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# The Distribution Rule and Genetic Analysis of Debris Flow in Longmenshan Fault Zone, Sichuan Province

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***Abstract:***

As a large-scale destructive geological disaster activity, debris flow has caused a large number of economic losses and casualties over the years. It is of certain practical significance to analyze the distribution characteristics and causes of debris flow. In order to explore the temporal and spatial distribution law of debris flow provenance, this paper selects the multi-phase remote sensing images of Sichuan Province from 1985 to 2020 for man-machine interactive interpretation, obtains the debris flow surface vector data for 58 times and 124 gullies, evaluates the interpretation results, selects six typical watersheds, and analyzes the distribution difference of debris flow and its relationship with terrain, vegetation cover, earthquake Relationship between human activity factors. The results show that debris flow disaster has obvious temporal and spatial characteristics, which is easy to occur in rainy season. At the same time, debris flow disaster is easy to occur in the main streams of Tuojiang River, Qingyi River and Minjiang River and Dadu River Basin. In addition, there are significant regional differences in the scale and morphology of debris flow gullies in various watersheds along the Longmenshan fault zone. The high-risk areas of debris flow disasters are mainly concentrated in the main streams of Tuojiang River, Qingyi River and Minjiang River and Dadu river basins, which are large in scale and long in length. The study area is more likely to breed large-scale debris flow when the altitude is 2500-5500 m, the slope is 15°-40°, and the elevation difference is 1800-4000 m. For different regional zones, the relationship between debris flow and vegetation coverage varies greatly. There is an obvious relationship between debris flow and vegetation coverage in Western Sichuan Plateau and eastern basin, while the occurrence of debris flow in rapid change zone is almost irrelevant to vegetation coverage. Therefore, we should pay attention to the Countermeasures of disaster prevention and reduction in rainy season and debris flow prone areas, increase vegetation planting and anchor soil. At the same time, we should focus on the rational planning of human activities and reduce unnecessary mining.

***Keywords:*** *Debris flow, Fault zone, Rapid change zone, Temporal and spatial characteristics, Vegetation, Earthquake, Human activities*

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## I. INTRODUCTION

Debris flow is a destructive large-scale geological disaster that causes great casualties and economic losses. Due to environmental changes and the intensification of human activities, the scale and frequency of debris flow have gradually increased in recent years. The number of debris flow outbreaks has increased rapidly since 2008 and reached the maximum in 2012, accounting for 23% of the total number of stone flow disasters from 2008 to 2015[1]. The instantaneous outbreak of debris flow causes great damage to the place where it occurs, and may block the river channel, form barrier lake and induce secondary danger, which has a great impact on the local economy and life. Its uncertainty also limits the land use[2]. China is seriously affected by debris flow disasters. Southwest China and Gansu Province represented by Sichuan Province, Yunnan Province, Chongqing and Tibet Autonomous Region, and Northwest China represented by Shaanxi Province are areas with high incidence of debris flow in China [2]. The occurrence of debris flow is related to topography, geology, climate, soil, vegetation, earthquake and human activities [3].

Satellite remote sensing has developed rapidly in recent years, with high image resolution, accurate data and wide coverage. Debris flow disaster assessment using visual interpretation combined with GIS (Geographic Information System) spatial technology is an efficient means [4]. Many scholars at home and abroad use remote sensing technology to extract debris flow point information, analyze the spatial distribution characteristics of geological disasters [5], and determine the geographical and climatic factors causing debris flow disasters [1,6,7] in combination with its temporal and spatial distribution law. On this basis, some scholars further evaluate the risk and susceptibility [3,8], understand the disaster law and disaster pregnant characteristics [9] and explore the human driving force [8]. However, the above research is mainly based on the occurrence site of debris flow. In fact, the scale of debris flow is different, and there are mass debris flows. Therefore, it is difficult to accurately evaluate the destructiveness of debris flow only relying on point vector data. There are some studies on debris flow provenance area as an index analysis, using area vector data to carry out area statistics and morphological characteristics analysis of debris flow gully, and explore the causes and disaster process of debris flow according to the topographic and geomorphic characteristics within this range [4,10-15]. Compared with point vector data, area vector data describes the characteristics of debris flow gully in more detail, which is convenient to explore the micro differences of gully in different regions, further calculate the dynamic parameters [16,17], establish a model for susceptibility evaluation [18,19], discuss the risk, and evaluate the risk of future disasters [20-29]. However, the research on Sichuan Province is mostly limited to the Wenchuan earthquake-stricken areas, and there is a lack of research on the temporal and spatial analysis of debris flow in the whole Sichuan Province.

Therefore, our group has carried out a large number of vectorizations of historical debris flow events according to the historical images of Google Earth. Based on the high spatial resolution remote sensing data before and after the debris flow disaster, the boundary of each debris flow gully is delineated according to the material source characteristics, and the shape and area of each debris flow are identified by using the surface data. A total of 55 debris flow event images from 2001 to 2019, a total of 124 debris flow gullies, are identified, and they are divided into 9 watersheds in Sichuan Province for zoning research. Through the interpretation of regional remote sensing data, firstly, the interpretation results are evaluated

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and six typical watersheds are selected. Then, based on the analysis tool of GIS, the distribution characteristics of debris flow in different time and watersheds are explored. Since the occurrence of debris flow is often related to mountain fluctuation, vegetation coverage, slope gradient of gully bank, heavy rainfall weather and loose material reserves [9], this paper discusses the driving force of debris flow disaster in the study area in combination with a series of spatial information such as topography, geological structure, meteorology and hydrology in each basin. The significance of this study lies in: first, explore the activity status of debris flow, grasp the basic characteristics of debris flow in different regions, and determine some high-risk areas of debris flow as the target areas of prevention and control; Second, based on the driving factors, provide suggestions for the prevention and control of debris flow, so as to prevent the possible losses caused by geological disasters, and provide a reference basis for the prevention and control of such major debris flow disasters in the future.

