Risk Assessment of Debris Flow in Longchi Area of Dujiangyan based on GIS and AHP

Hai Xiao¹*, Xingsheng Tang², Hongtao Zhang²

¹College of Architecture and Urban-Rural Planning, Sichuan Agricultural University, Dujiangyan, China
²College of Architecture and Urban-Rural Planning, Sichuan Agricultural University, Dujiangyan, China

*Corresponding author’s e-mail: 6178565@qq.com

Abstract. In this study, a combination of analytic hierarchy process (AHP) and geographic information system (GIS) was used to analyze and obtain remote sensing images and digital elevation models (DEM) in the area through field surveys. The seven factors of rock layer type, vegetation cover index (NDVI), slope, height, fault influence zone, river influence zone and highway influence zone were selected. The purpose is to study the distribution range and law of debris flow at different levels in the area. The results show that the area is a highly prone area for debris flow for sand-mud interlayer and NDVI less than 0.10, the slope between 30° and 45°, the height between 950-1300 meters, the fault impact zone within 400 meters, the river within 100 meters on both sides of the river, and the highway is 75 meters on both sides.

1. Introduction
Debris flow refers to the special torrent with landslides that are deep in mountainous areas or other gullies on the basis of their own conditions such as difficult terrain, loose rock, low vegetation coverage, and induced by heavy rain, snow, or other natural disasters. The Longchi area of Dujiangyan City is located in the center of the Wenchuan earthquake, and there are three seismic fault zones distributed in this territory. Therefore, the Longchi area is greatly affected by the earthquake, and the earthquake often changes the geological conditions of this area, which can provide the conditions for development and occurrence of debris flow. Runqiu Huang put forward that the geological disasters in the Wenchuan earthquake-stricken area will last for 20-25 years after the earthquake. During this period, the geological disasters will take a peak of 4-5 years as a cycle, and are declined in an oscillating manner, and finally recover to the status and level before earthquake [1]. Based on a field survey of debris flow disasters in the Longxi River Basin of Dujiangyan City, Caixia Li used the MFCAM model to conduct a risk assessment and analysis of debris flows in the Longxi River Basin [2]. Based on the GIS and AHP methods, Hairong Ma and others selected 8 factors such as lithology and slope to classify and evaluate the risk of debris flow on mountain highways [3]. At present, debris flow risk assessment is mainly based on GIS technology, combined with AHP or related driving models, using GIS data management and spatial analysis, demonstration mapping and other functions to achieve disaster analysis and risk assessment.
2. Data sources and research methods

2.1. Data sources
The 2018 Landsat satellite remote sensing image data of Dujiangyan City, DEM data of Dujiangyan City, geological map of Sichuan Province and administrative division map of Dujiangyan City were used in this work. The remote sensing image data and DEM data were downloaded from the Geospatial Data Cloud website. The geological map of Sichuan Province and the administrative division map of Dujiangyan City were obtained through the Sichuan Bureau of Surveying, Mapping and Geoinformation. Due to different data sources, they need to be unified to Xi’an 80 coordinate system, the administrative division of Longchi Town is used as mask data, and the satellite remote sensing image data, DEM data, geological distribution data, river distribution data, and main road data of Longchi area are processed.

2.2. GIS
GIS is a highly comprehensive discipline and is widely used in many fields. This study uses GIS's spatial data processing and analysis capabilities, combined with remote sensing software to extract NDVI from satellite remote sensing images, and perform data classification extraction and overlay analysis on the evaluation factors affecting debris flow in order to complete the danger of debris flow evaluation analysis.

2.3. AHP
AHP is a decision-making method that decomposes the elements that are always related to decision-making into different levels, and performs qualitative and quantitative analysis on this basis [4]. In this study, AHP is used to calculate the weight of each evaluation factor of debris flow, and the weight value of each evaluation factor is obtained.

The selection of debris-flow risk assessment factors depends on the formation and development of debris flow disasters. The formation of debris flow disasters is affected by many factors. In the mechanism of debris flow disasters, the main controlling factors and inducing factors of debris flow are often used as the main influencing factors of debris flow risk assessment [5]. Among them, the main controlling factors provide a material basis for the occurrence of debris flows, including terrain, vegetation, slope, rock formations, and fault zones, etc., which are the main basic conditions for breeding debris flows. Induced factors provide external power for the occurrence of debris flows. Debris flows often occur due to the presence of induced factors, including induced rainfall and human activities. Based on the geographical environment of Longchi area, this study selected 7 factors, such as rock formation type, NDVI, slope, elevation, fault affected zone, river influence zone, and highway influence zone, as the evaluation factors of the risk zone for the risk of debris flow disasters in the research area. Especially to point out that the rainfall is the important factor to induce debris flow disasters, but due to the small scope of Longchi regions in this study area and the random heavy rainfall in the history of the spatial distribution, therefore, it is not included in the evaluation system of rainfall as there are no differences in rainfall.

