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Classification Model of Slopeland Soil Erosion Degree in Taiwan

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Abstract Given that Taiwan did not undertake any form of comprehensive planning with regards to the utilization of slopelands in the early days, the country's agricultural resources have been adversely affected by the by changes in the economic structure. Consequently, in 1976, the promulgation of the Slopeland Conservation and Utilization Act allowed the government to clarify the scope of slopelands. At the same time, the "Classification Standards of Slopeland Utilization Limitation" was developed to classify slopelands into land suitable for agricultural, animal husbandry or forestry purposes or as land subject to strengthened conservation. The classification was done based on a number of factors including average slope, soil depth, soil erosion degree and parent rock. Among the factors, the degree of soil erosion is considered the most difficult to determine. To avoid false determination, this study selected 13,403 cadastral units from 15 land sections in 9 townships as sample areas to analyze the classification of slopeland in terms of degree of soil erosion: Da-an Section, Sun-tzu-lin Section, Li-yu-wei Section (of Chushan Township in Nantou County), Bei-shan-keng Section (of Guoxing Township in Nantou County), Jun-keng Section (of Shuili Township in Nantou County), Xin-wei Section, Liu-guei Section (of Liuguei District in Kaohsiung City), Jia-shian Section, Gong-Guan Section (of Jiashian District in Kaohsiung City), Ji-mo-lo Section (of Namasia District in Kaohsiung City), Sheng-mao-shu Section, Ko-tzu-lin Section (of Meishan Township in Chiayi County), Fan-lu Section, Gong-tian Section (of Fanlu Township in Chiayi County), and Da-pu Section (of Dapu Township in Chiayi County).

This study selected 15 soil erosion factors, including standard deviation of slope, standard deviation of aspect, terrain roughness, terrain curvature, landslide ratio of Fanapi typhoon, area ratio of badland, area ratio of dip slope, rockfall area ratio, debris slide area ratio, debris flow track area ratio, rainfall erosivity index, soil erodibility index, slope length factor, land coverage and management index, and normalized difference vegetation index (NDVI), to establish a classification model of slopeland soil erosion degree by discriminant analysis. According to receiver operating characteristic (ROC), the area under curve (AUC) of up to 0.785, suggesting that the classification model of slopeland soil erosion degree established in this study can be a useful reference for onsite investigators, enhancing the administrative efficiency of soil erosion degree determination.

Keywords Slopeland Utilization Limitation, Discriminant analysis, Soil erosion

1. Introduction

Hills cover two-thirds of Taiwan due to its geographical location; the island lies on the interface of the Eurasian Plate and the Philippine Sea Plate. Rapid economic development has led to the depletion of the natural resources available in the flat lands. Because of this, slopelands have become an important resource for land development. However, with the recent rise of public awareness in land conservation and ecological restoration, it has become more imperative to implement effective planning and management of slopeland conservation and utilization to ensure sustainable land development in Taiwan.

The Slopeland Conservation and Utilization Act promulgated in 1976 [1-2] states that "slopelands which are available for agricultural purposes shall be classified by the limits on its permitted scope of use." According to the "Classification Standards of Slopeland Utilization Limitation" [3-4], classifying slopelands into land suitable for agricultural or animal husbandry (Classes I-IV), forestry purposes (Class V), and as land subject to strengthened conservation (Class VI) is done according to average slope, soil depth, soil erosion degree and parent rock. The four factors mentioned above have their specific criteria, which serve as reference for investigators to use. The factor of soil erosion degree is determined by inspectors judging the erosion pattern and soil loss volume . However, because estimation of soil loss volume is always discretionary on the part of the investigators, the information is deemed subjective and therefore unreliable [5]. It is the goal of this study to develop a more objective classification model using scientific quantification.

To do so, the study looks at a number of studies developed to evaluate the development and application of soil erosion degree models in the past few years. Some experts, according to their own experience and on-site investigation, selected factors from the universal soil loss equation (USLE) as soil erosion factors, graded each of them, then assigned weights to each factor allowing soil erosion degree to be reflected in a chronological order before finally combining each factor and calculated weighted scores to find the susceptibility index of soil erosion degree [6-10]. There were some other studies which sorted proper factors from susceptibility features such as terrain, geology, location and hydrology for soil erosion and then, with a linear equation, calculated susceptibility of soil erosion degree for the analysis units [11-15]. In addition, some studies used artificial intelligence (AI) algorithms, including Artificial Neural Network and Support Vector Machine to evaluate soil erosion or degradation degree [16-21]. As the weight of a factor was not easy to estimate, some used decision analytic approaches (e.g. analytic hierarchy process, AHP) and assigned weights based on importance to determine soil erosion degree or danger degree 19, [22-24].

