Mapping the Earthquake Landslide Risk, A Case Study in the Sichuan-Yunnan Region, China

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Abstract. Rapid and effective assessment of the landslide risk and its spatial distribution after the earthquake provide good support for earthquake emergency rescue. In this paper, we develop a landslide risk map in the Sichuan-Yunnan region for post-earthquake emergency rescue with grid technology based on historical seismic landslide data of Wenchuan earthquake. The historical data of Wenchuan earthquake is extracted based on the Aster images. The seismic landslide risk assessment model is introduced based on logistic regression model, in which seismic intensity and slop of digital elevation model are selected as influence factors (input parameters). Then we grid the landslide risk estimation model to generate landslide risk maps in resolution of 90 m. So the risk maps are prepared before earthquake, the landslide risk can be quickly estimated after earthquake according to few information acquired from earthquake monitor network, such as magnitude, focal depth, earthquake location. Finally, a seismic landslide risk assessment system was developed to realize the application of the risk maps.

Keywords: Earthquake landslide · Risk assessment · Logistic regression · Gridding technology

1 Introduction

Statistics on earthquakes with magnitude MS $\geq$ 5.0 since the 1949 show that earthquake induced landslides are occurred located in most part of provinces in China, especially in western mountainous regions [1]. Research on the danger of seismic landslides has been a subject, which is worth of attention in the field of seismic engineering and has been extensively studied [2–8]. Parts of the researches are based on the map of seismic intensity zoning in China. Based on that, the landslide hazard distribution map is developed by introducing a landslide hazard assessment model. For example, the literature [9, 10] has established network diagram of earthquake landslide danger zones in Yunnan Province and the country. Research in this area can provide earthquake risk distribution before the earthquake. Thus it provides reference for disaster mitigation. In order to provide a good reference for disaster prevention in the region in the future, some researchers have drawn landslide danger maps based on landslides in historical earthquake cases and specific earthquake cases [11]. In general, existing studies focus more on the hazard

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distribution of landslides in the future earthquake (pre-earthquake) and can provide good support for disaster mitigation preparation. Therefore, the spatial distribution of landslide hazard maps usually generated by such studies is not high, such as in cities or regions. In fact, the landslide risk analysis after the earthquake has important significance and requirements for disaster reduction. For example, if the landslide risk and its relatively fine spatial distribution (such as 90 m) can be quickly evaluated in the initial stage after the earthquake, it can provide a reference for disaster relief departments to reduce the secondary earthquake damage caused by following landslide. In this paper, taking the Wenchuan earthquake as background, grid technology is introduced to develop a landslide hazard distribution map for post-earthquake emergency rescue by spatializing the traditional landslide risk assessment model.

2 Seismic Landslide Risk Assessment Model

At present, the models of evaluating seismic landslide risk including its spatial distribution are widely studied. We classified the models into two types: one is the model based on physics and engineering geology. It is based on the physical mechanism of landslide occurrence and uses mechanical models to quantitatively express the stability status of slopes, such as the model of limit equilibrium of slopes, Newark displacement analysis, and numerical simulation [12–14]. The establishment of this kind of model requires the collection of various data on geology, geomorphology, river hydrology, etc. The kind of model is more suitable for the monitoring and evaluation of single landslide. Another kind of model is based on the analysis of historical landslide data. The landslide risk in future can be deduced by analyzing the influence factors of historical landslide instability, and relying on empirical and mathematical algorithms, such as historical regression method, expert scoring method, etc. [15, 16]. The model considers the occurrence principles of landslide as a black box, so this kind of model is more suitable for regional landslide risk analysis and assessment. In this paper, the second kind model will be used to evaluate the risk of seismic landslides in the Sichuan-Yunnan region. The process of building model is shown in the Fig. 1. The model aims at the quickly response after earthquake. With the period, the information about earthquake is reliable.

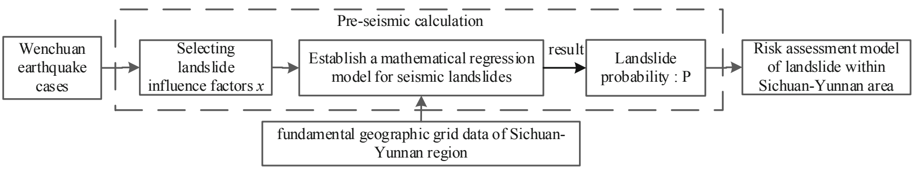

Fig. 1. The process of building risk assessment model of seismic landslide in Sichuan-Yunnan region

Considering the key purpose of post-earthquake emergency rescue, we select the slope and seismic intensity as the influencing factors of earthquake landslides. A logistic regression model is used to establish the model in the Sichuan-Yunnan region. The formula is

$$P = \frac{1}{1 + \exp(-\alpha - \sum_{n=1}^{n} \beta_n x_n)} \quad (1)$$

Where P is the probability of occurrence of landslide, x_n are the influence factors of seismic landslide; β_n are the regression parameters; α is a constant term.

