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GIS-Based Geological Hazard Mapping Using Statistical Analysis and Cell Assignment Method for Western Sichuan Region, China

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Abstract: Geological hazards pose severe threats to the natural ecological environment, which endanger human life, cause damage to the environment, and undermine social stability. Studying geological hazards is intended to minimize or reduce any potential losses or threats. Although geotechnical hazards present a complex problem, hazard mapping and zoning studies can improve predictions and reduce losses. Based on the principle of geological hazard zoning, this paper describes a GIS-based approach to regional mapping for geological hazards, including collapse, landslide, debris flow, and overall geological hazards. First, four main factors affecting the occurrence of geological hazards, namely, digital elevation model (DEM), soil property, vegetation type, and average annual rainfall, are determined for analysis. Afterward, the investigated region of western Sichuan province, China, is divided into cells using GIS. The factors are then valued and assigned to the cells for statistical analysis. According to the relationship between the development/occurrence of geological hazards and various influencing factors, the region is first zoned with different degrees of susceptibility. Moreover, the response degree values for different levels of susceptibility to different influencing factors are determined for each cell, and then the superposition values of response degree for each cell are calculated for different geological hazards. Finally, the mapping of each geological hazard is done based on the calculated superposition value ranges. The mapping result demonstrates that the proposed approach is efficient and practical for determining the hazard susceptibility of regional geological hazards in western Sichuan province. The conclusions of this study can provide valuable information regarding the prevention and management of similar disasters in a region.

Keywords: Geological Hazard, Hazard Mapping, GIS, Western Sichuan Region

1. Introduction

Geological hazards are highly destructive events that can kill or injure people, cause property loss, or damage the environment [1]. Reports indicate that the losses from geological disasters are enormous [2]. Various geological disasters cause China to suffer annual economic losses estimated at 13–14 billion yuan [3]. In recent years, reducing and mitigating geological disasters has become a significant concern for societies and countries [4]. Although geological hazards are a complex problem, the study of hazard mapping and zoning can provide more accurate predictions, and losses can be reduced.

In the 1960s, Leighton et al. [5] applied the sensitive factor theory to study landslide hazard zoning in California to develop slope land resources. In the following years, scholars from various countries established various geological hazard zoning models incorporating a variety of factors [6-8]. Chazan et al. [6] proposed the ZERMOS method for the theoretical study of landslide hazards, using local mountainous regions of the country as the study area. To establish this landslide hazard zoning model, the control factors affecting the spatial distribution of landslides are considered. According to the degree of their influence, the two main control factors are chosen. Since the 1980s, using many mathematical methods, such as statistical analysis, artificial neural networks, and superpositions, scientists have used Geographic Information Systems (GIS) as an essential tool for zoning work on the susceptibility to a variety of geological disaster [9-19]. Using GIS technology, Finny Michael et al. [9] developed a basic method for landslide analysis. A study conducted by Van Gupta and Joshi [10] utilized GIS to study geological hazards in mountainous areas, develop a geological hazards database, and design an analysis and evaluation model. Carrara and Cardinali [11] analyzed geological hazards by combining the GIS platform and statistical analysis model. Clouatre et al. [12] used GIS for analysis of landslide hazard zoning in Gatineau, Canada, taking into account bedrock slope, urban water system, and historical landslide data. Fernandez et al. [13] tested the geological disaster susceptibility zoning map in southern Spain. They proved that the landslide zoning map established by the matrix model can be more accurate and effective in predicting landslide hazards, and the prediction results are highly reliable. Pachauri et al. [14] gave an example of landslide hazard zoning based on geology and topography in the Garhwal region of the Himalayas. In the early 21st century [20-27], Lee et al. [20] developed the zoning model of landslide susceptibility using two artificial neural network methods based on GIS technology. They took the Yongin area of South Korea as the research area and subsequently drew the landslide susceptibility zoning map of this area. Using bivariate statistical analysis and the entropy index of entropy, Constantin et al. [21] investigated landslide susceptibility in Romania's Sibiciu Basin based on the influencing parameters, such as slope angle, slope aspect, curvature, lithology, and land use. GIS has steadily become an important field when studying the susceptibility of geological hazards in various countries [28-34].

According to the National Geological Disaster Bulletin (2006-2018) [35-41], geological hazards in central and western China mainly include collapses, landslides, and debris flows. In western Sichuan, located in western China, road traffic development is relatively weak, emergency response is relatively slow, and geological hazards are generally unpredictable and sudden. Whenever a geological disaster occurs in this region, the losses may be high, the post-disaster recovery is complex, and the recovery period is lengthy. Thus, research on geological hazards in this region will be an essential part of disaster prevention and mitigation in Sichuan province. In order to implement effective geological disaster monitoring and prevention, it is essential first to determine in which zones geological disasters are more likely to occur.

The study uses the GIS platform to investigate the western Sichuan region, adopts a reasonable method of geological hazard zoning through the GIS platform, and proposes a cell assignment method based on statistical data analysis from a qualitative and quantitative evaluation perspective. Geological hazard susceptibility in the western Sichuan region is zoned using the cell assignment method. This work provides a scientific and reliable basis for preventing and controlling geological disasters in western Sichuan and provides a point of reference for subsequent development of the region.

2. Geological Hazard Zoning Method

In the western Sichuan region, the four main factors affecting the occurrence of geo-logical disasters can be categorized as digital elevation model (DEM), soil property, vegetation type, average annual rainfall.

2.1. Statistical Analysis

In this section, the geological disaster data, including collapse, landslide, and debris flow in the western Sichuan region, are primarily qualitatively analyzed in conjunction with quantitative evaluation. The western Sichuan region is then divided into different degrees of susceptibility based on the relationship between the development/occurrence of geological disasters and various influencing factors.

2.1.1. DEM

According to the DEM data, the western Sichuan region can be roughly divided into three types of areas: 1) Low-altitude areas: 2000m and below; 2) Middle-altitude areas: 2000m-4000m; 3) High-altitude areas: 4000m above sea level. A statistical analysis has been performed on a total of 12,056 geological disasters that have occurred in the western Sichuan region with the DEM data. As a result, their relationship is shown in Figure 1.

It can be seen that a greater probability of collapse occurred in low-altitude areas, a medium probability of occurrence in mid-elevation areas, and a smaller probability of occurrence in high altitude areas. Landslides are more likely to occur in low-altitude areas, moderately likely to occur in mid-elevation areas, and less likely to occur in high-altitude areas. Debris flows have a greater probability of occurrence in mid-elevation areas, a medium probability of occurrence in low-elevation areas, and a smaller probability of occurrence in high-altitude areas.

