A Study on Rational Slopeland Classification and Use for Land Conservation in Taiwan

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Abstract

Located at the squeeze zone between the Eurasia Plate and the Philippine Sea Plate, Taiwan has geologically brittle and steep slopelands as well as short and torrential rivers. Following the 921 earthquake and combination of frequent typhoons with heavy rain attacks, natural disasters such as debris flow, collapse and landslide occur easily time after time. Also, because Taiwan has a small area and a highly dense population, the farmland resource is limited; economic structure changes drastically accompanying quick industrial developments. Land uses in flats are very near saturation and development and utilization of slopelands are therefore of growing concern. However, improper development activities also increasingly take place and cause issues in soil and water conservation. In order to enhance slopeland management, rational conservation and utilization shall be implemented according to utilization limitations and stability of the land so that slopeland resources can be utilized in a sustainable way.

This study aims to research rational utilization of slopelands and use for land conservation in Taiwan. Jhuoshuei River is selected as the scope of the case study, using watersheds as analysis units. Seven vulnerability factors are selected, namely total curvature, average slope, average elevation, SPI, standard deviation of aspect, land use and NDVI, in companion with a model of disaster susceptibility created based on logistic regression; this model interprets the success rate curve of disaster susceptibility and gives an Area under the curve (AUC) of up to 91.1%.

Keywords: Slopeland Utilization Limitations, Land Conservation, Logistic Regression, Disaster-prone area, Cluster Analysis.

Introduction

At the early stage slopeland utilization in Taiwan lacked integral planning. Farmland resources in the mountains were affected by the changing economy structures, Slopeland Conservation and Utilization Act was therefore promulgated in 1976 aiming to regulate the scope of slopelands[15,16]. Referencing prescriptions of United States Department of Agriculture[18,19,21,23,27,29,39]. "Classification standard of slopeland utilization limitations" was set forth for managing agriculture land resources of slopelands, where slopelands were classified based on their average gradient, soil effective depth, soil erosion degree and parental rock properties into Classes I-IV: agriculture and husbandry lands which are suitable for cultivation or pasturage; class V: lands suitable for forestry, where afforestation shall take place or the natural forest and plantation shall be maintained; Class VI: lands for enhanced conservation, where protective measures shall be enhanced to mitigate disasters from occurring[17,42]. Proper management and land use shall be enforced based on the classification for and effective distribution of slopeland preservation and utilization.

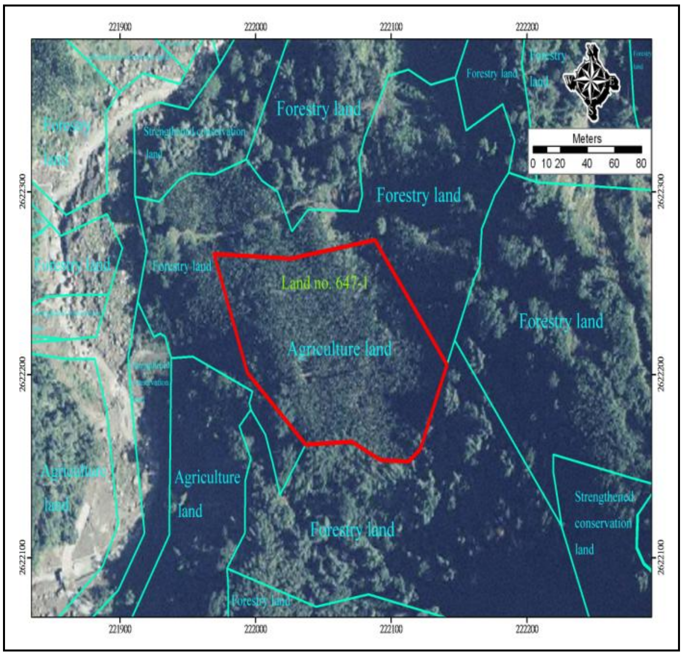

Fig. 1: Promulgated Map according to Existing Classification Standard of Slopeland Utilization Limitations - Using Da-An Section in Zhushan Township as example

In recent years, heavy rainfall and typhoon attacks resulting from climate changes frequently devastated the vulnerable mountains of Taiwan, improper development and exploration also affected the land in multiple aspects. All these have aroused public attention against the importance of land conservation. The classification of slopeland utilization limitations is an important link to national land conservation[33]. However based on the current classification, the disaster susceptible mountains areas are mostly classified as suitable for forestry, or lands that are suitable for agriculture and husbandry are interconnected to each other, as in fig.1. These lands are scattered in a fragmented manner. The severance of these lands brought up critical issues such as affecting natural scenery and local ecology; they are immediately harmful to land conservation whenever a typhoon or heavy rain occurs.