## II. OVERVIEW OF THE STUDY AREA AND DATA ANALYSIS

### 2.1 Overview of the Study Area

As shown in Fig. 1, Sichuan Province is located in the southwest of China, ranging from 97°20′50″ E ~ 108°32′33″ E, 26°02′53″ N ~ 34°18′54″ N, with a total area of about 485000 km$^2$. The main body is located in the geomorphic transition zone between the Qinghai Tibet Plateau and the plain in the middle and upper reaches of the Yangtze River. The Longmenshan fault zone divides it into Western Sichuan and Eastern Sichuan. Therefore, there are great differences in geography and climate. The average altitude in the west is 4000 m, located in the Qinghai Tibet Plateau, and the altitude in the eastern Sichuan Basin is 1500 m ~ 3000 m. The terrain of the whole province fluctuates greatly, with an average height difference of 560 m, the lowest altitude of 188 m and the highest altitude of 7556 m, with a difference of 7368 m. The mountains are high and the valleys are deep. 85% of the total terrain is mountainous and hilly, with more high mountains and middle mountains and less plains. It is mainly due to structural uplift and strong erosion of water, and the steps are scattered and changed obviously. The main climate of Sichuan is subtropical monsoon climate and plateau mountain climate. The average annual rainfall is about 1000 mm, mostly from June to September. Sichuan Province has many rivers, including Yalong River, Minjiang River, Tuojiang River and other major rivers. Due to abundant geomorphic types, large surface elevation difference, complex geological structure and unique climatic conditions, debris flows occur frequently in Sichuan Province and are concentrated in Longmenshan fault zone [2,7,30]. Longmenshan fault zone is located in Qinling fold zone and Cathaysian fold fault zone. The terrain fluctuates greatly, the mountains are high and the valleys are deep, the rivers are vertical and horizontal, and are seriously cut by the water system. The rivers can carry and erode the provenance, which is conducive to the formation of debris flow. Moreover, the diagenetic age of this area is late, the rock is exposed, the surface lithology becomes loose after long-term weathering, the strength is weak and unstable, and it is easy to collapse and be washed away by rain and flood, Become the source of debris flow. Its periodic tectonic movement controls the periodicity of debris flow disaster [1, 31].

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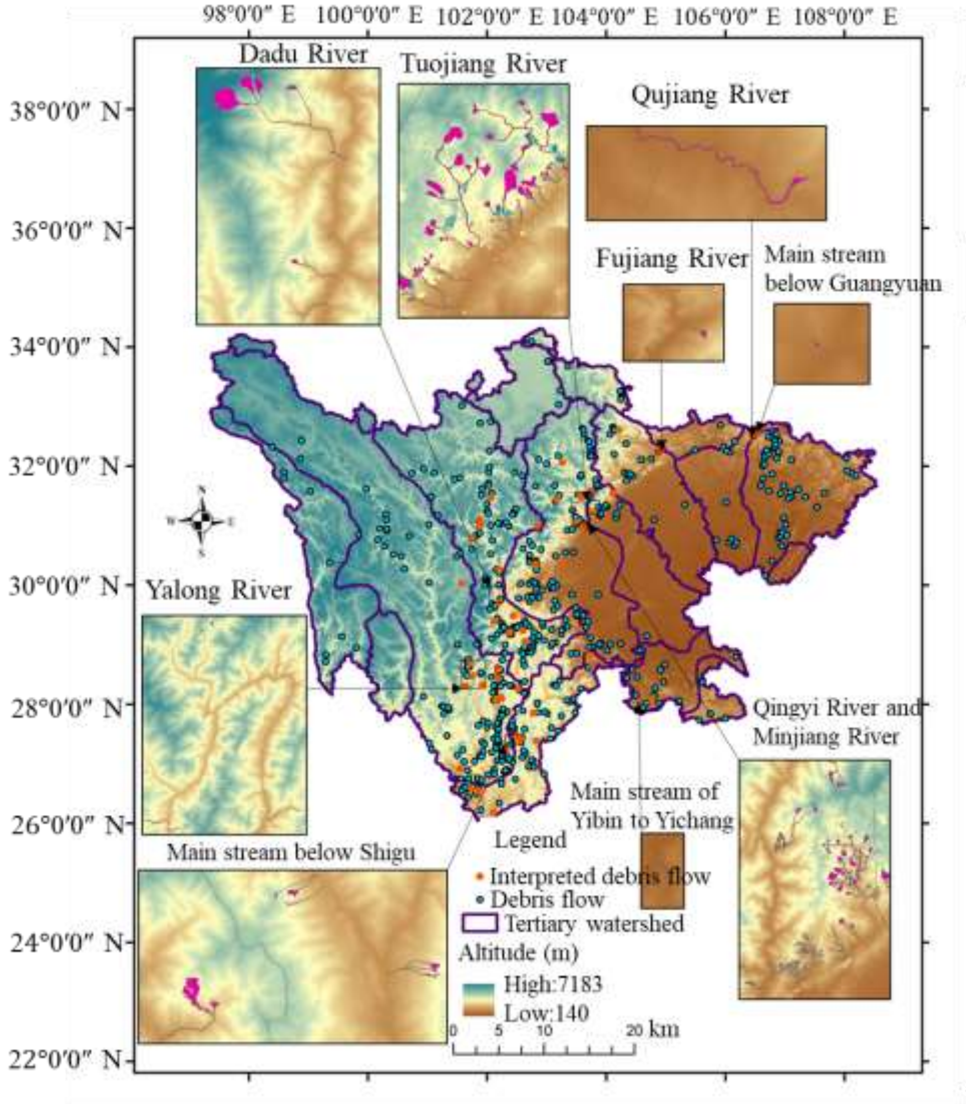


Fig 1: Spatial distribution of debris flow disaster in Sichuan Province

2.2 Data Analysis

In this paper, the basic data comes from Sichuan geological environment monitoring project, news reports and documents. The recorded disasters have an impact on human life. It records 665 debris flow events in 774 watersheds in Sichuan from 1984 to 2021. Therefore, the data source is highly representative. The high-resolution remote sensing data image uses Google Earth images from 1985 to 2020. The monthly precipitation data of Sichuan province comes from the corresponding documents released by the KNMI climate detector of the World Meteorological Organization of the United Nations (http://climexp.knmi.nl/select.cgi?id=someone@somewhere&field=cru4_pre). The terrain factors are obtained from the 30 m resolution DEM (Digital Elevation Model) grid data set (ASTER) obtained by the Advanced Spaceborne Thermal radiometer and Reflection Radiometer on NASA's land satellite (http://earthexplorer.usgs.gov (2017)). The vegetation cover data is from the NDVI remote sensing data with 1 km resolution of NASA (https://modis.gsfc.nasa.gov/data/dataprod/mod13.php). WGS_1984_UTM_Zone_48N projection is used for all grid data.

According to the images, the images with less cloud layer and high data source quality are selected. Combined with digital mapping and man-machine interactive interpretation, the optical identification is carried out through the visual difference between the material source and the surrounding environment, the boundary of each debris flow gully is delineated, the shape and area of each debris flow are identified by surface data, and a typical debris flow material source database is established.