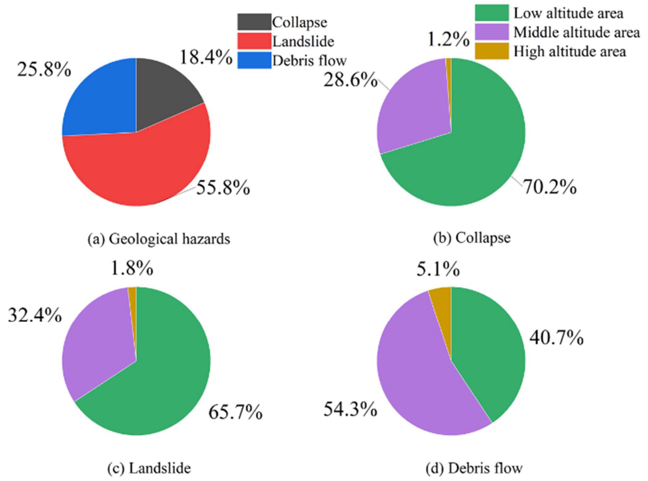

Figure 1. *The relationship between regional geological hazards and DEM data in Western Sichuan.*

Therefore, low-elevation areas can be roughly regarded as high susceptibility areas to collapses and landslides while middle-elevation areas have moderate susceptibility to collapses and landslides; Middle-elevation areas can be roughly regarded as high susceptibility area debris flow while low-elevation areas have moderate susceptibility to debris flow; High-altitude areas that basically do not occur geological disasters are regarded as low-prone areas for all investigated geological disasters. Based on the above analyses, the western Sichuan region is divided into a different degree of susceptibility for three geological hazards based on DEM data, shown in Figure 2 below.

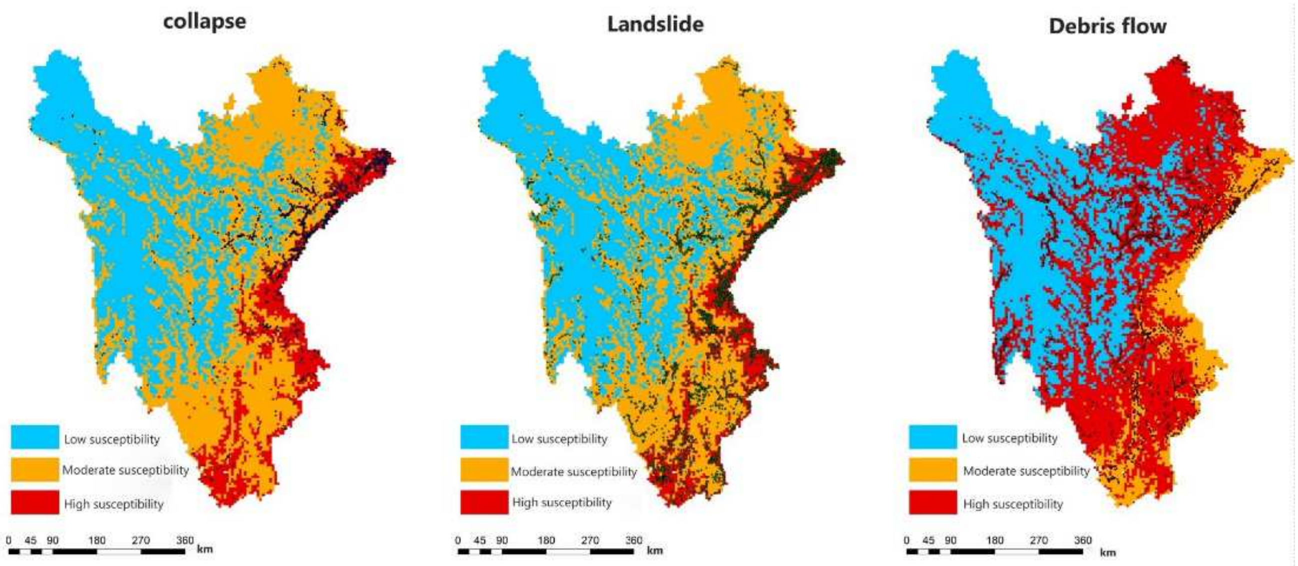

Figure 2. *Susceptibility zoning according to DEM.*

2.1.2. Soil Property

Using statistical analysis, Figure 3 examines the relationship between soil property and geological hazards in the western Sichuan region.

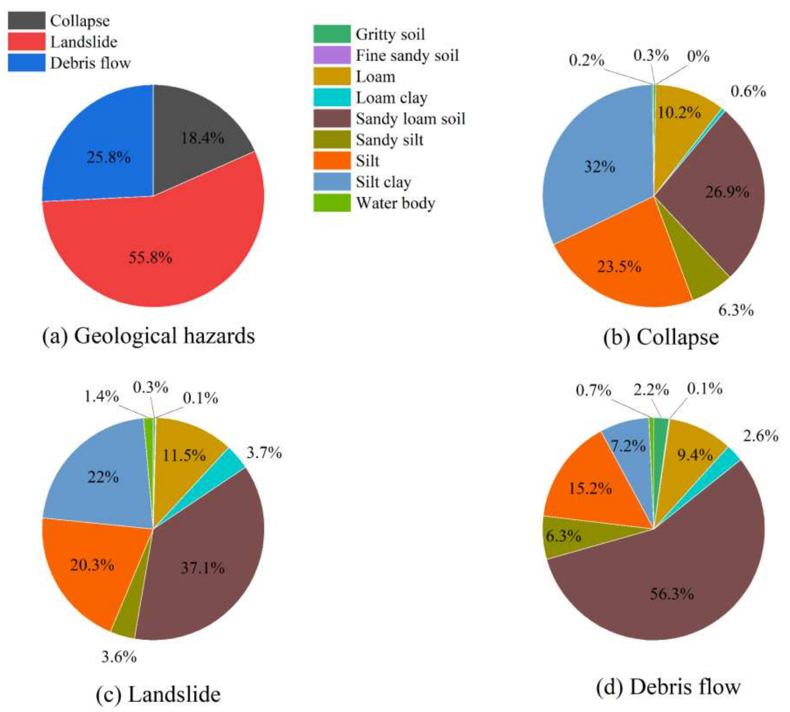

Figure 3. *The relationship between geological disasters and soil property data in western Sichuan.*

It can be seen that collapse occurred in silt clay, sandy loam, and silt areas with a high probability; moderate probability occurred in the loam area; less likely to occur in the sandy silt area, loam clay area, coarse sand area, water body area, and fine sand area. Landslides are more likely to occur in sandy loam areas, silt clay areas, and silt soil areas; moderate probability occurs in loam areas; less likely to occur in the loamy clay area, sandy silt area, water body area, coarse sand area, and fine sand area. Debris flows have a greater probability of occurring in sandy loam areas; a medium probability of occurrence in silt areas; less likely occurrences in loam areas, silt areas, sand and silt area, loamy clay area, coarse sand area, water body area, and fine sand area.

Based on the above statistics, according to the development and occurrence of geo-logical disasters in the western Sichuan region, the soil property is divided into three types:

(1) Soils for low susceptibility: soil type with a cumulative total of less than 10% of geological disasters;

(2) Soils for moderate susceptibility: soils with a cumulative total of 10%-20% of geological hazards;

(3) Soils for moderate susceptibility: soils with a cumulative total of more than 20% of geological disasters.