2. Material and method

2.1. Study area

This study selected sample areas located in the counties/cities included in the disaster area of Typhoon Morakot as announced by the Executive Yuan. It then proceeded to analyze the landslide ratio of township by overlaying the Typhoon Morakot landslide inventory provided by the Central Geological Survey. With the selection basis, this study focused on the first three townships and then chose certain sections from the overlaid cadastral maps. As a result, 15 land sections from 9 townships were selected as sample areas for the study. They are Da-an Section, Sun-tzu-lin Section, Li-yu-wei Section (Jhushan, Nantou), Bei-shan-keng Section (Guosing, Nantou), Jun-keng Section (Shuili, Nantou), Xin-wei Section, Liou-guei Section (Liouguei, Kaoshiung), Jia-sian Section, Gong-Guan Section (Jiasian, Kaohsiung), Ji-mo-lo Section (Namasia, Kaohsiung), Sheng-mao-shu Section, Ko-tze-lin Section (Meishan, Chiayi), Fan-lu Section, Gong-tian Section (Fanlu, Chiayi), and Da-pu Section (Dapu, Chiayi), as shown in Figure 1. By summarizing data from the Soil and Water Conservation Bureau, we found the land categories include farm and pasture land, forestry land, conservation land, road, dry field and construction site, and land parcel which can further be divided into state-owned and private lands [25]. The National Property Administration, Ministry of Finance, is the competent authority for the management of state-owned lands. According to the guidelines for the examination of Slopeland Utilization Limitation, we excluded the areas not in the investigation scope and found 13,403 lands with complete soil erosion degree examination data. Based on the classification standard of "Classification Standards of Slopeland Utilization Limitation," the study then distinguished them into four categories: extremely severe erosion, severe erosion, medium erosion, and slight erosion. The study area included 19 lands of extremely severe erosion, 1,209 lands of severe erosion, 5,344 lands of medium erosion, and 6,850 lands of slight erosion. With Jhushan (Nantou County) as an example, the distribution of slopeland soil erosion degree examination data is shown in Figure 2.

2.2. Selection of factors

Soil erosion is mainly controlled by the spatial distribution of erosivity and erodibility [26]. Erosivity is an indicator of the precipitation energy and ability to cause soil erosion, while erodibility refers to the susceptibility or resistance of a soil to detachment [27]. Therefore, in this study there are three categories that will affect soil erosion, including terrain category, and 8 factors such as average slope [28], standard deviation of slope, average aspect, standard deviation of aspect, average elevation, terrain elevation variation, terrain roughness, and terrain curvature [29]. As for erodibility in bare land category, 11 factors are taken into account: landslide ratio of Morakot typhoon, slide ratio of Fanapi typhoon, debris flow track area ratio, debris flow deposition area ratio, debris flow fan area ratio, rock slide area ratio, area ratio of dip slope, rockfall area ratio, debris slide area ratio, area ratio of badland, and alluvium area ratio [30]; there are 6 factors for USLE and NDVI category including, rainfall erosivity index [31], soil erodibility index, slope length factor, slope factor, land cover and management index, and normalized difference vegetation index [32-33]. These 25 factors are determined through remote sensing and ArcGIS; each one is statistically gathered for analysis of susceptibility of soil erosion degree. For analytical purposes, the study examined cadastral analysis units [21], converted them into bitmaps (Raster), and then found the average of factors for each cadastral unit in the study area.