Essential factors involved in a disaster susceptible area include a bountiful source of soil and stones, a sufficient water supply and a terrain that is prone to produce a landslide or debris flow [32]. Two methods can be used for the classification of susceptibility analysis: the qualitative method and the quantitative method[7]. The quantitative method can be further divided into 2 categories: statistical analysis and application of artificial intelligence. The statistics approach statistically analyzes parametric properties of susceptibility factors in terms of terrain, geology, orientation and hydrology of the disaster susceptible locations where disasters have already occurred, for sorting out appropriate factors; then calculate susceptibility values of respective analysis units in the entire area using a suitable linear equation.

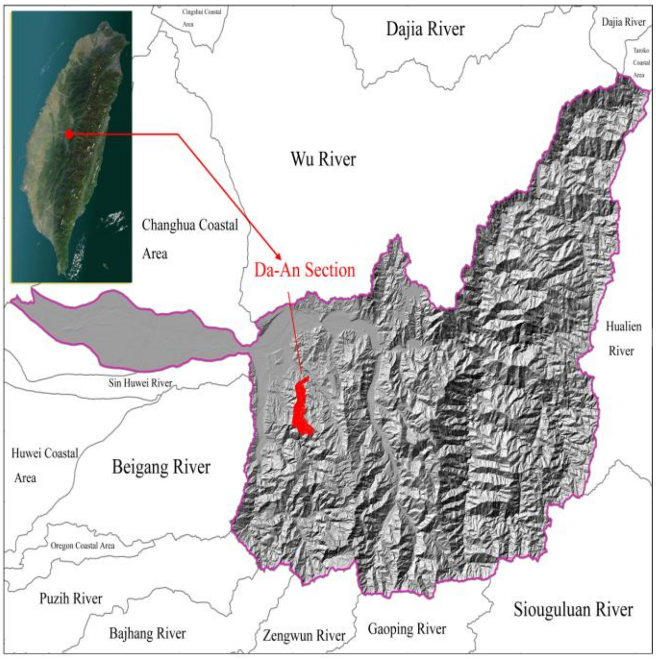

Fig. 2: Location of the Study Sites along Jhuoshuei River study Area

This can be used to predict the susceptibility of locations that possesses the similar combination of susceptible factors but have not yet experienced a disaster[4,5,8,11,20,43,45]. The Artificial Intelligence approach mainly consists of Neural Network and Fuzzy Set theory which are frequently used for the susceptibility analysis of disasters due to their powerful sorting capabilities [3,9,12,38,41,46].

The study screens out susceptibility factors of susceptible areas using the Jhuoshuei River Basin as the scope of study (Fig. 2.). Logistic regression is used for determining disaster-prone areas using watersheds as analysis units[30,31]. Rationality of land-use of slopelands is studied and analyzed based on integral concepts of the entire area.

The scope of Classification Standard of Slopeland Utilization Limitations only covers agricultural lands on the slopeland. This study targeted Da-An Section in Zhushan Township, covering approximately 9.41 km^2. There are 2,395 pieces land within that section, including mountain and forest, prairie, road, dry field and construction site. The lands are classified into separated as national lands and private ones. The national lands are properties of National Property Administration, Ministry of Finance. According to the stipulation in Classification Standard of Slopeland Utilization Limitations, Da-An Section has 317 pieces that are not covered by the classification. Therefore, Da-An Section only has 2,078 pieces for classification and analysis. The statistical results in terms of area are listed in table 1.

Table 1
Classification and Statistics for Da-An Section in Zhushan Township

Name Classification	Da-AnSection	
	Area (m^2)	Percentage (%)
Land Suited for Agriculture	4,064,697	43.19
Land Suited for Forestry	4,232,369	44.97
strengthened conservation Land	526,739	5.60
Range of undefinition	587,231	6.24
Total Area (m^2)	9,411,036	100

Research Method

This study conducted factor statistical tests and analyses based on 18 factors: land use, standard deviation of aspect, average elevation, terrain roughness, elevation variance, topographic wetness index (TWI) [14,25,36], stream power index (SPI) [35], terrain characterization index (TCI) [10,37], normalized difference vegetation index (NDVI) [24,40],length slope factor (LSF) [34], profile curvature, plane curvature, total curvature[47], terrain curvature, average slope , slope roughness, slope variance and watershed area. Through principle component analysis[6,26,28] and correlation coefficient tests, 7 factors (total curvature, average slope gradient, average elevation, SPI, standard deviation of aspect, land use and NDVI) were selected to disaster-prone area susceptibility analysis. Because land use is a categorical variables factor, the classification of 9 major land use types was used as an independent factor with the area percentage of watershed converted to continuous type for better analysis.

