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 water and soil 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.

Promulgated in 1976, "Slopeland Conservation and Utilization Act" aims to regulate the scope of slopelands. "Classification Standard of Slopeland Utilization Limitations" was set forth, classifying slopelands into lands suitable for agricultural, animal husbandry, or forestry purposes or as lands subject to strengthened conservation according to their average slope, soil effective depth, soil erosion degree, and parent rock. Overall inventory was carried out based on the said 4 factors to verify the classification standard of slopeland utilization limitations. However the currently verified lands are mostly suitable for forestry or for agriculture and animal husbandry. Scattered placement of these lands results in critical issues such as segmented land use and impaired landscape and ecotype. Especially for lands verified as disaster-prone, they are immediately harmful to land conservation when typhoon or heavy rain occurs. Therefore 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%. Subsequently the diagram of disaster potential classification results of the Jhuoshuei River is created via Cluster Analysis.

The classification of disaster susceptibility set forth by this study is to rationalize the standards for verifying slopeland utilization limitations. For areas having high disaster-prone and being unsuitable for agricultural land use, control classification implementations have been proposed based on land conservation orientations. This study may serve as a reference for the government to revise statutes regarding the utilization of slopelands.

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

Introduction

Because Taiwan's early slopeland use lacked comprehensive planning and hillside farmland resources were affected by the changing economic structure, the "Slopeland

Conservation and Utilization Act" was promulgated in 1976 to regulate slopeland (Council of Agriculture 1976; 1977). To manage slopeland resources, the Classification Standard of Slopeland Utilization Limitations was drafted based on the statutes from US Department of Agriculture (Doolittle et al. 2002; Dave and Nels 2003; David and Bill 2003; Francis 2006; Jeff 2007; Keith 2008; Robert 2006). Land Classes I-IV, for agriculture or animal husbandry purpose, which are suitable for cultivation or pasturage; Land Class V, for forestry purpose, which is suitable for forestry or maintaining the natural woods or the plantation coverage; and Land Class VI, for strengthened conservation, which is emphasized with conservative treatment for mitigating occurrence of hazards. (Council of Agriculture 1995; Soil and Water Conservation Bureau 1995). Each class is managed accordingly to effectively achieve proper utilization and conservation of slopelands.

Recently, climate change induced storms and typhoons that struck Taiwan's fragile slopeland. In addition, under many influences such as improper human development, conservation awareness for national land is raised among the Taiwanese people. Classification Standard of Slopeland Utilization Limitations is an important part of national land conservation(Lin et al. 2010). However, high disaster susceptibility regions are classified as mixed forestry-suitable lands or agriculture/husbandry-suitable lands according to existing regulation (see Fig. 1). This sporadic distribution causes serious problems such as land fragmentation and scenery, ecology damages, etc. These areas are vulnerable to disasters during storms or typhoons.

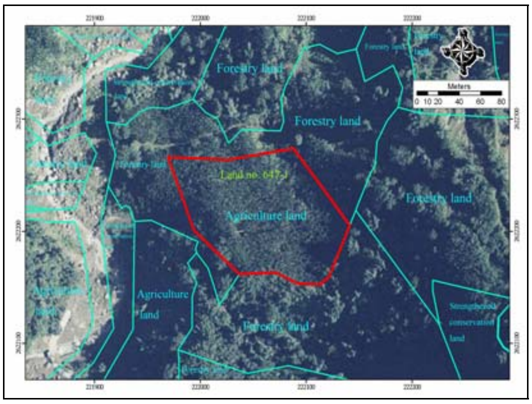

Fig. 1: Promulgated Map According to Existing Classification Standard of Slopeland Utilization Limitations - Using Da-An Section in Zhushan Township as Example