Using the GIS platform, the western Sichuan region was zoned according to different levels of susceptibility based on soil type, and the results are shown in Figure 4.

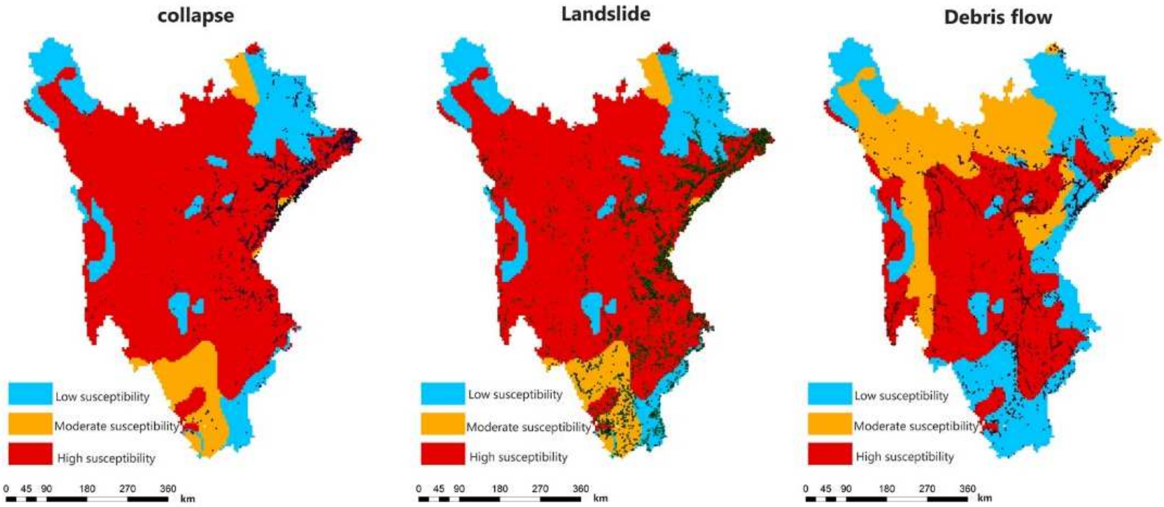

Figure 4. *Susceptibility zoning according to soil property.*

2.1.3. Statistical Analysis of Vegetation Types

Using statistical analysis, Figure 5 examines the relationship between vegetation type and geological hazards in the western Sichuan region.

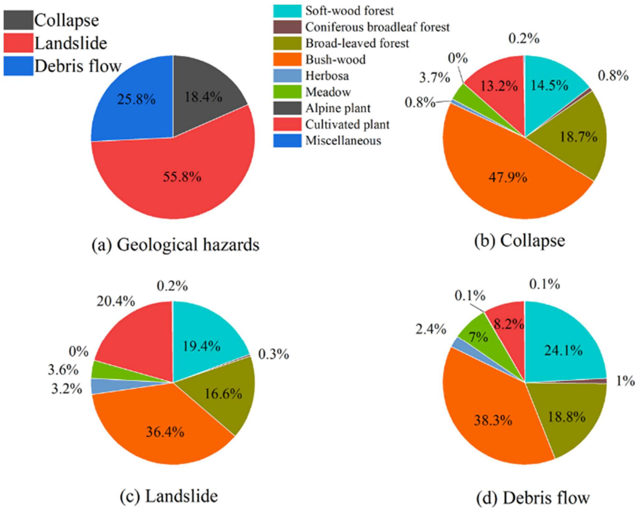

Figure 5. *The relationship between geological hazards and vegetation type data in western Sichuan.*

It can be seen that the collapse occurred in the shrub zone with a high probability; a moderate probability occurred in the broad-leaved forest zone, coniferous forest zone, and cultivated plant zone; less likely to occur in the meadow, grass, and alpine vegetation zones.

Landslides are more likely to occur in the shrub zone and cultivated plant zone; a medium probability of occurrence in the coniferous forest zone and broad-leaved forest zone; less likely to occur in the meadow belt, grass belt, alpine vegetation belt. Debris flows are more likely to occur in shrub belts and coniferous forest belts. The medium probability occurs in broad-leaved forest belts; a smaller probability occurs in cultivated plant belts.

Based on the above statistics, according to the development and occurrence of geo-logical disasters, the western Sichuan region is divided into three levels of susceptibility according to vegetation types.

(1) Vegetation type for low susceptibility: vegetation type whose total occurrence of geological disasters is less than 10%;

(2) Vegetation type for moderate susceptibility: vegetation type that accounts for 10%-20% of the total cumulative occurrence of geological disasters;

(3) Vegetation type for high susceptibility: vegetation type whose total occurrence of geological disasters accounts for more than 20%.

Using the GIS platform with the above division principle, the western Sichuan region was zoned according to different levels of susceptibility based on vegetation type, and the results are shown in Figure 6.

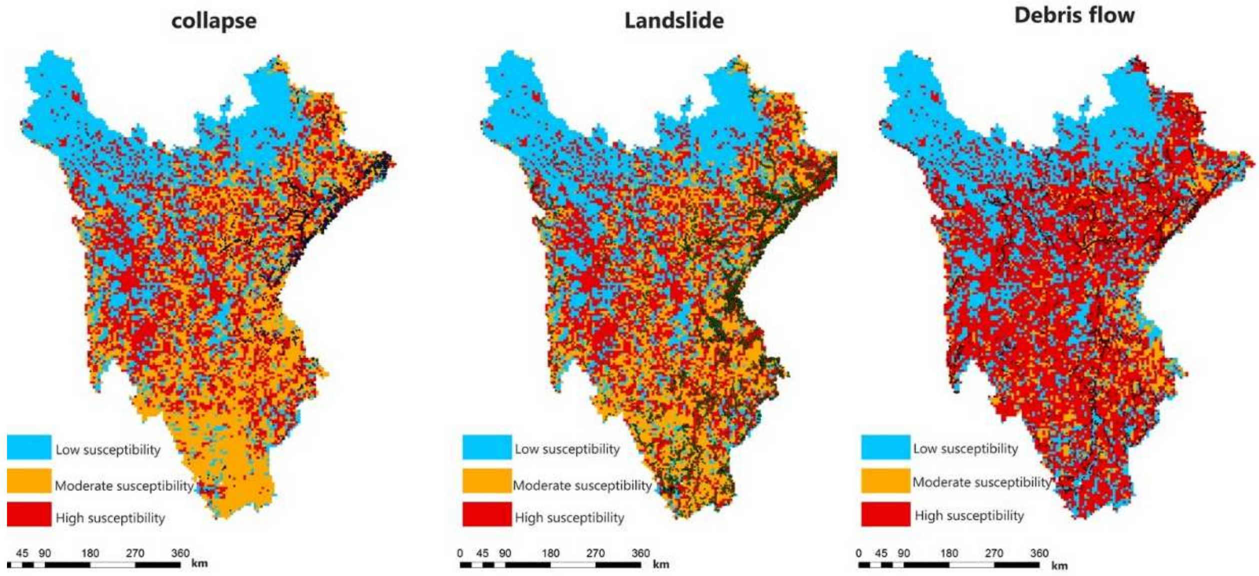

Figure 6. *Susceptibility zoning according to Vegetation types.*

2.1.4. Statistical Analysis of Annual Average Rainfall

The annual average rainfall data in Western Sichuan can be roughly divided into three types of areas: 1) low rainfall areas: annual average rainfall of 600mm and below; 2) Medium rainfall areas: average annual rainfall of 600mm-900mm; 3) High rainfall areas: average annual rainfall is 900mm and above. Combining the geological disaster data with the annual average rainfall data, the relationship between the two can be seen in Figure 7.

