The prediction of local landslide based on gis and neural networks

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Abstract: The stability of a landside is affected by various non-linear factors. Consequently, a large amount of spatial data have to be analyzed to predict the stability of landsides. Geographic Information Systems (GIS) have a distinct advantage in analyzing spatial data and they offer a good method for the prediction of landslides. Predicting landslides based on a neural network does not require a complicated mathematical model. A neural network can be used for the prediction of landslides by studying a large number of samples. The method of landslide prediction in this paper is based a coupled Geographic Information System (GIS) and neural network. The approach analyses various factors that influence the stability of landslides. These factors include external factors (such as rainfall, earthquakes, anthropogenic activity) and internal factors (for example, rock structure and topography), which can be described quantitatively. These quantitative factors and their spatial distribution comprise the basic elements of the landslide database. The database of landside predictions includes information on topography and hydrogeology. These quantitative factors are stored in the Geographic Information System and serve as the basis for prediction. To explain how to analyze the factors that affect landsides, this paper uses the western mountain area of Hubei (a province of China) as an example. The advantages of using a neural network-based predication method are introduced in this paper. The basic theory of neural networks is also introduced in this paper, using the BP neural network as an example. The neural network acquires the relationship between the factors of the landside and its hazard index after a large number of samples have been used to train the neural network. The neural network can be then be used for the prediction of landsides.

Résumé: La stabilité d'un landside est affectée par de divers facteurs non linéaires. En conséquence, une grande quantité de données spatiales doivent être analysées pour prévoir la stabilité des landsides. Les systèmes d'information géographiques (GIs) ont un avantage distinct en analysant des données spatiales et eux offrent une bonne méthode pour la prévision des éboulements. La prévision des éboulements basés sur un réseau neurologique n'exige pas un modèle mathématique compliqué. Un réseau neurologique peut être employé pour la prévision des éboulements en étudiant un grand nombre d'échantillons. La méthode de prévision d'éboulement en cet article est basée un système d'information géographique couplé (GIs) et réseau neurologique. L'approche analyse les divers facteurs qui influencent la stabilité des éboulements. Ces facteurs incluent les facteurs externes (tels que des précipitations, des tremblements de terre, l'activité anthropogène) et les facteurs internes (par exemple, structure de roche et topographie), qui peuvent être décrits quantitativement. Ces facteurs quantitatifs et leur distribution spatiale comportent les éléments de base de la base de données d'éboulement. La base de données des prévisions de landside inclut l'information sur la topographie et l'hydrogéologie. Ces facteurs quantitatifs sont stockés dans le système d'information géographique et servent de base à la prévision. Pour expliquer comment analyser les facteurs qui affectent des landsides, utilisations de cet article le secteur occidental de montagne de Hubei (une province de la Chine) comme exemple. Les avantages d'employer une méthode réseau-basée neurale d'affirmation sont présentés en cet article. La théorie de base de réseaux neurologiques est également présentée dans cet article, en utilisant le BP réseau neurologique de point d'ébullition comme exemple. Le réseau neurologique acquiert le rapport entre les facteurs du landside et son index de risque après qu'un grand nombre d'échantillons aient été employés pour former le réseau neurologique. Le réseau neurologique peut être alors soit employé pour la prévision des landsides.

Keywords: Geographic Information System (GIS), prediction of landslide, neural network, landslide hazard assessment

INTRODUCTION

Landslides are a common type of natural disaster, which can cause serious damage to the ecological environment and engineering construction as well as bringing enormous loss to people's lives and properties. However, there are still many difficulties in accurately predicting the occurrence of landslides. The reasons for this are: an incomplete understanding of landslide mechanics; there are many uncertain and unknown triggering factors; the character of most landslides is very complicated and non-linear in character. In addition, landsides have regional, multi-level and time-dependent characteristics. So a large amount of spatial data and factors must be processed in analyzing the stability of slope. Geographic Information System (GIS) and neural network technology offers a good technological platform and method to computerize the prediction of landsides. GIS has great advantages in analyzing and managing spatial data so that it offers a robust approach for landslide prediction. GIS has previously been employed for landslide prediction (Lan Hengxing 2002, Yin Kunlong 2001). The prediction of landslides by using artificial neural networks is a relatively new approach utilizing mathematical models. In this way we could set up the model through examining the quantitative data directly rather than by setting up a complicated mathematical model. There is a non-linear relationship between various kinds of geological factors and the hazard index of the slope. Artificial neural networks can be used to set up a model by studying a large amount of landslide samples. The model can then be used to predict landside location. The BP neural network had been used for this purpose (Feng Xiating 1995). We cannot only use the artificial neural network technology and Geographic Information System to predict the landside objectively but also show the spatial distribution of landslide occurrence.