Diaster-prone requires stone material sources, sufficient water supply, and appropriate terrain. These tend to induce landslide and debris flows(Lin et al. 2002). The analysis of diaster-prone susceptibilty can be classified as qualification and quantification（CGS 2007）. Quantification can be classified into statistical analysis and artificial intelligence utilization. Statistical methods analyze the statistical parameter characteristics of susceptibilty factors such as terrain, geology site, and hydrology, etc. Appropriate factors can be selected in conjunction with linear equations to calculate the diaster-prone area value of each unit within the entire area. This can then be used to predict the disaster possibility in areas yet to be hit by disasters but have similar factor combination characteristics (Carrara et al. 2008; Chang 2011; Chen et al. 2008; Tunusluoglu et al. 2008；Dong et al. 2009; Biswajeet 2010; Su 2010); Artificial intelligence comprises mostly of neural network and fuzzy set. Because of its powerful classification capability, it is often used in vulnerability analysis(Bai 2010; Chauhan 2010; Choi 2011; Vahidnia1 2009; Pradhan 2010; Sezer 2011).

This study focuses on Jhuoshuei River (see Fig. 2.) including the study site to filter susceptibilty factors in diaster-prone areas. Using watershed as unit, logistic regression is used to draw the high diaster-prone area(Lee et al. 2007, 2008), and the concept of region as a whole is used to explore rational land use in slopelands.

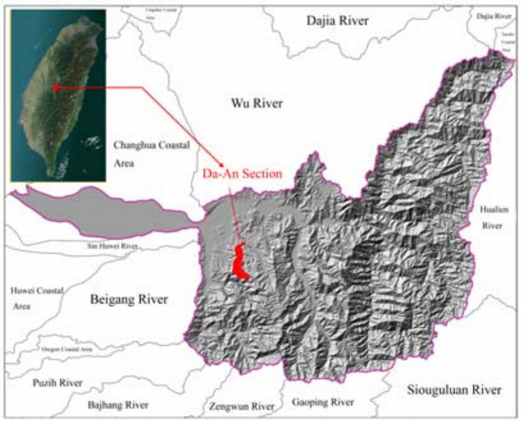

Fig. 2 Location of the Study Sites along Jhuoshuei River study Area

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 parcels 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 parcels that are not covered by the classification. Therefore, Da-An Section only has 2,078 parcels 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 (%)
LandSuited for Agriculture	4,064,697	43.19
LandSuited for Forestry	4,232,369	44.97
strengthened conservation Land	526,739	5.60
Range of undefinition	587,231	6.24
TotalArea (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) (Conoscenti et al., 2008; Gorum et al., 2008, Nefeslioglu et al., 2008), stream power index(SPI) (Wilson and Gallant, 2000), terrain characterization index (TCI) (Park et al., 2001; chen et al., 2011), normalized difference vegetation index (NDVI) (Rouse et al., 1973; Gilabert et al., 2002) , length slope factor (LSF) (Moore and Burch, 1986), profile curvature, plane curvature, total curvature, terrain curvature average slope , slope roughness, slope variance, and watershed area. Through principle component analysis (Cattell 1966; Kaiser 1960) 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

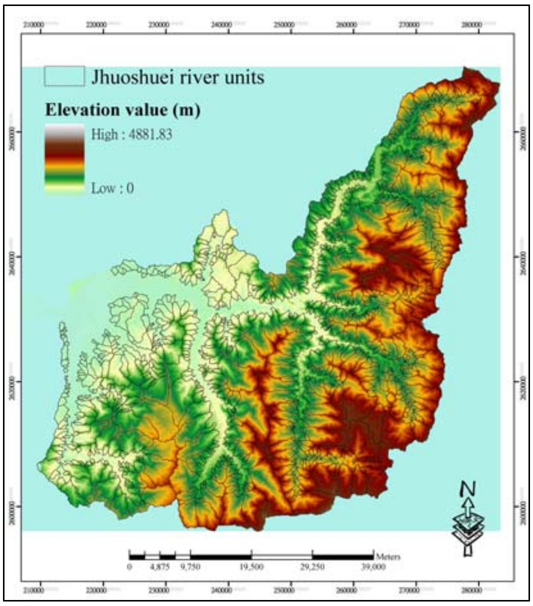

Fig. 3: Watershed units Drawn in Jhuoshuei River

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-diaster-prone groups. In other words, the various samples were randomly selected. 1:1 ratio between diaster-prone groups and non-diaster-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 (Feinberg 1985; Agresti 2002). 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):

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

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 diaster-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 diaster-prone group. If not, then it will be grouped under the non-diaster-prone group.

