RISK ASSESSMENT OF GEOLOGICAL DISASTERS ALONG THE G213 MAOXIAN-WENCHUAN SECTION BASED ON GF-6 DATA

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ABSTRACT:

China is a country prone to natural disasters, and roads are easily damaged in natural disasters. As the infrastructure of people's production and life and the lifeline of post-disaster rescue, roads play a very important role. There are many previous studies on geological disasters risk assessment, but few special researches on highway geological disasters risk assessment, especially quantitative risk assessment combined with remote sensing images. Therefore, the risk assessment of geological disasters along the road is of great significance for the prevention and control of geological disasters and the protection of life and property safety. Based on GF-6 data and other geographic data, this study used the comprehensive evaluation method to realize the geological disasters risk assessment of the Maoxian-Wenchuan section along the G213 line, and analysed and discussed the causes and spatial distribution of geological disasters along the G213 line. Our study presents several key findings, (1) The order of impact degree of each impact factor is road network density, soil erosion, slope, human activities, vegetation coverage, rainfall, and slope aspect, among them, the road network density factor plays a leading role, and the aspect factor is the least impact factor; (2) The geological disasters risk in the study area is divided into five categories: extremely low risk, low risk, medium risk, high risk, and extremely high risk. In general, the geological disasters risk of the research road section is relatively high, and the risk area division is consistent with the historical disaster point data. The research results can provide reference for the smooth development and implementation of road geological disasters risk assessment in the mountainous areas in southwestern China.

1. INTRODUCTION

The changeable topography and complex climate change have led to frequent geological disasters in China, and roads are easily damaged in natural disasters, which brings great inconvenience to our production and life (Gao et al. 2017). At present, road disasters such as landslides, debris flows, ground fissures, collapses and road collapses are extremely destructive to traffic safety, ecological environment and economic construction (Fan et al. 2022; Zhao et al. 2018). And the roads in the southwest mountainous areas are widely distributed and scattered. Traditional manual verification methods face problems such as low efficiency, large errors, high costs, and difficult supervision, and cannot provide efficient and accurate census data for targeted poverty alleviation (Cui et al. 2013). Therefore, it is of great significance for the prevention and investigation of geological disasters along the road to carry out the risk assessment of geological disasters based on the remote sensing data of GF-6, and combined with the data of topography, human activities and meteorology.

At present, many experts and scholars have carried out a lot of research on geological disasters risk assessment. For example, Liu et al. selected seven factors including slope angle, slope aspect, elevation, normalized vegetation index (NDVI), soil water content (SMC), and distance from rivers and roads as evaluation factors to realize the risk assessment of small landslides (Liu et al. 2021). In the landslide susceptibility evaluation study, Wang et al. found that it is difficult to evaluate the landslide susceptibility at the regional scale only considering rainfall. Therefore, in the study, the factors such as terrain, geology, faults, and lithology were integrated, and a more accurate result was obtained (Wang et al. 2020). Vincenzo et al. determined 8 landslide susceptibility evaluation factors in Mauritius as the study area, and this study can be effectively applied to other similar areas (Marsala et al. 2019). Scholars such as Zhao have comprehensively considered five factors of terrain, rainfall, gully density, geological type and vegetation coverage, and based on multi-factor evaluation model and GIS technology, they have evaluated the road slope hazards in northern Shaanxi, and classified the study area according to mild, moderate and the three levels of severe are divided into corresponding dangerous areas (Zhao et al. 2018). Although the above studies provide some reference for the risk assessment of geological disasters along roads, most of these studies are aimed at a single geological disaster in a certain administrative area, and it is impossible to comprehensively evaluate various geological disasters in a certain study area, and it is difficult to obtain accurate comprehensive evaluation results.

Therefore, this study takes the national highway G213 Maoxian-Wenchuan section located in the mountainous area in southwestern China as an example. Based on GF-6 data and various basic geographic data, the geological disasters risk along the G213 Maoxian-Wenchuan section is quantitatively analysed by comprehensive evaluation method. The geological disasters risk assessment map of the G213 Maoxian-Wenchuan section was obtained, and the spatial analysis was carried out to obtain the geological disasters risk assessment results in the study area. The research is of great significance for discovering the hidden major geological disasters along the road and providing scientific and reasonable geological disaster prevention measures and suggestions.

