Landslide recognition and ground truth in Xiangxi area/China

Rutschungserkennung und Geländekontrolle im Xiangxi-Einzugsgebiet/China

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Abstract

In order to produce a susceptibility map in Three Gorges reservoir area a tributary of Yangtze river (Xiangxi catchment) was mapped. To perform susceptibility analysis for the whole Xiangxi catchment, mainly a landslide recognition method based on Artificial Neural Network (ANN) model was applied. The Back-Propagation algorithm is adopted as a method to find the relationship between landslide occurrence (results), topographic information (input: slope angle, curvature, stream orders and distance to streams) and geological information (lithologies and bedding properties). The Geographical Information System ArcGIS was applied to extract and quantify input information for susceptibility analysis from Digital Elevation Model (DEM) and to present the results in a landslide susceptibility map.

Keywords: mass movement, induction factor, ANN, susceptibility analysis

Zusammenfassung

Für das Xiangxi Einzugsgebiet als Teil des Drei-Schluchten-Reservoirs wurde eine Suszeptibilitätskarte für Massenbewegungen angefertigt. Der Xiangxi ist ein direkter Zufluss des Yangtze. Hierzu wurden vorab die auftretenden Massenbewegungen in einem repräsentativen Bereich des Einzugsgebietes kartiert. Um die Suszeptibilitätsanalyse für das gesamte Einzugsgebiet zu erstellen, wurde eine Methode zur Rutschungserkennung, basierend auf einer Analyse mit künstlichen neuronalen Netzen angewandt. Um die Beziehung zwischen dem Auftreten von Massenbewegungen (Ergebnis) und den topographischen Informationen (Eingabeparameter: Hangneigung, Hangkrümmung, Flussklasse und Abstand zu Flüssen), sowie den geologischen Informationen (Eingabeparameter: Lithologie und Schichtlagerung) zu ermitteln, wurde der „Back-Propagation“ Algorithmus herangezogen. Das Geographische Informationssystem ArcGIS wurde zum einen dazu verwendet, die Eingabeparameter für die Suszeptibilitätsanalyse aus dem digitalen Geländemodell (DGM) zu extrahieren und zu quantifizieren, und zum anderen, um die Ergebnisse der Berechnung in einer Suszeptibilitätskarte für Massenbewegungen darzustellen.

Schlüsselworte: Massenbewegung, Einflussfaktor, künstliche neuronale Netze, Suszeptibilitätsanalyse

1 Introduction

Already at the beginning of Three Gorges Project, the problems about slope stability have been proposed for the locations of the present settlements and the new settlements of immigration. Since the impoundment of Three Gorges reservoir in 2002, thousands of landslides have been found in the reservoir area. The water level rose up from 66m asl. in Nov. 2002 to 135m asl. in June 2003. Qianjiangping landslide was reactivated and occurred in Jul. 2003 right after the first period of water level rise (WANG et al. 2004). In Oct. 2008 the water level was further raised up to 156m asl.. Since 2008 the water level has yearly fluctuated between 145m asl. and 175m asl. Such a huge reservoir with fluctuating impoundment does notably change the hydrological and mechanical situation around the reservoir.

Under this situation 1,736 landslides, with the total volume of about 1.339×10^{11} m^3 have been found in the 100 km^2 area of upper reaches of the Yangtze river. In this area about 94% of all landslides have been triggered by rain and impoundment (HE et al. 2008).

The spatial distribution of landslides in Three Gorges reservoir is strictly determined by the stratum, geological structure, form of river valley and shore type (HE et al. 2009). For such a large scale hydroelectric project, it is costly and even impossible to investigate the whole area. So in the framework of the Sino-German “YANGTZE-Project“ (Nachhaltige Bewirtschaftung des neu geschaffenen Ökosystems am Drei-Schluchten-Staudamm), a sub-catchment of Yangtze, the Xiangxi catchment, had been chosen as example to investigate the mass movements, land-use change and soil erosion under the effect of impoundment in Three Gorges reservoir (SCHOLTEN & SCHÖNBRODT-STITT 2012). Within the sub-project "landslides" (Gefährdungsanalyse von Hangrutschungen im Einzugsgebiet des Xiangxi-Flusssystems), the mass movements in the study area were investigated (EHRET et al. 2012).