To assess the models, this study adopted receiver operating characteristic curve (ROC) (Swets, 1988). In ROC, the area under the curve (AUC) serves as the basis for determing 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 (Chung and Fabbri, 2003).

The susceptibility value derived from logistic regression was applied via K-Means method of cluster analysis (Anderbeg, 1973) to establish diaster potential degree map, using the susceptibility value and debris flow catalog (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). By overlaying the map of classification standard of slopeland utilization limitations for analysis and verification to evaluate the different land distribution and its impact on national land conservation.

Results and Discussion

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

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

Of which, P the susceptibility value for diaster-prone area (range 0~1); $Slope\_AVG$ is the average slope; $Aspect\_STD$ the standard deviation of aspect; SPI is the stream power index; T_Cur is the total curvature; $Height\_AVG$ is the average elevation; $NDVI$ is the Normalized Difference Vegetation Index; $Landuse(1)$ is agricultural land use; $Landuse(2)$ is forestry land use; $Landuse(3)$ is transport land use; $Landuse(4)$ is water conservancy land use; $Landuse(5)$ is architecture land use; $Landuse(6)$ is public land use; $Landuse(7)$ is recreation land use; $Landuse(8)$ is rock salt land use; $Landuse(9)$ is other land use.

Logistic regression coefficient indicates that average slope, forestry land use, water conservancy land use, and other land use are the key factors in diaster-prone areas. In addition, "-" in the factors of logistic regression coefficient means reduction in the diaster-prone areas, such as NDVI, SPI, etc., and vice versa. 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.

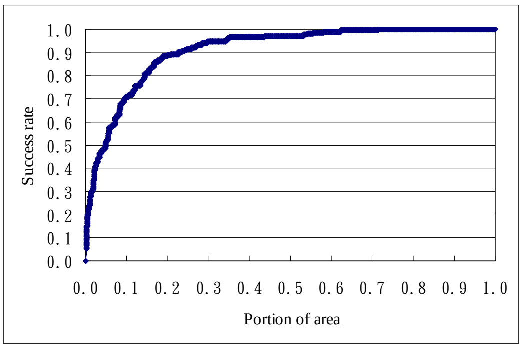

Fig. 4: Susceptibility Analytical ROC for disaster-prone areas in Jhuoshuei River

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

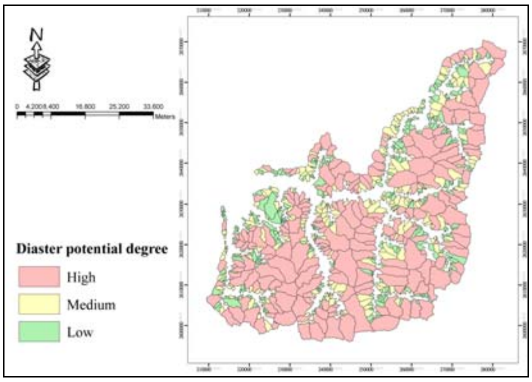

Fig. 5. Diaster-prone area potential degree map in Jhuoshuei River

The studied area was within Da-An Section of Zhushan Township of Nantou County and was selected from Jhuoshuei River, and it seems that the entire section is within high diaster-prone area (see Fig. 6). This indicates that the section's geology is fragile, with several agriculture-suitable lands sporadically distributed at the source of the high diaster-prone area. Consequently, when typhoon or storm strikes, this high diaster-prone area is to be used for agriculture in accord with the current Promulgated Land Category Results. This, however, is vulnerable to debris flows and endangers the safety and property of the downstream residents. From the perspective of national land safety and environmental protection, high diaster-prone area should be classified based on the concept of the entire region, and slopeland use and development should be strictly limited.

