# DEBRIS FLOWS: Disasters, Risk, Forecast, Protection

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# СЕЛЕВЫЕ ПОТОКИ: катастрофы, риск, прогноз, защита

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# Discussion on the characteristics and calculation method of material source for the debris flow in Tian Mo Gully

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The glacier debris flow is widely developed in the southeastern of Tibet, especially in recent years, which has been affected by global climate change, producing a large amount of loose material in this area, resulting in the frequent occurrence of glacial debris flow, which broke out three debris flows during the 2007 to 2010. The lives and property of the local residents caused losses, and also caused damage to the Sichuan-Tibet highway. Through investigation that the debris source was summarized into four types, which were the source of glacial moraine, the source of landslides, the source of channel erosion and the source of slope erosion. Among them, the glacial moraine source in valleys is accompanied by severe advance and retreat of the glacier in the marine valley. From June to September in 2017, the glaciers in the valley retreated to nearly 700m, the water in is frozen in winter, and the whole glacier advances slowly, eroding the loose accumulation of the bottom and the foot of the slopes on both sides of the gully. In summer, the glacier slowly melts back and releases a large amount of loose material that is originally frozen in the glacier, and which are easily started to participate in the debris flow. Referring to the method of source statistics in Wenchuan earthquake area, four kinds of sources in the whole basin are calculated respectively by using geometric graphic method. At present, the static reserves in the Tian Mo Gully channel are $155.75 \times 10^4$ cubic meters and the dynamic reserves are $49.57 \times 10^4$ cubic meters.

*Southeast Tibet, glacial debris flow, source classification, source calculation*

# К вопросу о характеристиках и методах вычисления объемов источников твердого питания селей в долине Тянь Мо

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Гляциальные селевые потоки активно сходят на юго-востоке Тибета, особенно в последние годы, что в высокой степени обусловлено глобальным климатом, в условиях которого происходит образование большого количества рыхлого материала. Это приводит к учащению случаев схода гляциальных селей, так, например, в 2007-2010 гг. в данном регионе сошло 3 селевых потока. Это привело к гибели местных жителей и нанесло ущерб их имуществу и Сычуань-Тибетскому шоссе. Проведенное исследование позволило разделить источники твердого питания селей на 4 типа: моренный, оползневой материал и материал, образующийся в результате глубинной и боковой эрозии. Образование морены связано со значительными отступаниями и наступаниями ледника в долине. Например, в долине Тянь Мо с июня по сентябрь 2017 г. ледники отступил примерно на 700 м. это объясняется тем, что зимой он находится полностью в твердом

состоянии и наступает медленно, эродируя свое ложе и нижние части прилегающих склонов. Летом ледник медленно тает, что сопровождается высвобождением большого количества рыхлого материала, который изначально был в теле ледника. Этот материал легко вовлекается в движение селевыми потоками. Используя метод статистики источников, применявшийся в районе Вэньчуаньского землетрясения, для четырех типов источников твердого материала во всем бассейне Тянь Мо были произведены вычисления с использованием графо-геометрического метода. В настоящее время статические запасы твердого материала в долине Тянь Мо составляют 155,75×$10^4$ куб. м, а динамические запасы – 49,57×$10^4$ куб. м.

*Юго-Восточный Тибет, гляциальные сели, классификация источников, подсчет объема источников*

## Introduction

Tian Mo Gully is located in the Gu country of Linzhi in southeast of Tibet (Fig. 1), the gully coordinates are N29°58'29. 6"/E95°18'19. 2", the East is about 48. 7km in the Bomi County, and the West distance Tongmai bridge 29. 5km. At 19 September 4, 2007, at 19 days, the debris flow of Tian Mo Gully, a total of about 134×104 cubic meters of solid material, blocked the pun and Tibet for about 1 hours, resulting in 1 death, 7 missing, destruction of the loose suspension bridge, G318 road traffic interruption for about 43 hours, and the direct economic loss of 5 million 200 thousand yuan [*Yu Zhongshui*, *et al., 2009*]. In July 25, 2010, 50×104 cubic meters solid material was discharged from the TMG, resulting in damage to the 800m roadbed and collapse of 1 bridge. In September 4, 2010, 45×$10^4$ cubic meters solid material was discharged from the Tian Mo Gully, resulting in damage to 900m highway roadbed [*GE Yong-gang*, *Cui Peng*, *et al., 2014*].