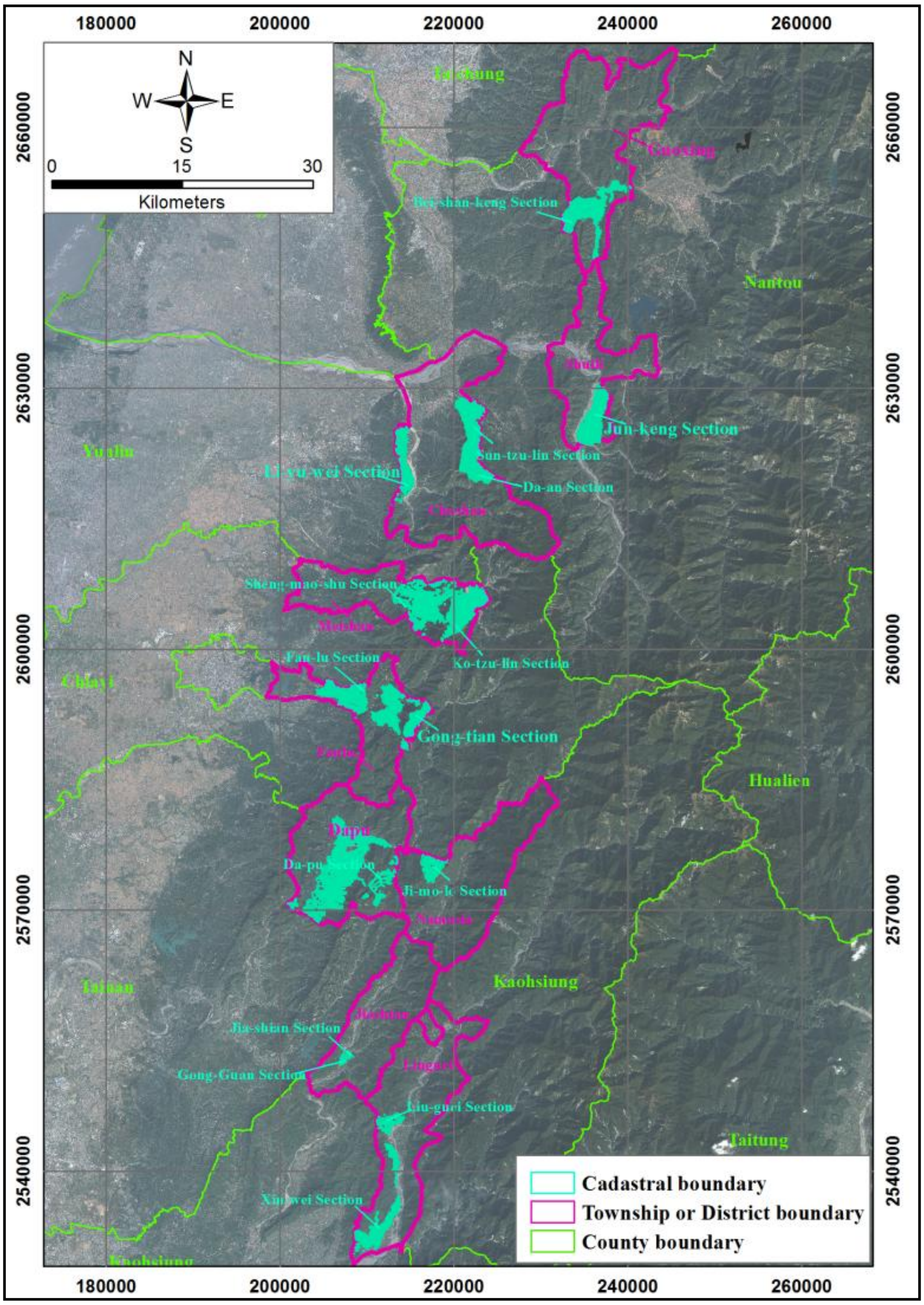


Figure 1: Location of the study area