More than 200 landslides with different scales have been mapped in the first phase (2008 - 2011). Particularly the area close to the main stream, which is directly affected by the impoundment and water level changes, and where most intensive mass movements have been found, was investigated in detail. To get a general idea about the landslide prone areas in the catchment, a landslide recognition calculation based on an Artificial Neural Network (ANN) model has been executed.

2 Study area

Xiangxi catchment is a first class tributary north of Yangtze (Fig. 1). It rises in the Shennongjia Forest region (ca. 3000m asl.) and recovers an area of about 3200 km^2. Its outlet is located about 40 km upstream of Three Gorges dam and has the elevation of 62m asl..

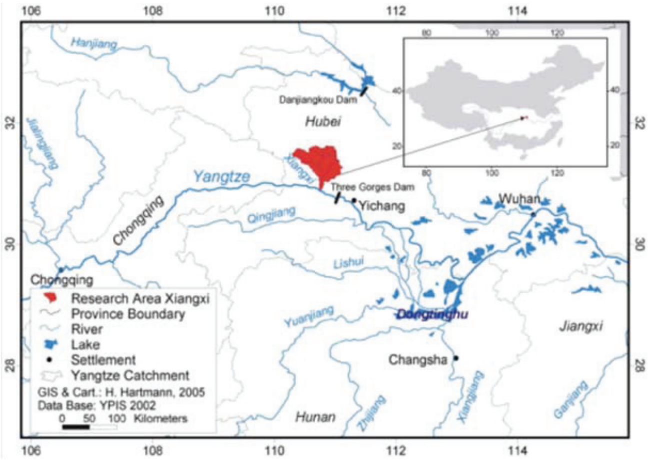

Abb. 1: Lage des Untersuchungsgebietes, Xiangxi Einzugsgebiet (in rot), nach YPIS (2002).

Fig. 1: Location of study area, Xiangxi catchment (in red), after YPIS (2002).

According to HE et al. (2008), the landslides in Three Gorges area can be divided into rock mass landslides including bedding landslides and dissected landslides, and colluvial landslides. Rockmass landslides refer to the landslides occurring in the stratums older than the quaternary period. Colluvial landslides refer to the landslides occurring in loose quaternary deposits. This classification can be also used for landslide classification in Xiangxi catchment, which has been mapped in the southern catchment. Bazimen landslide and Baijiabao landslide are two of typical dissected landslides in Xiangxi catchment, which were reactivated after impoundment of Three Gorges reservoir (HUANG & CHEN 2007; BI et al. 2012; DU et al. 2012). The landslides, which are mainly composed of colluvial materials, are the second main type of landslides in the catchment (HUANG et al. 2007).

3 Method

3.1 Artificial Neural Network (ANN)

In this paper the Back-Propagation model of Artificial Neural Network in software MatLab has been adopted for landslide recognition. Some relative characteristics of landslides, including bedding, lithology, slope angle, slope curvature and distance to stream, have been arranged in software ArcGIS and Microsoft Excel as input data for "model-training" to recognize landslides. ANN is a mathematical model imitating the function of biological neural networks. It consists of an interconnected group of artificial neurons and processes information using a connectionist approach to computation. Back-Propagation is an abbreviation for „back-ward propagation of errors“ and a common method of training ANN. It is a supervised learning method and a generalization of the delta rule. It is a learning rule algorithm of multilayered ANN model, which consists of input layer, hidden layer and output layer. Its learning algorithm can be divided into two phases: propagation and weight update.

In the view of a large amount of data for the study area, a model with only one hidden layer has been adopted. The hidden and output layer neurons process their inputs by multiplying each of their inputs by corresponding weights, summing the product, then processing the sum using a non-linear transfer function to produce a result. ANN "learns" by adjusting the weights between the neurons in response to the errors between actual output values and target output values. At the end of this training phase, the ANN represents a model that should be able to predict a target value from a given combination of input values (LEE et al. 2007).

3.2 Data processing

The landslides in Xiangxi catchment exhibit some common geographical characteristics. In this paper, lithology, slope angle, slope curvature and distance to stream are considered to be recognition characteristics. The whole catchment is divided into "training" area and "testing" area. The southern catchment, where is the back-water area of Yangtze, is adopted as "training" area (Fig. 2), the remaining part is "testing" area. Lithology of Xiangxi catchment is based on a geological map of scale 1: 250 000. Geological formations (Jurassic, Triassic, Permian, Devonian, Silurian, Ordovician, Cambrian and Pre-Cambrian) outcrop from west to east in the southern catchment (Fig. 2).