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2. STUDY AREA

2.1 Study Area

The G213 line starts from Langmusi (K1685.874) in Ruoergai County and ends in Wenchuan County Friendship Tunnel (K2177.059) in Aba Prefecture, Sichuan Province, China. It is 491.185 kilometres long and is the main channel in Aba Prefecture. The section from Songpan County (K1923.749) to Wenchuan County (K2104.561) of the G213 line is located in the Longmenshan fault zone. The landform features of mountains and valleys are obvious, and geological disasters occur frequently all year round. From January to October 2018 alone, more than 80 road passages were affected by geological disasters such as landslides, mudslides, and roadbed collapse, and they have the characteristics of multiple points, wide areas, strong suddenness and great harm. Therefore, this study selects the G213 Maoxian-Wenchuan section as the study object. This road section passes through 8 townships. The study area is shown in Figure 1.

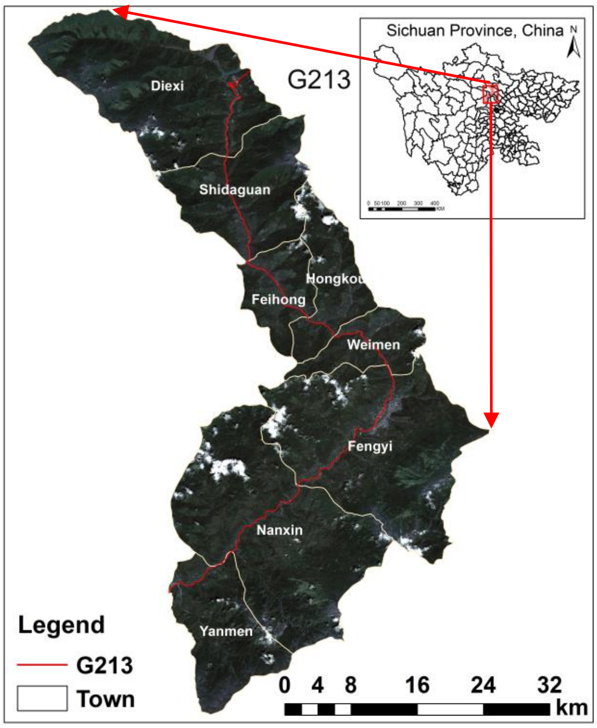

Figure 1. Schematic diagram of the study area.

2.2 Data Source

The remote sensing data used in this study is the GF-6 remote sensing image taken in July 2020. The panchromatic spatial resolution of GF-6 remote sensing images is 2m, and the multispectral spatial resolution is 8m. And other data include administrative division data, rainfall data, DEM data and soil erosion data, which are all from the Resource and Environment Science and Data Center of the Chinese Academy of Sciences (https://www.resdc.cn/), among which, the data type of administrative division data is vector data and the rest are raster data. The data of the disaster points come from the Sichuan Provincial Road Network Monitoring and Emergency Response Center. Data details are shown in Table 1.

Data	Type	Origin
GF-6	Raster data	National Space Administration Earth Observation and Data Center
Administrative division data	Vector data	The Resource and Environment Science and Data Center of the Chinese Academy of Sciences
Rainfall data	Raster data	
DEM	Raster data	
Soil erosion data	Raster data	
Disaster point data	Raster data	Sichuan Provincial Road Network Monitoring and Emergency Response Center

Table 1. Data source.

3. RESEARCH METHODS

To assess the risk of geological disasters along the G213 Maoxian-Wenchuan section, based on GF-6 data and other basic geographic data, this study selected the slope, aspect, soil erosion, vegetation coverage, road network density, human activities and rainfall in the region as the disasters risk assessment factors. The comprehensive evaluation method was used to establish the risk assessment model of geological disasters along the G213 Maoxian-Wenchuan section. Combined with GIS spatial analysis method, the spatial distribution of geological disasters along the section were analysed and evaluated. The framework of the geological disasters risk assessment model is shown in Figure 2.