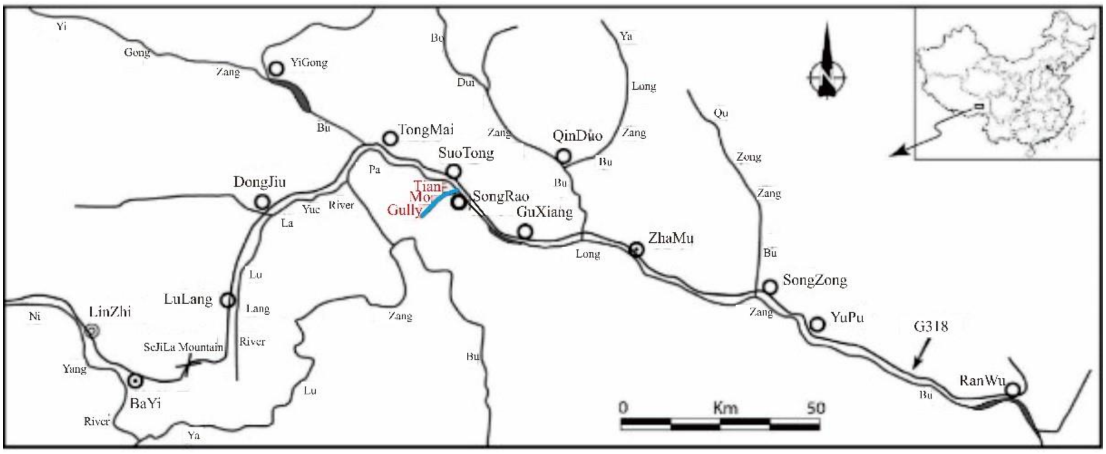


Fig. 1. Geographic location of Tian Mo Gully

Through the field investigation, there are still a lot of loose material in the channel, especially the modern glacial moraine type source, which may be started again, threatening the Sichuan Tibet highway on the right bank of the Palong Zangbu. In this paper, the types and characteristics of the provenance of Tian Mo gully are studied, and the accurate calculation of the dynamic reserves of the source is provided to provide a reference for the understanding and calculation of the source of the glacier debris flow in the basin.

## A survey of debris flow

*Topographic features*

Tian Mo Gou is located on the convex bank of the left bank of the park. It has three typical geomorphic units, namely, alpine, glacial (debris flow) canyon and foothill alluvial fan (Fig. 2). Specifically, the trench topography is southwestern high, and the North East is low. The shape of the ditch in the Tian Mo Gou is a spoon shaped, and there are 1 larger tributary trench. The drainage area is about 17.9 km$^2$, the main ditch length is 7.10 km, and the average groove bed ratio is 244%. The valley mouth is 2460m above sea level and the highest peak is 5560m, with a relative height difference of 3100m. The upper reaches of the valley are more than 3800m above sea level, and the glacier area is about 9.1 km$^2$. Steep topography and glaciation provide favorable terrain conditions for the development of debris flow.