Use various tools in ArcGIS to preprocess the original data of prediction variables, preprocess the original data into the delimited watershed, and process computational geometry, zoning statistical table, spatial connection, table crossing, grid calculator and so on. Based on the DEM data of the study area, the topographic relief data of disaster points are extracted by using GIS spatial analysis method and the interpreted debris flow disaster vector data as a mask. Using the spatial analysis function of ArcGIS software, firstly, DEM is extracted from the 1∶50000 Topographic Map, and then the interpreted 124 provenance bodies are superimposed and analyzed with DEM to obtain the elevation of the highest point and lowest point of each channel, and calculate the elevation difference, length, slope and other information.

## III. RESULT AND DISCUSSION

### 3.1 Evaluation of Interpretation Results

Through the above interpretation process, the database of some typical debris flow sources in the study area can be established, including the geographical location, area and morphological characteristics of debris flow. In the process of interpretation, due to incomplete images, some disasters lack pre disaster images, which makes it impossible to compare. The time of some images is too far away from the time of debris flow disaster, and most images can not reflect the disaster information at that time. For the disaster points that have occurred many times, the new disaster may broaden the channel, and the previous disaster scale cannot be judged. In the collected image data for many years, due to the different sensors carried by different satellites, the data quality and information obtained are different, so the interpreted data may have errors [29]. However, according to the same standard, the images interpreted in this paper compare the differences of vegetation coverage and rural settlements before and after the occurrence of debris flow disaster, so as to extract the source body, including landslide mass (colluvial deposit, landslide mass), slope deposit, gully deposit, accumulation fan and ice deposit. Therefore, the data used in this paper is representative. The typical debris flow database of Sichuan Province is established through the above methods, and the proportion of the number of debris flows interpreted by each watershed in the original database is calculated, as shown in Fig. 2.

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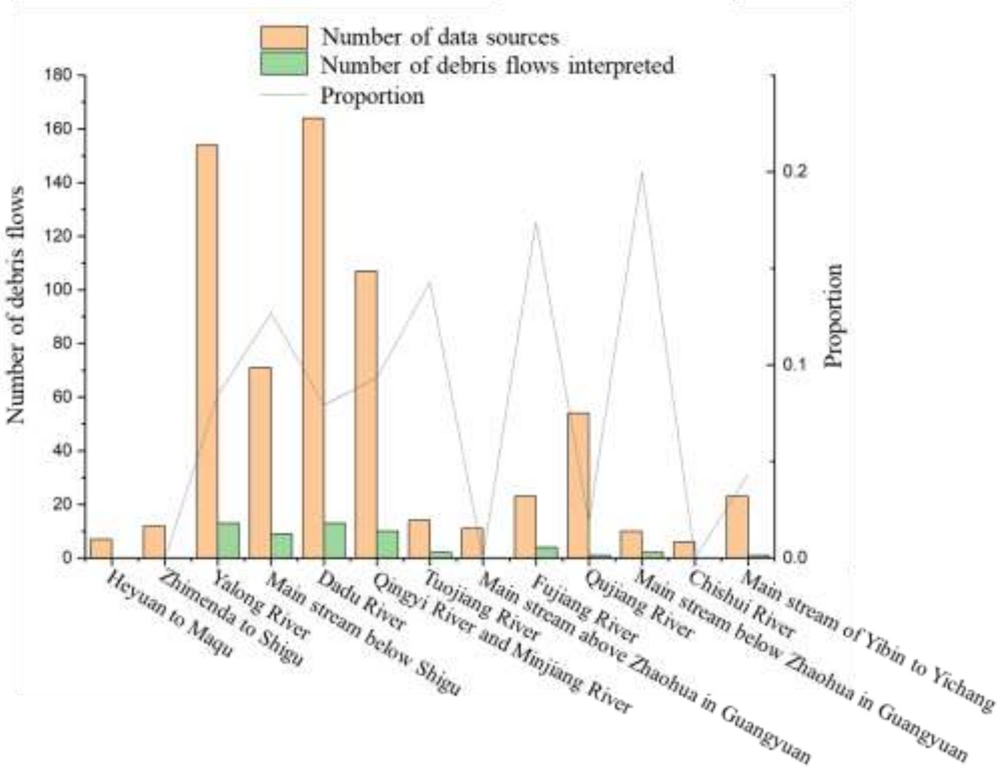


Fig 2: Proportion of the number of interpreted debris flows in the total number of debris flows in each basin

It can be seen from Fig. 2 that the proportions of the Tuojiang River Basin, the main streams of Qingyi River and Minjiang River, the Dadu River Basin, the Yalong River Basin, the main stream below shigu River and the Fujiang River Basin are more than 5%, indicating that the number of debris flows interpreted is relatively more and the database is more complete. The number of debris flows interpreted by the main stream below Zhaohua River in Guangyuan is relatively high. However, due to the less debris flow disasters in this basin in the data source, the interpreted debris flows are highly accidental, which cannot represent the characteristics of the basin, and the debris flow interpreted by Tuojiang River is a large-scale mass debris flow. Although the number of disasters is small, there are many data, which is still representative. In other watersheds, due to the small number of debris flow disasters in the data source, the lack of pre disaster and post disaster image comparison, or the small scale of debris flow and rapid vegetation restoration, it is difficult to distinguish debris flow images, and the typical debris flow interpreted is less and less representative.

### 3.2 Law of Temporal and Spatial Distribution

#### 3.2.1 Temporal distribution

The interannual variation of debris flow area in the study area is analyzed, and the results are shown in Fig. 3. It can be seen from Fig. 3 that the area of debris flow began to increase after the Wenchuan earthquake in 2008, and the area of debris flow disaster increased significantly after heavy rain in the

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earthquake area in 2010. It reached the maximum in 2012, about 45.67 $km^2$, and began to decrease significantly in 2013. It has recovered to a low level by 2015, which is consistent with the previous research results [22].