2.3.1. Determine evaluation factor weights. In this study, factors from C₁₁ to C₁₇ are used to represent rock type, NDVI, slope, elevation, fault impact zone, river influence zone, and highway influence zone in order. W represents the weight value of each evaluation factor obtained through AHP. In the evaluation criteria for the importance of the evaluation index, the importance comparison is performed between each of the above evaluation factors to construct a judgment matrix (Table 1).

| C₁-C₁₇ | C₁₁ | C₁₂ | C₁₃ | C₁₄ | C₁₅ | C₁₆ | C₁₇ | W   |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|
| C₁₁    | 1   | 1   | 1   | 5   | 1/2 | 1/2 | 1   | 0.1368|
| C₁₂    | 1   | 1   | 1   | 3   | 1/2 | 1/2 | 1   | 0.1273|
| C₁₃    | 1   | 1   | 1   | 3   | 1   | 1   | 1/2 | 0.1405|
The weights of the evaluation factors from $C_{11}$ to $C_{17}$ calculated by the AHP algorithm are $0.1368$, $0.1273$, $0.1405$, $0.0412$, $0.2246$, $0.1970$, and $0.1326$. The maximum characteristic root of the above judgment matrix is $\lambda_{\text{max}} = 7.0095$, according to formulas (1) and (2), consistency check is performed on the judgment matrix. After testing, $CI = 0.0016$ and $CR = 0.0012 < 0.1$ were demonstrated. Through this AHP, so the evaluation factor weights are more reasonable.

$CI = \frac{\lambda_{\text{max}} - n}{n-1}$

$CR = \frac{CI}{RI}$

2.3.2. Evaluation factor classification. Because the units of measurement of the debris flow evaluation factors and the degree of influence on the vulnerability of debris flow disasters are different, each evaluation factor must be normalized. According to the correlation between the evaluation factors and the susceptibility of debris flow disasters, and referring to relevant literature, the debris flow evaluation factors are graded using expert scoring methods (Table 2).

| Evaluation factor grade | Rock formation type | NDVI (%) | Slope (°) | Elevation (m) | Fault influence zone (m) | River influence zone (m) | Highway impact zone (m) |
|------------------------|---------------------|----------|-----------|--------------|--------------------------|-------------------------|------------------------|
| 1                      | Granite             | >0.15    | <15       | <950         | 800-1000                 | 150-200                 | 75-100                 |
| 2                      | Limestone           | 0.10-0.15| >60       | >2500        | 600-800                  | 100-150                 | 50-75                  |
| 3                      | Andesite            | 0.03-0.10| 15-30     | 950-1300     | 400-600                  | 50-100                  | 25-50                  |
| 4                      | Mudstone            | <0.03    | 30-45     | 1800-2500    | 200-400                  | 0-50                    | 0-25                   |
| 5                      |                     | 45-60    | 1300-1800 | 0-200        |                          |                         |                        |

3. Results and analysis

3.1. Analysis of rock type, NDVI and terrain
Geological distribution map of Longchi area was obtained from the geological map of Sichuan Province. Use the grid calculator in ArcGIS to assign a null value to 0, then assign the grade value of the rock formation type to the raster data in accordance with the debris flow evaluation factor classification criteria. To get a classification map of rock formation types in Longchi area. As shown in Figure 1, Granite, Limestone, Andesite, and Mudstone are in order from north to south, with Granite accounting for the largest proportion.

By using Erdas, the NDVI was extracted from the remote sensing images in Longchi area, and a thematic map of NDVI in Longchi area was generated. The NDVI contains a grid with a value of 0, and a grid with a value of 0 is an important boundary point for judging the features of the NDVI. Therefore, it is necessary to classify the grid to the vegetation in Longchi area firstly according to the grading standard of debris flow evaluation factors. The index thematic map is graded, then the raster calculator is used to assign a null value to 0 to obtain a map of the NDVI in Longchi area. As shown in Figure 2, most of the NDVI in this area is between 0.10 and 0.15, and the NDVI below 0.03 is mainly concentrated in the southern valley area.
The terrain analysis tool in ArcGIS was used to calculate the slope and elevation of DEM data of Longchi area according to the classification standards in Table 2. From Figure 3, it can be seen that the slope is less than 15° and is distributed in the north and south regions, mainly concentrated in the valley area. Most of the southern region has a slope between 15° and 30°. Figure 4 shows that the elevation from north to south decreases in sequence from 2500 meters to 950 meters.

