LANDSLIDE SUSCEPTIBILITY ANALYSIS USING AN ARTIFICIAL NEURAL NETWORK (ANN) MODEL: A CASE STUDY IN YUSHAN NATIONAL PARK, TAIWAN

Emmanuel Léonard[1], Shou-Hao Chiang[1,2]
1 Center for Space and Remote Sensing Research, National Central University, No. 300, Zhongda Rd., Zhongli District, Taoyuan City 32001, Taiwan
eleonardrosa@gmail.com
2 Department of Civil Engineering, National Central University, No. 300, Zhongda Rd., Zhongli District, Taoyuan City 32001, Taiwan
gilbert@csrsr.ncu.edu.tw

KEY WORDS: Remote Sensing, Landslide Susceptibility, ANN, GIS, Yushan National Park

ABSTRACT: Landslide phenomenon continues to be one of the worst natural disasters around the world. The clear need for accurate landslide susceptibility mapping has led to multiple approaches. This study aims to perform landslide susceptibility analysis for the Yushan National Park (YNP) in central Taiwan based on an Artificial Neural Network (ANN) Model using Remote Sensing data and Geographical Information System (GIS). In recent years, Machine Learning (Artificial Intelligence) and Data Mining techniques have been introduced as efficient tools in hazard and susceptibility analysis. ANN is one of the commonly used not only because it can deal with complex and non-linear relationships between slope stability and conditioning factors, but also minimize subjectivity. To perform ANN analysis, besides the static (predisposing) factors of landslide occurrence including topographic slope, aspect, curvature, elevation, topographic index, distance to geological lineament, some dynamic (triggering) ones have been selected in this study such as vegetation index (NDVI) and precipitation (rainfall).
All factors are analyzed with back – propagation training method to generate the landslide susceptibility map for the YNP. A landslide inventory map available for this study is used to validate the model. The results show where landslide is more likely to occur and highlight important factors that can explain the slope stability in YNP. Finally, this work can be used as a reference to assist slope failure, slope management and tourism planning considering landslide susceptibility in YNP.

1. INTRODUCTION

Landslides are present in all continents, play an important role in the evolution of landscapes and represent a serious hazard in many areas around the world (Guzzetti et al., 2012). This phenomenon not only cause every year enormous direct loss in term of lives, damages to buildings, properties and lifelines but also have a relevant indirect cost for the society, encompassing loss of productivity, reduction of real estate value, loss of tax revenue and other induced economic effects (Scaioni et al., 2014). The occurrence of landslides is the result of the interaction of complex and diverse environmental factors (Kawabata and Bandibas, 2009). These factors are divided into the static (predisposing or primary) and dynamic (triggering) causes. The first ones include natural fixed environmental settings such as topography, geology and geomorphology whereas the seconds include weathering, volcano, earthquake, rainfall and snow melting. One of the important step in landslide investigation is detection and/or monitor the activity of existing landslides using Remote Sensing techniques and Geographic Information System (GIS) tools. Once we understand the behavior of the phenomenon, the hazard assessment and susceptibility analysis can be effective to predict where landslide is more likely to occur. Moreover, through scientific analysis of landslides, landslide-susceptible areas can be assessed and predicted, and thus landslide damage can be decreased through proper preparation (Pradhan and Lee, 2007).

The purpose of this study is to develop a landslide susceptibility analysis using an Artificial Neural Network (ANN) Model in Yushan National Park (YNP). To achieve this aim, a sets of Remote Sensing data and GIS tools have been used. ANN has recently been an analytical tool for a wide range of applications in the fields of natural sciences such as speech recognition, human face recognition, satellite image classification, shape and texture recognition (Kawabata and Bandibas, 2009). One of the advantages of using an ANN for qualitative modeling of natural phenomena is that it can handle data at any measurement scale ranging from nominal, ordinal to linear and ratio, and any form of data distribution (Wang et al., 1995). In addition, it can easily handle qualitative variables making it widely used in integrated analysis of spatial data from multiple sources for prediction and classification (Kawabata and Bandibas, 2009).