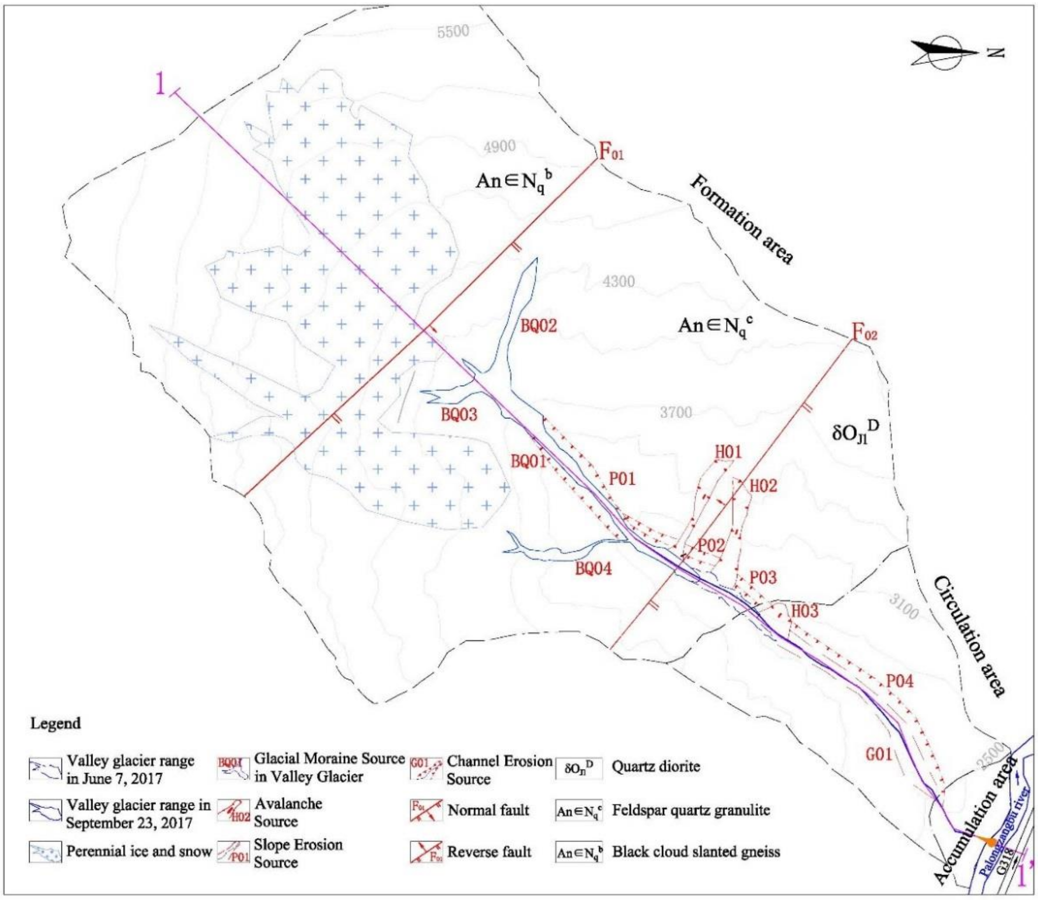


Fig. 2 Geological map of debris flow in Tian Mo gully

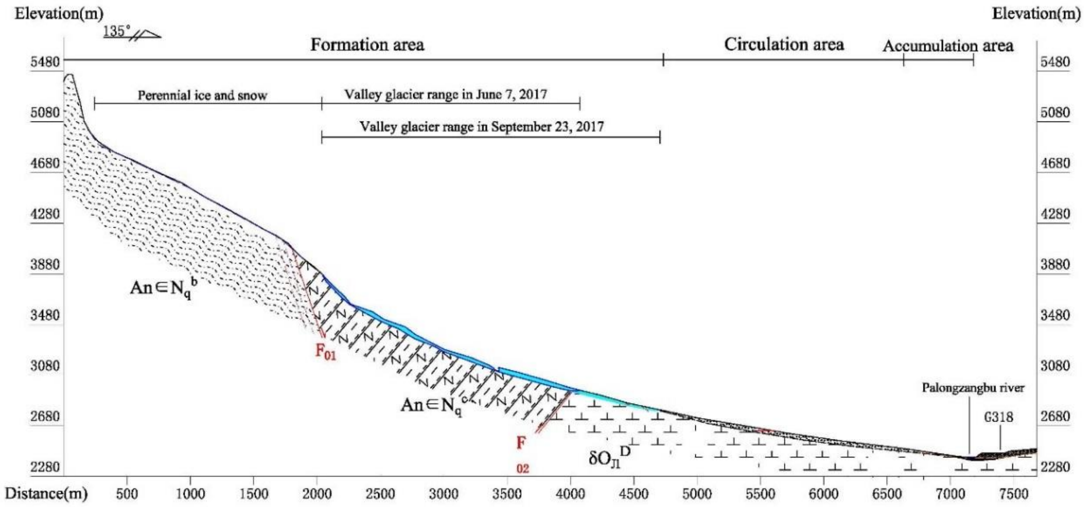


Fig. 3. Vertical profile of debris flow in Tian Mo gully

*Geological structure*

The Tian Mo Gou area belongs to the eastern side of the Yarlung Zangbo Suture Zone and the western end of the Jiali - Jialong Temple arc collision belt in the Gangdese Lhasa block. For a strong compression, collision, rotation, strike slip, rapid extension uplift geological structure is extremely complex orogenic belt. The fault structure develops in the main part of the basin, where the main axis is curved, and the secondary fold and fault axis are NW to NW. The fault structures in the Tian Mo Gou basin are mainly developed with F01 and F02 two faults (Fig. 2). The F01 fault is a positive fault, and the bedrock steep ridge is formed in the channel, the rock mass is broken and the rock mass is seriously weathered, and the F02 is a reverse fault, and two landslides are formed in the channel.

*Meteorology and hydrology*

The Panglong Zangbo River Basin is affected by the warm and humid India ocean and the Yarlung Zangbo Grand Canyon, which is rich in rainfall and forms an oceanic valley glacier. The two main categories are the hanging glaciers and valley glaciers. The hanging glacier is located at the top of the forming area, and the glacier is weathered strongly by freezing and thawing. The loose material accumulated at the foot of the slope. Valley glaciers are located in the channel of the formation area. With the global temperature rising, glaciers retreat in the trench and form a lot of new moraine.

**Source classification and calculation**

Some scholars put forward the need to study the solid supply type of debris flow, classify the main sources of glacial debris flow [*Tie et al., 2012*]. Some scholars pointed out that the Quaternary glaciers prevailed, and widespread moraine deposits and ice