3 Landslide Risk Map Development

3.1 Extracting Disaster of Wenchuan Earthquake

Wenchuan is located in Sichuan province, about 130 km from Chengdun– the capital of Sichuan Province. There are the Minjiang River passing by and an active area of the Longmen fault zone. In May 12th, 2008, a giant earthquake (Ms. 8.0) is occurred, which covers almost half China and Sichuan and Yunnan provinces are the most serious disaster area. The earthquake causes 69227 people death and thousands seismic landslides. We collect seismic landslide data from NASA's ASTER sensor, which has a wider spectral range with high-resolution images in 15 m. At present, users can apply for three levels of data products L1, L2, and L3. We download the ASTER_L3T images within two years after May 2008, that cover the disaster area of Wenchuan earthquake.

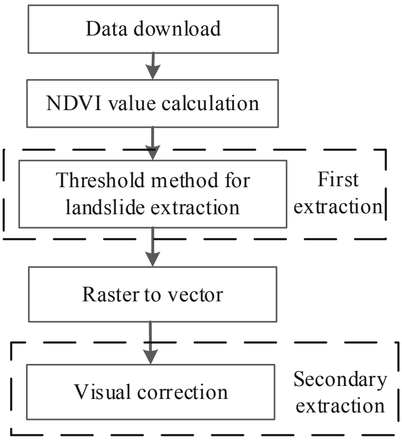

Fig. 2. The process of extracting landslide

The extraction of seismic landslide data is based on three visible light bands of the ASTER image. Due to the relatively small number of bands, the test find that just using supervised or unsupervised classification methods could not achieve good results. So we use the normalized difference vegetation index to make preliminary recognizing and then extract the landslides by visual interpretation as shown in Fig. 2. The normalized vegetation index is a comprehensive reflection of the type of vegetation, coverage form, and growth conditions in a unit pixel. The expression of the normalized difference vegetation index (NDVI) is:

$$NDVI = \frac{NIR - R}{NIR + R} \quad (2)$$

Among them, NIR stands for the near-infrared channel (0.7 to 1.1 μm) in the multispectral remote sensing image, and R stands for the visible red band (0.6 to 0.7 μm). Because it is sensitive to green vegetation, it is often used to detect the growth status of vegetation, vegetation coverage and elimination of some radiation errors. A negative value of NDVI indicates that the ground is covered cloud, water, snow, etc.; the value 0 indicates that there are rocks or bare soil; positive values indicate that there is vegetation coverage.

After the NDVI value is calculated, the preliminary landslide extraction is performed by ArcMap software based on the threshold range. The empirical threshold is generally in the range of 0–0.12. It is worth noting that the impact of earthquakes on vegetation is different due to the different seismic intensity zones. Thus the threshold range needs to be modified according to seismic intensity. After the preliminary extraction, manual visual interpretation is required to exclude the area that affected by rivers, dammed lakes, and farmland. Finally, more than 100,000 landslides are extracted and we eliminate the landslide area less than 1 km^2. The seismic landslides of Wenchuan earthquake are shown in Fig. 3.

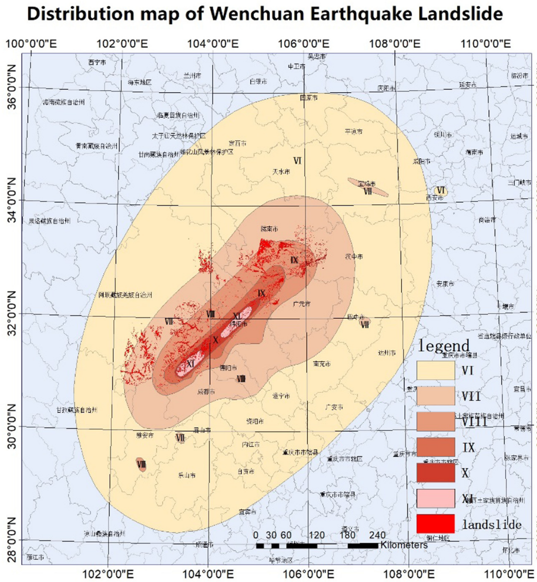

Fig. 3. Distribution map of Wenchuan earthquake landslide

3.2 Gridding Landslide Risk Assessment Model

Data of the model include the Wenchuan earthquake intensity distribution map, the slope map from SRTM90 m (http://srtm.csi.cgiar.org/), and the historical landslide vector map. We grid the data and corresponding model to develop grid landslide risk data for Sichuan-Yunnan region. The main steps are shown in Fig. 4.