2. STUDY AREA

Yushan National Park (Fig. 1) is in the heart of Taiwan, a 36 000 km^2 island located off the eastern part of Asia, and is an alpine national park. Yushan National Park (YNP; 23°19' N, 121°10' E) comprises 1,055 km^2 of the central mountain range (Hwang, 2003). Following the National Park Law of 1972, YNP, the largest national park in Taiwan, was established in 1985 in the purpose of ‘‘preserving the nation’s unique natural scenery, wild fauna and flora and historic sites and providing public recreation and areas for scientific research’’ (Lai, 2013). The elevations range is from 276 m above sea level to 3,950 m at the Yushan main peak. Two-thirds of the park is above 2,000 m in elevation, and there are >30 mountain peaks >3,000 m. Deep valleys and steep slopes (72% of terrain >55º) cause numerous landslides and waterfalls (Hwang, 2003).

Average annual rainfall in YNP is 3,000–4,700 mm. The monsoon season occurs during May–October, with typhoons most prevalent during July–September. The relative humidity is generally high (80–93%) throughout the year. The yearly average temperature of 20ºC, 10ºC and 5ºC in YNP corresponded to the 1,000-m, 2, 500-m, 3500-m in elevation, respectively (data from YNP). Snow generally occurs at elevations of >3,500 m during December–April. The monthly mean daily temperature for our study area at 500 m elevation is warmest in July (23.8ºC) and coldest in January and February (13.8ºC) (Hwang, 2003).

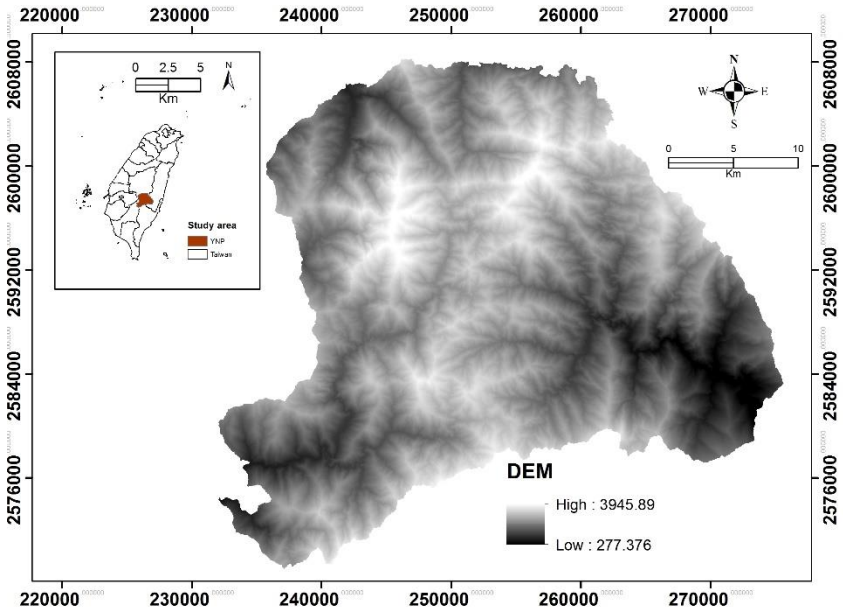

Fig. 1 Location of the study area in Yushan National Park, central Taiwan

3. DATA ANALYSIS USING GIS AND REMOTE SENSING

One of the specific objectives of this work is to use GIS and Remote Sensing data for landslide susceptibility analysis. Six predisposing (static) factors for landslide occurrence were used in this study: elevation, topographic slope, topographic aspect, topographic curvature, topographic index, and distance to geological lineament. Also, two triggering (dynamic) ones have been used including the Normalized Difference Vegetation Index (NDVI) and precipitation (rainfall). The above-mentioned factors (Fig. 2) were transformed into raster-type spatial database, and then the landslide-related input layers were extracted (samples) from this database. These factors were converted into a raster grid using sample tools in ArcGIS 10.2 for the application of the Artificial Neural Network.

