ISSN: 2414-1895 DOI: 10.6919/ICJE.202110_7(10).0034

Basic Characteristics and Cause Analysis of Debris Flow Disaster in Keze 2 # Gully of Jiuzhaigou Earthquake Area

Chen Huang[1], Youyi Zhang[1]

[1]School of civil Engineering and architecture, Southwest University of Science and Technology, 59 Qinglong Road, Mianyang, Sichuan 621010, China

Abstract

After the '8.8' Wenchuan earthquake in 2017, a small-scale debris flow occurred in Keze 2# gully in 2011. After the '8.8' Wenchuan earthquake, Jiuzhai gully was affected by heavy rainfall. On June 25, July 11, 2018, the gully again erupted large-scale debris flow and flood disasters. In recent years, affected by the '8.8' earthquake, a large number of loose materials have been produced in the basin. Under the action of rainfall, debris flow activities have occurred frequently in recent years. Some solid sources have been involved in the debris flow being transported to the downstream of the channel or accumulated in the accumulation area to remain stable. Therefore, after the debris flow activities in recent years have taken away some solid materials, the reserve of source animals in the basin has a certain downward trend. A total of 35 major geological hazards are developed in the source area of Ze 2 # gully basin, with abundant solid loose material sources, including 261.76×10⁴ m³ of landslide, 164.45×10⁴ m³ of channel accumulation and 196.9×10⁴ m³ of slope erosion. The total storage of loose material is 623.12×10⁴ m³, and the dynamic reserves that may participate in debris flow activities are 118.54×10⁴.

Keywords

Debris Flow; Source; Formation Mechanism; Heavy Rainfall.

1. Introduction

The strong earthquake caused the mountain broken, the material source surged, and the geological condition was extremely fragile. It will be in an unstable state for a long time after the earthquake, and the possibility of frequent geological disasters increases [1]. At the same time, due to the collapse in the basin, the looser source structure of slope and channel, and the increase of soil porosity, debris flow disasters are easy to break out under the action of heavy rainfall, and the debris flow activities are enhanced [2, 3].

After the '8.8' Jiuzhaigou earthquake in 2017, under the response of seismic force, collapse, landslide and unstable slope developed strongly, and large-scale geological disasters broke out under rainfall [4,5]. On June 20, 2017, debris flows broke out in Zhuozhuigou, Haizigou and Zechawagou in Jiuzhaigou area [6].

In this paper, through field investigation, UAV shooting and other work, the basic characteristics and genetic mechanism of debris flow disasters in Kize 2# gully in Jiuzhaigou earthquake area, supplement the current development status of debris flow in Jiuzhaigou earthquake area, and provide reference for the prevention and control of debris flow disasters in the next step.

2. Study area

The debris flow of Kize 2 # gully in # Jiuzhaigou seismic zone is located on the north side of Haizi in the next season of Jiuzhaigou seismic zone. The geographic coordinates of gully mouth are 33°7′28″

ISSN: 2414-1895 DOI: 10.6919/ICJE.202110_7(10).0034

north latitude, 103°55′20 ″ east longitude, 7.2 km long main gully, and 19.89 km^2 basin area (Fig. 1). In the basin, the gully is deeply cut and the branch gully is developed. The elevation of the highest point of the gully source is 4442 meters, and the elevation of the lowest point of the gully mouth is 2570 meters, and the height difference is 1864 meters. The debris flow gully mouth is about 19.5 km away from the gate of the earthquake area and 63 km away from Jiuzhaigou County. The gully mouth is located in the experimental area of Jiuzhaigou core earthquake area, the middle of the basin is mainly located in the buffer zone, the gully source and the upper part of the basin are located in the core area. The highway in the earthquake area passes at the front edge of Kize 2# gully mouth, and the traffic is convenient.