A big part of the catchment is based on Pre-Cambrian and Cambrian geological systems, which mainly consist of granite, limestone, dolomite and gneiss. This area has low frequency of landslide occurrence. 90% of landslides developed in the strata with intercalation of weak sediments in Jurassic and Triassic systems, as the investigation in the whole Three Gorges reservoir shows (HE et al. 2008). Landslides in the Xiangxi catchment occur most frequently in formations of Jurassic and Silurian (J3, J2, J1-2, J1, and S1). They are called "landslide-sensitive formations". The formations are assigned with indices according to the general mechanical characteristic of lithologies (Tab. 1). The lithology with weaker materials is assigned with higher value.

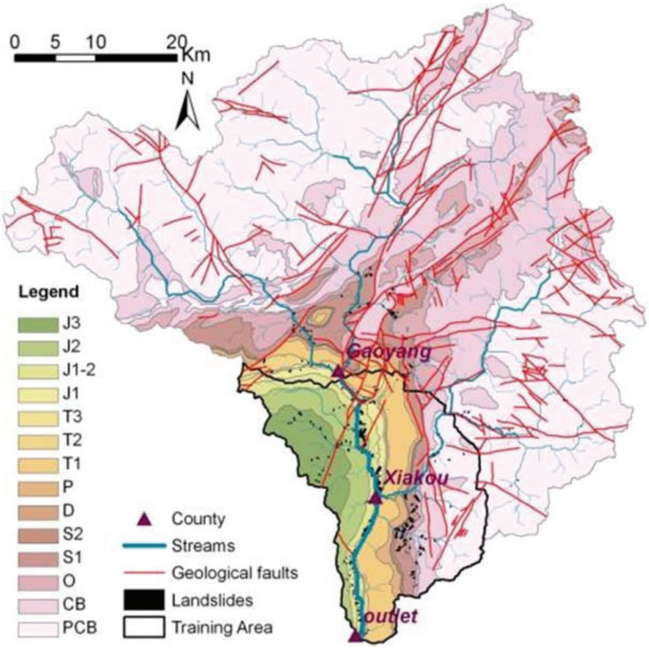

Abb. 2: Geologische Karte des Xiangxi Einzugsgebietes

Fig. 2: Geological map of Xiangxi catchment

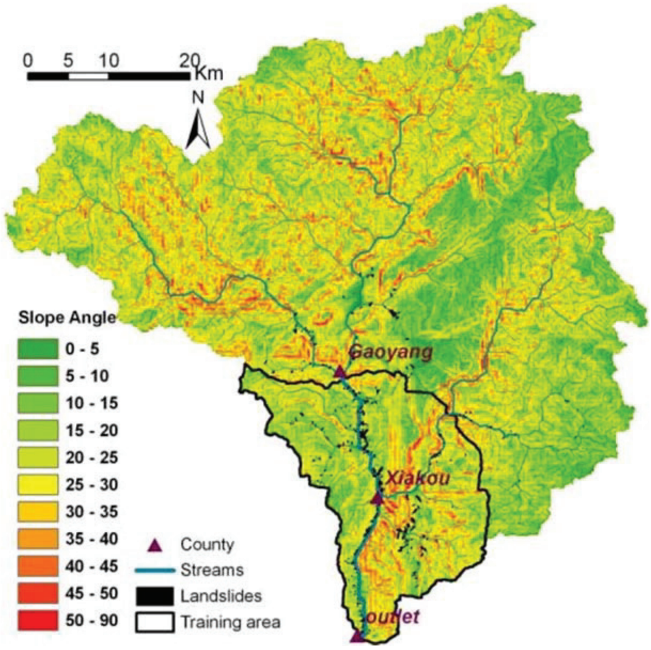

Abb. 3: Hangneigung im Xiangxi Einzugsgebiet.

Fig. 3: Slope angle in Xiangxi catchment.

Tab. 1: Geologische Formationen und zugewiesene Indices.

Tab. 1: Indices for geological formations.

