Applied Mathematics & Information Sciences
An International Journal

Landslide Hazard Assessment Based on Fuzzy Synthesis Judgment and Geographic Information System

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Received: 15 Sep. 2012, Revised: 5 Dec. 2012, Accepted: 3 Jan. 2013
Published online: 1 May 2013

Abstract: Taking Ganxigou valley in Sichuan Province as example, where earthquake occurred at 14:20 on May 12th, 2008, slope, aspect, elevation, river distribution, lithology, faultage, and highway distribution are selected to assess landslide risk after earthquake. The fuzzy synthesis judgment way is applied to evaluation, and GIS is effectively adopted in picking up value and making chart. Through verification, these evaluation systems are viable.

Keywords: Landslide hazard assessment, fuzzy synthesis judgment, Geographic Information System

1. Introduction

China is one of the most serious countries on geologic hazard in the world. Due to vast region, large span of longitude and latitude, and complex physiographic condition, geologic hazard has the character of high frequency, large region, and large loss damage which directly influence the development of national economy [1]. Region geologic hazard risk assessment model is the one of the most content in the disaster research.

Fuzzy synthesis judgment is successfully used in geologic hazard assessment, however, the accurate degree depends on enough information and reasonable limit value collection [2]. However, landslide is the common form in the geologic hazard. Reviews of landslide hazard mapping approaches are given by many researchers, such as Sassa et al., Carrara and Pike, Alexander, Corominas and Moya, van Westen et al. Keefer and Larsen [3–9]. Using Geographic Information System (GIS) as the basic analysis tool for landslide hazard can be effective for spatial data management and manipulation. Previous research has failed to consider the fuzziness uncertainty. This paper focuses on the fuzziness of landslide hazard, the synthesis of the Fuzzy Theory and Geographic Information System (GIS) are used in the landslide hazard assessment. Our research scope is the Ganxigou region in Sichuan province in China, where earthquake occurred at 14:20 on May 12th, 2008.

2. Research Region Introduction

The research region taken as an example is located in Ganxigou valley at Pengzhou city in Sichuan province in China, where earthquake occurred at 14:20 on May 12th, 2008. The physiognomy is high in the east and in the west, and low in the middle part. The average elevation is 1000 m.

Due to the complex geology structure, geology hazard is more developed which is influenced by Wenchuan violent earthquake. According to spot field investigation, there are three landslides, 6 collapses, and one instability slope (seen in Fig. 1).

According to the geological hazard risk analysis, the factors are decided by terrain and physiognomy, hydrological factors, geological factors, and human being engineering activity. And then the hierarchy graph of risk evaluation is built (see Fig. 2). The risk is decided by twice evaluations.

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Figure 1 Remote Sensing image of research region

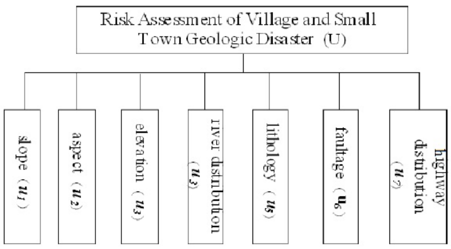

Figure 2 Hierarchy graph of risk evaluation influence factors of Ganxigou

3. Fuzzy Synthesis Assessment Method and GIS Theory

3.1. Fuzzy Synthesis Assessment Method and GIS Theory

Fuzzy Synthesis Assessment Model is a comprehensive analysis method which is based on the fuzzy transformation method, qualitative analysis and quantitative analysis combined give priority to fuzzy ratiocination, the union of precision and non- precision The technique flow chart of fuzzy synthesis assessment is seen in Fig. 3 including seven parts which are original index collection, comment rank collection, membership function, membership function matrix, weight vector, weighting composing, and result vector treatment.

(1) Given the evaluation index number is i, the original index collection is $U(Eq.1)$, and then

$$U = \{u_1, u_2, \cdots, u_i\} \tag{1}$$

After on-the-spot investigation of landslide hazard of Ganxigou valley, the original index collection U is composed by $u_1, u_2, u_3, u_4, u_5, u_6, u_7$ which stand for slope, aspect, elevation, river distribution, lithology, faultage, and highway distribution.