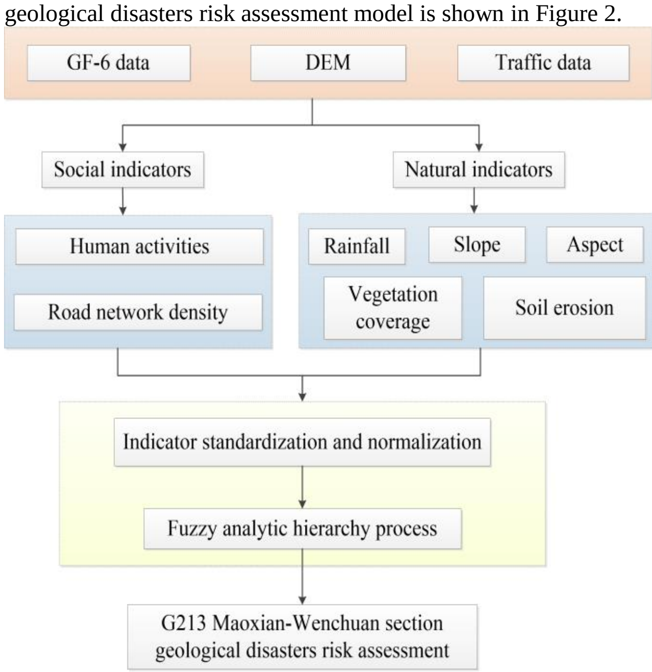

Figure 2. Framework of the geological disasters risk assessment model.

3.1 Spatial Quantification of Geological Disasters Risk Assessment Factors

The index system of geological disasters risk assessment includes target layer, criterion layer and factor layer. The target layer refers to the risk level of geological disasters, reflecting the risk of geological disasters in the study area; the criterion layer includes two types of indicators, natural and social, and the factor layer is the sub-indices corresponding to the two types of indicators in the criterion layer. Natural indicators include factors such as rainfall, slope, slope aspect, vegetation coverage and soil erosion; social indicators mainly include two factors: human activities and road network density.

3.1.1 Social indicators: (1) Human activities. Human activities disturbance refers to the disturbance of the ecological environment in a certain area affected by human activities, and it is an important indicator to evaluate the degree of regional human activity disturbance to the natural environment (Liu et al. 2018). With the rapid development of population, economy, science and technology, human demand for resources and energy is increasing day by day, and the damage of human activities to the environment is also expanding, which has seriously affected the environment on which human beings depend and created conditions for the occurrence of various geological disasters (Sun et al. 2021). Inspired by the literature (Sun et al. 2020), this study obtained the final quantitative results of human activity disturbance space by assigning different land use categories.

(2) Road network density. The road network density refers to the ratio of the total mileage of the road network in a certain area to the area of the area. The road network density reflects the influence of traffic activities, and the linear density interpolation method is generally used to calculate the road network density in the study area (Zhang et al., 2022).

3.1.2 Natural indicators: (1) Slope. The slope is the degree of steepness of the surface unit. Usually, the ratio of the vertical height *h* of the slope to the distance *l* in the horizontal direction is called the slope (or slope ratio). Many data show that different slope aspects directly affect the water and heat conditions of the slope, even if the elements of natural geography show regularity, it is an important factor for the development of geological disasters, and is closely related to the risk level of geological disasters. Inspired by the literature (Liu et al. 2021), this study first calculates the slope through the DEM of the study area, and then reclassifies the hazard of different slopes to obtain the spatial distribution map of the slope in the G213 Maoxian-Wenchuan section.

(2) Aspect. Aspect is defined as the direction of the projection of the slope normal on the horizontal plane, which has a great effect on mountain ecology. Inspired by the literature (Wang et al., 2020), this study first calculates the aspect by using the DEM in the study area, and then reclassifies the hazard of different slopes to obtain the spatial distribution map of the aspect in the G213 Maoxian-Wenchuan section.

3.1.3 Indicator normalization: The dimensions of each evaluation factor in geological disasters risk assessment are inconsistent, so the original data of each factor cannot be directly used for geological disasters risk assessment. Before the evaluation, it is necessary to normalize each factor, so that the data value of each factor is distributed between [0-1], and the influence of the inconsistency of the original data dimension is eliminated. Commonly used methods include Min-max method, Z-score method, fuzzy membership degree method, etc. (Wang et al. 2019). In this study, the fuzzy membership method is used to normalize each factor. Since different evaluation factors will show different positive or negative correlations to geological disasters risk, they should be calculated separately. The normalized formulas of the positive and negative indicators are shown in formula (1) and formula (2), respectively (Li et al. 2018).