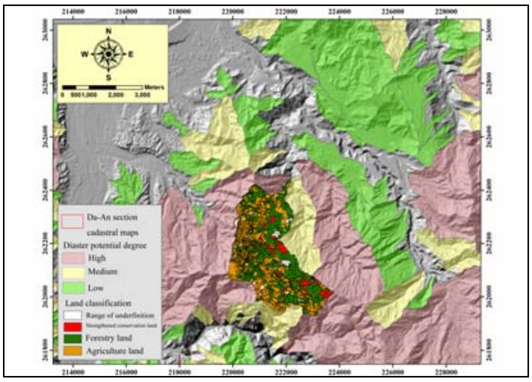

Fig. 6: Superimposed Susceptibility Classification Map of Da-An Section in Zhushan Township, Nantou County.

Conclusions and Suggestions

To solve the potential source of slopeland reclamation in high diaster-prone areas, this study proposes that the land classification within the high diaster-prone area should not be based on the 4 classification factors in Classification Standard of Slopeland Utilization Limitations. Rather, high diaster-prone zone should be drawn from the perspective of national land conservation, with land use controlling measures based on the classification and location. This can serve as a reference for the government to amend relevant regulations.

The study adopted logistic regression to establish high diaster-prone susceptibility assessment model to obtain the success rate of 0.911. Considering the current terrain, this study established susceptibility model for high diaster-prone areas using watershed as the analytical unit. In the future, susceptibility classification for high diaster-prone areas should be re-assessed and re-adjusted under existing engineering facilities.

In recent years, climate change has severely impacted Taiwan's national land, particularly by Typhoon Morakot. Therefore, national land use planning should be geared toward proper slopeland conservation and avoid damaging the overall environment/ecology as well as soil and water conservation. Of those, national land conservation which requires slopeland use capability classification standard should be classified more strictly. In addition to the 4 factors from Classification Standard of Slopeland Utilization Limitations, geological-hazard-sensitivity factor should be included in the classification factors to avoid slopeland hazards. This allows for effective national land management to achieve environmental/ecological conservation and sustainable development.

References

1.Agresti A ., Categorical data analysis (2nd ed.), John Wiley, 710p**(2002)**

2.Anderbeg M., Cluster Analysis for Applications(New York: Academic) **(1973)**

3. Bai S.B., Wang J., Lü G.N., Zhou P.G., Hou S.S. and Xu S.N., GIS-based logistic regression for landslide susceptibility mapping of the Zhongxian segment in the Three Gorges area, China, *Geomorphology*, 115 ,23－31 **(2010)**

4.Biswajeet P., Remote sensing and GIS-based landslide hazard analysis and cross-validation using multivariate logistic regression model on three test areas in Malaysia, Available online at www.sciencedirect.com**(2010)**

5.Carrara A., Crosta G. and Frattini P., Comparing models of debris-flow susceptibility in the alpine environment, *Geomorphology* 94,353–378**(2008)**

6.Cattell R.B., The scree test for the number of factors. Multivariate Behavioral Research, Vol.1, pp. 629-637**(1966)**

7.Central Geological Survey (CGS) of MOEA, Phase-I Implementation Plan for Geologic Survey of Upstream Catchment of Flood-prone Areas - General Report on Catchment Geologic Survey, landslide and Debris Flow Investigation and Occurrence Potential Assessment, 620p**(2007)**

8. Chang C.W., Lin P.S., Tsai C.L., Estimation of sediment volume of debris flow caused by extreme rainfall in Taiwan, *Engineering Geology* ,123, 83－90**(2011)**