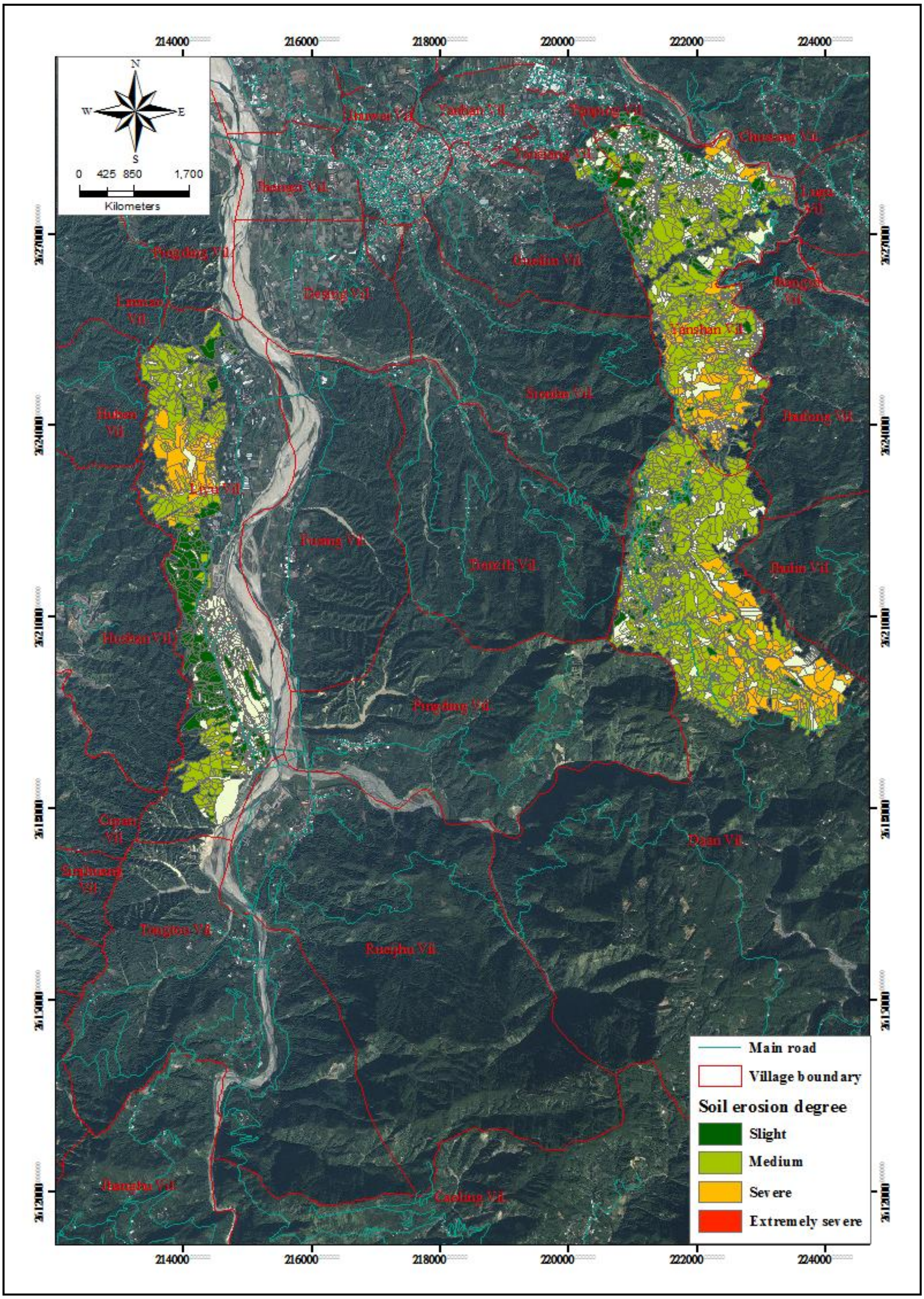
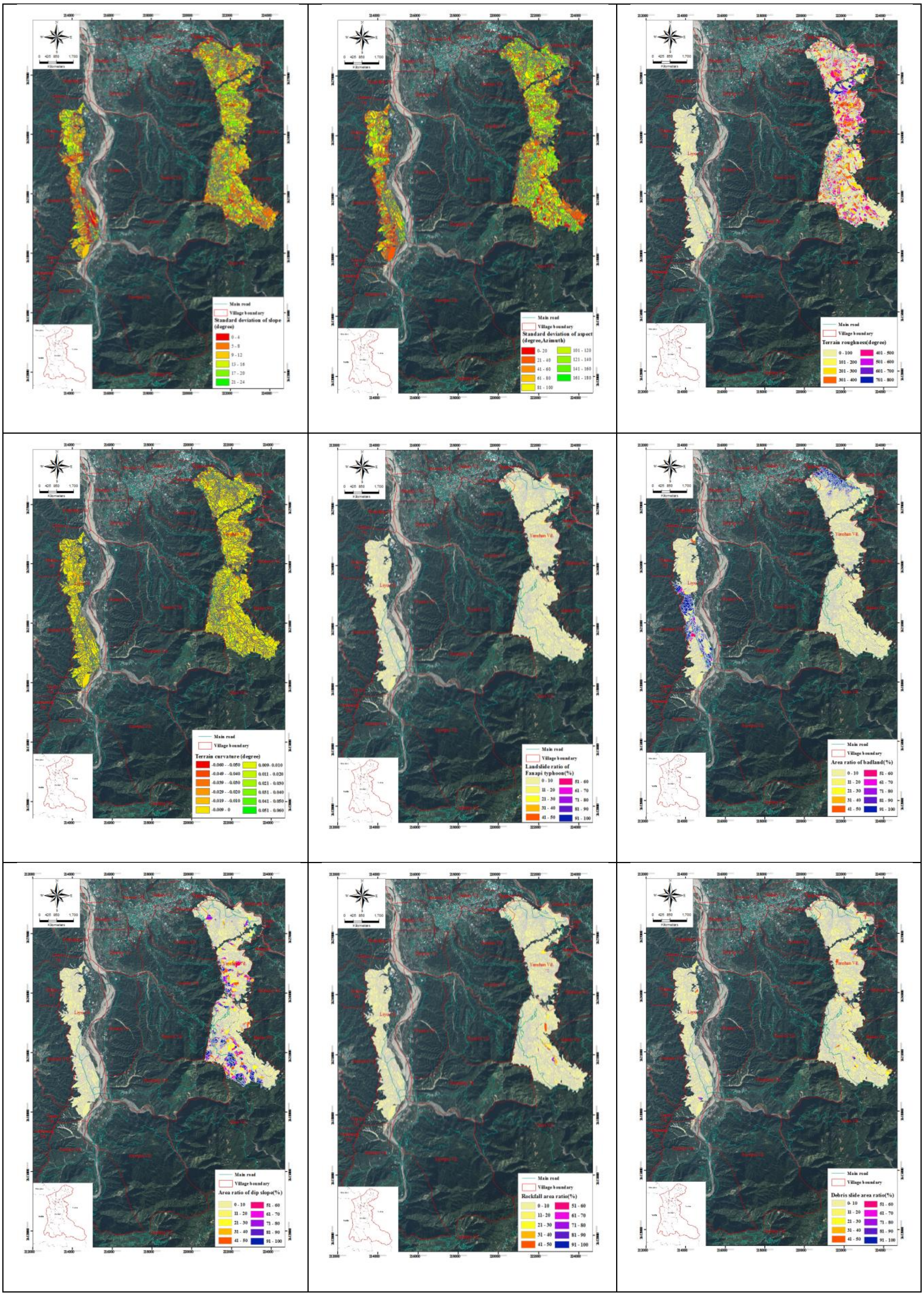