Jhuoshuei River is divided into 903 watershed units defined by each watershed outlet, as illustrated in fig. 3. The largest watershed area can reach 3,304.7 hectares and the smallest is 3.5 hectares.

Watershed units in Jhuoshuei River overlay the historical landslides as well as debris flow catalog [including post-Typhoon Herb (1996), before and after the 911 Earthquake (1999), before and after Typhoon Toraji (2001), before and after Typhoon Mindulle (2004), as well as before and after Typhoon Morakot (2009)] suggests 213 diaster-prone data entries in Jhuoshuei River. There are 690 non-disaster-prone groups. In other words, the various samples were randomly selected. 1:1 ratio between disaster-prone groups and non-disaster-prone groups. 213 are selected from each groups with a total of 416 entries. This was used to establish models.

Logistic regression model is a special form of logarithm linear model [1,22]. When a binary variable in logarithm linear model is treated as dependent variable and defined as the function of a series of independent variables, in the following form (1):

$$p_i = \frac{1}{1+e^{-(\alpha+\beta x_i)}} = \frac{e^{\alpha+\beta x_i}}{1+e^{\alpha+\beta x_i}} \qquad (1)$$

Of which, P_i is the probability of the ith event. It is a non-linear function consisted of x_i. This non-linear function can be converted into a linear function, where α and β are regression intercept and regression coefficient. This study defines the probability of this event as the classification index of high disaster-prone areas, with P_i=0.5 as the dividing threshold. If the classification index is greater than 0.5, the area will be grouped under the disaster-prone group. If not, then it will be grouped under the non-disaster-prone group.

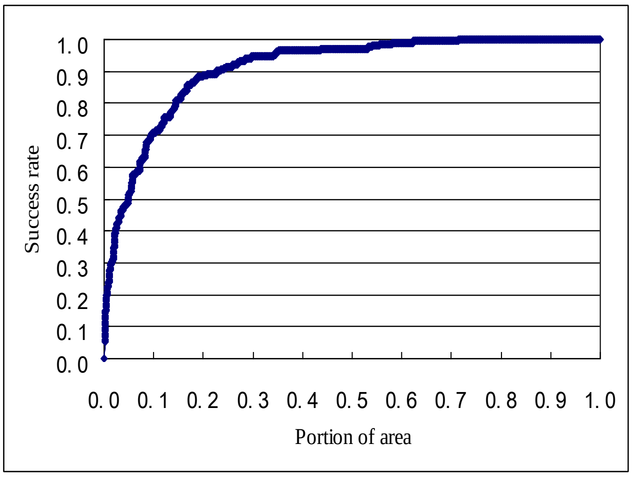

Fig. 4: Susceptibility Analytical ROC for disaster-prone areas in Jhuoshuei River

To assess the models, this study adopted receiver operating characteristic curve (ROC) [44]. In ROC, the area under the curve (AUC) serves as the basis for determining the quality of the method and result. AUC's range should be between 0~1. AUC should be as large as possible. When the area approaches the middle value of 0.5, the result is no better than random outcomes [13].

The susceptibility value derived from logistic regression was applied via K-Means method of cluster analysis[2] to establish disaster potential degree map, using the susceptibilities value and debris flow catalogue (post-Typhoon Herb, before and after 911 Earthquake, before and after Typhoon Toraji, before and after Typhoon Mindulle, as well as before and after Typhoon Morakot).

Results and Discussion

This study entered each factor into the logistic regression and obtained (2) as follows:

$$p = \frac{1}{1+e^{-\begin{pmatrix} 2.148\times Slope\_AVG-0.487\times Aspect\_STD \\ -11.474\times SPI+0.481\times T\_Cur \\ -0.989\times Height\_AVG-0.675\times NDVI \\ +2.993\times Landuse(1)+5.622\times Landuse(2) \\ +2.216\times Landuse(3)+179.780\times Landuse(4) \\ -12.856\times Landuse(5)-3.189\times Landuse(6) \\ -0.398\times Landuse(7)+6.105\times Landuse(8) \\ +13.783\times Landuse(9)+193.277 \end{pmatrix}}}$$

Of which, the susceptibility value for disaster-prone area (range 0~1); is the average slope; is the standard deviation of aspect; is the stream power index; is the total curvature; is the average elevation; is the Normalized Difference Vegetation Index; is agricultural land use; is forestry land use; is transport land use; is water conservancy land use; is architecture land use; is public land use; is recreation land use; is rock salt land use; is other land use.