Index	5	4	3	2	1	0	-1	-2	-3	-4	-5
Formation	J1	S1	J1-2	-	J2, J3	T3	T2	S2	CB, PCB	O	T1, P, D

With the software ArcGIS a digital elevation model (DEM) of Xiangxi catchment with 150 m×150 m resolution is adopted to analyze slope angle and slope curvature. The slopes composed of debris present a certain slope angle (Fig. 3). In Xiangxi catchment it is around 21° on average. Statistic values of average slope angle and its standard deviation of landslides in formation J2, J1-2, J1 and S1, where landslides have most frequently occurred, are presented in Tab. 2. The Slope curvature is a definition to describe the flat degree of a slope. It can be detailed calculated as profile curvature and plan curvature. Profile curvature is the curvature of the surface in the direction of slope. Plan curvature is the curvature of the perpendicular to the slope direction, which is referred to as the plan-form curvature. Slope curvature characteristics of the area are presented in Fig. 4.

Tab. 2: Durchschnittliche Hangneigung von Massenbewegungen in den besonders von Hangrutschungen betroffenen Formationen.

Tab. 2: Mean slope angles of landslides within the landslide-sensitive formations.

	Mean (°)	Standard Deviation
J2	19.5	5.0
J1-2	22.0	4.8
J1	21.7	5.2
S1	21.6	5.0

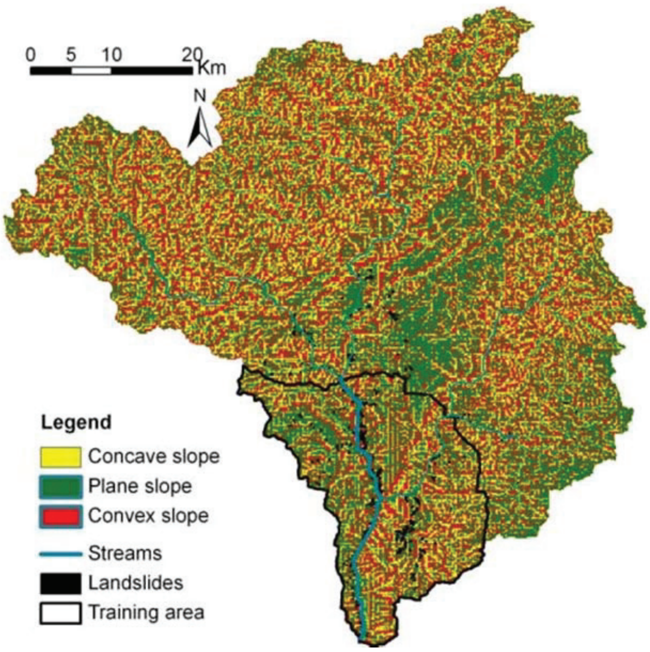

Abb. 4: Hangkrümmung im Xiangxi Einzugsgebiet.

Fig. 4: Slope curvature in Xiangxi catchment.

Based on DEM the hydrological system of catchment has been calculated. The streams have been classified to be four different orders according to flow discharge (Fig. 5). The landslide occurrence is definitely related to distance to stream. So the area close to stream has been divided into three influence zones (grade) by distance. Every unit in the catchment area is assigned with a value, according to distance to stream (Tab. 3).

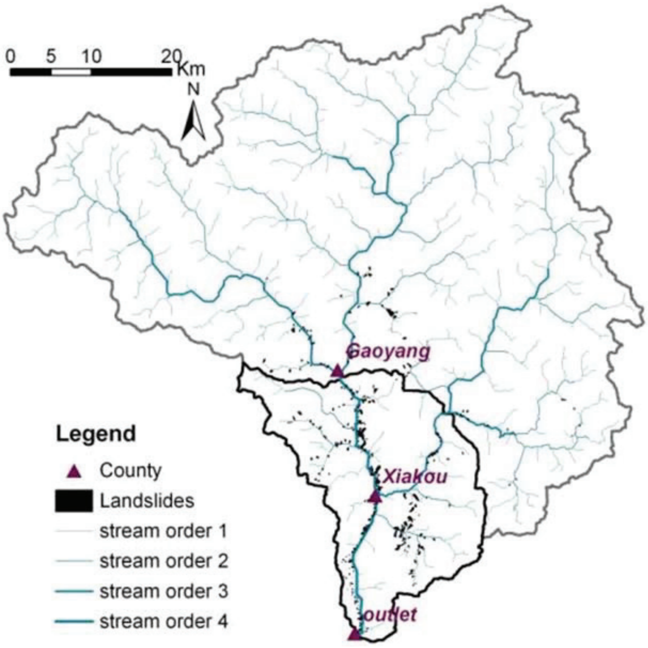

Abb. 5: Flussklassifikation im Xiangxi Einzugsgebiet.