SETTING UP THE LANDSLIDE DATABASE

The analyse of influence factors of landside disasters

Not only the static or intrinsic factors (such as lithology, rock structure, topography etc) but also the exterior factors (such as the rainfall, earthquake, anthropogenic activity, erosion) affect the stability of a landside. We should begin by analyzing these factors before we analyze the landside hazard in order that we can confirm the key factors, which affect the stability of the landslide. These factors should be divided into different groups, evaluated and digitized according to the degree that they affect the landside stability. The factors, which cannot be quantitatively assessed, may be analyzed using statistical methods. According to the character of the factor and follow-up need, we draw the map of every factor. Then we can set up the model of every digitalized factor on the base of GIS in order to assess the hazard of landslide (Lan Hengxing & Wu Faquan 2002).

Setting-up the landslide database

The landside database is made up of the landside factor database and the landside distribution database. The factors which affect the landslide hazards and their spatial correlations are expressed within layers in the GIS. These layers form the basis of the landslide factor database. The landslide database comprises the following databases: topographical, hydrogeological, and external factor database. The geological database includes: Stratigraphy, intact rock structure, lithology and rock mass structure in the landslide area. The topographical database includes: terrain contours, tension cracks and evidence of ground deformation and the morphology of the landslide. The hydrogeological database includes: rainfall, groundwater and hydrological regime. The external factor database includes *inter alia* earthquakes, anthropogenic activity and the influence of construction. The database of landslide factors provides the foundation for landslide prediction (Lan Hengxing & Wu Faquan 2002).

The database of landslide distribution should include following information: (1) The shape, size, location and history of the landslide; (2) Any available information reconnoitered in the past (the interpretation of aerial photographs, laboratory experiments, field investigations); (3) Any mitigation measures undertaken and the previous effects of past landslides; (4) Field mmonitoring data.

Example

Existing maps, reports and documents for the west of Hubei were collected and the geological, hydrogeological and terrain features of this area through studying information reconnoitered during field investigations from historic archives. At the same time, we collected the rainfall and earthquake records. We collected and digitized every relevant factor to set up the landslide factors database. We classified all these factors as follows: geological factors, hydrogeology factors, topographical factors and external factors.

THE ANALYSIS OF LANDSLIDE FACTORS

Geological factors

Several rock types occur in the area west of Hubei, ranging from cubic rocks, layered clastic rocks, weak rocks and carbonate rocks. The weak rocks are responsible for many of the landslides within the area (Table 1). The density of landslide within the weak rocks is $3.02/100km^2$ according to the survey, which is 8.16 times that of carbonate rock (Table 1). All of the rock landslides whose areas are larger than $3\times107m^2$ and most of soil landslides (accounting for 62% of the total) occurred in this kind of rock area (Table 1). The large number of landslides occurring within the weak rock can be explained by these strata being prone to softening when wetted, thus decreasing the shear strength and increasing the landslide risk.

Table 1. The statistics of each kind of landslide on different rocks in Exi State.

Geological rocks	Area affected (km^2)	Type of landslide	The number of survey pieces	Surface density Pieces/100km^2	Proportion of the total %
Cubic rocks	1260	Soil landslide	11	0.87	3.1
Layered clastic rocks	1592	Soil landslide	4	0.25	1.1
Weak rock	7294	Rock landslide Soil landslide	19 201	3.02	61.6
Carbonate rock	33067	Rock landslide Soil landslide	22 100	0.37	34.2
		Soil landslide	316		88.5

The regional trend of folding within Exi State is from west to east. The folds are mainly monocline or widened synclines. The inclined terrain of the folds is often apparent in this area. Landslide disasters mainly occurred in the same direction slope and dilapidation disasters mainly occurred in converse direction slope. The rock at the top of fold is often broken and shattered, therefore prone to failure. According to the statistics, within Exi State, 55 landslide disasters occurred in the main 72 folds. The axis of the fold is seldom revealed in the state. Landslide disasters occurred mainly along the axis of the fold. The surface density of landslide in such area is 1.82/km^2, accounting for approximately 2.2 times of that of the whole state.

The development of landslides tends to occur within the fault zones. The rock adjacent to the fault zones has been heavily fractured and weathered, which produces favourable geological conditions for landslides to occur. 74 landslide disasters occurred adjacent to the main 69 fault zones in Exi State. The surface density nearby the area is 21.9/km^2, which is about 27.4 times of that of the average. The fault zone from the north of Enshi to Jianshi represents such phenomenon.