water deposits were found to be sources of debris flow [*Hu Guisheng et al., 2011*]. There are some new and old moraine deposits of about 4×108 cubic meters in the ancient township gullies of the Palong Zangbo basin, which are the main source of the gully [*Cheng, Geng, Dang et al., 2007*]. In addition, [*Qiao et al., 2012*] researchers have established statistical models of debris flow reserves in Wenchuan earthquake extremely earthquake area by using statistical method and graphic method. So, it is very important to study the classification and accurate calculation method of debris flow.

*Glacial moraine source in valley glacier*

The new glacial moraine produced by the modern valley glacier is located in the 2800m-3900m elevation range of the Tianmo gully channel (Fig. 2, 3). The formation of this kind of source is mainly due to a large number of active valley glaciers at the bottom of the main gully of the glacier debris flow area in the basin of the Palong Zangbo basin. These glaciers have seasonal advance and regressive phenomena, and the measured back distance can reach about 700m in only 3 months. When the glaciers melt, the glacial moraine is deposited in the original place. The new moraine is loose in structure and poor in cementation, so it is easy to start (Fig. 4).

In this kind of source, the volume of the active glacier must be calculated first, and the amount of the source is calculated with the sand content of the active glacier (Fig. 5), and the sand content of the active glacier can be measured in the field.

$$S = \frac{1}{2} \cdot (a + b) \cdot h = h \cdot b - \cot\theta \cdot h^2 \quad (1)$$

Where $S$ indicates valley glacier cross section area, $h$ indicates glacier thickness, $a$ indicates bottom width, $b$ indicates top width, $\theta$ indicates natural angle of slope.

$$V_g = S \cdot l \quad (2)$$


Fig. 4. Retreat of glacier. ①perennial ice and snow, ②valley glacier, ③Channel Erosion Source

