A Sampled Method of Classification of Susceptibility Evaluation Unit for Geological Hazards based on GIS

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Abstract: In order to enhance evaluation precision for the susceptibility of regional geological hazard, this paper proposes a new method by which a large-scale study area can be automatically divided into minimum suitable evaluation units with taking slope unit as an object of study using geographical information system (GIS) and hydrological analysis tools. Based on this new method, Huangling County in Shaanxi Province has been classified into 6258 minimum suitable evaluation units, with a model for score of contribution to geological hazard susceptibility, the distribution of susceptibility score for each evaluation unit could be calculated, and then the susceptibility of regional geological hazard in Huangling County could be evaluated by each region accordingly. Evaluation results are as follows: 5 regions with different level of geological hazard susceptibility are divided in the area of Huangling County according to susceptibility score, among of them, regions with High Susceptibility account for 9.94% of total area in whole county, mainly situated in Luo River, Ju River and KouJia River Valley which are the key areas for prevention and cure of geological disaster in the future. The Sampled method can be extended to division of geological hazard susceptibility of other similar areas.

1 Introduction

The study for division of geo-hazard susceptibility in large area is essential to determination of transport line, location of buildings, as well as control of geo-hazard, etc. As a common method in geo-hazard susceptibility evaluation, the geo-hazard situation in the future is usually speculated according to the past and the present. Many scholars have made lots of attempts to find new approaches in the study of geo-hazard susceptibility evaluation based on the above rule and also gotten some successful experiences [1-2]. However, these methods generally have the following limitations: 1) regional limitations during application, for which the established models are only applicable to areas with similar conditions; 2) only suitable to the areas with frequent geological hazards and detail historical data available; and 3) no uniform criteria for determination of grid size among all evaluation methods based on specific grid size.

Recently, the technologies and models for division of geo-hazard susceptibility can be basically classified into inference model [3-4], statistics model [5-6] and deterministic model. Among them, the deterministic model is applicable to geo-hazard susceptibility evaluation in small watershed because it requires inputting elaborate data [2]. In the recent years, this method has been increasingly applied to the study for evaluation of geological hazard stability. For example, XIE

Mowen et al. (2003) [7] have put forward a GIS-based 3D model of slope stability analysis to calculate 3D safety factor of landslide. However, due to the inherent problems of deterministic model [8], such as simplifying the complex mechanics relationship to obtain statically determinate solution, as well as uncertainty of mechanical parameters required in model calculation, etc., this model can't be guaranteed to produce unique accurate solution [9]. Geo-hazard susceptibility evaluation can be effectively realized with the functions of spatial data management and analysis in GIS [2-7-10], but problems are still remaining, for example, how to select the minimum suitable size for the various factors of susceptibility evaluation.

On the basis of above considerations, this paper puts forward a digital elevation model (DEM) method for division of geo-hazard susceptibility evaluation unit in remnant loess plateau region. First, large scale area is classified into many suitable evaluation units with almost same lean angle and direction, providing the minimum calculation module parameters for geo-hazard susceptibility evaluation. Then distribution of geo-hazard susceptibility could be obtained through a great quantity of random calculation based on a GIS hydrological analysis model. This Sampled method can automatically divide the susceptibility evaluation into suitable units and evaluate geo-hazard susceptibility effectively and quantitatively in large scale natural slope.

2 Materials and Methods

2.1. Selections of Parameters for Geo-hazard Susceptibility Evaluation

The geo-hazard susceptibility is mainly divided according to the growing quantity and active degree of natural geological phenomenon and hazards such as landslide, collapse and mud-rock flow. The evaluation indexes include the existing colony statistics and formation conditions of geo-hazards. The existing evaluation indexes of the colony statistics mainly include quantity and size of geo-hazards. The formation conditions are selected as gradient, slope height, slope type, rock-soil structure and plant index, while the induced factors are selected as precipitation index and human engineering activity. All above seven major factors are to be considered as evaluation indexes.

2.2. Effect of Unit Size on Evaluation Parameter of the Geo-hazard Susceptibility

The effect of evaluation unit size on the geo-hazard susceptibility evaluation is realized through affecting the factors of the geo-hazard susceptibility evaluation, which is passed on step by step during the susceptibility evaluation. Under analyzing size of each evaluation unit, there is considerable works in the spatial distribution of various attributes among different parameters, so area frequency of various attributes among different parameters is used to present the effects of the evaluation unit size on the geological hazard susceptibility evaluation.

The factors which affect the geological hazard susceptibility mainly include the induced factors, including the geological environment and geological disasters, among of them, the most sensitive element is geological environmental conditions which can be subdivided as slope gradient, slope aspect, slope height and slope type, etc.

The certain imperfection more or less is existed in the various algorithms to get the slope gradient and slope aspect by means of DEM [12]. The impacts of evaluation unit size on slope aspect and slope gradient also have certain relationship. Apparently, the area frequency of northward slope gradient is much higher than those of units with other directions, which mainly because slope aspect of flat is also attributed to northward direction during aspect calculation [2].