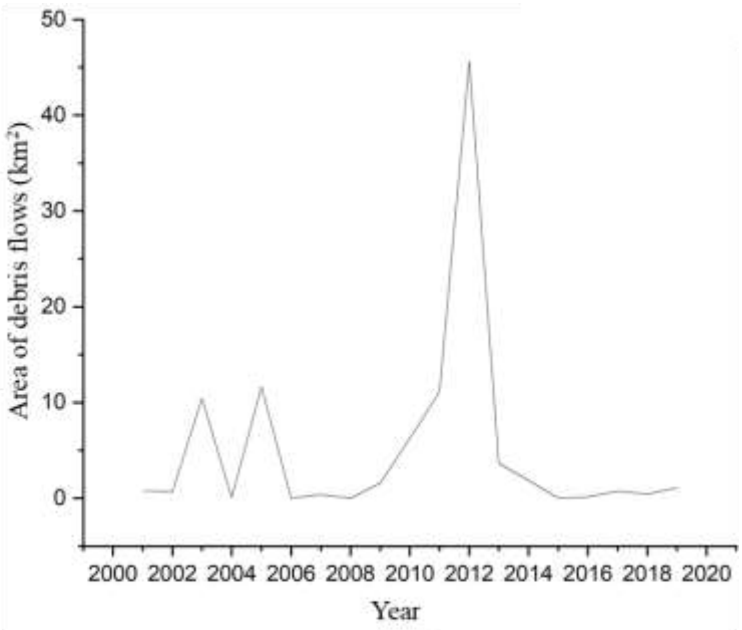


Fig 3: Interannual variation of debris flow area in the study area

Debris flow disasters in the study area basically occur from June to August, especially in August [30]. Sichuan Province has a subtropical monsoon climate, and the rainfall is mainly concentrated from July to September, with heavy rain, heavy rainfall and many local rainstorms. There is a significant positive correlation between the number of monthly debris flows over the years and rainfall in Sichuan Province. The mechanism of rainfall triggering debris flow is that a large number of water bodies enter the rock and soil to increase its water content, increase the sliding force of the slope and reduce the shear strength of the landslide [17]. In addition, water source is also the transportation medium of material source. By analyzing the relationship between debris flow area and rainfall in different watersheds (Fig. 4), it is found that the development of debris flow triggered by rainfall is significantly different. The average monthly precipitation induced by debris flow in the valley area of Western Sichuan Plateau (Yalong River, Dadu River Basin, Qingyi River and Minjiang River Basin, the main stream below Shigu River) increased less, while the monthly precipitation induced by debris flow in the eastern basin (Fujiang River and Tuojiang River Basin) increased more than in previous years, which is consistent with previous studies. First, the standard rainfall levels of basin and plateau are different, and there is good thixotropic liquefaction of precipitation in the plateau area, which leads to poor soil stability [1,7]. Second, the plateau area has complex geological structure, high mountains and deep valleys, frequent earthquakes, landslides and other geological disasters, and there are many loose materials in the area, which become the solid material source of debris flow disasters. These geological disasters also provide strong power for debris flow activities. Therefore, small precipitation can induce debris flow disasters, and the difference between the monthly precipitation inducing debris flow disasters and the usual monthly precipitation is small, the

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disaster scale caused by the daily precipitation reaching or approaching 25 mm in the plateau area is similar to the disaster induced by rainstorm in the basin [7]. Third, in high altitude areas, the water source required for the outbreak of debris flow is not only heavy precipitation, but also ice and snow melting [31]. Therefore, in the prevention and control of debris flow disasters in the future, we should be vigilant in case of short-term heavy precipitation in high-altitude areas according to the characteristics of different regions.

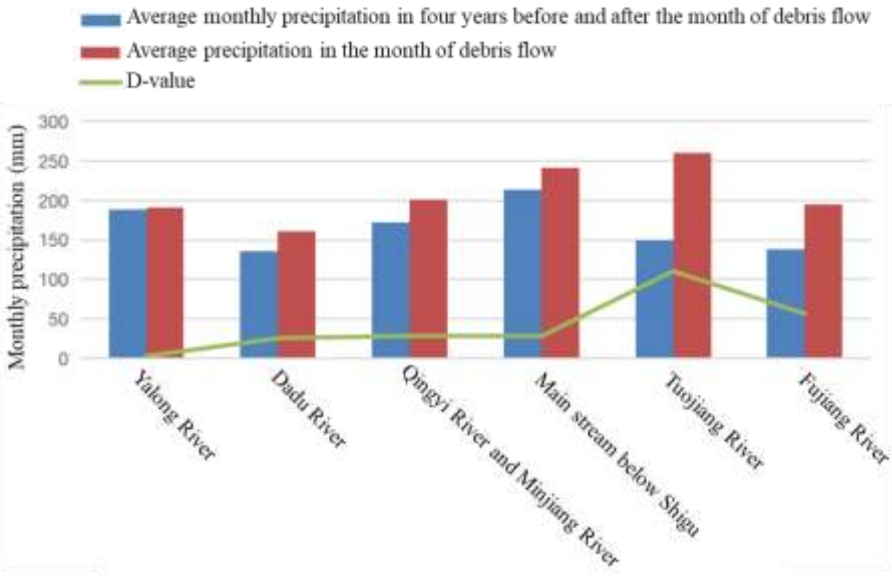


Fig 4: Monthly precipitation and monthly precipitation in past years triggering debris flow in each basin

3.2.2 Spatial distribution

Due to the differences of climate, geographical conditions, geological conditions and other factors in each basin, the distribution law and form of debris flow disaster are related to its geographical location, with obvious regional differences. The area of debris flow disaster in each watershed in the study area is counted and the spatial distribution map is drawn. The results are shown in Fig. 5.

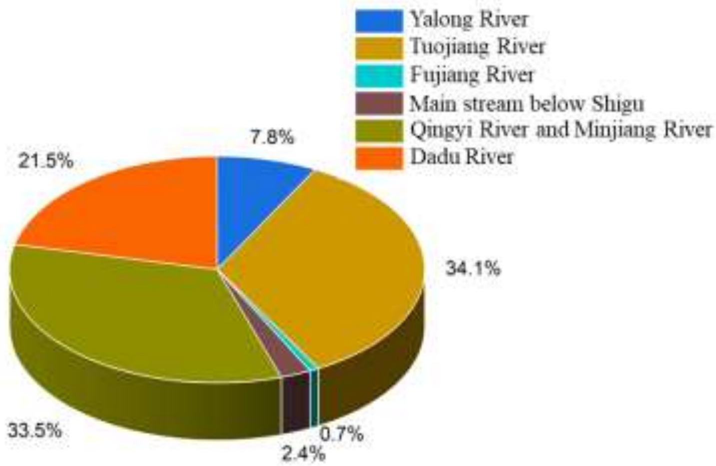


Fig 5: Proportion of debris flow disaster area in each watershed in the study area

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The high-risk areas of debris flow disasters in the study area are mainly concentrated in the main streams of Tuojiang River, Qingyi River and Minjiang River and Dadu River Basin. The area of debris flow disasters in these places' accounts for 89.1% of the area of debris flow disasters in the whole region, which is consistent with previous studies [7]. It can be seen from Fig. 3 that the Dadu River Basin at the junction of Sichuan Basin and Western Sichuan Plateau, the main stream below shigu, Qingyi River, Minjiang River and Yalong River Basin are densely distributed, but the main stream below shigu and Yalong River Basin are prone to small-scale debris flow. The Tuojiang River Basin is sparsely distributed, but the area of debris flow disaster is the largest, indicating that it is prone to large-scale mass debris flow.

