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Application of a neuro-fuzzy model to landslide-susceptibility mapping for shallow landslides in a tropical hilly area

Hyun-Joo Oh [a], Biswajeet Pradhan [b,c,*]

[a] Geoscience Information Center, Korea Institute of Geoscience and Mineral Resources (KIGAM), 30, Gajeong-Dong, Yuseong-Gu, Daejeon 305-350, Republic of Korea
[b] Institute for Cartography, Faculty of Forestry, Geo and Hydro-Science, Dresden University of Technology, 01062 Dresden, Germany
[c] Institute of Advanced Technology, Spatial and Numerical Modelling Laboratory, University Putra Malaysia, Serdang, Selangor Darul Ehsan 43400, Malaysia

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ABSTRACT

This paper presents landslide-susceptibility mapping using an adaptive neuro-fuzzy inference system (ANFIS) using a geographic information system (GIS) environment. In the first stage, landslide locations from the study area were identified by interpreting aerial photographs and supported by an extensive field survey. In the second stage, landslide-related conditioning factors such as altitude, slope angle, plan curvature, distance to drainage, distance to road, soil texture and stream power index (SPI) were extracted from the topographic and soil maps. Then, landslide-susceptible areas were analyzed by the ANFIS approach and mapped using landslide-conditioning factors. In particular, various membership functions (MFs) were applied for the landslide-susceptibility mapping and their results were compared with the field-verified landslide locations. Additionally, the receiver operating characteristics (ROC) curve for all landslide susceptibility maps were drawn and the areas under curve values were calculated. The ROC curve technique is based on the plotting of model sensitivity — true positive fraction values calculated for different threshold values, versus model specificity — true negative fraction values, on a graph. Landslide test locations that were not used during the ANFIS modeling purpose were used to validate the landslide susceptibility maps. The validation results revealed that the susceptibility maps constructed by the ANFIS predictive models using triangular, trapezoidal, generalized bell and polynomial MFs produced reasonable results (84.39%), which can be used for preliminary land-use planning. Finally, the authors concluded that ANFIS is a very useful and an effective tool in regional landslide susceptibility assessment.

1. Introduction

Frequent landslides constitute significant risk in Malaysia, causing damage that affects people and property almost every year (Pradhan, 2010a, 2010b). The majority of these events have occurred on cut-slopes or on embankments alongside roads and highways in mountainous areas, while some major failures have occurred in residential areas near high-rise apartments (Pradhan and Lee, 2010a, 2010b). Extensive damage was caused on such occasions in the study area, Penang Island (Lee and Pradhan, 2006). Through scientific analysis, it is possible to identify and evaluate susceptible areas in order to reduce the hazard by proper engineering adaptation to the slope stability.

In recent years, GIS has been generally used as the basic analysis tool for spatial management and data manipulation, because of its ability for handling large amounts of spatial data. In the literature, there have been studies on the landslide susceptibility evaluation using GIS, and many of these studies have applied probabilistic techniques (Lee and Pradhan, 2006; Pradhan et al., 2006; Oh et al., 2009; Ozdemir, 2009; Pirasteh et al., 2009; Youssef et al., 2009; Van Westen et al., 2008; Pradhan and Youssef, 2010; Regmi et al., 2010; Yilmaz, 2010).

The logistic regression approach, which is one of the commonly used statistical based techniques, has also been applied to landslide-susceptibility mapping (Lee, 2007a; Lee and Pradhan, 2007; Tunusluoglu et al., 2008; Akgun and Bulut, 2007; Akgun et al., 2008; Bai et al., 2010; Das et al., 2010; Nandi and Shakoor, 2010; Oh and Lee, 2010; Pradhan, 2010a; Pradhan and Lee, 2010a, 2010b).

In recent years, various data mining approaches such as fuzzy logic (Ercanoglu and Gokceoglu, 2002; Kanungo et al., 2006, 2008; Lee, 2007b; Muthu et al., 2008; Pradhan et al., 2009; Pradhan, 2010b, 2010d) and artificial neural network (ANN) methods

* Corresponding author at: Institute of Advanced Technology, Spatial & Numerical Modelling Laboratory, 43400, UPM, Serdang, Selangor Darul Ehsan, Malaysia. Tel.: +603 8946 8466; fax: +603 8946 6061.
E-mail addresses: Biswajeet.Pradhan@mailbox.tu-dresden.de, biswajeet@mailcity.com, biswajeet24@gmail.com (B. Pradhan).

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(Kanungo et al., 2006; Lee and Evangelista, 2006; Melchiorre et al., 2008; Chen et al., 2009; Pradhan and Lee, 2009, 2010a, 2010b, 2010c; Pradhan et al., 2010a, 2010b; Pradhan and Buchroithner, 2010; Pradhan and Pirasteh, 2010; Poudyal et al., 2010; Yilmaz, 2010) have been employed for landslide susceptibility mapping. In a recent paper, Pradhan et al. (2010a) have applied an artificial neural network model in landslide susceptibility mapping and validated the model using the existing landslide data. They have applied the neural network model at three study areas in Malaysia and cross applied their weight for landslide susceptibility mapping to achieve reasonable prediction accuracy (84%). In another paper, Kanungo et al. (2006) showed that the landslide susceptibility map derived from combined neural and fuzzy weighting procedure is the best among the other weighting techniques.