9. Chauhan S., Sharma M., Arora M.K. and Gupta N.K., Landslide Susceptibility Zonation through ratings derived from Artificial Neural Network, *International Journal of Applied Earth Observation and Geoinformation*, 12, 340－350 **(2010)**

10.Chen C.Y. and Yu F.C., Morphometric analysis of debris flows and their source areas using GIS, *Geomorphology*, 129 ,387–397**(2011)**
11.Chen S.C., Ferng J.W., Wang Y.T., Wu T.Y. and Wang J.J., Assessment of disaster resilience capacity of hillslope communities with high risk for geological hazards, *Engineering geology*,98 ,86-101**(2008)**
12. Choi J., Oh H.J., Lee H.J., Lee C. and Lee S., Combining landslide susceptibility maps obtained from frequency ratio, logistic regression, and artificial neural network models using ASTER images and GIS, *Engineering Geology*, www.elsevier.com/locate/enggeo**(2011)**
13.Chung C.F. and Fabbri A.G., Validation of spatial prediction models for landslide hazard mapping. *Natural Hazards*, 30, 451-472(2003)
14.Conoscenti C., Maggio C.D. and Rotigliano E., Soil erosion susceptibility assessment and validation using a geostatistical multivariate approach: a test in Southern Sicily, *Nat Hazards*, 46:287–305**(2008)**
15.Council of Agriculture, Executive Yuan, Slopland Conservation and Utilization Act; Water and Soil Conservation Act and Relevant Regulations**(1976)**
16.Council of Agriculture, Executive Yuan, Enforcement Rules of Slopeland Conservation and Utilization Act; Water and Soil Conservation Act and Relevant Regulations **(1977)**
17.Council of Agriculture, Executive Yuan, Instructions on Classification of Slopeland Utilization Limitations **(1995)**
18.Dave F. and Nels P., Land Homesite and Judging in North Dakota, North Dakota State University**(2003)**
19.David L. and Bill M.R., 4-H Land Judging in Kentucky, University of Kentucky College of Agriculture**(2003)**
20.Dong J.J., Lee C.T., Tung Y.H., Liu C.N., Lin K. P. and Lee J.F., The role of the sediment budget in understanding debris flow susceptibility, earth surface processes and landforms Earth Surf. Process, *Landforms*, 34, 1612–1624**(2009)**
21.Doolittle J.J., Malo D.D., Kunze B.O., Winter S.D., Land Judging in South Dakota , South Dakota State University College of Agriculture & Biological Sciences**(2002)**
22.Feinberg S., The analysis of cross-classified categorical data (2nd ed.),Cambridge, MA: MIT Press, 198p **(1985)**
23.Francis B., “Fundamentals of Land Evaluation in Nebraska”, Judging Soil and Land, Natural Resources Conservation and Survey Division University of Nebraska**(2006)**
24.Gilabert M.A., Gonzalez-Piqueras J., Garcia-Haro F.J. and Melia J., A generalized soil-adjusted vegetation index, *Remote Sensing of Environment*, 82, 303–310 **(2002)**
25.Gorum T., Gonencgil B., Gokceoglu C. and Nefeslioglu H.A., Implementa reconstructed geomorphologic units in landslide susceptibility mapping: the Melen Gorge (NW Turkey), *Natural Hazards*, 46: 323-351**(2008)**
26.Hotelling H., Analysis 0f a Complex of Statistical Variables into Principal Components, *Journal of Educational Psychology*, 24:417-520**(1993)**
27.Jeff S., Land Judging in West Virginia, West Virginia University**(2007)**
28.Kaiser H.F., The application of electronic computers to factor analysis, Educational and Psychological Measurement, Vol.20, pp.141-151**(1960)**
29.Keith, Instructions on Land Judging in Mississippi Extension Service of Mississippi State University**(2008)**
30.Lee C.T., Huang C.C., Lee C.F., Pan K.L., Lin M.L. and Dong J.J., Event-Based Landslide Susceptibility Analysis - an Example from Central Western Taiwan, *Geophysical Research Abstracts*, 9, 06216**(2007)**
31.Lee C.T., Huang, C.C., Lee, J.F., Pan, K.L., Lin, M.L., Dong, J.J., Statistical approach to storm event-induced landslides susceptibility, *Natural Hazards and Earth System Sciences*, 8, 941-960 **(2008)**
32.Lin P.S., Lin J.Y., Hung J.C., Yang M.D., Assessing debris-flow hazard in a watershed in Taiwan, *Engineering Geology*, 66: 295–313**(2002)**
33.Lin L.L., Wang C.W., Chiu C.L. and Ko Y.C., A study of rationality of slopeland use in view of land preservation, *Paddy and Water Environment*, DOI 10.1007/s10333-010-0231-5**(2010)**
34.Moore I.D. and Burch G.J., Modelling erosion and deposition: topographic effects,”Trans. Am. Soc: Agr. Enqrx, 29: 1624-1640 **(1986)**
35.Moore I.D., Grayson R.B. and Landson A.R., Digital Terrain Modeling: a Review of Hydrological, Geomorphological, and Biological Applications,Hydrological Processes, Vol. 5,3-30**(1991)**
36.Nefeslioglu H.A., Duman T.Y. and Durmaz S., Landslide susceptibility mapping for a part of tectonic Kelkit Valley (Eastern Black Sea region of Turkey), *Geomorphology*, 94: 401-418(2008)
37.Park S.J., McSweeney K. and Lowery B., Identification of the spatial distribution of soils using a process-based terrain characterization, *Geoderma*, 103, 249–272**(2001)**
38. Pradhan B., Lee S. and Buchroithner M.F., A GIS-based back-propagation neural network

