Analysis of material supply characteristics of debris flow based on land use types in the upper Min River, China

Mingtao Ding¹, Guohui Yang¹, Zemin Gao¹, Tao Huang¹

Faculty of Geosciences and Environmental Engineering, Southwest Jiaotong University, Chengdu 611756, China 1475906765

Mingtao Ding (Corresponding author), http://orcid.org/0000-0003-4839-7337, E-mail: mingtaoding@swjtu.edu.cn

Abstract. Land-use type is a natural choice of human social and economic activities. This study investigates the typical debris flow gullies of the upper Min River and analyses the supply characteristics and activity of its material sources under various land-use types using multi-stage remote sensing images data and geographic information system software. The results demonstrate the following: (1) the land-use type does not restrict the loose material source of debris flow near the fault zone; (2) the degree of cultivated land, forest (grass) land, bare land, and urban and rural construction land promote debris flow disaster formation in different channels far from the fault zone; (3) the gully exhibits significant influence on human engineering activities, and there are more loose material sources between the bare land and urban and rural construction land; (4) more loose material sources are observed in forest (grass) land and cultivated land in debris flow channels with vegetation development. In summary, before the Wenchuan earthquake, the debris flow source centroid is far from the debris flow channel, but after the earthquake, the debris flow material source centroid is near the debris flow channel.

1. Introduction

Recently, debris flow disasters have become more severe due to the intensification of natural variability and overexploitation of land resources. Concurrently, severe debris flow disasters have further destroyed land resources, forming a vicious loop that has significantly affected societal and economic sustainable development.

To investigate the relationship between debris flow disasters and land use types, we first look at how human economic activities interact with the formation and occurrence of debris flow. Cheng et al.¹ believed that unreasonable steep slope farming, bare land, and road construction often promote the outbreak of debris flow. However, the occurrence of debris flow disasters has nothing to do with land-use types under extremely high rainfall conditions; the debris flow will break out if the rainfall is high enough. Cannon² thought that debris flow was more likely to occur after fires in New Mexico, Southern California, and other places. The exposed loose material on the slope after the vegetation is destroyed the primary material source of the debris flow. In contrast, topography and stratum lithology can have a greater impact on the direction of debris flow development. Pabst et al.³ investigated vegetation types in the debris flow sediments in Oregon, USA. They analyzed the succession characteristics of vegetation in the debris flow gully and concluded that substrate variation, source, and distribution of propagules, competitive ability, and shade tolerance all impact vegetation succession patterns in the debris flow gully. Sorg et al.⁴ investigated the growth pattern of tree annual rings within the debris flow gully in the Swiss Alps using the tree annual ring reconstruction method.
The result showed that the most recent period of destructive events on the surface, as well as the spatial and temporal impact patterns of past debris-flow activities, can be determined using the annual ring method combined with maps. Bollschweiler et al. [5] analyzed the effects of historical mudflow events on plants using ecological knowledge by observing characteristic points of fir trees on both sides of the mudflow channel, such as trunk scars, exposed root systems, and tilted trunks. The findings show that the ecological landscape method is more suitable than the trunk chronology method for determining the effects of historical mudflow events on plants. Rood[6] chose a debris flow gully in the Vimy peak of the Canadian Rockies as a study area, demonstrating that while it is difficult for the vegetation in a debris flow gully to adapt to external disturbances, it eventually adapts with a rapid transformation.

The upper Min River is a typical ecologically fragile area, and intensive human economic activities further promote the development of debris flow[7-10]. In this study, typical debris flow gullies, such as Qipan Gully, Haermu Gully, and Seergu Gully, are selected to analyze the spatial distribution characteristics of loose sediment on the slope of debris flow gullies under different years and land-use types based on the statistical data of loose sediment in the gullies, and then discuss the debris flow loose-sediment source activeness.

2. Study area

The Min River upper reaches is located northwest of the Sichuan Basin, east of Aba Autonomous Prefecture, and east of the Tibetan Plateau (30°45′N–33°10′N, 102°35′E–103°57′E). The upper Min River’s mainstream is 330 km long, with a basin length of 267 km from north to south, a width of 152 km from east to west, and a basin area of 21,899 km², including most of the Wenchuan County, Mao County, Lixian County, Songpan County, Heshui County, and a small part of Dujiangyan City in Aba Tibetan Autonomous Prefecture[11-13] (Figure 1).