Positive factors:

$$x_{ij} = \frac{v_{ij} - \min_{1 \le i \le k}(v_{ij})}{\max_{1 \le i \le k}(v_{ij}) - \min_{1 \le i \le k}(v_{ij})} \tag{1}$$

Negative factors:

$$x_{ij} = \frac{\max_{1 \le i \le k}(v_{ij}) - v_{ij}}{\max_{1 \le i \le k}(v_{ij}) - \min_{1 \le i \le k}(v_{ij})} \tag{2}$$

in these equations, x_{ij} is the normalized score of the *j* value of the *i* evaluation factor, v_{ij} is the original value of the *j* value of the *i* evaluation factor, and *k* is the number of evaluation factors.

3.2 Geological Disasters Risk Assessment Weight

The fuzzy analytic hierarchy process (Fuzzy–AHP) is a decision-making method based on the traditional AHP, considering the ambiguity of people's judgment on complex things, and introducing a fuzzy consensus matrix. The biggest problem of AHP is that when there are many evaluation indicators at a certain level (such as more than four), it is difficult to guarantee the consistency of thinking (Hemant et al. 2022). In this case, Fuzzy Analytic Hierarchy Process (FAHP), which combines the advantages of fuzzy method and analytic hierarchy process, will be able to solve this problem very well.

Firstly, a fuzzy complementary judgment matrix is established. In the Fuzzy-AHP, the importance of one factor compared to the other is quantitatively expressed when comparing and judging between factors. The relative importance of any two factors about the evaluation target, usually the following [0.1-0.9] scaling method is used to give a quantitative scale (Radionovs et al. 2016). The expression of fuzzy complementary judgment matrix is shown in formula (3).

$$A = \left(a_{ij}\right)_{n*n} \tag{3}$$

where, *A* represents the fuzzy complementary judgment matrix, and a_{ij} represents the importance of the factor *i* compared to the factor *j*.

Secondly, calculate the weight of the fuzzy complementary judgment matrix, the formula is shown in (4).

$$w_i = \frac{\sum_{j=1}^{n} a_{ij} + \frac{n}{2} - 1}{n(n-1)} \tag{4}$$

where, w_i represents the weight of the single-level factor, a_{ij} represents the importance of the factor *i* compared to the factor *j*, and n represents the number of single-level factors.

Finally, the consistency test of the fuzzy complementary judgment matrix is also carried out. Whether the weight value obtained by the weight formula of the fuzzy complementary judgment matrix is reasonable still needs to be checked for the consistency of the comparison judgment. If the offset consistency is too large, the calculation result of the weight vector is unreliable (Guo et al. 2021).

The consistency test method of fuzzy complementary judgment matrix is as follows:
(1) Check the satisfactory consistency of *m* judgment matrices A_k:

$$\left(A_k, W^{(k)}\right) \le A, k = 1,2,..,m \tag{5}$$

2) Check the satisfactory compatibility between the judgment matrices:

$$I(A_k, A_I) \le A, k \ne 1; I = 1,2,\ldots,m \tag{6}$$

It can be proved that under the condition that the fuzzy complementary judgment matrix is uniformly acceptable, their comprehensive judgment matrix is also uniformly acceptable. When the above two conditions are met, the weight calculation result of the factor set *X* is reasonable and reliable; otherwise, the comparison judgment matrix needs to be adjusted or reconstructed.

The weights of each factor calculated by the fuzzy analytic hierarchy process are shown in Table 2.

Assessment factors	Weight
Human activities	0.1484
Road network density	0.1748
Slope	0.1492
Aspect	0.0991
Rainfall	0.1331
Vegetation coverage	0.1359
Soil erosion	0.1595

Table 2. Weight of risk assessment indicators.

3.3 Geological Disasters Risk Assessment

In order to further analyse the risk level, this study combined the weight of each factor on the risk with the geological disasters risk assessment factor, and carried out spatial weighted superposition in ArcGIS to establish a geological disasters risk assessment model in the study area (Formula (7)), and obtained the distribution map of each factor. The final results were classified by the natural discontinuity method, which identified breakpoints by class breakpoints with similar values in the classification, which can reduce the differences within different levels and maximize the differences between levels (Chen et al. 2021). According to the literature research results (Chen et al. 2021), the geological disasters risk and other places were divided into five categories, namely 0.00-0.14 extremely low risk, 0.14-0.24 low risk, 0.24-0.36 medium risk, 0.36-0.53 high risk and 0.53-1 extremely high risk.