model and its cross-application and validation for landslide susceptibility analyses, Computers, *Environment and Urban Systems*, 34, 216－235**(2010)**
39.Robert H., Land Judging in Colorado, Colorado State University**(2006)**
40.Rouse J.W., Hass R.H., Schell J.A. and Deering D.W., Monitoring Vegetation Systems in the Great Plain With ERTS, In Third ERTS Symposium, NASA SP-351, NASA, Washington, DC, Vol.1 , pp :309-317**(1973)**
41. Sezer E.A., Pradhan B. and Gokceoglu C., Manifestation of an adaptive neuro-fuzzy model on landslide susceptibility mapping: Klang valley, Malaysia, *Expert Systems with Applications*, 38, 8208－8219**(2011)**
42.Soil and Water Conservation Bureau, Council of Agriculture, Executive Yuan, Operation Manual on Classification of Slopeland Utilization Limitations of Taiwan Province**(1995)**
43.Su F., Cui P., Zhang J. and Xiang L., Susceptibility Assessment of Landslides Caused by the Wenchuan Earthquake Using a Logistic Regression Model, J. Mt. Sci. 7: 234–245**(2010)**
44.Swets J.A. Measuring the accuracy of diagnostic systems, Science, 240(4857), 1285-1293**(1988)**
45.Tunusluoglu M.C., Gokceoglu C., Nefeslioglu H.A., Sonmez H., Extraction of potential debris source areas by logistic regression technique, *Environmental Geology*, 54, 9-22**(2008)**
46.Vahidnia1 M.H., Alesheikh A. A., Alimohammadi A. and Hosseinali F., Landslide Hazard Zonation Using Quantitative Methods in GIS", *International Journal of Civil Engineerng*, Vol. 7, No. 3, 176-189**(2009)**
47.Wilson J.P., Gallant J.C., Digital terrain analysis, In Wilson, J. P. and Gallant, J. C. Terrain Analysis- Principles and Applications, John Wiley & sons, new york, 1-27**(2000)**