3.3 Driving Factors

According to the interpretation results, the distribution law of gully length is analyzed by watershed (Fig. 6), and it is known that the length of debris flow gully in the study area is concentrated near 2000 m. For different watersheds, the length of debris flow in Dadu River Basin reaches the peak at about 3500m, the length of debris flow in Tuojiang River Basin reaches the peak at about 3000m, with large scale and long length, while the Qingyi River and Minjiang river basins are concentrated at 2000m and the gully is relatively wide. The main streams below Fujiang River, Yalong River and shigu River are concentrated below 2000 m, with small scale and short length. The main factors affecting the scale and shape of ditches are topography, earthquake, vegetation and human activities.

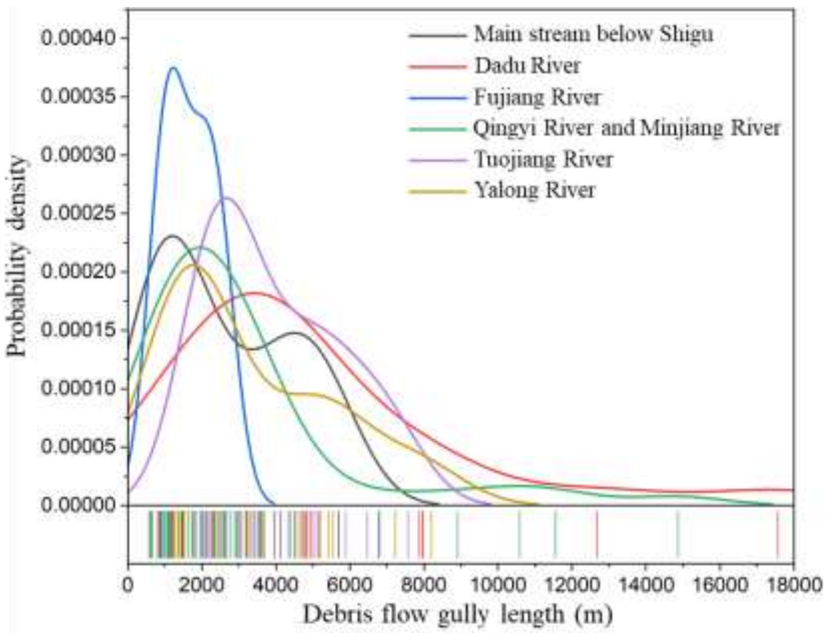


Fig 6: Length distribution of debris flow source channel in each watershed

3.3.1 Topography

According to the topographic characteristics of Longmenshan fault zone, the elevation is divided into 11 levels at an interval of 500 m [7]. The source area of the highest point of debris flow source in each

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interval is counted by basin, as shown in Fig. 7. It can be seen from the figure that with the increase of the altitude of the highest point, the area of debris flow increases first and then decreases. When the debris source gully head of the landslide body is located at 2500-5500 m above sea level, it is easier to breed large-scale debris flow, and the area of debris flow is large, accounting for 77.55% of the area of material source at the whole elevation. The analysis shows that this is mainly because the elevation range of 2000-4000 m is mostly near the river, which is seriously cut by the water system, resulting in stronger rock mass unloading on the free surface, which is conducive to the formation of large-scale landslide. The vegetation at the elevation of 2500-4000 m is mainly distributed in shrubs and coniferous tree belt [31,32]. The exposed surface of shrubs produces a large amount of runoff that can transport sediment, and the activities of animals in shrubs break the protection of surface plants, which makes the sediment loose and easy to be transported by water flow [33]. low altitude areas have little topographic relief and are difficult to form large-scale debris flow disasters. Areas below 2500 m are mainly coniferous forests and broad-leaved forests. Trees (arbor roots are generally 2-10 cm) and shrubs (shrub roots are generally 0.5-4 cm) are mixed, with good vegetation coverage, strong anchoring effect of longer roots on Soil and high soil stability [31,32]. Some studies have shown that debris flow disasters mostly occur in the upper part of the canyon section, and the geological disasters often occur in the lower part of the canyon section are collapse and debris accumulation of landslide body [6].

According to different watersheds, it can be found that the main streams of Qingyi River and Minjiang River, Tuojiang River and Dadu River are relatively easy to breed debris flow disasters in higher altitude areas (more than 4000 m). Although the provenance body in this area is easy to be weathered and eroded, exposing the bedrock and reducing the number of landslide bodies, due to the high altitude and large topographic fluctuation, the debris flow disasters are often large in area and long in length. In addition, the gentle slope with an elevation of more than 4000 m is herbaceous, with shallow roots, undeveloped vegetation, weak anchoring effect on the soil and poor soil stability. Therefore, the debris flow in this elevation area is relatively developed.

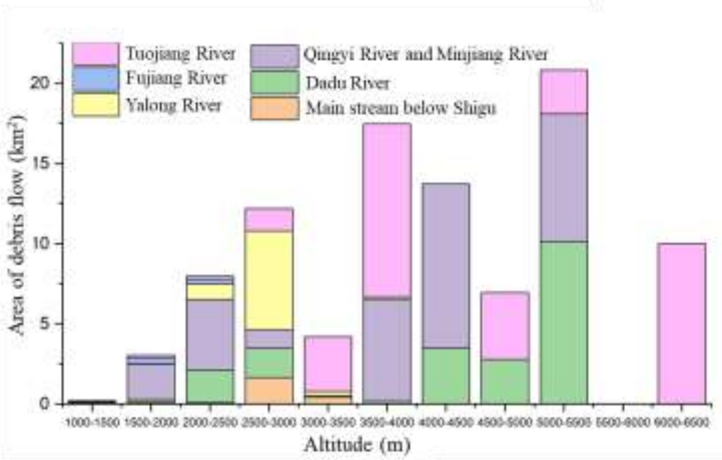


Fig 7: The relationship between the elevation of the highest point of debris flow source and debris flow area

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According to the interpretation results, the height difference between the highest point and the lowest point of each debris flow material source is calculated, and the debris flow gully is classified at an interval of 200 m [26]. In total, the gully height difference in the study area is divided into 26 levels, and then the material source area of each interval is counted by watershed, the results of which are shown in Fig. 8. By comparing and analyzing the distribution laws of various watersheds, the height difference of debris flow in Tuojiang River, Qingyi River, Minjiang River and Dadu river basins is wide, mainly distributed above 1800 m, mainly because they are vertical and horizontal in Longmen Mountains, cross cutting the earth structure along the terrain, with large surface fluctuation and rich surface morphology [26]. Therefore, in the prevention and control, we should pay extensive attention to the debris flow disaster prone areas with a height difference of 1800-5400 m. The Yalong River Basin in the northwest Qinghai Tibet Plateau and the eastern basin, whose debris flow scale is small, are in the range of 0-2000 m due to their flat terrain, small surface fluctuation and small elevation difference of debris flow.