4. RESULT ANALYSIS

4.1 Analysis of Geological Disasters Risk Assessment Factors

Figure 3 shows the results of spatial quantification of geological disasters risk assessment factors in G213 Maoxian-Wenchuan section.

It can be seen from the land use classification map in Figure 3 (a) that the land use types in the study area are mainly forest land, and the residential areas are mainly villages, mostly scattered, and some towns are concentrated along the road. There are also bare lands along the road, which are easy to develop into landslides, collapses and other disasters under the influence of various factors. From the quantitative map of human activities space in Figure 3 (b), it can be seen that human activities in the study area are scattered and distributed, and the aggregation is not strong, only a small amount of aggregation in Fengyi Town. This is because the terrain in the study area is mainly mountainous, which is not suitable for the construction of large cities, and the distribution of settlements is mainly villages.

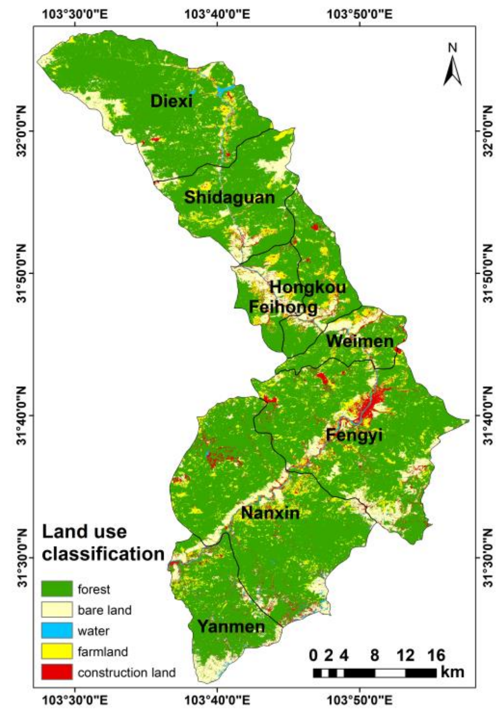

Figure 3(a). Land use classification.

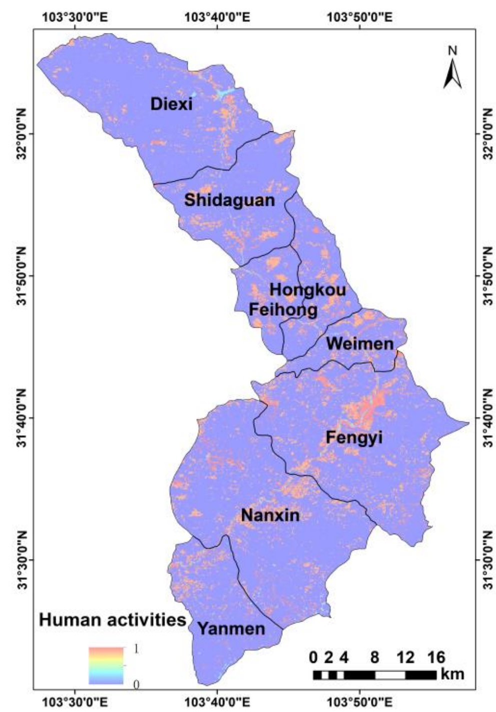

Figure 3(b). Human activities.

From the spatial quantization map of road network density in Figure 3 (c), it can be seen that the road network density of Fengyi Town, Nanxin Town and Yanmen Town is relatively large, radiating a certain area along G213, and the road network density of other towns is roughly the same, which is also concentrated around G213. This is mainly because G312 is the lifeline of the region and is also a vital and essential line locally. From the spatial quantification map of slope in Figure 3 (d), it can be seen that the slope distribution of villages and towns where each road section is located is relatively uniform. There are areas with higher slopes on both sides of G213, because G213 is located in the Longmenshan fault zone and the alpine canyon landform is obvious.

