Analysis on the Susceptibility of Debris Flow along a Highway in Gannan

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Abstract. Under the background of the rapid economic growth in China, domestic infrastructure construction is also constantly improving. Thereof, the rapid development of highways and railways is outstandingly expanding. During the construction and operation of highways and railways, geological disasters often occur along the railway, which seriously endanger people's lives and property and sustainable economic and social development. Among them, debris flow is one of the most serious geological disasters that endanger highway safety. The proposed Zhuoni-Hezuo Section of Fengxian (Shaanxi) to Hezuo (Gansu) Expressway is an important part of the expressway in Gansu Province. The debris flow along the expressway, debris flow, seriously threatens the safety construction and later operation of the proposed highway. Taking the debris flow along the proposed expressway as the research object, this paper comprehensively collects the geological data of the area, studies its characteristics of distribution, formation and movement on that basis, and summarizes its formation conditions and mechanism, then evaluates its susceptibility. This paper is a certain reference for the study of debris flow in the region and the governance over it in next step.

Keywords: Debris flow, Formation conditions, Dormation mechanism, Geographic Information System

1 Introduction
In recent years, China's geological disasters outbreak frequently, such as landslides, debris flows, which result in great losses. Taking debris flow into consideration, it is true that debris flow occurs frequently in China and, the occurrence of it is often sudden and rapid, accompanied by landslides, floods and other destruction phenomena. The hazards caused by it are more extensive and serious than those caused by single landslides and floods [1]. Among them, Gansu Province has witnessed many mudslide disasters, with a distribution range of about 110,000 hm², accounting for 24.29% of the province's land area, and there are more than 8,000 debris flow valleys, which is one of the areas with high-geological disaster occurrence and one of the four major debris flow disaster areas in China [2].
Susceptibility assessment of debris flow is the premise of risk assessment, which is to predict the possibility of future occurrence of geological disasters in the region through the analysis and assessment of debris flow formation conditions or formation conditions combination [3,4,5,6,7]. Based on the field investigation, this paper combines the GIS platform to analyze the influencing factors of debris flow occurrence [8,9,10], evaluates the sensitivity of debris flow along the highway, and provides a basis for the prevention and control of debris flow in the next step.

2 The General Condition of the Study Area
The proposed Gannan Expressway is an important part of the provincial expressway network in Gansu province. It is located in in Gannan Tibetan autonomous prefecture of Gansu province, and the northeastern part of the Qinghai-Tibet plateau, the western part of the Loess Plateau and the transition part of the Longnan mountainous region. The debris flow developed in the area under study mainly happens in the slope valley along the highway. Part of the proposed highway passed through the debris flow circulation area and the accumulation area in the form of subgrade bridges and culverts. Due to the certain development of debris flow along the highway, it threatens the construction and safe operation of the proposed Gannan Expressway.

3 The Basic Characteristics of Debris Flow
Due to the complex geological structure, various types of rock and soil, different topography and landforms, and relatively developed faults and folds, the geological hazard -- debris flow in the proposed highway area are more serious under the combined impact of natural disasters such as heavy rainfall, climate and earthquake, as well as the influence of engineering activities. Through remote sensing interpretation of GIS and field investigation in the scope of 300 meters on both sides of the proposed highway, 44 debris flows were found along it.

Geologists have done a lot of research on the classification of debris flow types. At present, the types of debris flow are classified by geologists in terms of landform, provenance, water source characteristics, outbreak frequency, material composition, fluid properties and outbreak scale. According to the above criteria, the debris flow along the highway can be divided into the following types. According to the classification of water sources, the debris flow along the highway is rainstorm (rainfall) type debris flow; according to the classification of source causes, the debris flow on along the highwayline is mostly slope erosion type debris flow; According to the classification of landform characteristics in catchment area, the debris flow along the highway is mainly Valley-type debris flow; according to the classification of the outbreak frequency, the debris flow in the Lintan county area along the highway generally occurs once every 3 to 5 years, or once every 5 to 10 years, it is identified as the intermediate frequency debris flow; the frequency of the debris flow in the Zhuoni county area is generally about 2 to 3 times per year or even once in over ten years, which is a medium-high frequency debris flow; according to the composition of the material, the debris flow along the highway is mostly of mudstone type; according to the classification of fluid properties, the debris flow along the highway is mostly viscous debris flow; according to the classification of scale of once debris flow outbreak along the highway, the debris flow is small-scaled debris flow and medium-scaled debris flow, which 21 are small landslides, accounting for about 48% of the total; 23 are medium debris flow, accounting for about 52% of the total.