It can be seen that the probability of collapse occurred in the moderate rainfall area; the moderate probability occurred in the area with high rainfall; the smaller probability occurred in the low rainfall area. Landslides are more likely to occur in areas with high rainfall; moderate probability of occurrences in areas with moderate rainfall; less likely to occur in areas with low rainfall. Debris flows have a greater probability of occurring in areas with moderate rainfall, a medium probability of occurrence in areas with high rain-fall, a smaller probability of occurrence in areas with low rainfall.

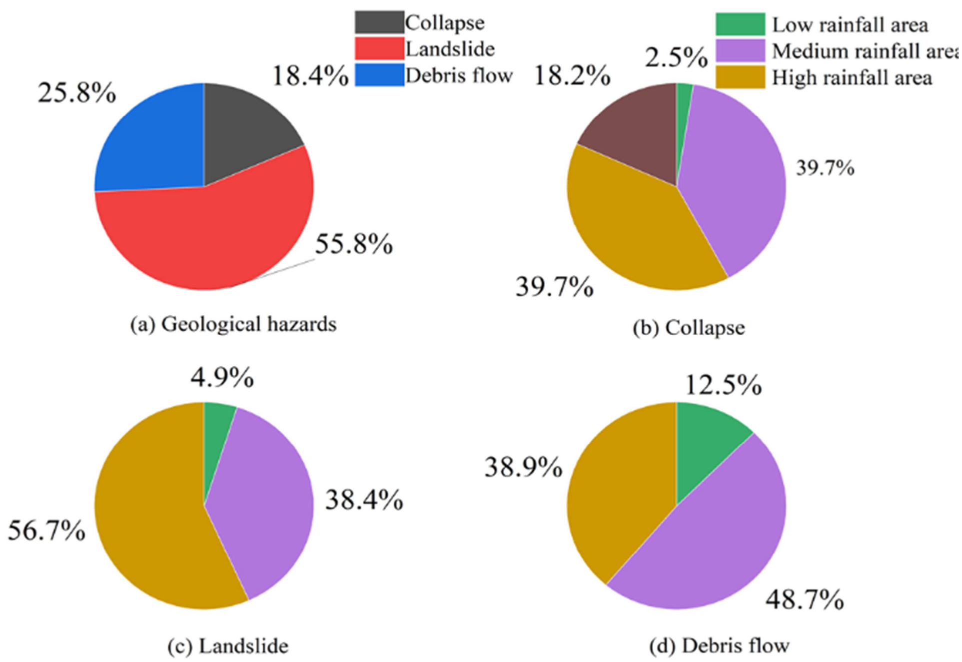

Figure 7. *The relationship between geological hazards and annual average rainfall data in Sichuan.*

Therefore, moderate rainfall areas can be roughly regarded as high susceptibility areas to collapses and debris flow but moderate susceptibility to landslides; High rainfall areas can be roughly regarded as high susceptibility to a landslide but moderate susceptibility to collapses and debris flow; Areas with low rainfall that basically do not occur geo-logical disasters are regarded as low susceptibility to geological disasters. Based on the above analyses, the western Sichuan region is divided into different levels of susceptibility to three geological hazards based on annual average rainfall, shown in Figure 8 below.

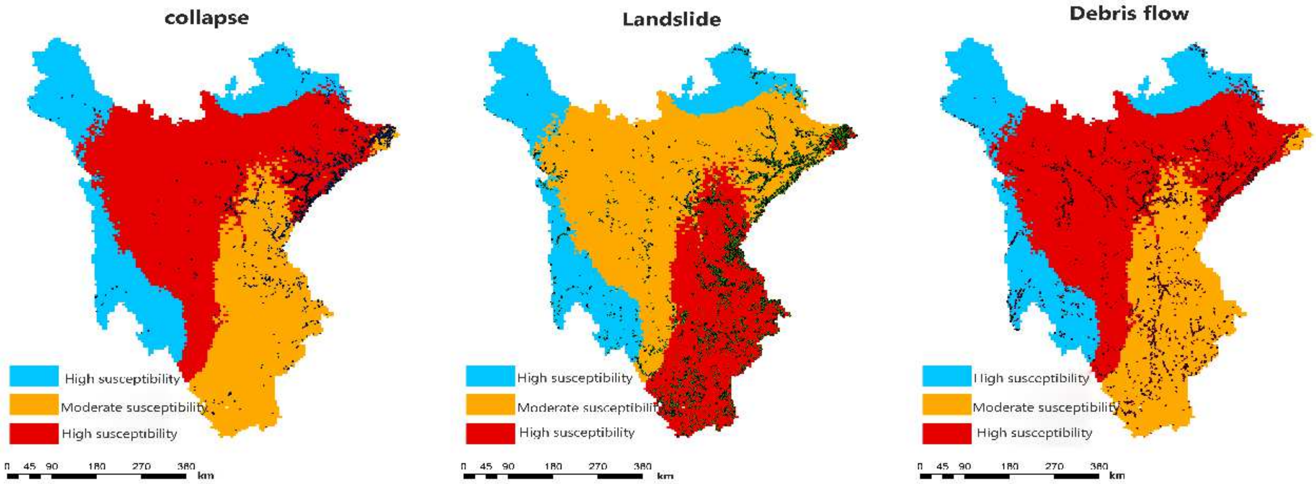

Figure 8. *Susceptibility zoning according to annual average rainfall.*

2.2. Cell Assignment Method

In the cell assignment method, the research region is first divided into specific cells through the GIS platform; geohazard data and various influencing factors data are then assigned to the cells; finally, geological hazards are mapped according to the cell assignment results calculated by statistical analysis and superposition. As a quantitative evaluation method, this method combines the statistical analysis results in the above section based on the data of DEM, soil property, vegetation type, and annual average rainfall.

First, the administrative division of Sichuan Province is divided into cells, and the area of each cell is about 24km^2. The Western Sichuan region is selected as the clipping area, and 13,996 cells are obtained after clipping. The investigated region divided with cells is shown in Figure 9 below. Secondly, the data of four influencing factors were as-signed to 13,996 cells in the western Sichuan region in the way of cell assignment on the GIS platform.