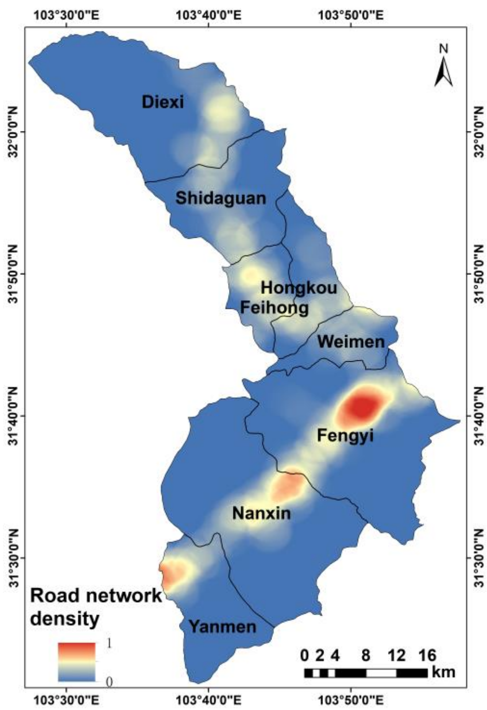

Figure 3(c). Road network density.

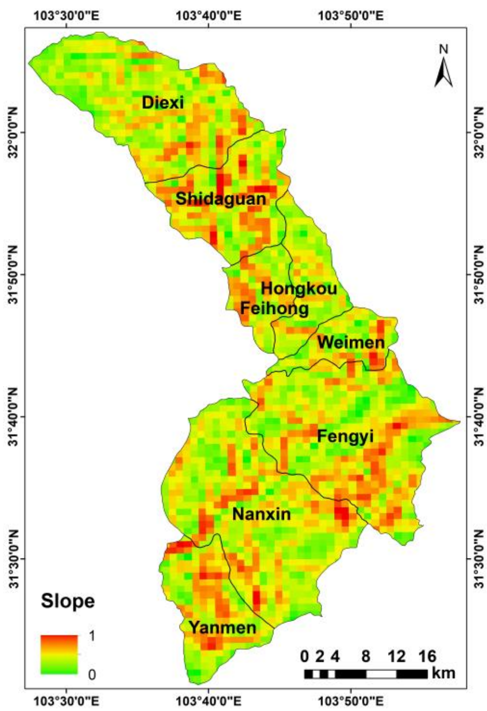

Figure 3(d). Slope.

According to the spatial quantification map of slope aspect in Figure 3 (e), the distribution of slope aspect in the study area is relatively balanced. The areas with high risk of slope aspect are Shidaguan Town, Feihong Town and Hongkou Town, while the risk of Diexi Town is low, and the risk of other towns is moderate. From the spatial quantitative map of soil erosion in Figure 3 (f), it can be seen that the soil erosion degree of Fengyi Town and Shidaguan Town is more serious, Feihong Town and Nanxin Town also have a certain degree of soil erosion, and Diexi Town, Hongkou Town, Weimen Town and Yanmen Town have less soil erosion.

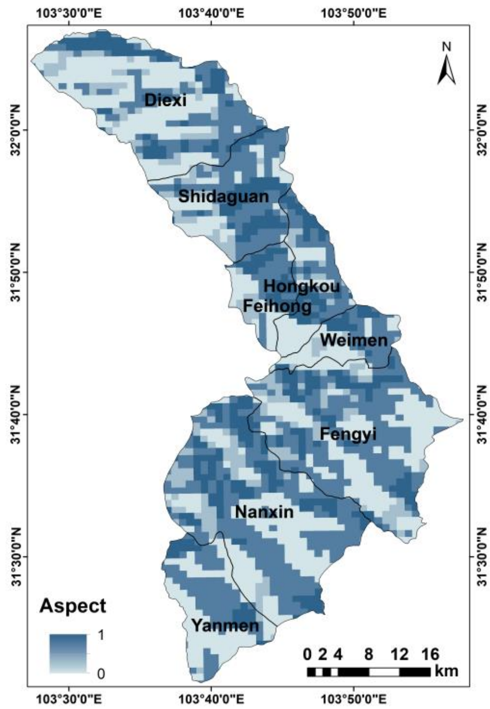

Figure 3(e). Aspect.