![Figure 1. Geographical location of typical debris flow gully in the upper Min River.](image)

3. Data and Processing

3.1 Data source

Google Earth images from 2007, 2009, and 2013 were chosen as the base data for this study (Table 1). Image cropping is the process of removing areas outside the interested area based on specific requirements. The standard study area extent data are first imported into the ENVI 4.8 software and converted to the region of interest (ROI). Further, irregular cropping was performed by the Subset Data via ROI tool. Then, the final image map of the study area was obtained (Figure 2).
### Table 1. Google Earth image resolution of representative debris flow gullies in the upper Min River.

| Image       | 2005 | 2009 | 2013 |
|-------------|------|------|------|
| Qipan Gully | 2.15 | 1.07 | 0.54 |
| Haermu Gully| 2.15 | 1.07 | 0.54 |
| Seergu Gully| 2.15 | 1.07 | 0.54 |

### Figure 2. Representative debris flows gully images in the upper Min River.

#### 3.2. Data Processing

#### 3.2.1 Land use classification

Based on the national land classification standard, the distribution characteristics of land types were visibly identified using Google Earth images with the support of ENVI 4.8 software. A certain number of uniformly distributed regions of interest was circled for each type of land. In addition, the training samples were combined with standardized processing to perform supervised classification of the upper reaches of Min River into arable land, forest (grassland), and bare land using the maximum likelihood method. In this study, the slope surfaces on both sides and backsides of Qipan Gully were classified into five categories: arable land, forest (grass) land, urban and rural construction land, bare land, and glacier; the slope surfaces on both sides and backsides of Haermu Gully and Seergu Gully were classified into four categories: arable land, forest (grass) land, urban and rural construction land, and bare land (Figure 3).
3.2.2 Material source surface circling of debris flow gully

The Qipan Gully, Haermu Gully, and Seergu Gully material sources are the products of internal and external dynamic geological effects on both sides of the gully, and the surface land use demonstrates different degrees of influence on the erosion intensity of the slope surface. In ArcGIS software, the geographically aligned image map was used to circle the debris flow source surface based on the land use type of each gully. In addition, a visual interpretation method was employed to obtain the debris-flow source surface remote-sensing interpretation map in different years (Figure 4), which has a resolution of 1.5–3.0 m.

3.3. Data analysis methods

3.3.1 Analysis method of debris flow source distribution characteristics

(1) Elevation: Using ArcGIS software platform, based on a remote sensing image map of each period, typical debris flow gully DEM, and debris-flow source surface data, we convert debris-flow
source surface data to vector points, with each point being the shape center of debris flow source surface. Thus, the elevation distribution of each debris flow gully for different years and various land-use types was obtained.

(2) Slope: We use the raster calculator in ArcGIS to add the three slope classification layers, land-use type, and circled source surface and set the layer values of thousands, hundreds, tens, and single digits before the summation operation to comprehensively analyze the distribution of various land-use types under different slope conditions.

3.3.2 Debris flow gully activity analysis method

The 2007, 2009, and 2013 source surface data are directly converted into point elements. It is difficult to evaluate the point elements of different locations in three different periods as the same point element. However, the same point element in different locations can be categorized using a unique assignment of the attribute table, and the calculation principle of the Near tool is shown in Figure 5.

![Point to point distance](image1.png)  ![Point to line distance](image2.png)  ![Point to polygon distance](image3.png)

**Figure 5.** Calculation principle of Near tool.

4. Results and Discussion

4.1. Characteristics of typical debris flow gully source distribution

When the elevation distribution of each type of land use is compared with the source points (Figure 6), the distribution interval of cultivated land (pink curve) is smaller, and it is mainly distributed on the slopes on both sides near the entrance of Qipan Gully. The average slope on both sides is about 24°, which can be used as cultivated land in the mountainous area where the slow land is limited. The vertical comparison reveals that there is no mudflow source distribution in the upper area of arable land, and the arable land has almost no contribution to the mudflow sources in Qipan Gully. Glaciers (lavender curve) are mainly located at the top of the trench and in the upper and middle areas above an average altitude of 3200 m.