4 The Formation Condition of Debris Flow
The formation conditions of debris flow in the study area can be summarized into four aspects: suitable topographic conditions, abundant material resources, sufficient water resources and active human activities. The four conditions are briefly described below:

4.1 Favorable topographical condition
From the vertical point of view, the minimum height difference between the high point of the catchment and the mouth of the debris flow basin in the study area is 110 m, and the maximum is 600 m, the minimum length of the main ditch area is 290 m, the maximum is 3 510 m, and the longitudinal slope of the ditch is 4.95. %~40%, the average longitudinal slope about 18%, the minimum catchment area 0.07 km², and the
maximum 3.92 km², which provides favorable conditions for the formation of debris flow; from the horizontal point of view, the source area is mostly "V" shaped valley, and the slope of the two sides of the valley is about 20 ° ~ 40 °, so the ditch is favorable for the formation of landslides, collapse, surface slip and other unfavorable geological phenomena; from the plane point of view, most of the debris flow basins are funnel-shaped, which is more conducive to the collection of surface water.

4.2 Abundant loose deposits

The surface layer of the mountain in the study area is often covered with a layer of loose deposits of the quaternary system, resulting in poor stability of the surface of the slope, and small scaled collapse and slip phenomenon sometimes occurs. Residual slope sediments on valley slopes, slope diluvium at channel, weathering of bare bedrock in mountain and adverse geological phenomena on both sides of channel all provide material sources for the formation of debris flow.

4.3 Abundant water source

The study area has abundant precipitation. Rainstorms and continuous rains frequently happen, and there are also extraordinarily heavy rainstorms. The average annual precipitation is 580 mm, and most of precipitation are concentrated in May-September, accounting for 83%-88% of annual precipitation. Heavy rain and torrential rain generally occur in April-October, and mainly concentrated in June-August. The catchment area is up to 3.24 km². Therefore, this short-duration, high-intensity precipitation and favorable catchment conditions in the study area provide sufficient water source for the outbreak of debris flow.

4.4 Active engineering activities

Due to the rapid increase of population and the rapid development of industrial and agricultural production, people's exploitation of natural resources is deepening and the scale of exploitation is growing. The number of debris flows induced by human factors such as unreasonable excavation of railway, highway and buildings in on the rise.

5 The Formation Mechanism of Debris Flow

The formation mechanism of the geological disaster, namely debris flow is the basis of its entire movement process. Through the studying of the formation mechanism of debris flow, it is possible to truly understand the specific situation of its formation movement from the essence and the root cause. The formation mechanism of debris flow geological disasters is the basis of its entire movement process, by studying the formation mechanism of debris flow, it is possible to truly understand the specific situation of its formation movement from the essence and the root cause.

The above interpretation of the basic characteristics of the debris flow, the formation conditions in the study area and the remote sensing of GIS reveals: most of the debris flow ditch in the study area developed in the erosion and gully land forms, the valleys are strongly cut and the terrain is undulating and the relative height difference is large so it is easy to cause the instability of the slope and unfavorable geological phenomena such as landslides and collapses, so that it directly contributes to the debris flow. The larger groove bed ratio increases the instability of loose solid matter and provides a certain potential energy and the steeper slope increases the flow velocity on the slope surface and the confluence velocity of the channel, which indirectly affects the way and quantity of solid material supply. The smaller catchment area is more prone to the formation and movement of debris flows. The leaf-shaped and funnel-shaped watershed forms are very beneficial to the collection of water flow, and can quickly provide sufficient hydrodynamics for debris flow outbreaks; Under the action of structure and weathering, the rock mass is broken and the surface layer is thicker, the reserves of loose solid material are relatively abundant, through slope erosion, lateral erosion, collapse and trench bed uncovering provides a large number of material sources for debris flow; Under the circumstance featured by favorable terrain and abundant material resources, the study area also has the characteristics of short duration and high intensity rainfall. Heavy rain impacts on valleys and slopes of river basins, and some water enter the surface to form underground runoff, which can soften the soil structure and lead to structural instability of the soil on slopes, often inducing slope damage, and its solid...
matter slides into the channel to supplement debris source for debris flow. Some water form surface runoff and flow into the trench along the surface, which not only removes more sediment from the surface through the surface erosion, but also recharges solid material of debris flow by side erosion ditch bank and digging ditch bed during channel circulation. In the rainy season, the water flow peaks creates stronger dynamic conditions, which drives abundant loose material sources to form debris flows.