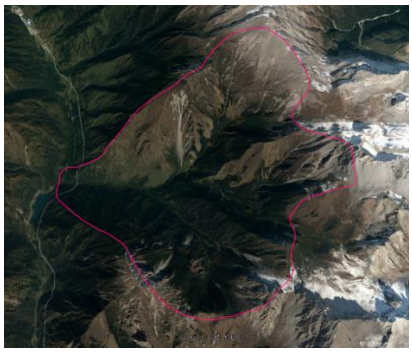

Fig. 1 Geograph of Keze 2 # ditch

Jiuzhaigou area shows mild climate, moderate precipitation, cool and dry monsoon climate characteristics. At the center of Jiuzhaigou earthquake zone, near Norilang, 2389 m above sea level, the annual average temperature is 7.3 °C. The monthly average temperature of the highest month in July is 16.8°C, and the lowest month in January is -3.7°C. The highest daily temperature was 32.6°C and the lowest was -17.0°C. The maximum snow depth is more than 150 mm from October to April of the next year, and the frost-free period is about 100 days. The total solar radiation is 115cal/cm2 per year, the annual sunshine hours is about 1800h, the accumulated temperature of daily average temperature ≥10°C is 3000~3500°C, the annual average absolute humidity is 8~10mbar, and the relative humidity is 60 %~70 %.

According to the observation statistics of Shuzhengzhai Rainfall Station in Jiuzhaigou from 1971 to 2016, the average annual precipitation is only 552.3mm. Precipitation is concentrated in rainy season (May – September), accounting for about 75 % of the annual precipitation. According to the 25-year observation data of the county meteorological station, the annual maximum precipitation was 750.2 mm (1990), and the minimum precipitation was only 359.2mm (1996). The maximum precipitation was 100.5 mm in July, and the rainstorm with daily precipitation greater than 30 mm could be three times every four years. Among them, the rainstorm with daily precipitation greater than 50 mm had only three times in 25 years, and the observed maximum daily precipitation was 51.3 mm. The annual and monthly average rainfall statistics of Jiuzhaigou County are shown in Fig. 2.

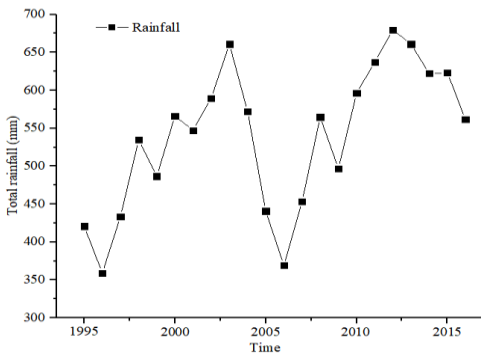

Fig. 2 Annual average rainfall in Jiuzhaigou County

ISSN: 2414-1895 DOI: 10.6919/ICJE.202110_7(10).0034

Jiuzhaigou County is located in the deep-cut alpine gorge zone in the transition of large geomorphic units between the Qinghai-Tibet Plateau and the Sichuan Basin. The terrain gradually decreases from northwest to southeast. Jiuzhaigou County is located on the complex anticline of the northern segment of the Minshan Mountains in the western trough area of Sichuan Province. There are obvious fault zones on the west, north and south sides, which constitute a complex structure. In general, the structure of Jiuzhaigou County is the south-north structural belt of the Minjiang River and the Baima arc structural belt (Fig. 3).