Fig. 5: Stream order division in Xiangxi catchment.

Tab. 3: Indices bezüglich Flussklasse (order) und Abstand zum Fluss (grade).

Tab.3: Indices based on stream order division and distance to stream (grade).

Interval	Grade 1	Grade 2	Grade 3	Rest area
Order 4 (600m)	5	2	0	-5
Order 3 (500m)	4	1	-1	
Order 2 (400m)	3	0	-2	
Order 1 (300m)	2	-1	-3	

3.3 Result

The arrangement of data for training phase is presented in Tab. 5. The information about lithology, slope angle, slope curvature and distance to stream is transformed to be input values, which are prepared as input values for ANN model. For the training phase, the target output value in the phase of "learning" is whether an area is landslide or not. The landslide area is assigned with value 1 and the rest area is assigned with 0.

Tab. 5: Input und Outputs während der Trainingsphase

Tab. 5: Summary of input and output in training phase.

Attribute	Input				Output
	Lithology [-5, 5]	Slope angle [0, 90°]	Curvature	Stream influence [-5, 5]	Landslide 0/1
unit 1					
unit 2					
⋮	⋮	⋮	⋮	⋮	⋮

In the test area, every unit gets an output value from the well trained model. The values are limited between zone (0, 1) and classified into 5 grades: very high (0, 0.005), high (0.005, 0.03), medium (0.03, 0.05), low (0.05, 0.1) and very low (0.1, 1). The result is presented in a susceptibility map in Fig. 6.

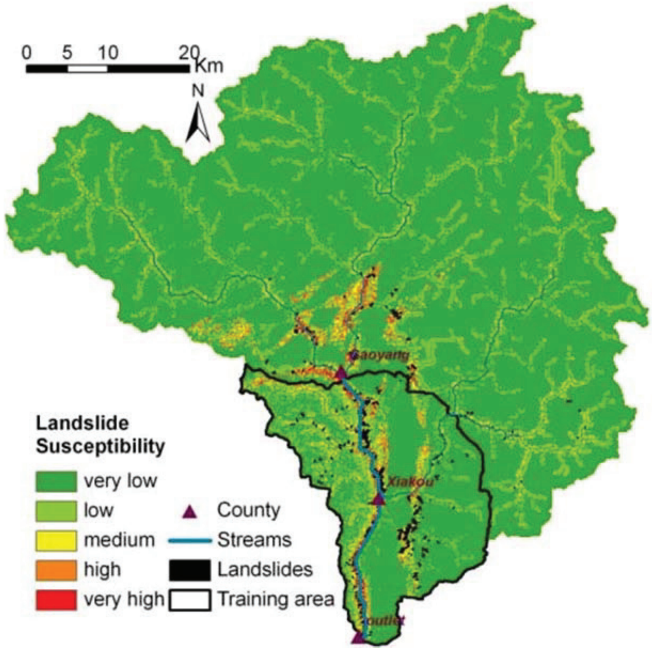

Abb. 6: Suszeptibilitätskarte für Massenbewegungen im Xiangxi Einzugsgebiet, erstellt mittels künstlichen neuronalen Netzen.

Fig. 6: Landslide susceptibility classification of Xiangxi catchment based on ANN analysis.

4 Conclusion

A case study of landslide recognition has been executed through ANN model in Three Gorges reservoir. Through Back-Propagation algorithm, back-water area is adopted as training area. Based on the data including DEM, geological information and landslide mapping, the whole catchment is classified into 5 landslide susceptibility classes as result. In the process of landslide susceptibility analysis in Xiangxi catchment, following conclusions have been achieved:

- Based on landslide mapping in training area, ANN model with Back-Propagation algorithm is a practical method for landslide recognition. The susceptibility classification could be a general guide for the catchment.
- The colluvial landslides in Xiangxi catchment exhibit some common characteristics of lithology and geomorphology, which could be helpful to identify landslides in this area.
- The water level change in Yangtze has influence on landslide occurrence in the back-water area. The landslides frequently occur in the area close to main stream in southern catchment.

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