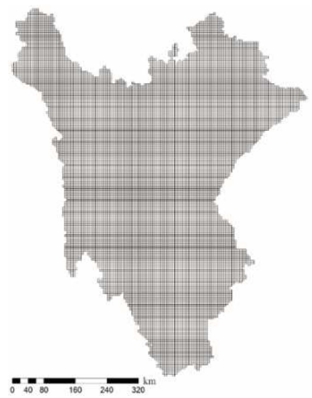

Figure 9. *Western Sichuan region divided into cells.*

As the locations of geological hazards are different, the frequency of geological hazards in each cell is also different. Referring to the studies [42-43] of the geological disaster zoning model, the cells are divided with five different frequency levels of geological hazard to the following standards, shown in Table 1.

Table 1. *Frequency levels of geological hazards in the cells of the western Sichuan region.*

Frequency of geological hazards				
Low frequency	**Lower frequency**	**Medium frequency**	**Higher frequency**	**High frequency**
1-10	11-20	21-30	31-40	41-100

Extract the cells assigned with each frequency level of geological hazards. Extraction is shown in the following formula:

$$C_{Assignment} = F_{DEM} \cup F_{Soil} \cup F_{vegetation} \cup F_{Rainfall} \cup D_{collapse} \cup D_{landslide} \cup D_{debris\ flow} \quad (1)$$

Where: C——Assignment cell;

F——Data values of influencing factors, namely DEM, soil property, vegetation type, and average annual rainfall;

D——Frequency of occurrence of geological hazards.

According to formula (1), the assigned cells of geological hazards are extracted, and extraction results are shown in Table 2.

Table 2. *Number of Cells with different frequency levels of geological hazards in western Sichuan region.*

Extract objects	Extraction frequency					total
Geological hazards	1-10	11-20	21-30	31-40	41-100	
Collapse	789	22	4	1	0	816
Landslide	2112	83	11	3	2	2211
Debris flow	1492	15	2	0	0	1509

The cells of geological hazards in western Sichuan are outputted into a map shown in Figure 10 below. Since the sum of low-frequency and lower-frequency cells accounted for more than 99% of the total and the low-frequency cells are the main ones, we can get an accurate result by directly analyzing the cells in which geological hazards occurred with the low-frequency level.

There is a total of 13,996 cells in the western Sichuan region, and there are 816, 2630, and 1509 cells that have collapsed, landslides, and mudslides, respectively, accounting for only 5.8%, 18.8%, and 10.8% of the total. In order to be able to partition the geological hazard susceptibility levels of all cells, it is necessary first to analyze the cell attributes of geological hazards. Then, through attribute superposition, the calculation results representing the zoning attributes of different susceptibility levels are assigned to each cell. Finally, the regional geological hazard zoning result of western Sichuan is obtained.

1) Collapse

Based on the susceptibility zoning results for each influencing factor of geological hazards in Section 2.1, the ratio of cells in different levels of susceptibility to collapse to the collapse cells (that is, cells in which collapse is regarded as low-frequency level shown in Table 2) for the four influencing factors are calculated by GIS and plotted in Figure 11a. The same information but for the ratio to the total cells of the region is also shown in Figure 11b.

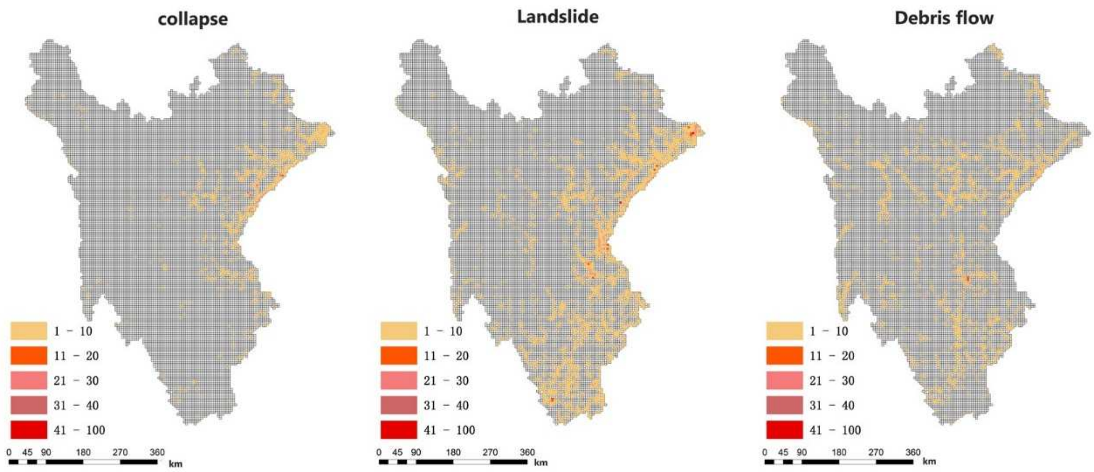

Figure 10. *Cells with a different frequency of geological hazards.*

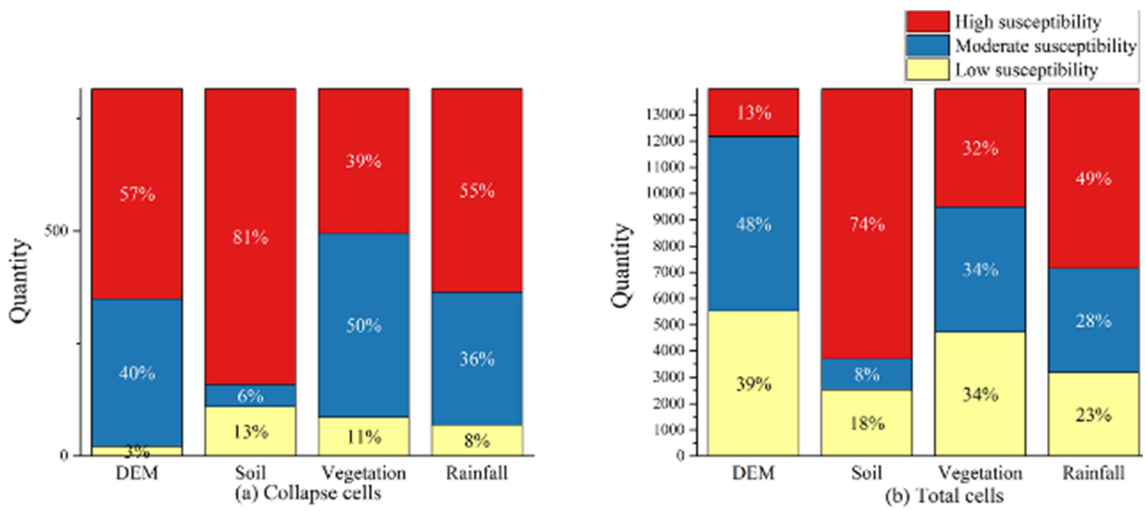

Figure 11. *The ratios of cells in different levels of susceptibility to the collapse cells (a_i) and the total cells of the western Sichuan region (p_i).*

Based on the calculated cell ratio data by GIS, referring to the studies [10-12] on the innovative methods of cartography, a method is proposed to evaluate the response degree of different susceptibility zones of various influencing factors and convert the susceptibility levels into an intuitive response numerical value of the degree, calculated in the following formula:

$$\overline{e_i} = \frac{a_i}{p_i} \quad (2)$$

Where: $\overline{e_i}$—response degree value corresponding to a certain level of susceptibility zone of the i-the influencing factor;

a_i—ratio of cells with a certain level of the susceptibility zone to geological hazard cells for the i-th influencing factor;

p_i—ratio of cells with a certain level of the susceptibility zone to the total cells of the western Sichuan region for the i-th influencing factor.