Recently, there have been no noticeable changes in land-use practices in Haermu gully. The four land-use types in Figure 6 have relatively consistent elevation distribution trends. Notably, the elevation distribution of cultivated land (blue curve) in the table’s sections I and II is higher than that of the source point (black curve). The range of sections I and II accounts for most of the entire gully. Combining this statistical data with remote sensing image analysis revealed that the source in Haermu gully is mostly distributed at about 2500 m, whereas the distribution of cultivated land is slightly higher in elevation than the source point.

The recent trend in elevation distribution of various lands uses in Seergu gully is relatively consistent. There have been no significant changes in land use types over the years. When comparing the elevation distribution of each type of land use with the source of debris flow (Figure 6), the bare land (orange curve) and urban and rural construction (blue curve) types are similar to the source. The slope on the right side of the Seergu gully was damaged, exposing the bedrock, intensifying soil erosion, and loose soil and debris flow down the slope, adding to the debris flow’s material sources.
Most of the loose material in the Qipan gully slopes under different slope conditions are distributed in the slope interval of $30^\circ$–$40^\circ$ (Figure 7), which is related to the topographic and geomorphological characteristics of the Min River’s upper reach. The slope in the Qipan gully channel is steep since it is in the juvenile stage. In the glacier area, the softer terrain is distributed only at the foot of the slope on both sides of the channel and the top of the gully. In the range of less than $40^\circ$ slope, the loose material increases with the slope; it reaches the maximum at about $40^\circ$ slope. The resting angle is too large to retain loose material. From the chronological changes (Figure 7), the area of loose material in the bare land and glacier areas increased significantly in 2009 and 2013, and the strong seismic effect intensified gully downcutting, making it difficult to retain the initially preserved avalanche slope accumulation on the steep walls of the valley slopes on both sides of the gully channel, with back source tens of meters high. In addition, some gullies formed under the effect of freezing and thawing collapse bodies or continuous avalanche slide groups, becoming the source of debris flow material under severe seismic effects. There are limited sources of arable land and urban and rural construction land among the remaining land-use types, and the section above the gully channel’s outlet (explosives depot) is a narrow gully bed area due to the influence of the Qipan gully channel’s geomorphology.

The loose material on the Haermu gully slopes is generally distributed in the slope interval from $20^\circ$–$40^\circ$, and the major types of material source supply include forest and grassland. The total area of distributed material sources was 221,221.5 m$^2$, 794,250.2 m$^2$, and 200,026.6 m$^2$ in 2005, 2009, and 2013, respectively, in terms of temporal changes, with the most significant number of material sources in 2009 (Figure 7). Loose material on the slopes of Seergu gully is generally distributed in the slope interval of $30^\circ$–$40^\circ$, and bare land is the major land type for the supply of material sources. The total area of distributed material sources was 54,800 m$^2$, 124,590 m$^2$, 118,852 m$^2$ in 2005, 2009, and 2013, respectively, in terms of temporal changes, with 2008 being the turning point for the surge of material sources.
4.2 Analysis of the physical source activity of the debris flows trench.

In the glacial permafrost within the Qipan gully debris flow, the distance of the source surface shape center from the gully in 2007 is smaller than that in 2009 and 2013, and the distance difference in 2009 and 2013 is insignificant; the difference between distance in each year in the bare land and forest land is insignificant (Figure 8a). The distance of the loose material from the trench keeps getting far with time in the frozen soil, which is slightly different from a previous analysis. However, it is also consistent with the reality that when the mound descends due to gravity erosion, the loose material from the center migrates toward the main trench. The center of the mound moves up and away from the trench if the lower part of the mound is washed away by surface runoff.

In the forest land, cultivated land, and urban and rural construction land within the Seergu gully in Heishui County, the distance was significantly more prominent in 2007 than in 2009 and 2013. There was no significant difference between distance in 2009 and 2013, and no significant difference between distance in bare land in any of them (Figure 8b, c). Thus, seismic effects induced the transport of loose material on the surfaces of forest land, arable land, and urban and rural construction land. In addition, because these types of land use are closely related to artificial production activities, human activities facilitate the transport of loose material in debris flows\footnote{14,15}.