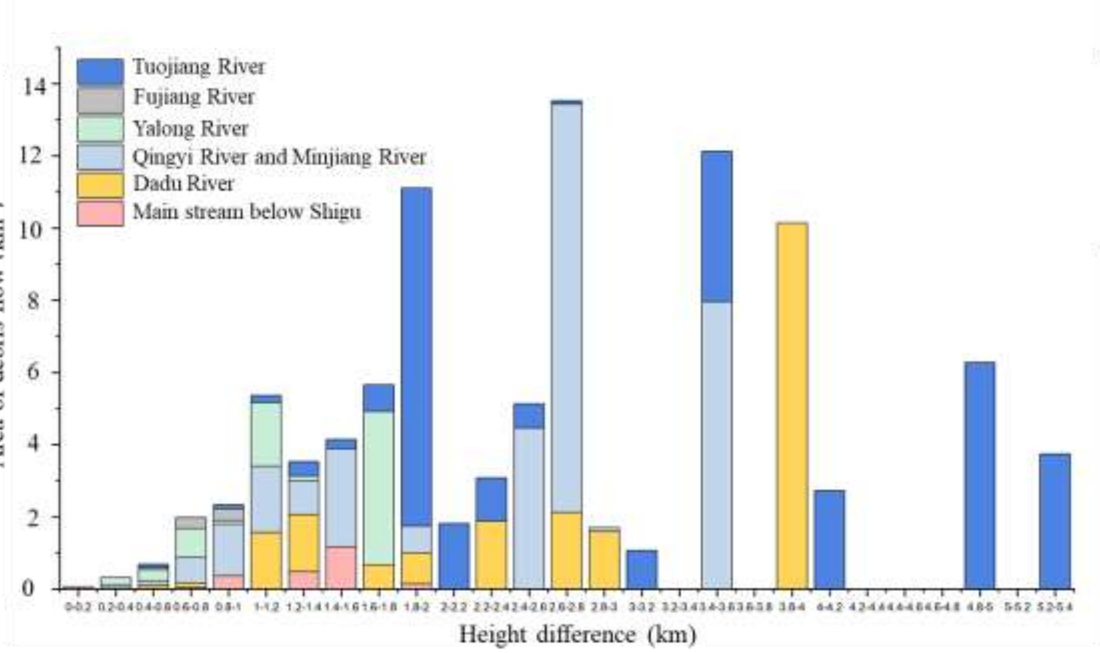


Fig 8: Relationship between debris flow area and elevation difference in various basins

Based on the 1:50000 DEM data, the slope in the study area is investigated. According to the topographic conditions, the slope is divided into 17 equivalent intervals, and the interval slope of each interval is 5° [7]. The area distribution of slope debris flow in different intervals is obtained, as shown in Fig. 9. The results show that the debris flow is the most developed when the slope is 15°- 40°, accounting for 54.92% of the whole range. The main reason is that when the slope is too low, it is difficult to destabilize the slope. The larger the topographic slope is, the larger the range of slope tension zone is, the more concentrated the stress at the slope toe is, and the component of material source gravity increases upward along the slope, which also makes the free surface of the slope more developed, affects the supply and discharge of surface water runoff and groundwater, and destroys the surrounding lithology, The slope is more prone to instability, which makes the debris flow disaster more developed [3,5]. When the slope is greater than 45°, the local loose clastic material is thinly developed, the shallow landslide is more difficult to occur, and the debris flow is more difficult to develop. The debris flow is mainly generated from the

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shallow debris flow layer of Tuojiang River, which is almost prone to produce debris flow. Therefore, the Tuojiang River Basin should focus on the debris flow prone areas with a slope of more than 45°, and other basins should focus on the areas with a slope of 15°- 40°.

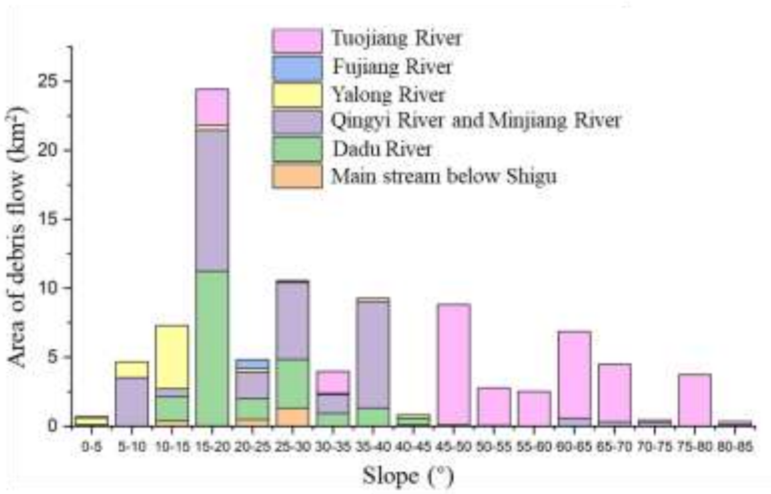


Fig 9: Relationship between debris flow distribution and slope

3.3.2 Earthquake

Earthquake is an external factor that affects the occurrence of debris flow disaster. The relationship between debris flow distribution and fault is analyzed. The results are shown in Fig. 10. The results show that debris flow mostly occurs near the fault and within 0-50 m.

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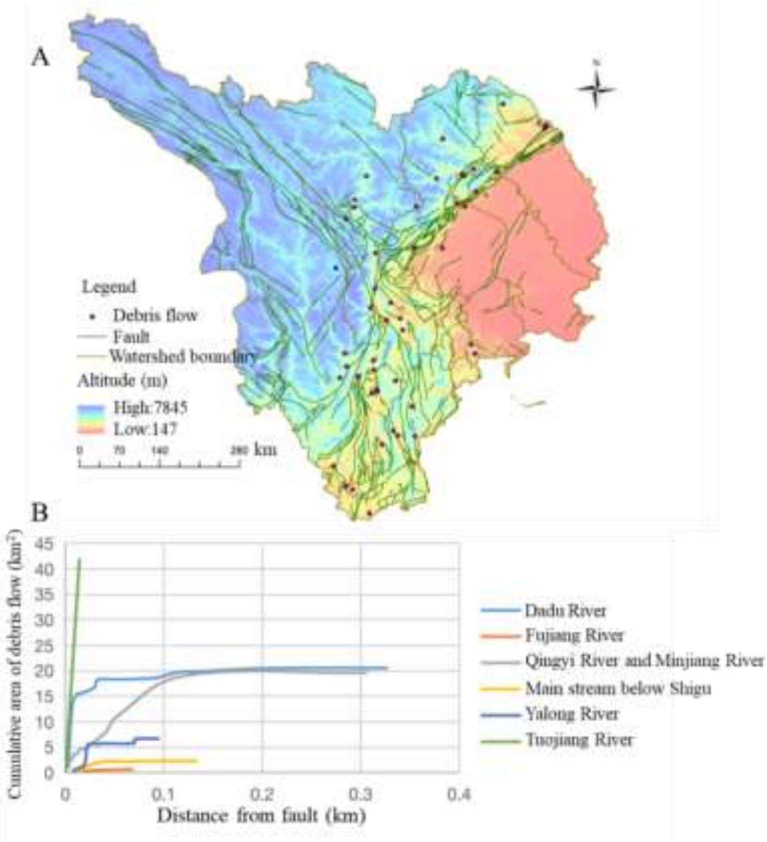