According to Equation (2), the calculation results can be classified into three situations:

(1) $\overline{e_i}$>1: a higher occurrence possibility of a certain geological hazard for a zone with a certain level of susceptibility classified with i-th influencing factors, and it increases with the increasing $\overline{e_i}$;

(2) $\overline{e_i}$=1: a critical occurrence possibility of a certain geological hazard for a zone with a certain level of susceptibility classified with i-th influencing factors;

(3) $\overline{e_i}$<1: a lower occurrence possibility of a certain geological hazard for a zone with a certain level of susceptibility classified with i-th influencing factors, and it decreases with the decreasing $\overline{e_i}$;

Calculated according to Equation (2), the response degree value ($\overline{e_i}$) of the different levels of susceptibility zones for the various influencing factors of collapse are shown in Table 3.

Table 3. *Response degree $\overline{e_i}$ of the different levels of collapse susceptibility zones for the various influencing factors.*

Influencing factors	**Responsiveness value $\overline{e_i}$**		
DEM	Low altitude area	Middle altitude area	High altitude area
	0.07	0.84	4.41
Soil	Low altitude area	Middle altitude area	High altitude area
	0.75	0.71	1.09
vegetation	Low altitude area	Middle altitude area	High altitude area
	0.32	1.47	1.22
Rainfall	Low altitude area	Middle altitude area	High altitude area
	0.37	1.28	1.13

Response degree $\overline{e_i}$ is calculated for each cell in the western Sichuan region for the four different influencing factors. The summation of $\overline{e_i}$ values for different influence factors is then obtained and noted as E, expressed in Equation (3). The larger the E value is, the more likely the collapse in the cell will occur. Thus, according to E values, the western Sichuan region is divided into three different types of collapse-prone zones.

$$E = \sum_{i=1}^{n} \overline{e_i} = \sum_{i=1}^{n} \frac{a_i}{p_i} \quad (3)$$

Then the maximum superimposed value E for the four influencing factors is calculated as 8.25, and the minimum one is 1.51. The gap between the maximum and minimum one is divided evenly into three intervals, and E value ranges for classifying different levels of susceptibility area to the collapse in the western Sichuan region are reported in Table 4.

Table 4. *Ranges of the superimposed value E for classifying the collapse-susceptibility area in the western Sichuan region.*

Value range of E values		
Low-susceptibility of collapse-prone area	**Moderate-prone area of collapse**	**High-prone area of geological hazards**
1.51≤E≤3.76	3.76<E≤6.01	6.01<E≤8.25

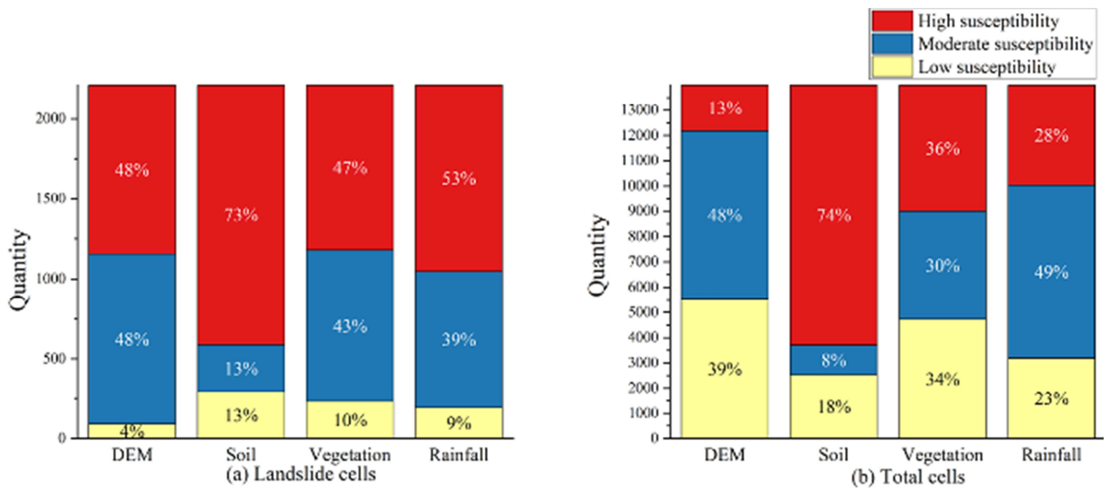

Figure 12. *The ratios of cells in different levels of susceptibility to the collapse cells (a_i) and the total cells of the western Sichuan region (p_i).*

2) Landslide

Figure 12 illustrates a_i and p_i information for landslide cases that are calculated with the above process. Accordingly, the calculated response degree $\overline{e_i}$ of the different levels of landslide susceptibility zones for the various influencing factors of collapse is shown in Table 5. Table 6 reports the E value ranges for classifying different levels of landslide susceptibility area in the western Sichuan region.

Table 5. *Response degree $\overline{e_i}$ of the different levels of collapse susceptibility zones for the various influencing factors.*

Influencing factors	Responsiveness value $\overline{e_i}$		
DEM	Low altitude area 0.10	Middle altitude area 1.01	High altitude area 3.68
Soil	Low altitude area 0.73	Middle altitude area 1.58	High altitude area 1.00
vegetation	Low altitude area 0.31	Middle altitude area 1.41	High altitude area 1.31
Rainfall	Low altitude area 0.38	Middle altitude area 0.79	High altitude area 1.86

Table 6. *Ranges of the superimposed value E for classifying the landslide susceptibility area in the western Sichuan region.*

Partition object	Value range of response degree superimposed value E		
	Low prone area of geological hazards	Areas prone to geological hazards	High-prone area of geological hazards
Western Sichuan Region	1.52≤E≤3.86	3.86<E≤6.20	6.20<E≤8.53

3) Debris flow

Figure 13 illustrates a_i and p_i information for debris flow cases that are calculated with the above process. Accordingly, the calculated response degree $\overline{e_i}$ of the different levels of debris flow susceptibility zones for the various influencing factors of collapse is shown in Table 7. Table 8 reports the E value ranges for classifying different levels of debris flow susceptibility area in the western Sichuan region.