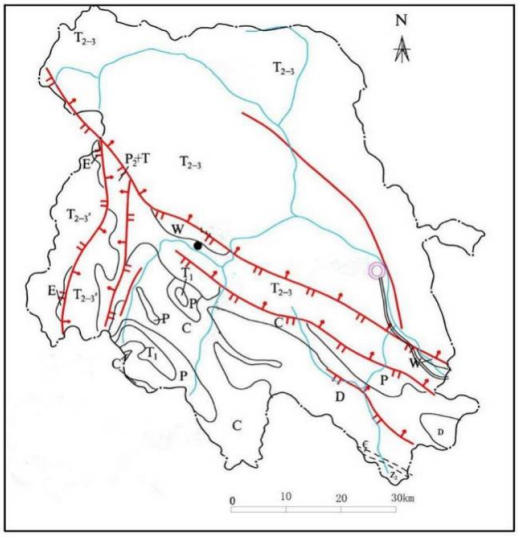

Fig. 3 Distribution map of faults and folds near the county

3. Formation Conditions of Debris Flow Disaster

3.1 Development characteristics of debris flow gully in Keze 2 # gully

The debris flow in Keze 2# gully is composed of main gully and 2 tributaries (1# tributary, 2# tributary). The debris flow in Keze 2# gully is funnel-shaped, and the highest point in the region is located in the eastern side of the basin, with an elevation of 4442 m. The lowest point is located at the intersection of the gully mouth and the road in the earthquake area, with an altitude of about 2570 m and a relative height difference of 1872 m. The basin area is 19.89 km^2, the main gully length is about 7.2 km, the valley is 'V' shape, and the average longitudinal slope of the main gully is about 268.2 ‰. Two branch ditches were developed on the left bank of the basin, and the branch ditches developed as ‘Ya’. Characteristic parameters and ditch bed longitudinal ratio drop see table 1.

Table 1. Statistical table of characteristic parameters of main gully and tributaries in Keze 2 # gully

Serial number	Channel name	Catchment area(km^2)	Channel length (m)	Maximum elevation (m)	Minimum elevation (m)	Relative height difference (m)	Average grade (‰)
1	Kize 2 # main ditch	19.89	7200	4442	2570	1864	268.2
2	1 # branch ditch	6.18	3085	4420	2990	1430	463.53
3	2 # branch ditch	4.31	3148	4060	2830	1230	390.72

The main gully of Kize 2 # gully is 7.2 km long, and the gully width is 20 – 60 m. The upstream is narrow, and the middle and lower reaches are relatively open. The slope gradient on both sides is generally 25° – 50°. Due to the cutting erosion of water flow, the slope at the foot of the slope is generally greater than 50°, and the local is cliff. Longitudinally, the overall gully of Keze 2 # gully can be divided into 5 sections according to its longitudinal slope change and gully characteristics. The gully bed ratio drop and gully characteristics of each section are shown in Table 2.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202110_7(10).0034

Table 2. Sectional statistics of longitudinal slope of main ditch bed in Keze 2 # ditch

Segmentation	Channel length(m)	Peak(m)	Nadir(m)	Elevation difference(m)	Average grade(‰)
First stage	1755	4210	3800	410	233.62
Second stage	2000	3800	3100	700	350.00
Third stage	1255	3100	2800	300	239.04
Fourth stage	1280	2800	2640	160	125.00
Fifth stage	916	2640	2570	70	76.42

3.2 Watershed zoning characteristics

The whole ditch area of Keze 2# ditch is not composed of typical formation area, circulation area and accumulation area, especially no typical circulation area. According to the formation conditions and movement mechanism of debris flow and the distribution of loose solid source of debris flow, the whole gully region is divided into three sections, and the characteristics of each section are shown in Table 3. The first section is the gully bottom elevation above 3100m, which is the clear water accumulation ~ formation area of Keze 2# gully debris flow. The upper bedrock of this section is exposed, mainly subjected to cold weathering erosion, and the development of adverse geological phenomena is weak. The lower part of this section is shrub meadow area, and the bank slope is mainly Quaternary slope deposits and residues. Due to the erosion and erosion of channel flow, the stability of bank slope along the channel is poor. The second section is the 2640~3100m section of the gully bottom elevation, which is the formation~circulation area of debris flow. In this section, the channel is tortuous, wide and narrow, the longitudinal slope of the channel is slow, and the accumulation of debris flow in the channel is rich in loose material sources, which provides rich material sources for the formation of debris flow. The wide and narrow phases and the sharp corners are easy to block the channel. The relatively flat area below the elevation of 2640 m at the outlet of Kezegou is the debris flow accumulation area.