Fig 10: Relationship between debris flow distribution and faults

The area of debris flow in Tuojiang River Basin, main stream of Qingyi River and Minjiang River, Dadu River Basin and Yalong River Basin is obviously related to the distance from the fault. The area increases rapidly within the range of 0-50 m, and the area near the fault is large. With the distance from the fault, the area increase of debris flow decreases rapidly, and the scale of debris flow in these basins is also relatively large. The area of debris flow disaster in the main stream below Fujiang River and shigu is less affected by the distance from the fault, and the scale of debris flow is also relatively small.

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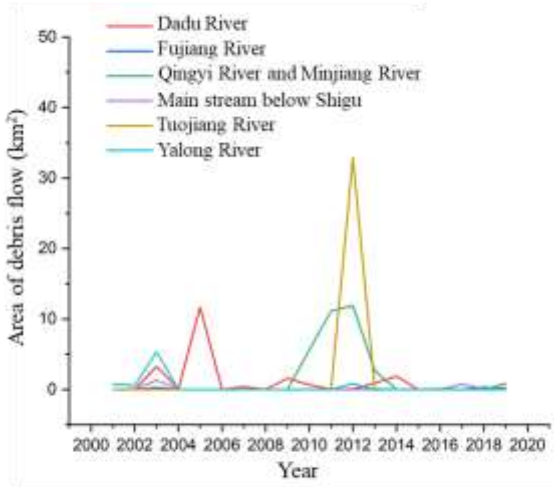


Fig 11: Interannual variation of debris flow area in different basins

The mechanism of earthquake triggered debris flow is that a large number of loose materials are produced after the earthquake, some of which are separated from the parent body and piled up in the gully, and some are piled up on the steep bank slopes on both banks, which provides sufficient material source for the outbreak of debris flow and reduces the starting conditions. Subsequent aftershocks or rainfall may activate new landslides or debris flows, resulting in high-frequency, large-scale and high-risk characteristics of post-earthquake debris flows [6]. In addition, the earthquake also damaged the debris flow prevention and control works, including the direct earthquake damage of retaining works and the indirect earthquake damage typical of flow around damage and scouring damage [35]. The significant reduction of debris flow disasters after 2015 is due to the large consumption of debris flow sources within a few years after the earthquake, the migration of fine-grained materials from debris flow sources in the debris flow basin, the gradual restoration of vegetation and the gradual enhancement of shear resistance of debris sources. Therefore, in the absence of triggering conditions, the debris flow sources will gradually reduce, reduce their activity and tend to be stable. In addition, with the establishment of protective engineering, the area of debris flow disaster decreases gradually [24,28]. However, for the rainy season in strong earthquake areas, relevant departments should still be vigilant, make disaster prevention plans and rescue plans, and minimize the damage of debris flow disasters in strong earthquake areas. Combined with the interannual variation of debris flow in various watersheds, large-scale debris flow disasters occurred in Tuojiang River Basin, Qingyi River Basin, Minjiang River Basin and Dadu River basin after the Wenchuan earthquake in 2008(Fig. 11), which also confirms that the occurrence of debris flow disasters in these watersheds has a great correlation with earthquakes. In the process of debris flow prevention and control, we should pay more attention to the consideration of earthquake factors.

### 3.3.3 Vegetation

The driving factors of debris flow such as local climate, precipitation, soil conditions and geological conditions will affect the vegetation coverage. Therefore, the development of debris flow provenance is affected by the vegetation coverage. After trying the buffer zones of 100 m, 200 m and 500 m, it is found that the buffer zone with a radius of 100 m cannot cover all the areas affected by vegetation. The buffer

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zone with a radius of 500 m is too large to represent the vegetation coverage in the debris flow disaster area. The buffer zone with a radius of 200 m can better reflect the vegetation coverage around each gully. Therefore, a buffer analysis of 200 m is made for the five debris flow sources with the largest area in each watershed [34]. Using NDVI data, the average vegetation coverage in the month before and ten years before and after the debris flow in each buffer zone is obtained, and the results are shown in Fig. 12. It can be seen from the figure that in the Western Sichuan Plateau and eastern basin area (Yalong River, trunk stream below shigu, Tuojiang River Basin), the vegetation coverage in the month before the occurrence of debris flow is lower than that in previous years. The occurrence of debris flow has an obvious relationship with the vegetation coverage rate, and debris flow disasters are prone to occur in the period when the vegetation is relatively undeveloped. It is mainly because the roots of plants can penetrate into the soil layer and anchor the soil, and the staggered distribution can slow down the flow of water, so as to improve the anti-erosion and scouring ability of soil [3,31]. Therefore, in these areas, vegetation planting should be increased to anchor the soil. The occurrence of debris flow in the rapid change zone (Fujiang River Basin, Qingyi River and Minjiang River Basin, Dadu River Basin) is almost irrelevant to the vegetation coverage. This is mainly because this area is a rainstorm area and the soil saturation is limited. When the soil water content reaches a certain threshold due to heavy rainfall, the limited reinforcement effect of vegetation on the soil is destroyed and it is unable to retain more water sources. Moreover, the roots are staggered with the soil, and the sliding force generated by soil scouring is transmitted to the vegetation roots. In addition, the occurrence of debris flow is often accompanied by strong winds in different directions, which makes the plants unstable and move in all directions. It has increased the damage to the soil surface, and itself has become the material source of debris flow, promoting the outbreak of debris flow [31]. After the outbreak of debris flow, vegetation may block the gully and form debris flow dam. When triggered again, it may form a larger scale of debris flow [31], therefore, increasing vegetation coverage does not necessarily reduce the outbreak of debris flow in these watersheds, and other measures should be taken to strengthen the soil.

