the average integrity coefficient, the average incision index, the average area and average gully length of high-frequency debris flow gullies are lower than the mid-frequency and low-frequency debris flow gullies. Anymore, the average gully slope of high-frequency debris flow gullies is higher than the mid-frequency and low-frequency debris flow gullies (**Table 5**).

According to the statistic result, it is difficult for us to find the regulation between 3 types of debris flow gullies and difficult for us to apart the low-frequency from mid-frequency debris flow gullies accord to the topographic parameters, but there have obvious topographic parameters to apart the high-frequency debris flow gullies from mid-frequency and low-frequency gullies according to the topographic parameters, the threshold of these parameters can be seen in **Table 6**.

5.3. Glacier Erosion and Debris Flow Catchment Area

In general, the form of debris flow gully was related to the erosion process of earth surface, the large-scale incising landforms have larger drainages contributing water and material to large-scale debris flow volume. Since the large catchment are generally more active than the small one. Usually, the form condition is similar to the activity of debris flow gullies which locate in the same area, and the difference of catchment area among these debris flow gullies in the same condition basin was not so obvious. But **Table 5** shows that most of the debris flow catchment area in Moxi basin are 1 - 20 km^2, the smallest one is 0.25 km^2, biggest one is 470 km^2, which catchment area is 1880 times of the smallest one. Anymore, there are 4 gullies basin area more than 100 km^2, and the total catchment area of these 4 gullies are more than 70% of the total area of Moxi basin. Why the obvious differences of catchment area exist in Moxi basin? According to the survey and analysis of the distribution of

Table 4. The distribution characteristics of debris flow gullies in Moxi basin.

Relative location to Moxi fault	Numbers	Ratio（%）	Average area(m2)	Average relative altitude difference (km)	Average channel length (km)
Eastern side	13	26.5	6.6	1.4	3.7
Western side	36	73.5	21	2.2	6

Table 5. The relationship between debris flow-frequency and topographic parameters in Moxi basin.

Topographic parameters	Low-frequency	Mid-frequency	High-frequency
Average integrity coefficient (δ)	0.87	1.2	0.4
Average incision index (h′)	0.7	0.7	0.5
Average area (km^2)	97.8	138.6	9.9
Average gully length (km)	6.9	20.2	3.9
Average gully slope (‰)	445	492	622

Table 6. The threshold difference of topographic parameters between debris flow frequency.

Topographic parameters	Low-frequency or mid-frequency	High-frequency
Average integrity coefficient (δ)	>0.5	<0.5
Average incision index (h’)	>0.5	<0.5
Average area (km^2)	>10	<10
Average gully length (km)	>4	<4
Average gully slope (‰)	<500	>500

glaciers and debris flow gullies in Moxi basin, there are glaciers locate in the up-stream of these 4 debris flow gullies which catchment area are more than 100 km^2. These debris flow gully catchment area are bigger than those have no glacier locate in stream. In the stream, the bigger the glacier is, the bigger the catchment area of debris flow gully is. Anymore, all of the glaciers in Moxi basin are located in the western of Moxi fault, where distribute 73.5% of total debris flow gullies, and which average catchments area, average gully length and average relative altitude difference are bigger than those located in the eastern of Moxi fault. The catchments area, gully length, gully slope and gully number of debris flows in Moxi basin are affected by the glacier obviously.

The huge volume of moraine locate in the up-stream of debris flow stream in Moxi basin formed by glacier movement in early period is one of the important reasons to effect the formation of debris flow. The erosion caused by the flow from glacier melt incised the gully bed strongly, and formed the steep gully slope which helps the loose moraine transporting from the up stream to the down stream during the process of debris flow. The survey shows that there have large volume of moraine in the up stream of those debris flow stream which in the western side of the basin. The volume of this loose moraine has a positive relationship with the run out volume of debris flow.

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