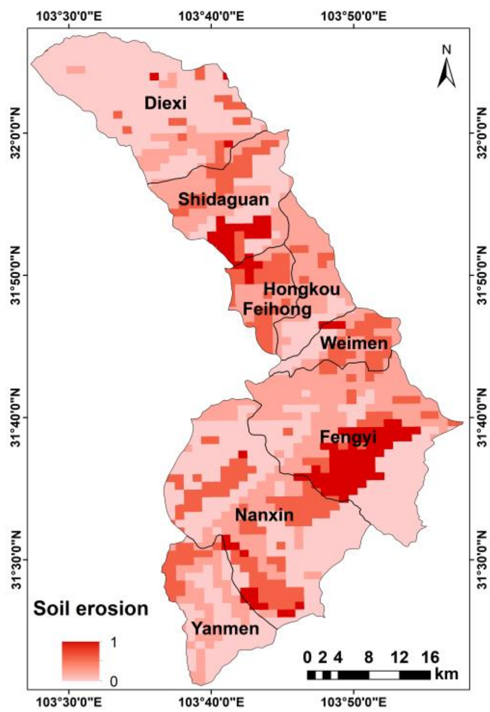

Figure 3(f). Soil erosion.

According to the spatial quantification of rainfall in Figure 3 (g), the rainfall in the study area is abundant. Among them, the northwest and southeast have more rainfall, and the central region has less rainfall. From the spatial quantification of vegetation coverage in Figure 3 (h), it can be seen that the study section is located in the mountainous area, with dense vegetation and wide distribution. There is no obvious difference in vegetation coverage among the towns where each road section is located. There are many residential areas on both sides of the road, so the vegetation coverage is smaller than in other places.

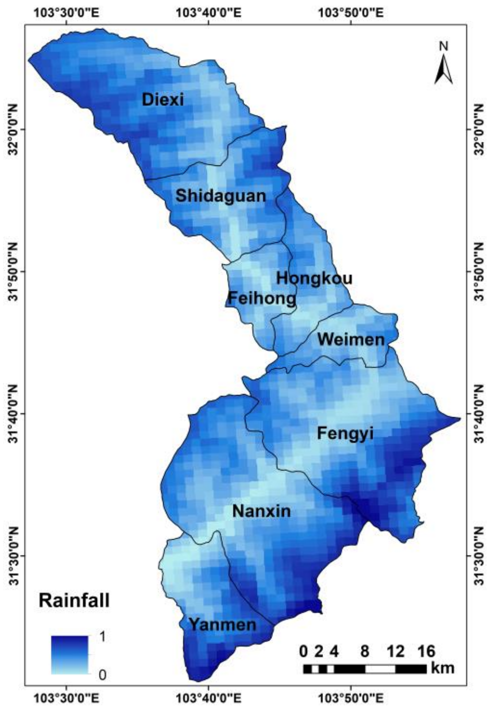

Figure 3(g). Rainfall.

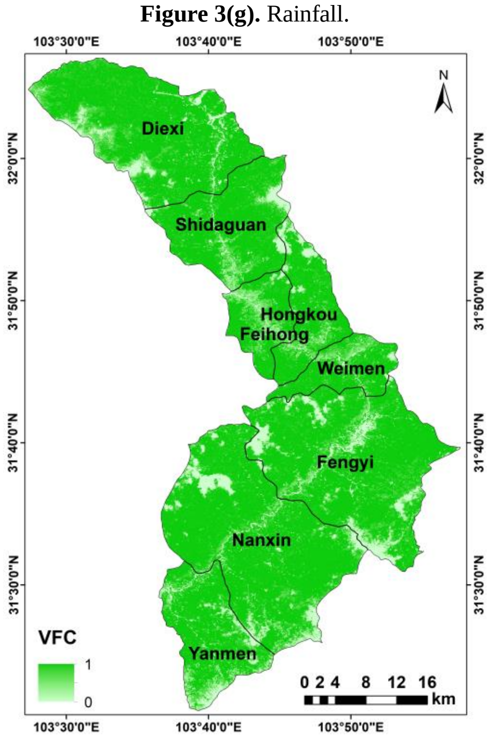

Figure 3(h). Vegetation coverage.