5. Conclusion

1. In the upper reaches of the Min River, where debris flow gullies are close to the rupture zone, the seismic energy is so high that changes in land use patterns no longer affect the degree of damage to slope surfaces on both sides of the debris flow gullies. Bare land and urban and rural construction sites produce a more loose material in the trench with intense human engineering activities. In addition, the loose material can be directly converted into mudflow fluid material under the effect of heavy rainfall.

2. Generally, from the trends of debris-flow source form centers in 2005, 2009, and 2013 in Haermu gully, Seergu gully, and Qipan gully, the source form centers were far from the channel in...
2005 before the earthquake. However, after the earthquake in 2009 and 2013, the source form centers were closer to the channel, and the debris flow became more active.

**Acknowledgments**

This research was financially supported by the National Natural Science Foundation of China (Grant No. 41871174) and the project of Science and Technology Department of Sichuan Province (Grant No. 2020YFSY0013).

**References**

[1] Anderson M G and Collison A J 1996 Using a combined slope hydrology/stability model to identify suitable conditions for landslide prevention by vegetation in the humid tropics. Earth Surface Processes and Landforms. 21 8 737-747.

[2] Cheng J D, Huang Y C, Wu H L, Yeh J K and Chang C H 2005 Hydrometeorological and land use attributes of debris flows and debris floods during typhoon Toraji, July 29–30, 2001 in central Taiwan. Journal of Hydrology.306 1-4 161-173.

[3] Cannon S H. 2001 Debris-flow generation from recently burned watersheds. Environmental & Engineering Geoscience.7 4 321-341.

[4] Pabst R J and Spies T A 2001 Ten years of vegetation succession on a debris-flow deposit in Oregon. J. Water Resources Association. 37 6 1693-1708.

[5] Sorg A, Bugmann H, Bollschweiler M and Stoffel M 2010 Debris-flow activity along a torrent in the Swiss Alps: Minimum frequency of events and implications for forest dynamics. Dendrochronologia. 28 4 215-223.

[6] Bollschweiler M, Stoffel M and Schneuwly D M 2008 Dynamics in debris-flow activity on a forested cone - a case study using different dendroecological approaches. Catena. 72 1 67-78.

[7] Wei S C 2008 Geological environment analysis and application research for land use planning. Hangzhou: Zhejiang University.

[8] Ding M T, Huang T, Zheng H and Yang G H 2020 Author Correction: Respective influence of vertical mountain differentiation on debris flow occurrence in the Upper Min River. China. Scientific reports. 10 1 17124.

[9] Ding M T, Tang C and Miao C. 2020 Response analysis of valley settlements to the evolution of debris flow fans under different topographic conditions: a case study of the upper reaches of Min River. China. Bulletin of engineering geology and the environment. 79 3 1639-1650.

[10] Zemin Gao, Mingtao Ding, Tao Huang and Xiewen Hu. 2021. Geohazard vulnerability assessment in Qiaojia seismic zones, SW China. International Journal of Disaster Risk Reduction. 52 101928.

[11] Liu J F, You Y, Chen X C, Fan J R and Key L 2010 Identification of potential sites of debris flows in the upper Min River drainage, following environmental changes caused by the Wenchuan earthquake. Journal of Mountain Science. 7 3 255-263.

[12] Wang P, Zhang B, Qiu W L and Wang J 2011 Soft-sediment deformation structures from the Diexi paleo-dammed lakes in the upper reaches of the Min River, east Tibet. Journal of Asian earth sciences. 40 4 865-872.

[13] Ding H, Li Y, Ni S J, Ma G W, Shi Z M, Zhao G H, Yan L and Yan Z K 2014 ZIncreased sediment discharge driven by heavy rainfall after Wenchuan earthquake: A case study in the upper reaches of the Min River, Sichuan, China. Quaternary international. 333 122-129.

[14] Gan, B. R, Liu X N, Yang X G, Wang X K and Zhou Z W 2018 The impact of human activities on the occurrence of mountain flood hazards: lessons from the 17 August 2015 flash flood/debris flow event in Xuyong County, south-western China. Geomatics, Natural Hazards & Risk. 9 1 816-840.

[15] Dorn R I 2016 Identification of debris-flow hazards in warm deserts through analyzing past occurrences: Case study in South Mountain, Sonoran Desert, USA. Geomorphology (Amsterdam, Netherlands). 273 269-279.