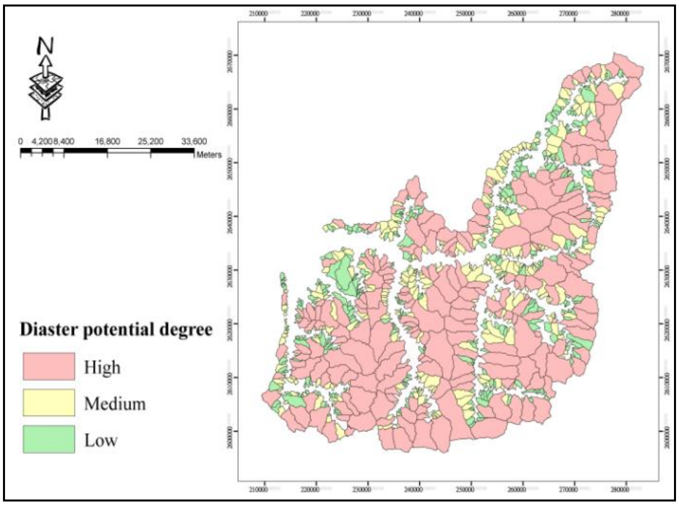

Fig. 5: Disaster-prone areas map in Jhuoshuei River

Logistic regression coefficient indicates that average slope, forestry land use, water conservancy land use and other land use are the key factors in disaster-prone areas. The coefficient derived from logistic regression is then entered into the 903 watershed analytical units in Jhuoshuei River. The success rate curve is illustrated in fig. 4 with AUC of 0.911, suggesting this model has good results.

Disaster-prone areas map is made from the susceptibility value of disaster-prone areas and the historical debris flow catalogue via cluster analysis (Fig.5).

The entire Da-An Section of ZhuShan Township in Nan-Tou County selected from the Jhuoshuei River within the scope of this study is in a disaster-prone area which shows segmented geological formation disaster-prone area (fig. 6). Several agriculture and husbandry lands are scattered at the sources of potential areas. Therefore based on the currently proclaimed land classification results, agricultural utilization in the disaster-prone areas is prone to induce debris flow disasters in the event of heavy rainfall or typhoons, resulting in threats to the downstream residents in terms of properties and livelihood safety. Based on the needs of national land security and ecological preservation, land classification of disaster-prone areas shall be carried out with an integral concept that covers the entire region, combined with strict limitations specified on the utilization of slopelands.

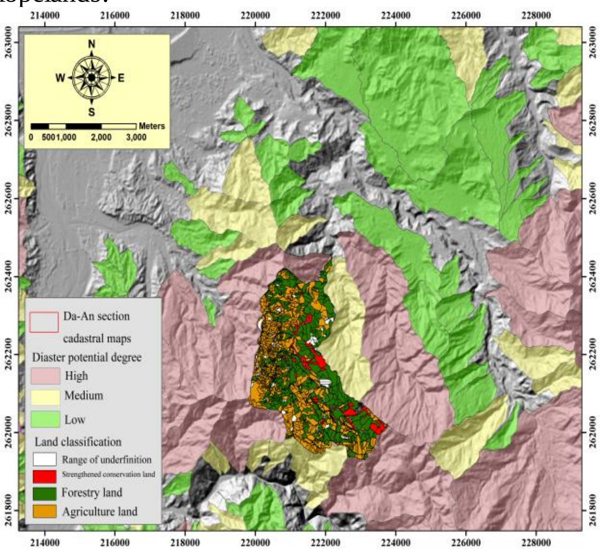

Fig. 6: Superimposed Susceptibility Classification Map of Da-An Section in Zhushan Township, Nantou County

Conclusion

The study aims to clear up potential sources of disaster susceptible slopelands within the disaster-prone areas. The classification of lands within the disaster-prone areas shall not be judged based on the 4 factors used for the verification of slopelands utilization classification. Instead, disaster susceptible areas shall be defined based on a national land conservation point of view, with control measures enforced on land utilization by classification and zoning of these areas. The study further aims to provide references to the government for the revision of relevant statutes and regulations. The study uses logistic regression to build up a disaster potential analysis model of which a success ratio of 0.911 is found. Since the study builds up disaster potential model by considering the existing topographic conditions and taking watersheds as study units, it is suggested that in the future, with the intervention of existing engineering facilities, a new assessment shall be made to adjust the potential degree of disaster-prone areas.

In recent years, climate changes, particularly Typhoon Morakot, had severely impacted the national land. Therefore the planning of national land shall be rationally oriented on slopeland preservation so as not to damage the overall ecology of the environment for soil and water conservation. Whereas land conservation is an important standard for the classification of slopeland utilization limitations, the existing standard for classification shall be modified to a more restricted attitude. Besides the 4 factors used for classifying the utilization of sloplands, geologic disaster susceptibility factors shall be further incorporated to mitigate the occurrence of slopeland disasters and to effectively manage the preservation of national lands so as to achieve goals of environmental and ecological protection and a sustained overall development.

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