4.2 Spatial Analysis of Geological Disasters Risk Assessment

The final geological disasters risk distribution map is obtained by calculating the geological disasters risk evaluation factor by weight (Figure 4). According to Figure 4, the risk level of geological disasters in Fengyi Town, Nanxinxiang Town and Yanmen Town is mainly extremely high risk. In particular, Fengyi Town, where human activities are intense and road networks are dense, is more prone to disasters. High risk areas are mainly distributed in Diexi Town and Feihong Town, while Shidaguan Town, Hongkou Town and Weimen Town are mainly low risk and extremely low risk. To verify the results of the geological disasters risk assessment along the G213 Maoxian-Wenchuan section, this study compares and analyses the 12 geological disaster points actually collected from 2019 to 2020 and finds that, 50% of the disaster points are distributed in the extremely high risk area, 33% of the disaster points are distributed in the high risk area, and 17% of the disaster points are distributed in the medium risk area. It can be seen that the results obtained by the comprehensive evaluation method are in good agreement with the actual occurrence of geological disasters.

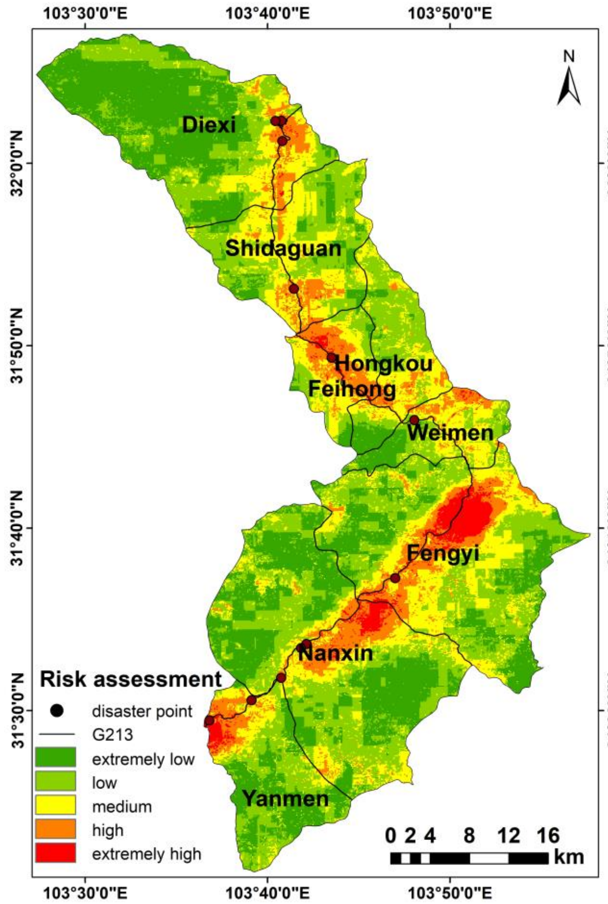

Figure 4. Risk assessment results of geological disasters along the G213 Maoxian-Wenchuan section.

5. CONCLUSION

In this study, the comprehensive evaluation method is used to carry out the risk assessment of geological disasters along the G213 Maoxian-Wenchuan section. The conclusions are as follows:

(1) Seven factors, such as slope, aspect, soil erosion, vegetation coverage, human activities, rainfall and road network density,

were selected as evaluation factors, and the weights of each factor were calculated by the fuzzy analytic hierarchy process, and the weights were as follows: road network density> soil erosion> slope> human activities> vegetation coverage> rainfall> aspect. Among them, road network density factor plays a leading role, while slope aspect factor is the least impact factor.

(2) According to the risk assessment results of geological disasters along the G213 Maoxian-Wenchuan section, the extremely high risk areas are mainly distributed in Fengyi Town, Nanxin Town and Yanmen Town, and the high-risk areas are mainly distributed in Diexi Town and Feihong Town, while Shidaguan Town, Hongkou Town and Weimen Town are mainly low risk and extremely low risk. Overall, regions with high risk are regions along the road, while regions with low risk are mountainous regions with lush vegetation. At the junction of townships, highway disaster prevention and control is weak, and the probability of highway natural disasters is extremely high. It is necessary to focus on strengthening monitoring and prevention. By comparing with the historically collected disaster points, it is found that the geological disasters risk assessment results are in good agreement with the actual situation.

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