More recently, new techniques have been used for landslide-susceptibility mapping. New landslide susceptibility assessment methods such as neuro-fuzzy (Lee et al., 2009; Pradhan et al., 2010c; Vahidnia et al., 2010), support vector machine (SVM) (Yao et al., 2008; Yilmaz, 2010) and decision tree methods (Nefeslioglu et al., 2010) have been tried and their performances have been assessed. As mentioned in the above literatures, some soft computing techniques such as fuzzy modeling and artificial neural networks have been commonly used to produce landslide susceptibility maps; however, the neuro-fuzzy modeling has been employed only in a few cases for such purpose (Lee et al., 2009; Pradhan et al., 2010c; Vahidnia et al., 2010). The neuro-fuzzy model of Kanungo et al. (2005) is not directly related to the adaptive neuro-fuzzy inference system (ANFIS) proposed in this paper; nonetheless it produced remarkable results. In their paper, they have assigned membership degrees to landscape factors based on their contributions to the landslide occurrence followed by an ANN method to solve the regression and classification problems.

In a recent paper, Pradhan et al. (2010c) assessed landslide-susceptibility using five different models by employing neuro-fuzzy approach and reported more than 90% prediction accuracy for the landslide-susceptibility maps of the Cameron Highlands in Malaysia. In that paper, they have reported that the higher prediction accuracy achieved by the neuro-fuzzy approach could be due to the over-leaning during the training of the ANFIS model. Therefore, in order to check the performance of the neuro-fuzzy model in landslide-susceptibility mapping and for the method to be more generally applied, more case studies should be conducted (Lee et al., 2009; Pradhan et al., 2010c). From the literatures mentioned above, it is evident that the methods employed when mapping landslide susceptibility are highly important for the performance of a landslide susceptibility map of different geographical regions. For this reason, this paper attempts to use an adaptive neuro-fuzzy inference system (ANFIS) for landslide-susceptibility mapping in a landslide-prone area in Malaysia. An ANFIS was applied and validated in the study area, using a geographic information system (GIS). The ANFIS algorithm used in this study is based on both expert knowledge using fuzzy inference system (FIS) and supervised learning (ANN): some spatial entities (areas) already classified are available and are used to classify new entities. The study aimed at developing a method that can be used with minimal changes in other locations. The results of the present study may provide a contribution to the landslide susceptibility literature.

This paper is organized in four major parts. The first part describes the characteristics of the study area; the second part presents the data production and landslide-conditioning factors; the third part presents the methods, development and training of ANFIS algorithms; and application of ANFIS for landslide-susceptibility mapping in the study area and the fourth part provides the validation of the landslide susceptibility maps, using the receiver operating characteristics based area under curve method.

2. Study area characteristics

In this research, a landslide-prone area in the Penang Island in Peninsular Malaysia (Fig. 1) was selected for landslide susceptibility assessment, using an ANFIS based neuro-fuzzy model. The application site lies between the latitudes 5°20′N and 5°22′N, and the longitudes 100°15′E and 100°17′E, and covers an area of 8.064 km^2. In this area, most of the 48 landslides were compiled from various data sources based on the classification scheme proposed by Varnes (1984). Most of these shallow landslides occurred where the maximum daily rainfall was more than 100 mm (Pradhan, 2010a).

The landuse in the study area is mainly peat swamp forest, plantation forest, inland forest, scrub, grassland and ex-mining area. The slope angle of the area ranges from 0° to as much as 61°. The relief of the study area varies between 0 and 451 m.s.l. Based on Malaysian Meteorological Department, the temperature of Penang Island ranges between 29 and 32 °C and the mean relative humidity varies between 65% and 96%. The highest temperature is during April–June, while the relative humidity is the lowest in June, July and September. The rainfall amount varies approximately between 58 and 240 mm per month in the study area.

Geologically, the study area is located on the western flank of the main range, which is composed of biotite granite (Pradhan, 2010a). The granite in the Penang Island is classified on the basis of proportions of alkali feldspar to total feldspars (Ahmad et al., 2006). The presence of granite rocks, granitic soils and boulders and the hillside development in the study area give rise to distinct landslides problems. The problems of landslides involving granitic rocks, boulders and granitic soils in the Penang island are not new, as documented previously by Tan (1990). Hilly roads cutting through the granitic terrains invariably cut into the deep weathering profiles of granitic rocks and soils, exposing in particular the core stones and bedrock surface, are prone to landslides. Similarly, the excavation and blasting for cut-slopes in housing schemes and condominium developments also expose the granite to deep weathering, leading to instability problems. In addition, the presence of colluvial deposits and boulders, which have

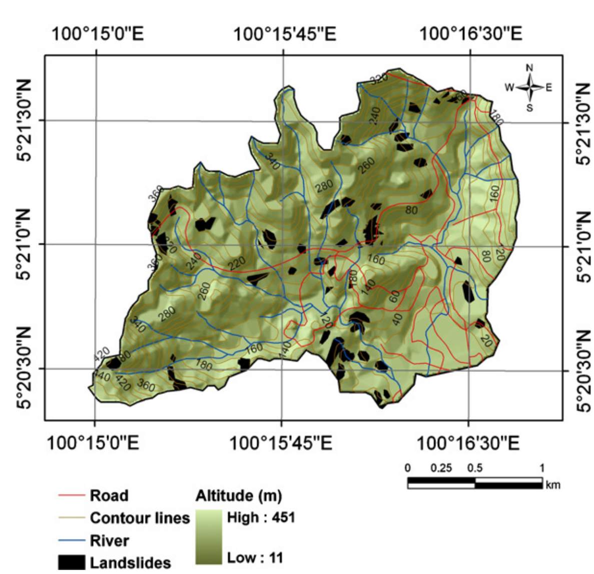

Fig. 1. Study area showing the landslide locations.