2.3. Selection of Suitable Evaluation Size based on Topographic Feature

The selection of suitable evaluation unit has definitely related to the size of study area, the accuracy of topographic data, the elevation difference in contour data and the geo-morphological environment. Hereinto, topographic element is key factor which affects occurrence of geological
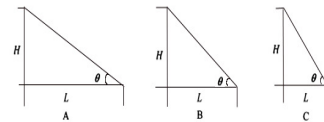

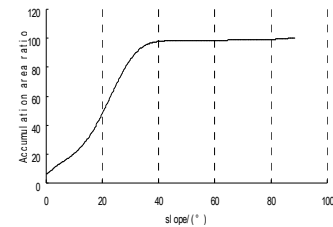Fig.1 Topographical categories based on slope ranges
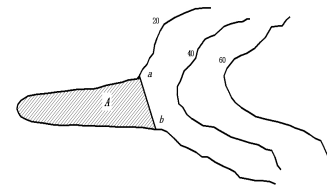

Fig.2 Distribution frequency of slope ranges

Fig.3 Errors occurred in irregular triangle irregular network interpolation processes

hazards. The gradient is the sensitive parameter which affects slope stability. In general, the topography can be divided into three types as gentle slope, middle slope and steep slope. The steep slope is more likely to emerge geological hazards than the gentle slope. As shown in the Fig.1, L is horizontal length, H is horizontal height, and θ is slope angle. (A) is for the gentle slope with $\theta \leq 10°$; (B) is for the middle slope with θ about $40° \sim 50°$; and (C) is for the steep slope with $\theta \geq 50°$.

H value is directly related to the size of study area. As for Huangling County, H value of the slope in more than 70% area ranges $10° \sim 40°$. (Fig.2)

The calculation of gradient and slope aspect can be divided into two stages: (1) interpolate values in the contour data to obtain face values; (2) calculate the gradient and slope aspect on the basis of face values. Some errors may occur during this process (Fig.3). The gradient value of region A in the figure is calculated as 0, with northward slope aspect, but actually, the gradient of region A is rather moderate and the slope aspect may not be northward [2]. This result is mainly caused by systematic errors (the initial slope aspect is northward). In general, the more regular the geometry of contour lines is, the lower the probability of errors will be occur in the calculation of slope gradient, slope aspect and slope-type.

2.4. Method of Selecting Suitable Evaluation Unit

According to the above analysis, various factors may influence the selecting of suitable geological hazard evaluation unit. However, the sensitivity of each element to the selection unit is quiet different. The most sensitive element is landforms.

Among the formation conditions of geological disasters, the development stage of river and valley has an obvious effect and integrated control on the formation of regional landslide and collapse. The evaluation unit divided by infancy cleugh can comprehensively reflect a variety of control and influence factors. This study adopts infancy cleugh slope as the evaluation unit which is a kind of catchment area formed by watershed and river
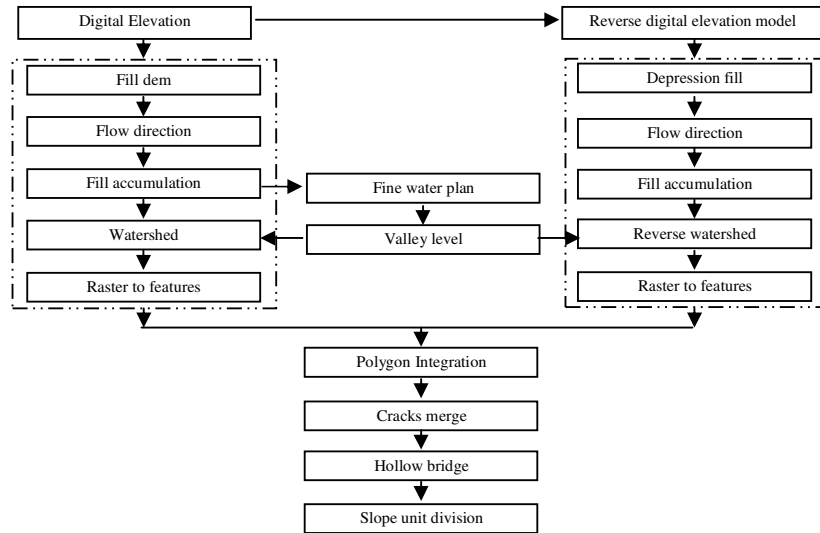

Fig.4 Flow chart for obtaining slope unit by DEM

valleys, so it is the basic topography unit of geological disasters. Evaluation units can be divided automatically on basis of DEM by computer according to hydrology method (Fig.4).

