Application of RS & GIS in Regional Landslides Susceptibility Mapping and Spatiotemporal Characteristics Analysis

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Abstract. Landslide susceptibility mapping is one of the most important aspects of landslide early warning and prediction. Therefore, it is very necessary to improve the accuracy of landslide susceptibility assessment by focusing on the mapping results. Besides, as the obvious spatial and temporal heterogeneity of regional landslide susceptibility, revealing and mastering the spatial and temporal distribution characteristics of landslide susceptibility and analyzing their possible genetic mechanisms, have significant guidance for the development of landslide prevention measurements. With the integrated application of RS and GIS technology, firstly, this paper acquires and manages the landslide impact factors in the study area, then the regional landslide susceptibility zonation map is drawn, and finally, the spatiotemporal characteristics of the regional landslide susceptibility distribution are analyzed. It is shown that RS and GIS can play very important roles in the regional landslide susceptibility mapping and spatiotemporal characteristics analysis.

1. Introduction
Natural disasters are phenomena that can cause harms to human life or damages to human living environment. As one of the most important types of geological disasters, the landslide has been developed into one of the seven natural disasters in the world [1-2]. The losses caused by landslide disasters are very huge. The regional landslide susceptibility mapping and their spatiotemporal characteristics analysis can play a key role in landslide prediction and prevention.

Regional landslide susceptibility mapping is a process from point to region. Landslide susceptibility in different areas is not the same because the landslide impact factors at different times and spatial locations may be different, that is, the non-uniformity of landslide susceptibility. With the development of Remote Sensing (RS) and Geographical Information System (GIS) technology, the problem of non-uniformity during regional landslide susceptibility mapping can be well solved. GIS has been widely used in landslide susceptibility mapping [3-6]. Generally, the Spatial Information Multi-Grid (SIMG) of GIS is firstly used to divide landslide susceptibility mapping grid units [7]. Then, the RS and GIS technology are used to obtain the data of each grid. Finally, landslide susceptibility of each grid is calculated by some assessment models.

On the above premise, further study on the distribution characteristics of regional landslide susceptibility in time and space is of great significance for taking targeted landslide prevention measurements to reduce the losses of life and property. The temporal characteristics of landslide susceptibility refer to the changes of landslide susceptibility with time, while the spatial characteristics of landslide susceptibility refer to the spatial distribution of landslide susceptibility. This paper tries to apply RS and GIS technology to the regional landslide susceptibility mapping and their spatiotemporal characteristics analysis. Firstly, RS and GIS are used to acquire and manage the landslide impact
factors in the study area, then the regional landslide susceptibility zoning map is drawn based on GIS, and finally, the spatiotemporal characteristics of the regional landslide susceptibility distribution are analyzed with the application of GIS.

2. Acquisition and Management of Landslide Impact Factors Based on RS & GIS

According to landslide occurrence conditions, a landslide is related to many impact factors. The landslide susceptibility mapping is an important subject in landslide research. To conduct landslide susceptibility evaluation, the primary task is to determine the landslide impact factors, and different combinations of impact factors will result in different landslide susceptibility degrees calculated by landslide susceptibility model. So, it is very important to select the appropriate impact factors to establish the landslide susceptibility assessment model. According to literatures and expert opinions, twelve landslide impact factors were chosen for landslide susceptibility assessment in this paper, that are, lithology, slope, aspect, distance to stream, elevation, plan curvature, profile curvature, geological structure, distance to road, distance to construction, land use and normalized difference vegetation index (NDVI).

With the development of RS and GIS technology, the acquisition and management of spatial data are becoming more and more convenient and efficient. So in this paper, RS and GIS technology are firstly used to obtain the attribute of each landslide impact factor. Then each landslide impact factor is divided into a few subclasses according to the attribute based on GIS. Finally, the distribution of each landslide impact factor is obtained and managed by GIS, Figure 1 shows the remote sensing image and Digital Elevation Model (DEM) of the study area, Wanzhou, which is a district of Chongqing City located at the hinterland of the Three Gorges Reservoir, and the landslide impact factors extracted from them with the integrated application of RS and GIS are shown in Figure 2.

Figure 1. Remote Sensing Image (left) and DEM (right) of the Study Area
3. Regional Landslide Susceptibility Mapping Based on GIS

3.1. Landslide Susceptibility Assessment Model
The key of landslide susceptibility assessment is to select a good assessment model. In recent years, the study of landslide susceptibility assessment shows that there are many models with good accuracy. In this paper, we chose a hybrid assessment model of analytic hierarchy process, normal frequency ratio and cloud model (AHP-NFR-CM) to calculate the landslide susceptibility. This hybrid model has been verified a good accuracy and robustness [8]. So it is suitable for landslide susceptibility assessment. Among the hybrid model, AHP is used to construct the pair-wise comparison matrices and calculate the weight of each landslide impact factor, NFR is used to obtain the sub-weights of each landslide impact factor and CM is used to solve randomness and fuzziness.

3.2. GIS-based Spatial Information Multi-grid
Spatial information multi-grid (SIMG) is the inevitable product of the development of GIS technology. It is proposed to solve the effective sharing and utilization of massive spatial information in wide-area network environment combining grid technology and GIS. In order to divide computing grid and increase computing efficiency, an attribute based spatial information multi-grid (ASIMG) is proposed. The core idea of ASIMG is to perform multi-level meshing through the area of each landslide impact factor attribute to the total area by setting a threshold. The threshold can be obtained by the following formula.
\[ T_{\text{area}} = \frac{\text{Area}_{ij}}{\text{Area}_i} \]

Where \( \text{Area}_i \) represents the total area of layer \( i \), \( \text{Area}_{ij} \) represents the area of impact factor \( j \) in the layer \( i \), and \( T_{\text{area}} \) represents the threshold.