6 Analysis of Debris Flow Susceptibility

6.1 The evaluation Principle

(1) To evaluate the potential debris flow hazards that endanger the safety of people's lives and property and affect the safety of the proposed expressway.

(2) To comprehensively consider the various geological environmental conditions and influencing factors affecting the development of debris flow.

(3) To combine qualitative analysis with quantitative evaluation.

6.2 The assessment foundation

The occurrence of debris flow is related to many active factors in the basin, which will change dynamically after being affected by heavy rain or other factors. In this paper, 15 parameters are selected as the basic factors, and collated according to their significance. Each factor is quantified by four levels of susceptibility. Thus, a quantitative scoring table of susceptibility degree of debris flow gully is compiled. Based on the geological environment conditions affecting the development of debris flow, this paper evaluates the susceptibility of debris flow through “Quantitative Scale of Debris Flow and Difficulty”.

| Numb-er | Influencing factor                      | Quantitative division |
|---------|----------------------------------------|-----------------------|
|         |                                        | Extreme (A)           | Moderate (B) | Mild (C) | Slight (D) | Poin-t    |
| 1       | degree of disaster                     | very serious          | 21          | 16       | 12         | no serious |
| 2       | sediment recharge length ratio along the course (%) | >60                   | 16          | 12       | 8          | <10        |
| 3       | activity of main sulcus                | bend or block         | 14          | 11       | 7          | no change  |
| 4       | longitudinal slope of river gully      | >12º                   | 12          | 9        | 6          | <3º        |
| 5       | regional structure                     | strong uplift area, Fault fracture | 9          | 7        | 5          | stable region |
| 6       | vegetation coverage rate (%)           | <10                    | 9           | 7        | 5          | >60        |

Table 1. Quantitative scoring table of debris flow gully susceptibility
6.3 Evaluation Method
Fifteen factors affecting the development of debris flow as shown in the table above are scored one by one, and then the susceptibility of debris flow along the highway in the study area is evaluated by synthesizing the scores. The criteria for the classification are shown in the table below.

Table 2. Debris flow grade score table

| Number | Influencing factor | Quantitative division | Extremely prone (A) | Moderately prone (B) | Mildly prone (C) | Slightly prone (D) |
|--------|--------------------|-----------------------|---------------------|---------------------|-----------------|-------------------|
| 8      | lithology effect   | soft rock, Loess      | 6                   | 5                   | 4               | 1                 |
| 9      | loose reserves (10^4 m³/km^2) | >10                  | 6                   | 5~10                | 4               | <1                |
| 10     | hillside gradient  | >32º                  | 6                   | 25º~32º             | 4               | <15º              |
| 11     | trench cross section | v-shaped valley, U-shaped valley | 5               | wide U valley       | 4               | compound section  |
| 12     | loose average thickness (m) | >10                  | 5                   | 5~10                | 4               | <1                |
| 13     | drainage area (km²) | 0.2~5                 | 5                   | 5~10                | 4               | >100              |
| 14     | relative height difference of watershed (m) | >500                  | 4                   | 300~500             | 2               | <100              |
| 15     | degree of river channel blockage | serious              | 4                   | medium              | 3               | slight            |

6.4 Evaluation Result
According to the above principles, bases and methods, 44 spots of debris flow ditches with hidden dangers in the area are assessed, the specific assessment results are shown in Table 3. The results showed that there was no debris flow that extremely easily occurred in the study area, and 32 were moderately easy to occur, accounting for 73% of the total, and 12 were mildly susceptible, accounting for about 27% of the total. Therefore, the debris flow in the study area is mainly moderate and mildly susceptible.

7 Conclusion
This paper takes 44 debris flows along the Gannan Expressway as the research object, and also investigates and researches on the debris flow along the highway through GIS remote sensing interpretation, field investigation and statistical analysis. The main conclusions are as follows:
(1) By analyzing the distribution characteristics of debris flow along the route, it shows that the debris flows in the study area are spatially distributed along both sides of the valley, with the characteristics of
uneven overall distribution and relatively concentrated in some parts of areas, and most of them developed in 
the tectonic denudation landforms featured with high mountains and deep trenches; it shows seasonal, 
sudden and periodic characteristics in terms of occurrence time; the main hazards mainly are burying and 
destroying by rush of water.