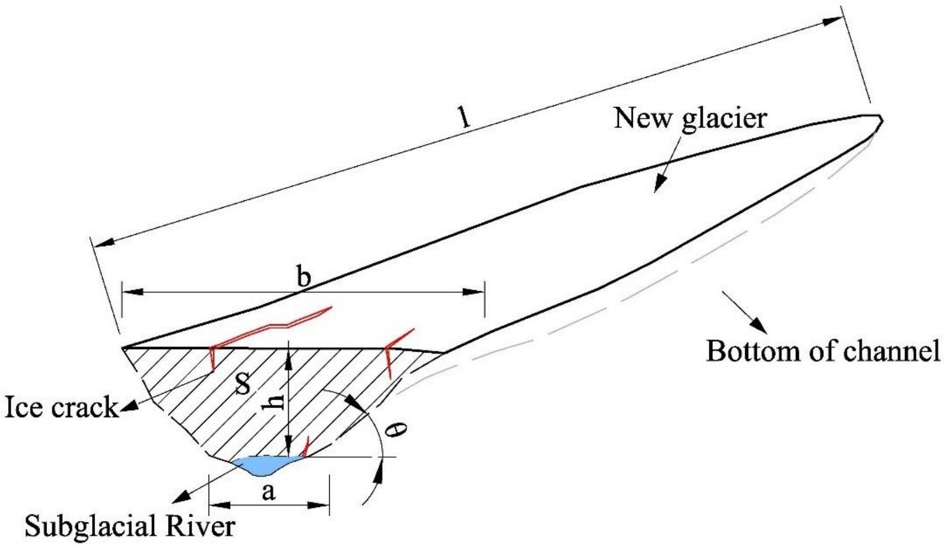


Fig. 5. Calculation model of moraine source.

Where $V_g$ indicates valley glacier volume, $l$ indicates valley glacier length.

$$V_{01} = V_g \cdot \gamma \quad (3)$$

Where $V_{01}$ indicates glacial moraine source in valley glacier, $\gamma$ indicates glacier sand content.

*Avalanche source*

The source of avalanche is a common source of debris flow in various areas. The cause of this kind of source is the collapse and landslide of the debris flow forming area or the slope of the circulation area. The loose material formed by the collapse and landslide is accumulated on the slope foot or into the main ditch and converted into debris flow source (Fig. 6).

After collapse and landslides, loose material accumulates at the foot of the slope. The static reserves of debris flow can be calculated by measuring the geometric parameters of the accumulation body by field or remote sensing. The dynamic reserves of debris flow should be estimated with the natural rest angle beta of the new moraine on the basis of the static reserve calculation, and the measured natural rest angle of the Tian Mo gully is 37 degrees.

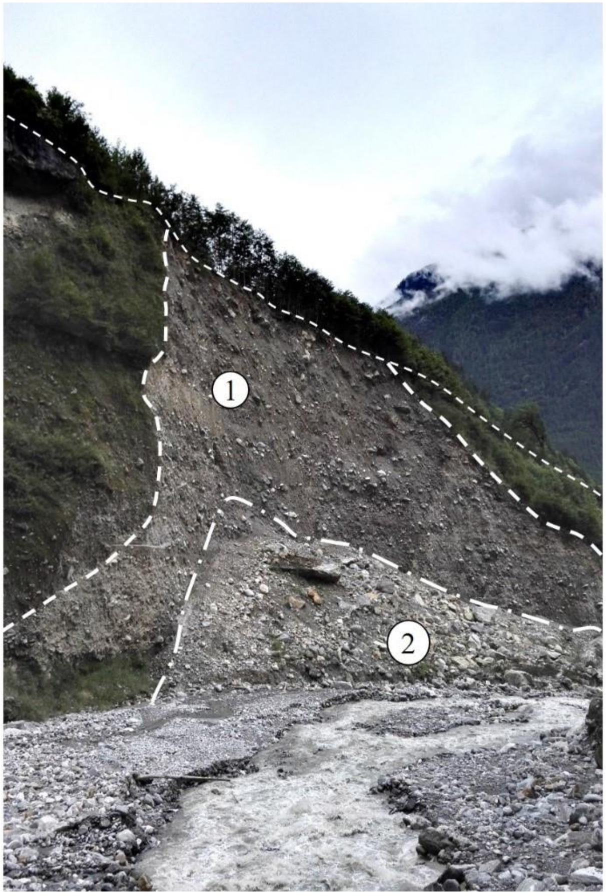


Fig. 6. Avalanche source. ①Back wall of landslide, ②Avalanche Source.