4) Overall geological hazards (collapses, landslides, and debris flow)

According to Figure 7 and the above calculation process, the number of geological hazards in the medium and high susceptibility areas for rainfall factors is basically the same. Consequently, they are considered to be high susceptibility areas for geological hazards, as shown in Figure 14. Accordingly, the calculated response degree $\overline{e_i}$ is shown in Table 9, and E value ranges for classifying the susceptibility area are reported in Table 10.

Table 7. *Ranges of the superimposed value E for classifying the collapse-susceptibility area in the western Sichuan region.*

Influencing factors	Responsiveness value $\overline{e_i}$		
DEM	Low altitude area 0.21	Middle altitude area 2.43	High altitude area 1.27
Soil	Low altitude area 0.95	Middle altitude area 0.53	High altitude area 1.35
vegetation	Low altitude area 0.54	Middle altitude area 1.80	High altitude area 1.17
Rainfall	Low altitude area 0.65	Middle altitude area 1.28	High altitude area 1.01

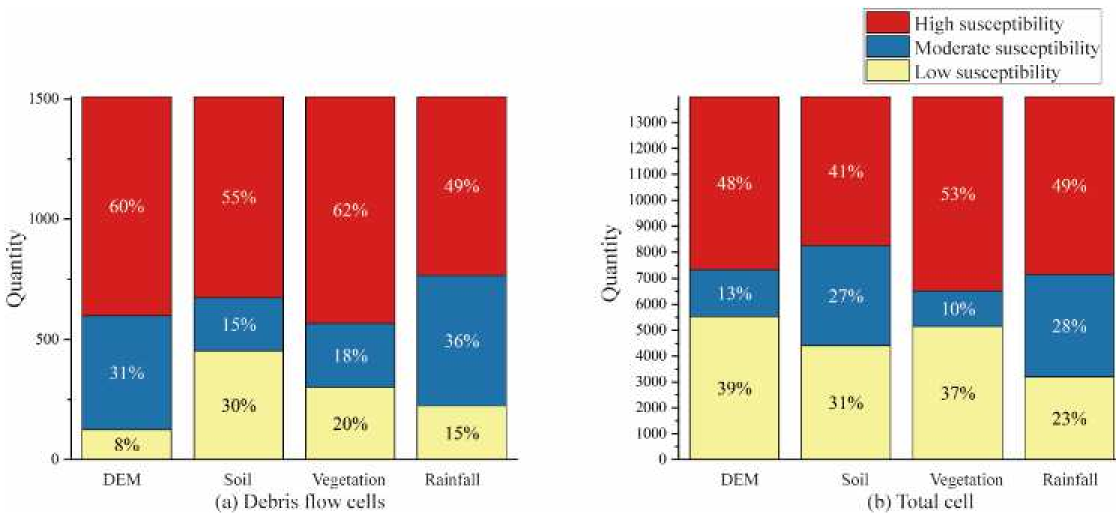

Figure 13. *The ratios of cells in different levels of susceptibility to the debris flow cells (a_i) and the total cells of the western Sichuan region (p_i).*

***Table 8.** Ranges of the superimposed value E for classifying the collapse-susceptibility area in the western Sichuan region.*

Value range of response degree superimposed value E		
Low-prone area of geological hazards	**Areas prone to geological hazards**	**High-prone area of geological hazards**
1.93≤E≤3.57	3.57<E≤5.21	5.21<E≤6.86

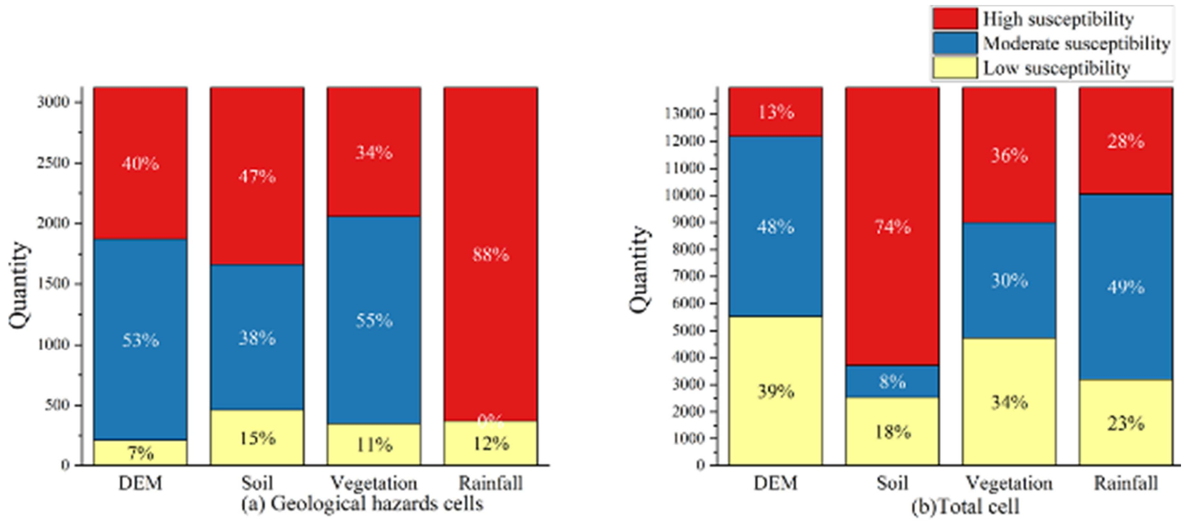

***Figure 14.** The ratios of cells in different levels of susceptibility to the geological hazards cells (a_i) and the total cells of the western Sichuan region (p_i).*

***Table 9.** Response degree $\bar{e}_i$ of the different levels of geological hazard susceptibility zones for the various influencing factors.*

Influencing factors	Responsiveness value $\bar{e}_i$		
DEM	Low altitude area 0.17	Middle altitude area 1.12	High altitude area 3.09
Soil	Low altitude area 0.82	Middle altitude area 0.94	High altitude area 1.14
vegetation	Low altitude area 0.34	Middle altitude area 1.58	High altitude area 1.06
Rainfall	Low altitude area 0.52		High altitude area 1.14

***Table 10.** Ranges of the superimposed value E for classifying the geological hazard susceptibility area in the western Sichuan region.*

Value range of weight E		
Low-prone area of geological hazards	**Areas prone to geological hazards**	**High-prone area of geological hazards**
1.85≤E<3.35	3.35≤E<5.05	5.05≤E≤6.95

3. Geological Hazard Susceptibility Zoning

Based on the analyses in the above section and the studies [44-46], regional geological hazard mapping in the western Sichuan region can be achieved through five steps outlined as follows:

1) Using GIS platform, one can establish a graphical database that includes geological condition data and geological hazard data in western Sichuan;
2) Digitizing the influencing factors and geological hazards in the western Sichuan region and assigning the corresponding attribute values to them;
3) A GIS platform was used to divide the western Sichuan region into 13996 independent cells, then the data values of four types of influencing factors and geological disaster frequency were added to each cell;
4) Response degree Superposition values (E values) was calculated for each cell of the western Sichuan region, and according to the E values, the region was classified into three geological hazard susceptibility groups: low susceptibility, medium susceptibility, and high susceptibility;
5) Using the GIS platform, a regional geological hazard mapping was derived through the classification and presentation of the cells according to different susceptibility levels of geological hazards, followed by the verification of zoning results with geological hazards data.