Table 3. Debris flow zoning characteristics table

Domain	Channel length (km)	Peak (m)	Nadir (m)	Elevation difference (m)	Average grade (‰)	Catchment area (km^2)	Geological condition
Full trench	7.2	4442	2570	1872	260.00	19.89	Two branch grooves are developed and the grooves bend more. The bank slope of the gully region is mainly steep slope, the general slope is 30 ~ 45 °, and the local slope is 45 ~ 50 °. The width of the gully downstream of the main gully is large, and the general width is 10-70 m. The branch channel is narrow, and the general width is 5-20 m, which is a ' V ' valley.
Water power zone	3.76	4442	3100	1342	356.91	16.35	The upper bedrock is exposed, and the development of adverse geological phenomena dominated by cold weathering and denudation is weak. The lower part is dominated by shrub meadow area, and the slope stability is general.
Formation of circulation areas	2.54	3100	2640	460	181.10	3.37	On both sides of the channel, the bank slope is steep, the landslide phenomenon is more developed, the bed blockage is medium, the channel source is rich, and the longitudinal slope of the upstream bed is large, which provides a rich source for debris flow.
Accumulation area	0.916	2640	2570	70	76.42	0.17	The accumulation fan is relatively complete, leading edge width 200 ~ 250m, back width 10 ~ 30m, longitudinal length 900m, slope 5 ~ 10 °.

According to field investigation, debris flow occurred many times in the history of Kize 2 # gully debris flow in Jiuzhaigou earthquake area. The debris flow broke out in 2011, which lasted about 0.5 hours. According to the estimation of the debris flow, the total amount of outflow was about 0.1 million square. Cause Kize ditch water turbidity, seriously affecting the downstream Haizi landscape. After the '8.8' earthquake in Jiuzhaigou in 2017, the collapse, potential unstable slopes and landslides in Keze 2 # gully were increased due to the strong surface damage caused by the M7.0 earthquake, which greatly increased the source of landslide and channel, and increased the possibility and scale of debris flow in 2018. According to the field survey, from 14:00 BT on June 25 to 10:00 BT on June 26, 2018, the Jiuzhaigou earthquake area continued heavy rainfall, with the maximum hourly rainfall of 28.6 mm. According to the personnel of the construction unit at that time, the debris flow broke out at 8: 00 p. m. on June 25, resulting in the erosion of the road bridges and culverts in the original

ISSN: 2414-1895 DOI: 10.6919/ICJE.202110_7(10).0034

earthquake area at the gully mouth, the siltation of the under-construction flood control ditches on both sides of the road, and the erosion of the pre-buried pipe culverts of the construction unit. The section from Kezegougoukou to Zechawazhai has serious water accumulation, and the mud rushes to the downstream Ruo Rilang Falls scenic spot. In order to prevent flood inundation, the relevant departments rush to cut off the highway in the earthquake area to guide and discharge flood. The site survey in May 2019 shows that the debris flow in 6.25 in 2018 caused serious damage to existing projects in the basin. The existing 1# sand bar was filled, the left diversion wall of the existing 2# grid dam was washed down and damaged 22 m, and the existing 3 # comb dam was filled and the left abutment was destroyed. According to the outbreak scale of the debris flow, it can be known that the debris flow belongs to large debris flow.

3.2.1 Characteristics of clear water power zone

According to the field investigation, combined with the characteristics of topography and channel erosion and deposition, the catchment area of 3100 m~4442 m elevation is clear water collection and debris flow initiation area. The relative height difference is 1342 m, the gully area is about 16.35 km2, accounting for 82.2 % of the whole debris flow. The gully length is about 3.76 km, and the average longitudinal slope of the gully is 356.9 ‰. Most of the bedrock in the clear water area is exposed, and the loose accumulation layer is thin, which is formed by cold weathering erosion. It is mainly bedrock slope. There is no sign of large deformation and failure on both sides. There are local accumulation bodies with collapse and instability. On the whole, the source is less. It is the main clear water catchment area of Keze gully, and the hydrodynamic condition for the formation of debris flow. The strong scouring of the downstream gully bed by gully water is beneficial to the initiation of loose solid source along the gully, and the area is dominated by scouring erosion. The valley characteristics in this area are shown in Figs. 4 and 5.