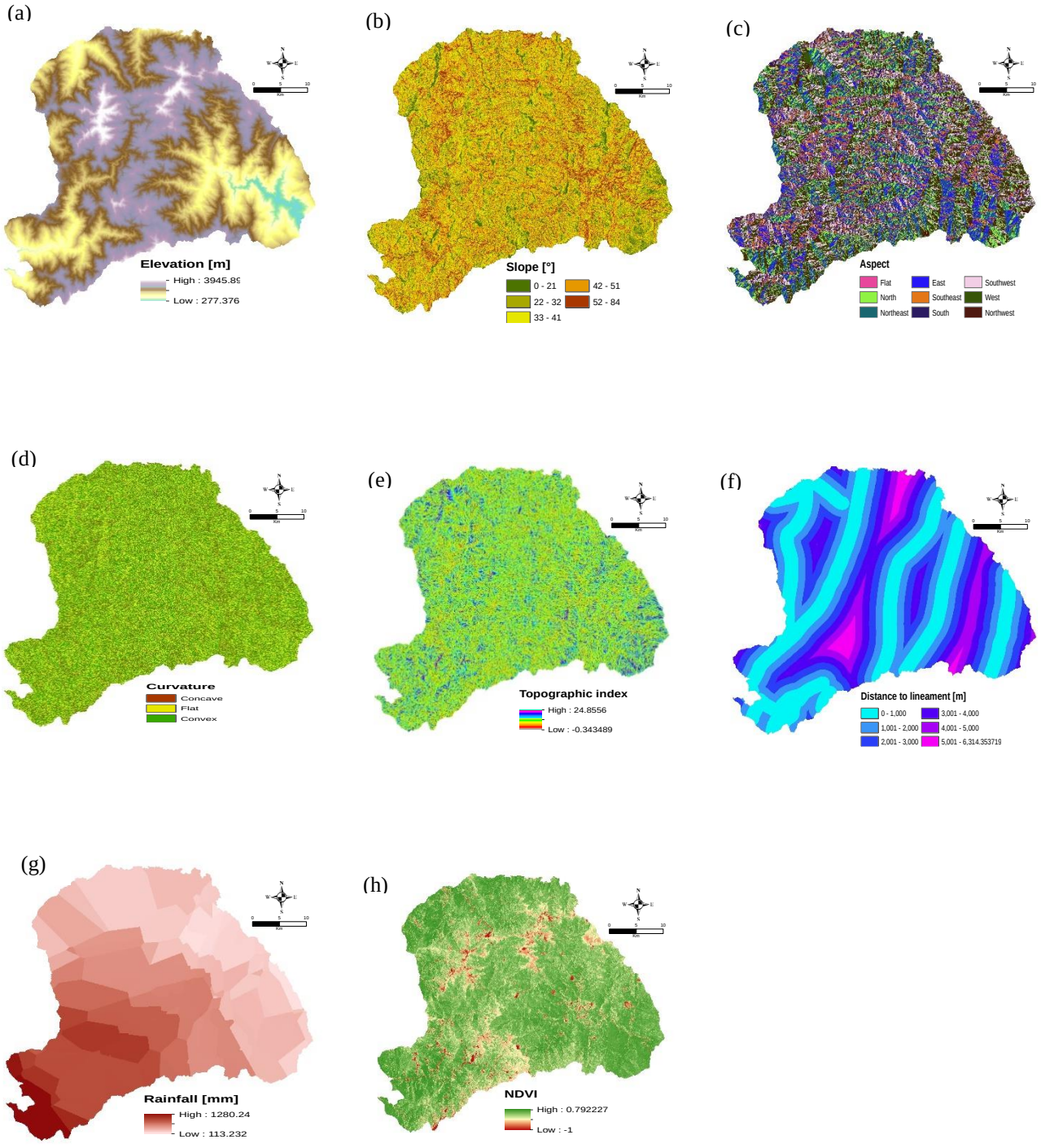

Fig. 2 Input data layers: (a) Elevation; (b) Slope; (c) Aspect; (d) Curvature (e) Topographic index; (f) Distance to lineament; (g) Rainfall; (h) NDVI

4. METHODS

4.1. Artificial Neural Network Model

The main purpose of ANN model is to build a new model of the data generating process so that it can generalize and predict outputs from inputs that has not previously been seen (Kawabata and Bandibas, 2009). In this study, we have used the back-propagation training algorithm which is the most frequently used neural network model. Artificial neural networks are trained using a learning rule and a set of examples of associated input and output values. Backpropagation is a learning rule algorithm of multilayered artificial neural networks, which consists of an input layer, hidden layers, and an output layer. 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 nonlinear transfer function to produce a result.