*Channel erosion source*

Gully erosion source is a common source of debris flow. The source of Tian Mo gully is a debris flow deposit or moraine accumulated at the bottom of the channel. Under the action of rainfall, the flow of the channel inside the channel produces a strong downward erosion and erosion effect on the loose accumulation body in the gully bed, and gradually forms the erosion gully. With the continuous improvement of the hydrodynamic conditions, the loose material at the bottom of the channel is started to form mud. Shi Liu (Fig. 8).

$$\Delta_1 cod = \frac{1}{2} co \cdot cd = \frac{1}{2} h \cdot h \cdot tg\alpha = \frac{1}{2} h^2 \cdot tg(90° - \theta) \quad (4)$$

Where $\theta$ indicates Natural angle of slope, $h$ indicates Original groove depth.

$$V_{03} = \Delta_1 cod \cdot L_3 \quad (5)$$

Where $V_{03}$ indicates Channel Erosion Source Dynamic reserve, $L_3$ indicates Length of accumulation body of trench bed [*Qiao Jianping, 2012*].

The volume of channel erosion source (formula 5, 6) can be calculated by measuring the depth of gully erosion in several typical trench sections B, the top of the channel top and the bottom width at the bottom of the channel and the channel length at the bottom of the channel at the bottom of the channel at the bottom of the channel at the bottom of the channel B.


Fig. 7. Slope erosion and channel erosion source. ①Slope Erosion, ②Channel Erosion Source

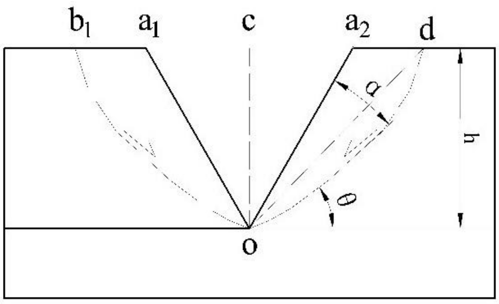


Fig. 8. Calculation model of channel erosion type source [*Qiao Jianping, 2012*]

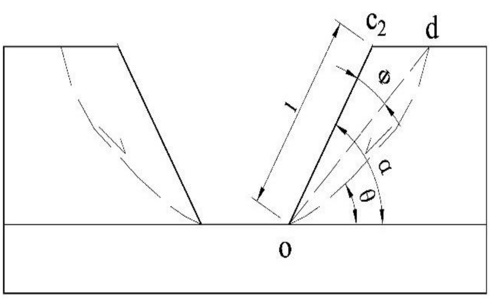


Fig. 9. Calculation model of slope erosion type source [*Qiao Jianping, 2012*]

*Slope erosion source*

Slope erosion is also a common source of debris flow in various regions. The source of this kind of material is under the effect of weathering, and the surface of the ramp on both sides of the channel of the formation zone is transformed into the debris flow source (Fig. 9).

$$\Delta c_2 od = \frac{1}{2} c_2 o \cdot c_2 d = \frac{1}{2} l \cdot l \cdot tg\theta = \frac{1}{2} l^2 tg(\alpha - \theta) \quad (6)$$

Where $\theta$ indicates the density of Natural angle of slope, α indicates Measured slope angle, $\Phi$ indicates Angle between an avalanche and a natural angle of rest, $l$ indicates Measured slope length [*Qiao Jianping，2012*].

$$V_{04} = \Delta c_2 od \cdot L_4 \quad (7)$$

Where $V_{04}$ indicates Slope Erosion Source Dynamic reserve, $L_4$ indicates Length of accumulation body of trench bed.