Figure 2: Distribution of slopeland soil erosion degree examination data in Jhushan, Nantou


Main road
Village boundary
Standard deviation of slope (degree)
0 - 4
5 - 8
9 - 12
13 - 16
17 - 20
21 - 24
Main road
Village boundary
Standard deviation of aspect (degree,Azimuth)
0- 20
21 - 40
41 - 60
61 - 80
81 - 100
101 - 120
121 - 140
141 - 160
161 - 180
Main road
Village boundary
Terrain roughness(degree)
0 - 100
101 - 200
201 - 300
301 - 400
401 - 500
501 - 600
601 - 700
701 - 800
Main road
Village boundary
Terrain curvature (degree)
-0.060 - -0.050
-0.049 - -0.040
-0.039 - -0.030
-0.029 - -0.020
-0.019 - -0.010
-0.009 - 0
0.009- 0.010
0.011 - 0.020
0.021 - 0.030
0.031 - 0.040
0.041 - 0.050
0.051 - 0.060
Main road
Village boundary
Landslide ratio of Fanapi typhoon(%)
0 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Main road
Village boundary
Area ratio of badland(%)
0 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Main road
Village boundary
Area ratio of dip slope(%)
0 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Main road
Village boundary
Rockfall area ratio(%)
0 - 10
11- 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
Main road
Village boundary
Debris slide area ratio(%)
0- 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100