The use of ANN for modelling information patterns involves two stages: the training stage, wherein the weights of the connection between neurons are adjusted and the classification stage, wherein the trained ANN uses input patterns to predict outputs. Typically, the back-propagation algorithm trains the network until some targeted minimal error is achieved between the desired and actual output values of the network. Once the training is complete, the network is used as a feed-forward structure to produce a classification for the entire data.

4.2. Accuracy assessment

This study assesses the performance of the output maps using the Area Under the Receiver Operating Characteristic curve (AUC). The landslide susceptibility analysis results were verified using ground reference data with 1079 unstable cells (landslide area). The ROC curve explains how well the model and attributes predict the landslide. Then, the AUC, ranging from 0-1 can assess the prediction accuracy qualitatively.

5. RESULTS AND DISCUSSIONS

After the maximum number of iterations was terminated to 2,000 epochs, the root means square error (RMSE) value has met 0.019. The verification of the model was performed by comparing the ground reference data with the landslide susceptibility map. Then, the fitted model was compared to the inventory using AUC. The results show that the AUC is 0.81. The probability of landslide occurrence determined by the ANN model were applied to create the landslide susceptibility map using GIS tools (Fig. 3).

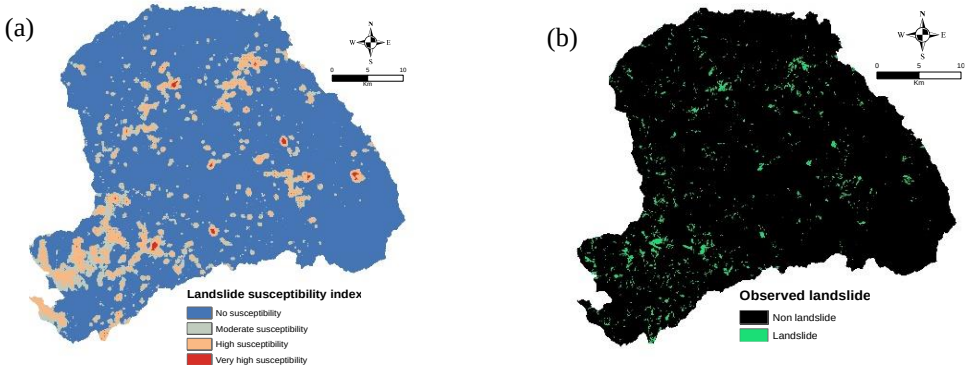

Fig. 3 ANN modeling result: (a) Landslide susceptibility map; (b) Observed landslide

The values were classified into four classes for visual interpretation: no susceptibility index, moderate susceptibility index, high susceptibility index and very high susceptibility index.

The landslide susceptibility index in the map is highly correlated to landslide occurrence observed in the area. Basically, there is an obvious relationship between topographic settings and landslide occurrence. Fig. 3 shows that most of the landslides occurred in the Southwest and North part of YNP. Moreover, the major part of these landslides occurs in the altitude range of 730 m to 2400 m a.s.l. Deep valleys and steep slopes (72% of terrain >55º) cause numerous landslides and waterfalls in YNP (Hwang, 2003). Rainfall and NDVI are two main triggering factors in this model. The current results show that landslides are more likely to occur when the total rainfall is up to 1,000 mm. Also, almost all landslides occurred in non-vegetated areas. Which means the NDVI values are very low in those areas.

6. CONCLUSION

An artificial neural network approach has been used to estimate areas susceptible to landslides using a spatial database for Yushan National Park. This study has successfully generated a trained ANN to produce a landslide susceptibility index map. The selected factors are sufficient to qualitatively and quantitatively model the relationship between landslide occurrence and these factors. Geographic representations of the model prediction show satisfactory results for the back-propagation algorithm based on the comparison between ground reference data and the landslide susceptibility map resulting from plotting the network predictions. Using the weights, the landslide susceptibility maps was created and verified. The verification results showed prediction accuracy (AUC) of 0.81. This work can be used as a reference to assist slope management and tourism planning considering landslide susceptibility in YNP.

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