3.3. Regional Landslide Susceptibility Zoning Based on GIS

According to the division results of ASIMG, landslide susceptibility assessment results of different villages and towns of the study area are calculated by the hybrid AHP-NFR-CM model. Then, the regional landslide susceptibility distribution map is drawn by using GIS technology as shown in Figure 3. It can be found that landslide susceptibilities in different villages and towns are obvious different, which reveals prominent spatial heterogeneity. According to the distribution map of landslide susceptibility in the study area, landslide susceptibility degrees in the central, western and eastern regions are higher, while in southern and southeastern regions are slightly lower. Besides, the landslide susceptibilities in the villages and towns along the Yangtze River are generally higher.

Figure 3. Landslide Susceptibility Zoning Map of the Study Area

Figure 4. Distribution Map of the Landslide Susceptibility Degrees of Villages and Towns

On the basis of landslide susceptibility results in different villages and towns of the study area, the mean values of landslide susceptibility of different villages and towns are calculated by GIS. In Figure 4, the number represents the susceptibility degree, which indicates that the bigger the number, the higher the degree. Besides, it can be clearly seen that the susceptibility degrees of most villages and towns are more than 0.5, which reveal very high susceptibility degrees.

4. Spatiotemporal Characteristics Analysis of Regional Landslide Susceptibility Based on GIS

The above landslide susceptibility mapping results show that because the conditions of each village or town in the study area are different, their corresponding susceptibility degrees maybe different, which means obvious spatial heterogeneity. In order to understand the distribution characteristics and possible reasons of regional landslide susceptibility in time and space, it is very necessary to analyze the spatiotemporal characteristics with the application of GIS.

4.1. Temporal Characteristics Analysis of Regional Landslide Susceptibility and Impact Factors

4.1.1. Correlation Analysis between Regional Landslide Susceptibility and Rainfall

According to the statistics of the landslides occurrence in the study area every year, landslides occurred most in the flood season (April-September) which is also the rainiest months as depicted in Figure 5. It can be clearly seen that rainfalls in flood season account for about 85% of the total annual rainfall. Rainfall infiltration will destroy the balance of slope and finally make the slope slide. Besides, rainfall will also raise the river water level and widen river course, erode slope foot, destroy the stability of slope and finally result in landslide disaster.
4.1.2. Correlation Analysis between Regional Landslide Susceptibility and NDVI. In order to analyze the regional landslide susceptibility under NDVI in different months, this paper firstly keeps other parameters unchanged, and then calculates the susceptibility with AHP-NFR-CM model. Due to the limitation of computing ability, here, only a small part of the study area is used to carry out regional landslide susceptibility analysis. The results are drawn in Figure 6.

Figure 5. Monthly Average Rainfall Distribution of the Study Area

Figure 6. Landslide Susceptibility Mapping in Different Month with the Corresponding NDVI Value
From Figure 6, it can be concluded that landslide susceptibility mapping results under NDVI in different months appear different in some local areas, but the overall differences are not very large. Due to the limitation of data acquisition, the accuracy of NDVI is not very good, so the final assessment results may not be significantly different. In addition, NDVI is not advanced in the weight ranking of landslide impact factors, that is to say, it is not the most important factor compared with others. Therefore, although NDVI shows differences in different months, the differences of landslide susceptibility results may not be obvious.

4.2. Spatial Characteristics Analysis of Regional Landslide Susceptibility and Impact Factors

Regional landslide susceptibility is related to many impact factors, due to the space limitation in this paper, just a few impact factors are selected to analyze the spatial characteristics of regional landslide susceptibility. For an instance, Figure 7 is the thematic map of the relationship between landslide susceptibility and slope displayed with GIS. From the histogram in Figure 8, it can be seen that the height of the histogram increases first and then decreases as the slope increases. This trend suggests that landslide in area with smaller and larger slope will be less likely to occur. Besides, the landslide occurrences are mainly concentrated in the range of slope about 10 to 35 degrees, which indicates that landslides in the study area are mainly gentle slope landslides.

5. Conclusion

Landslide susceptibility is impacted by many factors. In a large region, these landslide impact factors may be changed in different areas, which lead to the landslide susceptibility heterogeneity. So the impact factors of different locations in study area are the fundamentals of landslide susceptibility mapping. Because of their advantages, RS and GIS can be applied to acquire and manage landslide impact factors conveniently and efficiently. In addition, through the spatiotemporal characteristics analysis of landslide susceptibility and impact factors in the study area with the application of GIS, it is concluded that landslide susceptibility degrees are changed in different places and different times as their corresponding values of landslide impact factors are different. This suggests that landslide susceptibility is of obvious spatial and temporal heterogeneity, and the heterogeneity is mainly attributed to the differences between the landslide impact factors. Besides, through statistical analysis, correlation analysis and spatial analysis based on GIS, slope, elevation and distance to streams have greater impacts on landslide susceptibility. Furthermore, according to the spatiotemporal analysis results about the main landslide impact factors, some corresponding targeted measurements can be taken for the landslide prevention and treatment.

6. Acknowledgments

This study was supported by the National Natural Science Foundation of China (41672263), the
National Key Research and Development Program of China (2018YFC0407800) and the Natural Science Foundation of Hubei Province (2015CFA134). The authors also greatly appreciate the anonymous reviewers and the academic editor for their careful comments and valuable suggestions to improve the manuscript.

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