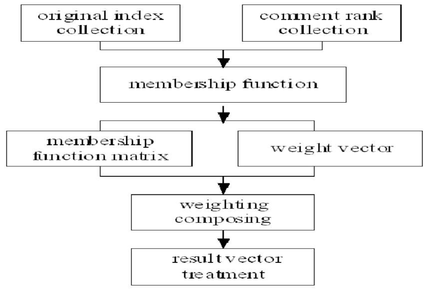

Figure 3 Flow chart of fuzzy synthesis assessment

(2) Given the evaluation rank number is j, the comment rank collection is V (Eq. 2), and then

$$V = \{v_1, v_2, \cdots, v_j\} \tag{2}$$

Moreover, according to investigation, comment rank collection V is composed by v_1, v_2, v_3, v_4 which stand for highest risk, higher risk, lower risk, and low risk of the rank of landslide.

(3) There are many methods to define the membership function, such as fuzzy statistics method, classification function method, comparison method, and so on. Classification function method has several forms which are triangle function, trapezoid function, and so on. According to data condition, unit condition, evaluation rank, single and combination method is selected. Trapezoid classification function is used to discuss the membership degree. Effectively, every index has a membership function collection F_i (Eq. 3), and every rank has a son membership function f_j.

$$F_i = \{f_1, f_2, \cdots, f_i\} \tag{3}$$

In this paper, the membership degree of quantity factor for the risk rank can be obtained by fall half trapezoid distribution function [10]. On the basis of actual condition, the membership degree function graph can be obtained. Membership degree function graph of elevation is seen in Fig. 4.

(4) According to membership function, membership degree which indexes in U are relative to the ranks in V can be calculated, membership function matrix R (Eq. 4) is formed.

$$R = \left\{ \begin{matrix} x_{11} & x_{12} & \cdots & x_{1j} \\ x_{21} & x_{22} & \cdots & x_{2j} \\ \vdots & \vdots & \vdots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} \end{matrix} \right\} \tag{4}$$

Thereinto, $r_{i,j} = \mu(u_i, v_j)(0 \le r_{i,j} \le 1)$ expresses the membership grade of which u_i is judged by v_j.

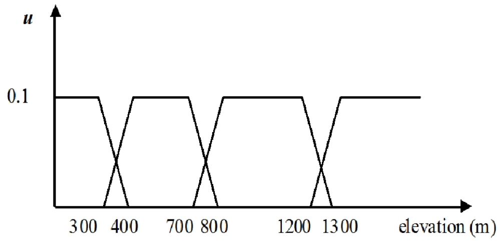

Figure 4 Membership degree function graph

$R = (r_{i1}, r_{i2}, \cdots, r_{ij})$ situated on No. i place in the matrix R stands for single factor judgment of u_i, which is the fuzzy subset in V.

(5) There are many methods to decide weight, such as direct judgment, 0-1 twain-twain antitheses, 0-4 twain-twain antitheses, multi-proportion antitheses, system grading by importance, Analytical Hierarchy Process (AHP), and so on [11].

According to overall consideration, we adopt Analytical Hierarchy Process (AHP) [12] to define the weight W (Eq. 5).

$$W = [a_1, a_2, \cdots a_i] \tag{5}$$

On the basis of several times to consult specialists and on-the-spot investigation, linear algebra function is used to obtain the maximum eigenvalue and corresponding eigenvector. Eigenvector is the rank of evaluation index, and then normalization treatment can obtain the weight of evaluation index (Table 1).