Fig. 4 Upstream aerial photographs of main ditch, 1 # branch ditch clear water area and formation area

Fig. 5 Upstream aerial photographs of clear water area and formation area of 1 # and 2 # branch ditches

ISSN: 2414-1895 DOI: 10.6919/ICJE.202110_7(10).0034

3.2.2 Characteristics of forming circulation area

The elevation range of the circulation area is 2640 m–3100 m. The channel length is about 2.54 km, the average longitudinal slope is about 181.1 ‰, and the total area is about 3.37 km2. The main channel in provenance area is 'U' type valley, and the local channel is 'V' type valley. The bottom width of the channel varies greatly, and the general width is 10~60 m. The upstream channel in the forming circulation area is narrow, and the general width is 3~5 m. The channel is mainly 'V' type valley, and the local channel is relatively open, and the downstream channel is generally 10~60 m. The channel in the circulation area is straight, the bank slopes on both sides of the valley are steep, and most of the bedrock is exposed. Affected by earthquake, structure and weathering unloading, the bedrock is broken and easy to form a collapse body. The loose material covered in the local section of the bank slope is mainly residual slope and collapsed slope gravel soil, which is generally 3~5 m thick. Under the action of surface runoff, the surface loose rock and soil are taken away locally, which is the main source of fine particle composition in debris flow. The characteristics of erosion and deposition in the circulation area are mainly characterized by erosion and local deposition (see Figs. 6 and 7).

Fig. 6 Forming the upstream of circulation area

Fig. 7 Middle and lower reaches of flow accumulation area

3.2.3 Characteristics of accumulation area

According to the survey, the channel range of section 2570 – 2640 of altitude elevation in the Kizegou debris flow basin is the accumulation area. The integrity of the accumulation fan is good, and the overall distribution is fan-shaped. The front width of the accumulation fan is 250 m, and the rear width is 10–30 m. The length of the fan is about 900 m, and the total area is about 0.17 km^2. At present, the thickness of the accumulation body in the accumulation area is about 10–15 m. The overall characteristics of the particles are mainly the accumulation of crushed stones and gravels, with a small amount of silt and dead wood, and the proportion of crushed stones can reach 55%–65%. The stone size is 5~40cm, the maximum stone 1.8m×1.5m×0.9m, medium grinding circle.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202110_7(10).0034

At present, the gully is mainly passed along the right side of the fan, and the front edge of the accumulation area is the highway in the earthquake area (Fig. 8), which is the main area of human activities and is the object of debris flow protection. The drainage ditch is constructed by the water department in the gully mouth section of the accumulation area. The drainage ditch extends from the Kize 2 # gully to the Norilang Falls downstream of Zezhawazhai, about 4.5 km long. The existing drainage ditch meets the road in the earthquake area three times, and passes in the form of bridges and culverts, as shown in Figure 9.

Fig. 8 Aerial Photographs of Trench Threat Objects (Earthquake Area Highways)

Fig. 9 No. 2 Bridge and Culvert of Drainage Ditch

4. Overall characteristics of provenance distribution

According to the field investigation, there are three main sources of debris flow in Keze gully: landslide accumulation, gully accumulation and slope erosion accumulation. The total reserves of the three sources are 623.12×10^4 m^3 and the dynamic reserves are 118.54×10^4 m^3. In addition, there are abundant litter and litter sources in the channel, about 500.