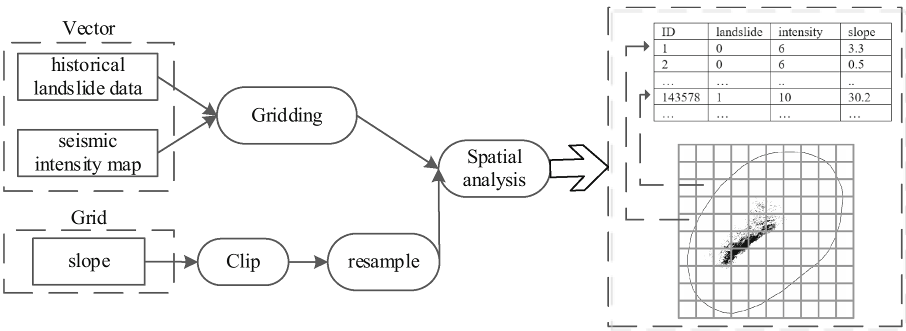

Fig. 4. Main steps of gridding the model

4 Application of the Landslide Risk Data

We develop seismic landslide risk evaluation system with the support of the landslide risk data. The system has the function to analyze the seismic influence range, estimate seismic landslide risk for emergency response. As shown in Fig. 5, risk dasymetric map of seismic landslide in Sichuan-Yunnan region (take the intensity VI as an example) has been calculated. After earthquake the system can quickly estimate the possible landslide risk by generating seismic intensity map according to few information (earthquake magnitude, focal depth, earthquake location), which almost the only information just after earthquake (i.e. 1 h after earthquake). The landslide map will provide good guidance to emergency response and rescue.

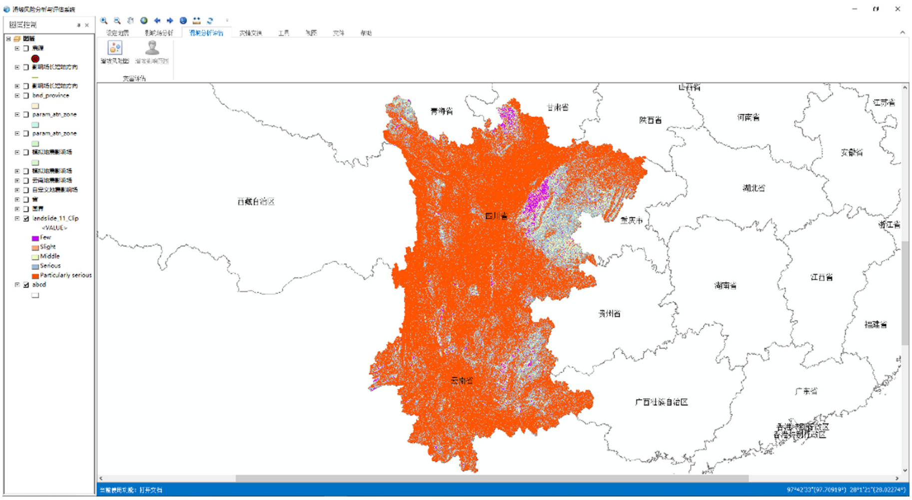

Fig. 5. Interface of seismic landslide risk evaluation system

5 Conclusion

How to quickly estimate possible landslide risk caused by earthquake within short time after earthquake is a very useful and challenging work for earthquake emergency response and rescue. We aim to quickly estimate seismic landslide risk for emergency response and rescue in this study. Logistic regression model is selected, in which seismic intensity and slope are used as input parameters. The historical landslide data of Wenchuan are used to make regressive analysis. Then seismic landslide maps and corresponding evaluation system are developed with gridding method. So the evaluation process of seismic landslide is simplified and improve the effectiveness of the evaluation. We will further optimize the evaluation model and process in the future.

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