*Calculation of Debris Flow Source in Whole River Basin*

Through the field investigation, the source of the Tian Mo Gou formation area is investigated and calculated. According to the graphical method, the dynamic reserves and static reserves of the different types of material sources are calculated first, and then the total dynamic reserves and static reserves of the whole basin debris flow are obtained.

$$V_0 = \sum_{i=1}^{n} (V_{01i} + V_{02i} + V_{03i} + V_{04i}) \quad (8)$$

Where $V_0$ indicates Debris flow reserves in the whole basin.

Through the summary of the previous article, the source types of the Tian Mo grove are combed, and the static reserves and dynamic reserves of various types of material sources are calculated according to the relevant formulas (Table 1, Table 2).

Table 1. Calculation of the source amount of debris flow in Tian Mo Gully

| **Number** | **Type** | **Location** | **Static reserve ($10^4$ $m^3$)** | **Dynamic reserve ($10^4 m^3$)** |
|---|---|---|---|---|
| H01 | Avalanche Source | The slope of the left bank of the main ditch at the elevation of 3000m | 5.40 | 1.62 |
| H02 | Avalanche Source | The slope of the left bank of the main ditch at the elevation of 900m | 11.89 | 3.57 |
| H03 | Avalanche Source | The slope of the left bank of the main ditch at the elevation of 800m | 17.02 | 5.11 |
| P01 | Slope Erosion Source | 3000-3500m upstream of main channel | 54.79 | 16.44 |
| P02 | Slope Erosion Source | 900-3000m upstream of main channel | 3.81 | 1.14 |
| P03 | Slope Erosion Source | 800-2900m upstream of main channel | 8.45 | 2.53 |
| P04 | Slope Erosion Source | 2500-2800m in the middle and lower reaches of the main ditch | 6.67 | 2.00 |
| G01 | Channel Erosion Source | 2500-2800m in the middle and lower reaches of the main ditch | 21.21 | 6.36 |

| | | | | |
|---|---|---|---|---|
| BQ01 | Glacial Moraine Source in Valley Glacier | upstream of main channel | 30.70 | 9.21 |
| BQ02 | Glacial Moraine Source in Valley Glacier | The 4000m left bank gully in the upper reaches of the main ditch | 2.59 | 0.78 |
| BQ03 | Glacial Moraine Source in Valley Glacier | The 4000m right bank gully in the upper reaches of the main ditch | 0.55 | 0.17 |
| BQ04 | Glacial Moraine Source in Valley Glacier | The 3100m right bank gully in the upper reaches of the main ditch | 2.16 | 0.65 |
| Total | | | 155.75 | 49.57 |

Table 2. Accumulation of debris flow in Tian Mo Gully

| **Glacial Moraine Source in Valley Glacier ($10^4m^3$)** | | **Avalanche Source ($10^4m^3$)** | | **Channel Erosion Source ($10^4m^3$)** | | **Slope Erosion Source ($10^4m^3$)** | | **Total ($10^4m^3$)** | |
|---|---|---|---|---|---|---|---|---|---|
| Static reserve | Dynamic reserve | Static reserve | Dynamic reserve | Static reserve | Dynamic reserve | Static reserve | Dynamic reserve | Static reserve | Dynamic reserve |
| 36.00 | 10.80 | 34.31 | 10.29 | 21.21 | 6.36 | 67.05 | 20.11 | 155.75 | 49.57 |

## Conclusions

According to the calculation of the debris flow in the Tian Mo Gou, there are still 155. 75×104 cubic meters of static reserves and 49. 57×104 cubic meters of dynamic reserves. There are 36×104 cubic meters of glacial deposits in modern valley and 10. 80×104 cubic meters of dynamic reserves in the valley formation area, which are very active, and are easy to start in summer temperature rise and rainfall conditions. The geometric model method can accurately calculate the debris flow source, but the debris flow channel failure is not considered in this aspect. So in future research, we need further improvement. In addition, with global warming, this part of the source will become more active. Debris flows with such source characteristics are very common in the valley of the valley, and the next step will be further investigation and verification in the area. The static and dynamic reserves of glacial moraine source calculation models proposed in this paper can provide reference for the calculation of the source of debris flow in the area.

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