4.1 Collapse accumulation

There are 25 landslides in the area, which are mainly distributed in the main gully and the slope sections of each branch gully valley. The distribution elevation is 2600~4300 meters, and the total source is about 261.76×10^4 m^3, accounting for 42.01 % of the total source, of which the dynamic reserve is 56.11×10^4 m^3. There are 14 main gully sections of collapse-sliding accumulation, 9 on the right bank and 5 on the left bank. A total of 11 landslides were developed in each branch ditch, 3 in the right bank and 8 in the left bank.

4.2 Channel accumulation body

There are a total of 10 sections of the gully accumulation body. The total accumulation length of the gully accumulation source in the Kezegou Basin is 3794 m, and the accumulation area is $32.89\times10^4m^3$. The total is about $164.45\times10^4m^3$, accounting for 26.39 % of the total amount of material sources. The dynamic reserves that may participate in debris flow activities are $32.89\times10^4m^3$.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202110_7(10).0034

4.3 Slope erosion material source

Mainly distributed in the main ditch and branch ditch formed circulation area on both sides of the slope section. The area of debris flow gully in Keze gully reaches 19.89 km2, while the area of available slope provenance reaches 19.69 km2. The static reserve is about $196.9\times10^4 m^3$, accounting for 31.60 % of the total provenance. Considering comprehensively, the dynamic reserve is about 15 % of the total static reserve, about $29.54\times10^4 m^3$.

Judging from the current situation, once the continuous heavy rainfall or heavy rainstorm makes the upper channel groove cut down, causing the instability and failure of high and steep deposits on both sides of the groove. Secondly, because the main gully is relatively straight, it is easy to drive a large number of material sources to participate in debris flow activities in heavy rain season, which provides rich material source conditions for the development of debris flow.

5. Source startup mode

5.1 Start-up mode of channel accumulation source reserves

Due to the accumulation of a large number of loose materials in the channel after the '8.8' earthquake, under the action of rainfall, the formation of flood after surface water confluence has a strong downward erosion effect on the loose deposits in the gully bed, and gradually forms deep gully, which provides an effective free surface for the accumulation slope on both sides. Then the tractive collapse of the ditch, the final collapse into debris flow. The start-up process of debris flow source can be roughly divided into four stages: undercutting erosion (A), gully formation (B), collapse and blockage (C), erosion and collapse (D), see figure 10.

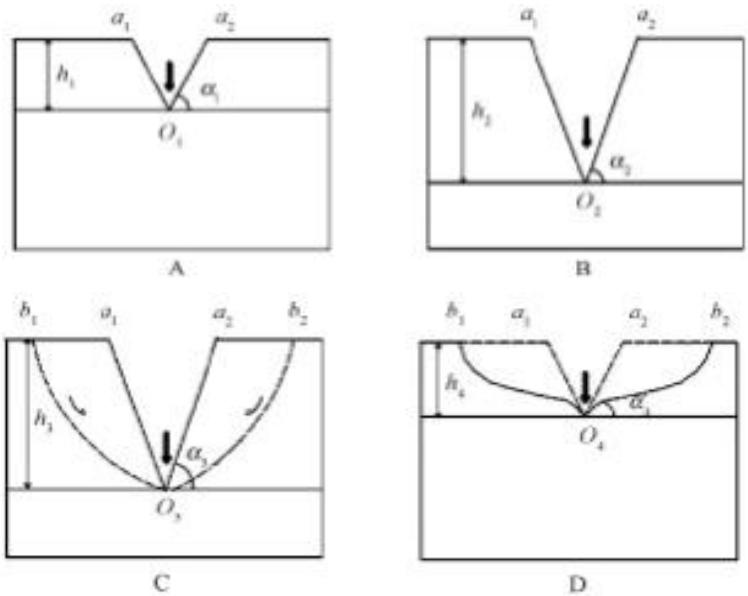

Fig. 10 Schematic diagram of provenance start-up mode of debris flow gully under gully erosion and collapse O -gully erosion baseline. a − The width of undercutting gully. b-potential collapse surface. h - Ditch depth. α-slope angle