3.2. Analysis of fault influence zones, river influence zones and highway influence zones
According to the geological map of Sichuan Province and the classification criteria of fault zones in Table 2, multi-loop buffer analysis is performed on the seismic fault zone in Longchi area, and the grade value is assigned to the grid data to obtain the classification of seismic fault influence zone in Longchi area. It can be seen from Figure 5 that the seismic fault zone is in the form of three strips from the southwest to the northeast, and is concentrated in the south central region.

Based on the remote sensing image of Longchi area, the area features of the river are created and vectorized. According to the grading standards in Table 2, multi-loop buffer analysis is performed on the vector river data, and it is output as raster data to obtain the river impact in Longchi area with a grading chart. It can be seen from Figure 6 that the river network density in the northern and central regions is relatively high, but the river width in the southern region has increased significantly due to the influence of topographical factors.

Also based on the remote sensing image of Longchi area, highway is created area features and vectorized. According to the grading standards in Table 2, multi-loop buffer analysis is performed on the vector highway data, and the output is raster data to obtain the highway in Longchi area. Impact band grading diagram. Figure 7 shows that highways are mainly concentrated in the southern region due to the influence of human activities, and the more concentrated settlements can cause the higher density of the highways.
3.3. Debris flow risk assessment and analysis
An evaluation database is established for the above 7 evaluation factors. According to the weight value of each evaluation factor obtained by AHP and the debris flow evaluation factor classification criteria, a weighted summation is used for all evaluation factors, such as formula 3.

\[
S = 0.1368 \times C_{11} + 0.1273 \times C_{12} + 0.1405 \times C_{13} + 0.0412 \times C_{14} + 0.2246 \times C_{15} + 0.1970 \times C_{16} + 0.1326 \times C_{17} \tag{3}
\]

S represents the degree of danger of debris flow susceptibility in the study area. The larger the S value is, the higher the debris flow susceptibility is. With reference to relevant literature, according to the grading standards and principles of the S value, the S value is divided into high, medium, low, and micro according to the susceptibility of debris flow disasters to ≥ 2.5, 1.5-2.5, 1.0-1.5, and ≤ 1.0 degree. Figure 8 shows that the area of highly dangerous debris flow is 8.62 km², mainly distributed in the rivers and gullies in the south of Longchi area. The area of moderate danger of debris flow is 36.92 km², mainly in the south slopes of the Longchi area and the rivers and gullies in the north. The area of high-risk area is 28.58 km², mainly distributed in the northern slopes of Longchi area. The area of non-dangerous area is 10.29 km², mainly distributed in the flat areas of northern Longchi area.

4. Conclusion
In this study, through the selection of the debris flow disaster assessment factors and the classification of the evaluation indicators in the Longchi area of Dujiangyan City, and using the AHP to calculate the weight of each assessment factor, the spatial analysis tools of ArcGIS and Erdas were used to complete the assessment of Dujiangyan. The risk assessment of debris flow disasters in Longchi area of the city, combined with the actual statistics of debris flow and field investigation and analysis in Longchi area, has obtained relatively ideal results, which provides relevant references for the risk assessment of debris flow in local areas on the seismic fault zone.

References
[1] Runqiu Huang. (2011) Effect analysis of geological disasters after the earthquake in Wenchuan. Journal of Engineering Geology., 19(2): 145-151.
[2] Caixia Li, Yu Ma. (2019) Causes, characteristics and hazard assessment of the debris flows in Longxi river basin, Sichuan province. Geology and Resources., 28(3): 298-304.
[3] Hairong Ma, Xinwen Cheng. (2016) Hazard evaluation of debris flow along highway based on GIS and AHP. Highway Engineering., 41(1): 33-37.
[4] Bingjiang Zhang. (2014) Analytic hierarchy process and its application case. Publishing House of Electronics Industry, Beijing.
[5] Xilin Liu, Chuan Tang. (1995) Debris flow risk assessment. China Science Publishing, Beijing.