Terrain and physiognomy

Landslides usually occur on convex slopes in this area (including convex sections of compound landslides). We investigated 364 landslide disasters in the mountain area west of Hubei, with 222 landslide disasters occurring on convex slopes, accounting for 61% of the total landslides. Most of landslides occur within the soils, which accounts for 95.3% of the total landslide disasters that occurred on convex slopes.

Landslides are an important mechanism contributing to slope denudation. 111 landslides responsible for slope erosion were investigated in Exi State. 106 of the slopes were to be affected by landslides, which accounted for 95.5% of such slopes and accounted for 48.8% of the total landslides. Landslides seldom developed in the hard rock slopes, the surface density of landslides being 0.37/100km^2. The surface density of landslides is about 0.45 times of the average of the whole region.

Hydrogeology

Slopes affected by long-term high groundwater levels are prone to failure. When the slope is supplied by groundwater or surface water there is a large amount of groundwater within the slope. In slopes where groundwater flow occurs within pre-existing pathways are more prone to failure. This condition is important to the occurrence of large soil landslides; 217 landslides were investigated in this state. Artesian water showed itself and long-time surface water supply was found in 118 landslides, which account for 54.4% of the total landslides. 106 soil-landslide disasters of such kind were investigated which account for 56.7% of the total soil landslides.

The fluctuations of water level in the rivers, lakes and reservoirs are important for the occurrence of the landslide disasters adjacent to the banks of rivers, lakes and reservoirs. The occurrence of landslide disasters adjacent to the bank is closely connected with the softened, saturated ground with dynamic and static pore water pressures generated in soil when the water levels fall. Such landslide disasters commonly occur during periods of rapid fall in the water levels, such as following a flood event. Bazimen landslide in Xiangxi is a typical example of such a landslide. The landslide reactivated in 1982, 1983 and 1987, when the water level fall suddenly after the Gezhouba Reservoir was filled with water from the Changjiang River.

Effect of human activities on project

Engineering projects usually result in human induced landslide disasters. There are about 5200 km of roads, 720 reservoirs and 10500 km of water channels in the western mountain area of Hubei. The construction of industrial or civil building in urban and rural areas occupies about 426700 hectares of land. Human activities such as excavation / blasting have induced landslides. For example, 1202 landslide disasters occurred along the roads in Exi State during the period between June and July 1983. Reservoir construction resulted in dug landslide disasters and the landslide near the Cheba Reservoir is a typical landslide of such a kind. 42 landslide disasters (31 soil landslides and 11 rock landslides) occurred along the roads according to the investigation. There are about 700 reservoirs and related 10500 km of associated channels in the state. 17 large landslide disasters occurred due to seepage from irrigation works. Channel leakage is the main reason for such landslide disasters. Inappropriate agricultural activities are the destroying the forest and cultivating on the hillside fields whose slope angles are more than 25^0. 323 soil landslides were investigated in the area. 233 landslide disasters occurred on the slope whose angle is more than 25^0, which account for 72.1% of the total. Most of landslide disasters occurred as the consequence of deforestation and reclamation of land, which results in the loss of forest and soil.

THE LANDSLIDE PREDICTION BASED ON NEURAL NETWORK

The relationship among the landslides is nonlinear so that it is difficult to predict their occurrence using common mathematical techniques. A large amount of data has been collected as part of the landslide prediction program. The processes occurring within the interior of landslides are not widely understood, therefore cannot be predicted with any certainty. However, we can study the uncertainty and engineering experiences about landslide in order to explore new methods to predict landslides using neural networks. If there is a large amount of data to train neural networks, the neural network, which had been trained, could reflect the nonlinear relationship among the landslides. The trained neural network could then be used as a tool to predict landslides (Lin Lusheng & Feng,Xiating 2002).

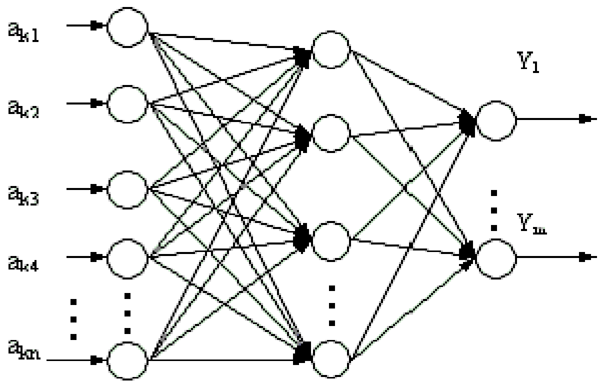

Figure 2. The structure of a three-layer BP artificial neural network.