5.2 Start-up mode of slope erosion animal source reserves

The source of erosion on the slope is residual on the slope, and there is a certain distance from the gully. Most of them will not actively participate in debris flow activities, and the slope of the source point of debris flow activities is relatively large. They mainly participate in debris flow activities after entering the gully along the slope under rainstorm erosion. Some can reach the bottom of the slope or enter the gully, and then be carried away by debris flow. The start-up model can be roughly divided into three processes : rainstorm scouring, handling stops, along the inflow ditch, see figure 11.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202110_7(10).0034

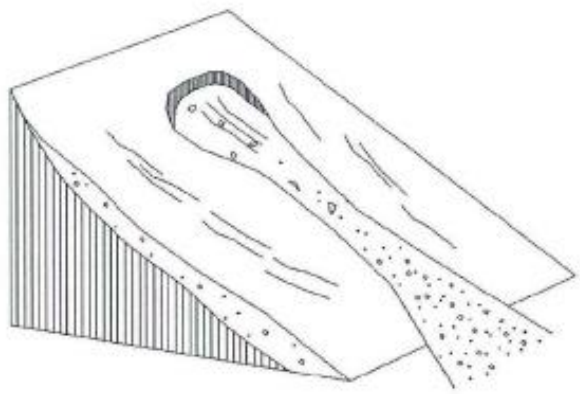

Fig. 11 Start-up mode of source reserves of erosion on slope surface

5.3 Sources of dead wood and litter

Most of these sources are distributed on the slope surface, or are carried by the scour of flood, and the accumulation is blocked in the channel. For rootless and under the action of debris flow, the dry woods in the gentle valley section will move to the middle and lower reaches of the channel with the action of debris flow. If large trees or narrow channels are encountered, they will stop silting due to external blocking.

5.4 Debris flow material supply mode and transformation

Under the control of topography, channel conditions and hydraulic conditions in the debris flow basin of Keze gully, the way of material supply and transformation of dynamic and static reserves participating in debris flow is different. According to the above classification description according to the source distribution characteristics, combined with the common characteristics of various sources, combined with the topography and geomorphology of debris flow formation in the area, channel conditions, hydraulic conditions and other factors, the transformation and supply mode of debris flow in Keze gully can be divided into the following three cases :

Landslide recharge : On the slope surface with good vegetation and steep slope, under the action of long duration and heavy rainfall, the overburden is easy to reach saturation or supersaturation. Under the action of its own gravity and hydrodynamic pressure, the instability starts to form a landslide and enters the channel to participate in debris flow activities.

Surface runoff erosion recharge: agricultural cultivation and deforestation in the debris flow gully region affect soil and water loss in the basin, but the vegetation on the bank slopes on both sides of the gully is generally good, and the soil and water loss is not serious.

Stable slope gully bed collapse recharge: early debris flow deposits in gully bed and loose deposits close to both sides of the main gully, by the long-term erosion and cutting of the gully flow, the formation of channel erosion and side erosion, easy to local formation of gully bank collapse, gully bed material restart, especially under the action of debris flow, with the increase of short-term runoff, erosion capacity increases, scouring the loose deposits in the gully bed, making these loose solid materials are wrapped to supplement the source of debris flow material.

6. Forming process

6.1 Antecedent rainfall

Although the occurrence of debris flow is a sudden process, the early rainfall is of great significance in its formation process. According to the observation data, there is a large-scale heavy rainfall before the debris flow in the main gully of the debris flow in the Keze 2# gully. The role of early rainfall is mainly to make the loose soil saturated, increase the bulk density, reduce the anti-sliding force, reduce the stability, and landslides, providing favorable conditions for the occurrence of debris flow.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202110_7(10).0034

6.2 Rainstorm excitation

The short-duration heavy rainfall played a decisive role in the initiation of debris flow. The maximum rainfall in this heavy rainfall hour reached 38.6 mm, and the heavy rainfall prompted the occurrence of large-scale debris flow in the Kize 2 # gully.