Table 1 weight value of evaluation index

Index	slope	aspect	elevation	river distribution
weight	0.1016	0.0434	0.0275	0.0780
Index	lithology	faultage	highway distribution	
weight	0.1706	0.3411	0.2378	

(6) Fuzzy weight vector and fuzzy membership matrix are operated, and the result vector B (Eq. 6)can be obtained.

$$B = W \circ R = [b_1, b_2, \cdots, b_j] \tag{6}$$

3.2. GIS Theory

Spatial analysis is one of the most merits of Geographic Information System (GIS), which is based on the space position and morphological characteristic of geographical object, has the characteristics of operate space data, synthesis operate space data and attribute data, extracts and produces new spatial information. Overlay analysis is commonly used among the spatial analysis functions.

Grid unit division is one of the common methods. Huo Ai-di et al. studied a sampled method of classification of susceptibility evaluation unit for geological hazards based on GIS [13]. The area of Ganxigou valley is $22.3595km^2$. On the basis of overall consideration, the grid unit is selected by $50m \times 50m$, and then there are more than 15000 evaluation units.

Quantization treatment is needed to all of the layers for the reason of evaluation index not be obtained from the original layer database.

The data of slope, aspect and elevation can be obtained from Digital Elevation Model (DEM) data, yet, the data river distribution, lithology, faultage, highway distribution can be got from the buffer zone analysis function of Geographic Information System (GIS).

3.3. Fuzzy Synthesis Assessment Based on GIS

Given the number of grids is i, which evaluation index is $\{g_1, g_2, \cdots g_i\}$. Any one grid can create j grids according to the membership function, and then the attribution data is the membership degree [14]. And then all of the membership degree grids can constitute grid matrix R, that is to say, fuzzy relationship matrix. Take advantage of overlay analysis function of GIS, $B = W \circ R$ can be calculated.

$$R = \begin{bmatrix} g_{11} & \cdots & g_{i1} \\ \vdots & \ddots & \vdots \\ g_{1j} & \cdots & g_{ij} \end{bmatrix}$$

After models built are operated in the software of ArcGIS 10.0 version, all of the grid image can be got and displayed on the platform of ArcMAP (Fig. 5). And the final result is that define the risk rank of landslide, moreover, every grid risk rank can be obtained.

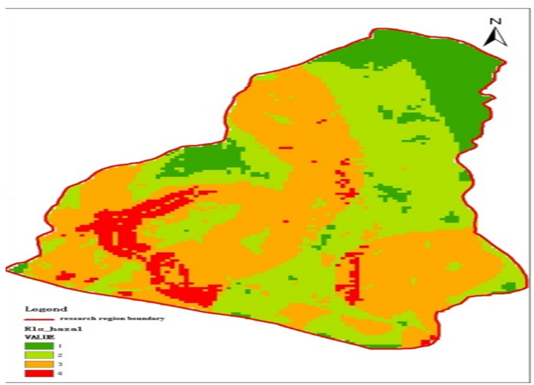

Figure 5 Grid image of ArcMAP platform

4. Result

According to the risk rank graph, the risk of Ganxigou valley is higher. Four regions are classified. Low risk region is distributed in the upstream basin, midstream flat ground and downstream flat ground which is concentrate distribution and single space is large. The low risk region area is 2.9581km^2, occupying 13.23%. Lower risk region distribute in the east of the Ganxigou valley, which runs through the whole area from north to south. The lower risk region area is 9.8203km^2,occupying 43.92%. Higher risk region distribute the southwest and southeast of the Ganxigou valley, whose area is 9.8203km^2, occupying 43.92%. Highest risk region distribute southwest of the Ganxigou valley, and single space is large, whose area is 1.3237km^2, occupying 5.92%.

5. Summary

Fuzzy synthesis judgment can deal with complexity and uncertainty in landslide risk assessment, which has wonderful usability. According to fuzzy synthesis judgment and Geographic Information System, calculation is very easy, and the result is scientific and rational. However, the application of fuzzy theory is recent, and some questions to be resolved, such as detaining the weight vector and the membership degree threshold value.

Acknowledgement

This work carried out with the financial contributions from Chinese National Natural Science Fund (No. 51208016, No. 41172254), Beijing Natural Science Fund (No.12H10086), and Beijing Education Commission Fund.

The authors are grateful to the anonymous referee for a careful checking of the details and for helpful comments that improved this paper.

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