Commonly used neural network models are made up of three layers: An input layer, a hidden layer and an output layer. When a neural network is used to address a complex non-linear problem, it must first learn the mapping of input to output. The learning process, or training, forms the interconnections (correlations) between neurons and is accomplished using known inputs and outputs, and presenting these to the neural network in some ordered manner. The strength of these interconnections is adjusted using an error convergence technique, so that a desired output will be produced for a given input. Once formed, the interconnections remain fixed and the neural network is used to carry out the intended task. In this section, the structure of the neural network is explained by describing the path followed by the trained neural network in performing a computation. A three-layer neural network is shown in Figure 2. The theory of how a neural network works is explained as follows:

$$A_{kn}=\{a_{1n}, a_{2n}, \ldots\ldots, a_{mn}\} \quad (k=1, 2, 3, \ldots, m, n=1, 2, 3\ldots, n) \tag{1}$$

where A_{kn} is the input data of the neural network, k is the number of samples in the input layer and n is the number of neural network cells.

The corresponding expected output $Y_K=(y_1, y_2\ldots\ldots, y_q)$, The hidden layers can be calculated as follows:

$$S_j = \sum_{i=1}^{n} W_{ij} a_j - \theta_j \qquad (j=1, 2, \ldots\ldots, p) \tag{2}$$

where W_{ij} is the weight of the interconnection between input layer and hidden layer. θ_j is threshold value of the hidden layer and P is the number of hidden layer cells. Various factors which affect the landslide hazard can be tracked as the data from the input layer and the index of hazard may be tracked as the data of the output layer (Figure 3).

Only quantitative, high quality samples can be used to train the neural network, so that it can be used to predict landslides. The more quantitative and the higher the quality of data, the more capable the neural network becomes at predicting landslides. So the samples should include all of the landslide mechanisms as an independent variable. After a large amount of samples have been used to train the neural network, it may be able to predict the main landslide characteristics.

The neural network can be used to predict the landslide after it has been trained. The distribution map of history landslide and the main factor distribution map could be added by using GIS. Then we achieve the digitized information about landslide, which would be applied to predict landslide by using a trained neural network. According to the hazard index that we achieve from the prediction we can classify the landslide susceptibility into four levels: low, moderate, high and very high. The landslide susceptibility could be expressed by using different colours in the landslide distribution map (Zhang Guirong & Yin Kunlong 2003).

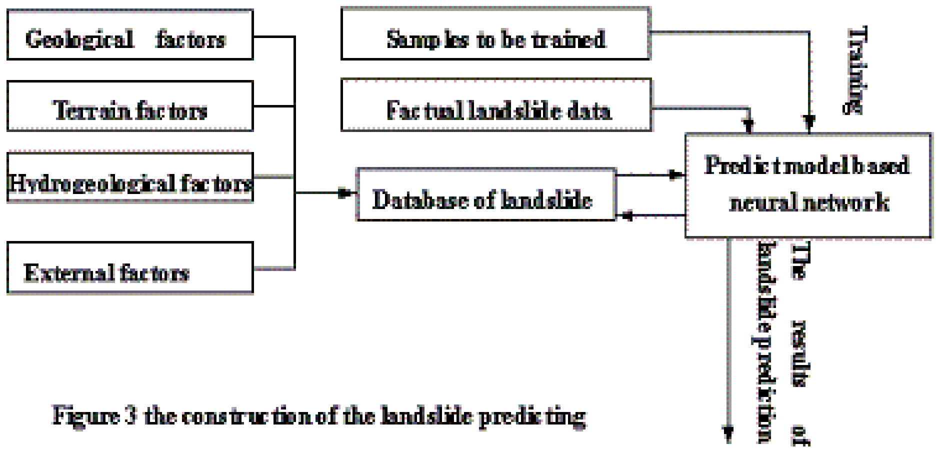

Figure 3 the construction of the landslide predicting

CONCLUSIONS

The prediction of landslides is highly complex. However, with the development of computer technology, GIS and neural networks have the potential to play an important role in landslide prediction. Traditional methods of predicting landslides are combined with the technology of GIS and neural networks so that we can predict landslides using new methods. This new method of predicting landslides will offer the theoretical direction for the prediction of landslides, which makes sense of landslide distributions. We have to carry out a large amount of background research and set up many databases with perfect function and consolidate it through practical application in order to set up the system of landslide prediction.

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