In hydrological analysis, the depression of DEM data should be filled firstly; and then, the flow diagram of whole region can be obtained according to the filled DEM; finally the cumulative flow of each unit can be obtained based on the flow diagram. By setting the minimum number of catchment cells when the flow goes through a grid cell, the catchment area of whole region can be obtained. Obviously, the larger catchment area can be obtained with the increasing of the minimum number of catchment cells. Thus, with setting different minimum number of catchment units, researches with different precision level can also be carried out in the study area. From the perspective of topography, watershed boundaries shall be the dividing line. In order to determine the valley line,
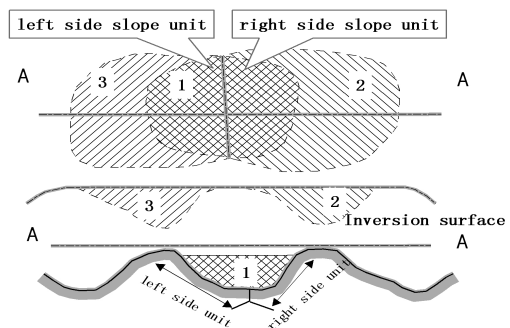

Fig.5 Watershed by DEM and reverse DEM

the hydrologic catchment basin is analyzed with the

reverse DEM data, namely, reversing the original DEM along a horizontal line, the original DEM high points will become low ones and then the new catchment.

Boundary to be obtained will become a valley line (Fig.5). The first catchment area can be obtained through the original DEM data, while the second and the third catchment areas can also be got according to the reverse DEM. Meanwhile, the first catchment area can also be divided into the left and right parts, namely it is slope unit which is required.

3 Results and discussions

It is divided into 6258 units by third-level ditches and gullies of the tributary in the infancy cleugh (Fig.6) based on 1:50 000 DEM of the survey area. The deeper black in Fig.6 means the greater possibility of disaster and the higher susceptibility of disaster. Susceptibility value is calculated according to the following formula.

$$F = \sum_{i=1}^{n} F_i \cdot W_i \times 100 \tag{1}$$

where F is contribution score of geological hazard susceptibility; F_i is individual contribution score of evaluation factor i, it is obtained by the normalized calculation of seven major analytical values, including the slope, slope height, slope type, rock-soil structure, vegetation index, precipitation index, and human engineering activities. The weight value W_i could be determined for each index based on analyzing the formation conditions of geological hazards and combined the previous research results (see Tab.1).

Tab.1 Quantitative calculation of evaluation Unit

Index	slope high	Slope type	Slope angle	Geotechnical Structure	Vegetation	Rainfall	Engineering
Weight	0.15	0.15	0.2	0.17	0.08	0.05	0.2

To simplify the calculation, the results are divided into five categories which scores are respectively <14, 14-17, 18-22, 23-31, >32, and the susceptibility corresponds to very low, low, medium, high, and very high respectively.

Based on the classification and division of quantification calculation, focal analysis is utilized to eliminate individual anomaly points. With comprehensive consideration of all kinds of factors, the division map of geological hazard susceptibility was made as Fig.6. It shows that the regions with high susceptibility account for 9.94% of total area in

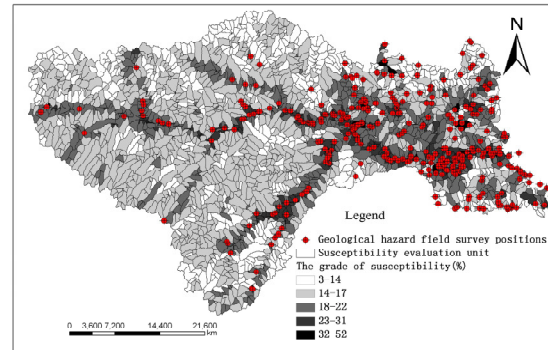Whole County and mainly distribute in Luo River,

Fig.6 Measured geological disaster point distribution

Ju River and KouJia River Valley.

Fig.6 shows significantly regional characteristics in the distribution of hazards in Huangling county. The topography caused by the new tectonic movement controls the distribution and type of hazards. More geological hazards are developing in the region where affected by unreasonable construction activities. For example, the eastern part of Fig.6 has a vulnerable environment with low vegetation coverage and serious soil erosion. People living there destroyed the natural slope toe and made down the slope stability when building the village roads, the overloading building also caused instability of the slope and result in the landslide of Yintai Mountain. The western parts of Fig.6 are low mountain and loess gully and rocky remnant plateau. There are less geological hazards due to sparse population and minor human constructing activities.

4 Conclusions

1) In light of the quantized impact factors in the evaluation of geological hazard susceptibility, this paper using GIS as technical platform and hydrological analysis tools, developed a suitable new method by which a large-scale study area can be automatically divided into minimum suitable evaluation units with slope unit as a study object. The method can be extended to division of geological hazard susceptibility of other similar areas. 2) This method has been practiced in the detailed survey of geological hazards in Huangling county of Yan'an city, Shaanxi province. The division map of geological hazard susceptibility which is gained from the calculation is in good agreement with the actual survey result. 3) The smallest suitable evaluation unit is selected as the object of geological hazard susceptibility analysis. This can highlight the

formation conditions of geological hazards and the influencing factor of terrain. It is of great significance for the monitoring of geological hazards.

Acknowledgments

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