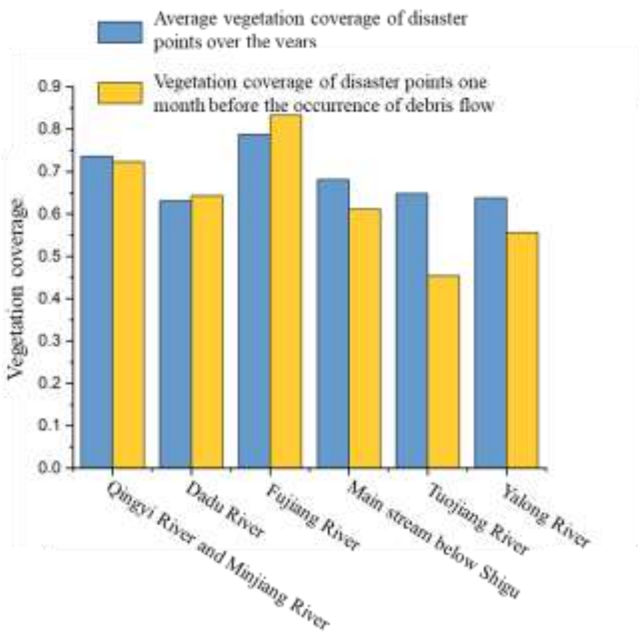


Fig 12: Vegetation coverage near debris flow sources in each watershed

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3.3.4 Human activities

Human daily activities and construction have largely caused the changes of various elements in the environment and the overall change of the environment. Population density, production mode and land use are all related to the occurrence of geological disasters [8]. Among them, engineering activities have a direct impact on geological disasters, including land reclamation, highway construction, hydropower resources and mineral resources development. Among the 665 recorded debris flow disasters, 8 occurred near the highway, and 1 was interpreted, which was located in Dadu River Basin, with an area of 0.01 $km^2$. 5 occurred in the power station, 3 were interpreted, which was located in Yalong River Basin and Dadu River Basin, with an area of 2.76 $km^2$. 18 occurred in the mining area, and 2 were interpreted, which were located in Dadu River Basin, Qingyi River Basin and Minjiang River mainstream basin, with an area of 1.01 $km^2$. The small area of debris flow disaster near the highway is due to the state's emphasis on post disaster reconstruction projects, especially the construction of transportation infrastructure. Because traffic affects other infrastructure construction, the disaster area can receive timely and comprehensive support from provinces and cities, so the recovery and reconstruction are relatively fast [36].

These human activities first destroy the growth of vegetation, loosen the soil, reduce the stability, and increase the water and soil loss. In addition, sometimes it is necessary to excavate the slope toe, dig tunnels, or even blast in the construction. These activities produce a large amount of waste and accumulate in the project area, providing a large amount of material sources for geological disasters, which significantly increases the susceptibility, risk and scale of geological disasters in these areas [8,32], Especially in the Dadu River Basin. Therefore, the land reclamation and utilization should be reasonably planned to avoid over development. During the project construction, the time should be reasonably planned to avoid the rainstorm period as far as possible, and the waste should be cleaned up in time to avoid being washed out during the rainfall.

## IV. CONCLUSIONS

(1) In terms of time, debris flow disasters are prone to occur in the rainy season from June to August. The area of debris flow disasters increased significantly from 2008 to 2012, reached the maximum in 2012, about 45.67km, decreased significantly in 2013, and recovered to a low level in 2015. Spatially, debris flow disasters are prone to occur in the main streams of Tuojiang River, Qingyi River and Minjiang River and Dadu River Basin. We should pay attention to the Countermeasures of disaster prevention and reduction in rainy season and debris flow prone areas. In the valley area of Western Sichuan Plateau (Yalong River, Dadu River Basin, Qingyi River and Minjiang River Basin, and the main stream below shigu), the less increase of monthly precipitation will induce debris flow, while the larger increase of monthly precipitation in the eastern basin (Fujiang River and Tuojiang River Basin) will induce debris flow.

(2) There are significant regional differences in the scale and morphology of debris flow gullies in various watersheds along the Longmenshan fault zone. The high-risk areas of debris flow disasters are

mainly concentrated in the Tuojiang River, the main stream of Qingyi River and Minjiang River and the Dadu River Basin. The area of debris flow disasters in these places' accounts for 89.1% of the area of debris flow disasters in the whole region. The length of debris flow in Dadu River Basin reaches the peak at about 3500 m, the length of debris flow in Tuojiang River Basin reaches the peak at about 3000m, and the Qingyi River and Minjiang river basins are concentrated at 2000m, with large scale and long length. The main streams of Fujiang River, Yalong River and shigu River are concentrated below 2000m, with small scale and short length.

(3) The study area is more likely to breed large-scale debris flow when the altitude is 2500-5500 m, the slope is 15° - 40°, and the elevation difference is 1800-4000 m. The main streams of Qingyi River and Minjiang River, Tuojiang River and Dadu river basins are relatively in high altitude areas (more than 4000m), and the height difference range is wide. The slope of Tuojiang River basin above 45° is easy to cause debris flow. The northwest Qinghai Tibet Plateau (Yalong River Basin, the main stream below shigu) and the eastern basin (Fujiang River Basin) are in the range of 0-2000 m due to their flat terrain, small surface fluctuation and small elevation difference of debris flow. The area of debris flow in the main streams of Qingyi River and Minjiang River, Tuojiang River and Dadu River is obviously related to the earthquake, and the scale increases significantly after the earthquake. The area of debris flow in the Tuojiang River Basin, the main streams of Qingyi River and Minjiang River, Dadu River Basin and Yalong River basin is obviously related to the distance from the fault. The area increases rapidly within the range of 0-50 m. The area of debris flow in the area close to the fault is larger, and the farther it is from the fault, The area of debris flow increases and decreases rapidly, and the scale of debris flow in these basins is relatively large. The area of debris flow disaster in the main stream below Fujiang River and shigu is less affected by the distance from the fault, and the scale of debris flow is relatively small. In Western Sichuan Plateau and eastern basin areas (Yalong River, trunk stream below shigu River and Tuojiang River Basin), there is an obvious relationship between the occurrence of debris flow and vegetation coverage. Debris flow disaster is easy to occur in the period of relatively undeveloped vegetation. In these areas, vegetation planting should be increased and soil should be anchored. The occurrence of debris flow in the rapid change zone (Fujiang River Basin, Qingyi River and Minjiang River Basin, Dadu River Basin) is almost irrelevant to the vegetation coverage. Human production activities destroy vegetation cover and reduce soil stability. Engineering activities produce a large number of wastes, which provide a large number of material sources for geological disasters and promote the occurrence of debris flow disasters. In Dadu River Basin, the main streams of Qingyi River and Minjiang River should focus on the rational planning of human activities and reduce unnecessary mining.

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