6.3 Rolling development

The flood peak formed by heavy rainfall confluence has a huge water pressure on the gully bed and bank slope. The flood side eroded the bank slope and planed the groove, and then expanded the scale of the original landslide. The addition of loose solid materials started the debris flow. The debris flow moved forward, and increased its lateral erosion and plan erosion ability. Such rolling development and continuous material addition along the way make the debris flow scale more and more large, and the fluid flow velocity is accelerating. However, there are existing blocking projects in the middle and lower reaches of the gully in the circulation area. The existing blocking projects have good storage capacity before the outbreak of debris flow. Therefore, the existing blocking projects have played a certain role in blocking and stopping the siltation of the ’6.25’ debris flow, and reduced the flow velocity of the debris flow, so that the kinetic energy of the debris flow movement is reduced, and the siltation is stopped at a wide and slow position in the gully mouth accumulation area.

6.4 Accumulation

After the debris flow of Keze 2# gully enters the accumulation area, along the channel of accumulation area, after the channel is filled, the diffusion angle becomes larger, and the accumulation fan overflows and stops silting, forming irregular fan-shaped accumulation, completing the whole movement process of debris flow.

7. Conclusion

1) Affected by the strong surface damage of the ‘8.8’ Jiuzhaigou earthquake in 2017, the potential unstable slopes and landslides in the Keze 2 # gully increased, resulting in a substantial increase in the source of landslide and gully materials, increasing the scale of debris flow outbreak in 2018.

2) Kize 2 # gully debris flow is valley debris flow. Under the strong earthquake dynamic action, the regional mountain loose, gully slope collapse, landslide and other adverse geological development.

3) Under the action of rainstorm, the loose material on the slope is carried into the channel during the confluence process. In the process of downstream, the loose material in the channel is rolled by scouring and uncovering the bottom, and moves downstream in the way of snowballs, thus forming debris flow and increasing the scale of debris flow.

4) During the formation of debris flow, the terrain in the gully is steep, the basin area is large, and the longitudinal slope of the gully is large, which provides favorable topographic conditions for the convergence of water and sediment. The loose deposits in the gully provide abundant loose solid sources for the occurrence of debris flow.

Acknowledgements

This research was funded by the National Key Research and Development Program of China (2018YFC1505401).

References

[1] Wei C L, Zhang Y, Feng W K,et al. 2019. The development intensity and regularity of geological disasters in the upper reaches of Minjiang River Analysis [J]. Journal of Engineering Geology, 27(3):640-650.

[2] Liu J, You Y, Chen X, et al. 2014. Characteristics and hazard prediction of large-scale debris flow of Xiaojia Gully in Yingxiu Town, Sichuan Province, China [J]. Engineering Geology. 180: 55-67.

[3] Li N,Tang C, Bu X H,et al. 2020. Characteristics and Evolution of Debris Flow in Wenchuan County after ' 5.12 ' Earthquake Analysis [[J].Journal of Engineering Geology, 28(6):1233-1245.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202110_7(10).0034

[4] Fan X, Scaringi G, Xu Q, et al. 2018. Coseismic landslides triggered by the 8th August 2017 Ms 7.0 Jiuzhaigou earthquake (Sichuan, China): factors controlling their spatial distribution and implications for the seismogenic blind fault identification [J]. Landslides. 15(5): 967-983.

[5] She J X, Xu Q, Yang W N, et al. 2021. Early identification and analysis of geological hazards in Jiuzhaigou earthquake [J/OL]. Journal of Engineering Geology: 1-10 [2021-06-17].

[6] Li N, Tang C, Shi Q Y, et al. 2021. Study on the causes and disaster-causing mechanism of '6.21' debris flow in Jiuzhaigou seismic area [J]. Journal of Engineering Geology, (Network first publishing)