The resulted mapping for individual geological hazards of collapse, landslide, and debris flow is illustrated in Figure 15, while the one for overall geological hazard is shown in Figure 16. Statistical analysis is carried out using the mapping results of different geological hazards for the western Sichuan region and the observed geological hazard data. The occurrence number of different geological hazards in different mapped susceptibility zone and their ratio to the total number are reported in Table 11. Through the verification from the table, the geological hazard mapping developed by this study is in accordance with the actual geological hazard situation of the western Sichuan region.

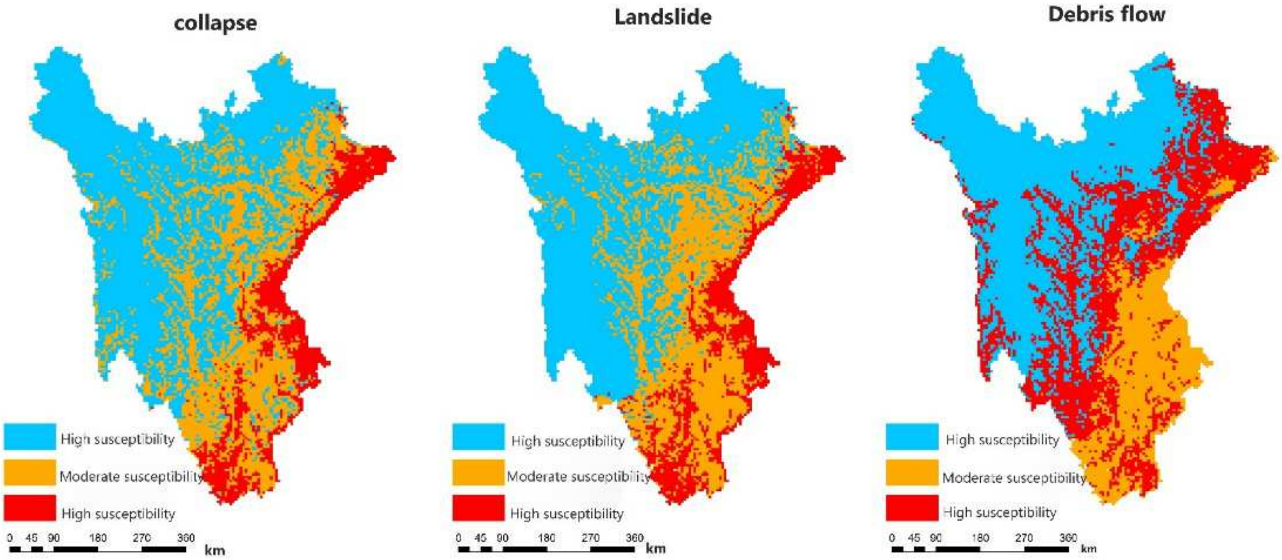

Figure 15. *Susceptibility zoning of collapses, landslides, and debris flows in Western Sichuan.*

Table 11. *Ranges of the superimposed value E for classifying the collapse-susceptibility area in the western Sichuan region.*

Susceptibility region	collapse		Landslide		Debris flow		Overall	
	Number	Percentage (%)	Number	Percentage (%)	Number	Percentage (%)	Number	Percentage (%)
Low	106	4.8	476	7.1	333	10.7	231	2.1
Middle	556	25.0	1944	28.9	1178	37.9	3017	27.7
High	1561	70.2	4304	64.0	1598	51.4	7638	70.2

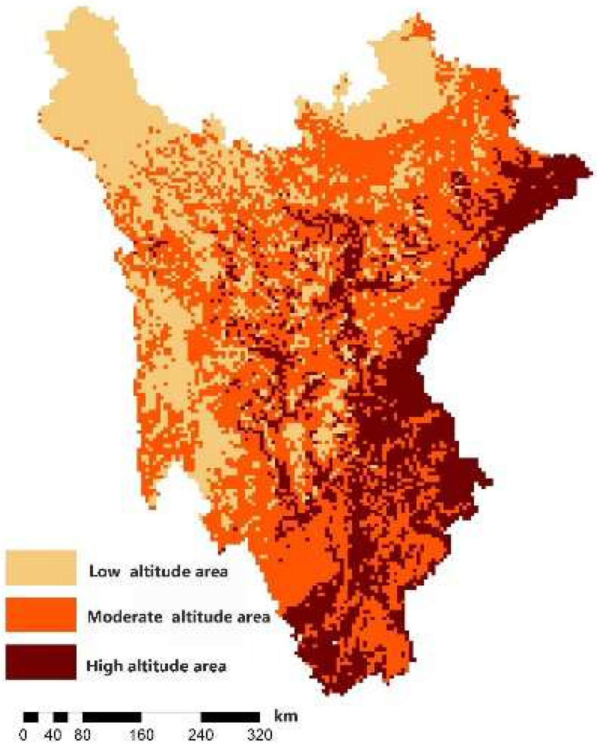

Figure 16. *Susceptibility zoning of overall geological hazard in western Sichuan region.*

4. Conclusion

By gathering and analyzing data, the study tries to understand the current situation of geological hazards in western Sichuan, Sichuan Province, China. Geological hazard mapping of the western Sichuan region is conducted using the GIS platform in conjunction with data from natural geological conditions and geological hazards in the region.

Four main factors affecting the occurrence of geological hazards, namely, Digital Elevation Model (DEM), soil property, vegetation type, and average annual rainfall, are selected for the first statistical analysis. The region is then divided into different degrees of susceptibility based on the relationship between the development/occurrence of geological disasters and various influencing factors. Implementing the cell assignment method based on a statistical analysis of data, using qualitative and quantitative analyses, response degree values (e) of the different levels of susceptibility for different influencing factors for each cell is determined, and then the superposition values (E) of response degree for each cell is calculated for different geological hazards. Finally, the mappings of geological hazards (including collapse, landslide, debris flow, and overall geological hazard) are achieved according to the E value range calculated.

Providing databases and theoretical support for engineering construction and project development in western Sichuan, the research results have played an essential role in ensuring the construction and development of national infrastructure. Due to the subjective nature of the selection of influencing factors and the use of zoning methods in the study, fully objective evaluation can be challenging, which is also a limitation of this study. Therefore, eliminating the interference of subjective factors will become one of the key considerations in a future study of geological hazard evaluation.

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