(2)This paper is based on the analysis of the formation conditions of debris flow in the study area, this 
paper concluded that abundant loose solid substances are the basic requirements for the formation of debris 
flow in this area, the erosion and gully terrain are important for the formation of debris flow in this area, and 
abundant precipitation is a necessary requirement for the formation of debris flow in this area, moreover 
active engineering activities create favorable conditions for the formation of debris flow in this area. These 
four factors cooperate and complement with one another to jointly create the formation conditions for debris 
flow in this area.

(3)The analysis of the susceptibility of 44 debris flows in the study area by means of quantification 
assessment of debris flow susceptibility reveals that the debris flow along the highway is mainly moderately 
susceptible and mildly susceptible, and no debris flows in the area are the ones that extremely easily happen. 
Among them, 12 are slightly susceptible to debris flow, accounting for 27% of the total, and 32 are 
moderately susceptible to debris flow, accounting for 73% of the total. However, when encountering with 
heavy rain or torrential rain, the probability of occurrence is 85%, and the chance of a debris flow outbreak is 
relatively high, which shows that water is an extremely important factor contributing to the occurrence of 
storm-type debris flows.

(4)Because the collection and collation of information and data are still incomplete, this paper has not 
conducted discussion on other motion parameters such as impacting force, climbing height, and curve height 
of each debris flow developed along the highway in the process of exploring the characteristics of debris 
flow movement, which can be discussed as the focus in the next stage of analysis and research.

References

[1] Bin-rui Gan, Xing-nian Liu, Xing-guo Yang, Xie-kang Wang, Jia-wen Zhou: 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 and 
Risk, 2018,9(1).

[2] C. J. Van Westen, A. C. Seijmonsbergen, F. Mantovani: Comparing Landslide Hazard Maps. Natural 
Hazards, 1999, Vol.20 (2-3), pp.137-158.

[3] Pirrung D, Futterer H, Grobe J, et al: Magnetic susceptibility and ice-rafted debris in surface 
sedi-ments of the Nordic Seas: implications for IsotopeStage 3oscillations. Geo-Mar Lett, 2002, 22 
(2):1-11.

[4] M. Nishio, M. Mori: ANALYSIS OF DEBRIS FLOW DISASTER DUE TO HEAVY RAIN BY 
X-BAND MP RADAR DATA. Remote Sensing and Spatial Information Sciences, 2016, XLI-B8.

[5] MAKINO Hiroshi, NISHIMURA Naoki, MANTOKU Masaaki, ISHIKAWA Yoshiharu, 
NISHIMOTO Haruo: Recognition, opinion and evaluation of sabo by the residents around debris 
flow disaster stricken area in Miyake Island. Journal of the Japan Society of Erosion Control 
Engineering, 2015,68(4).

[6] Martino Bernard, Mauro Boreggio, Massimo Degetto, Carlo Gregoretti: Model-based Approach for 
Design and Performance Evaluation of Works Controlling Stony Debris Flows with an Application 
to a Case Study at Rovina di Cancia (Venetian Dolomites, Northeast Italy). Science of the Total 
Environment, 2019,688.

[7] Tan Chun, Chen Jianping, Pan Yuzhen, Niu Cencen, Li Mingxu: Fuzzy Matter-Element Evaluation 
Method for Analysis of Debris Flow Risk Assessment. Advanced Materials Research, 2012,1615.

[8] Chen Xingzhang, Hui Chen, Yong You, Chen Xiaqing, Liu Jinfeng: Weights-of-evidence method 
based on GIS for assessing susceptibility to debris flows in Kangding County, Sichuan Province, 
China. Environmental Earth Sciences, 2016, Vol.75 (1).

[9] Xu Wenbo, Yu Wenjuan, Jing Shaocai, Zhang Guoping, Huang Jianxi: Debris flow susceptibility 
assessment by GIS and information value model in a large-scale region, Sichuan Province (China).
[10] Chien Yuan Chen, Fan-Chieh Yu: Morphometric analysis of debris flows and their source areas using GIS. Geomorphology, 2011, 129(3-4).