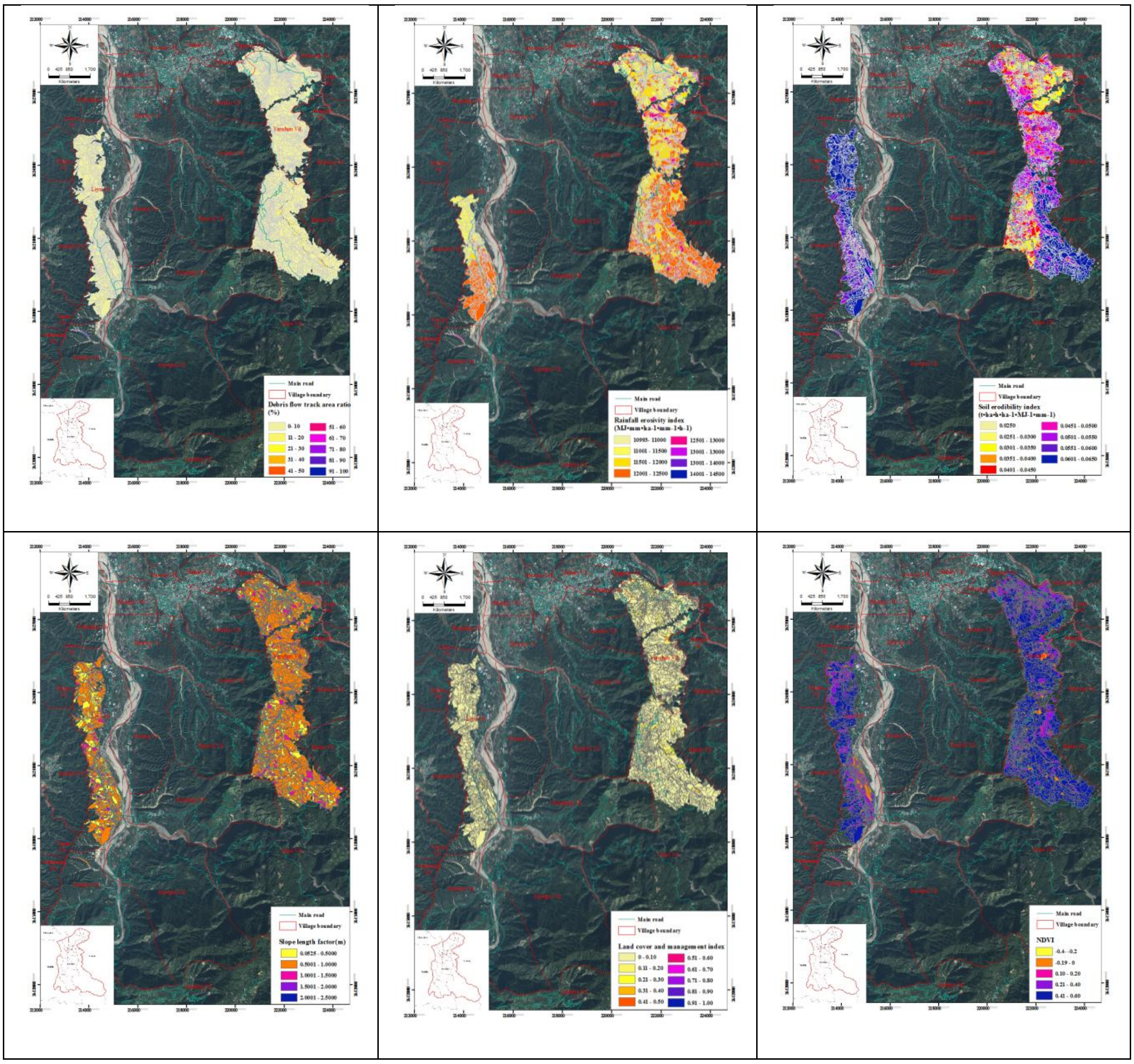


Figure 3: Distribution of soil erosion factors (example: Jhushan, Nantou)

2.3. Factors of Soil erosion

To examine these factors, this study used principle component analysis (PCA) for significant factor analysis [34-36], as shown in Table 1, and correlation coefficient analysis. This way, the efficiency of subsequent analysis will not be reduced due to excessive interdependency between two factors. 15 factors for soil erosion were selected: standard deviation of slope, standard deviation of aspect, terrain roughness, terrain curvature, landslide ratio of Fanapi typhoon, area ratio of badland, area ratio of dip slope, rockfall area ratio, debris slide area ratio, debris flow track area ratio, rainfall erosivity index, soil erodibility index, slope length factor, land cover and management index, and normalized difference vegetation index. For spatial distribution of the factors (example: Jhushan, Nantou), please refer to Figure 3.

Table 1The result of PCAof soil erosion factors

Soil erosion susceptibility categories	**Soil erosion factor**	**Principle Component Type**	**Unit**
Terrain category	Terrain roughness	First principle component	Degree
	Terrain elevation variation	First principle component	Dimensionless

	Standard deviation of slope	First principle component	Degree
	Standard deviation of aspect	Second principle component	Degree(Azimuth)
	Terrain curvature	Fourth principle component	1/m
Erodibility in bare land category	Landslide ratio of Morakot typhoon	First principle component	Percentage
	Landslide ratio of Fanapi typhoon	First principle component	Percentage
	Area ratio of badland	Second principle component	Percentage
	Area ratio of dip slope	Fourth principle component	Percentage
	Debris slide area ratio	Fifth principle component	Percentage
	Rockfall area ratio	Sixthprinciple component	Percentage
	Debrisflowtrack area ratio	Seventhprinciple component	Percentage
USLE and NDVI category	Rainfall erosivityindex	First principle component	$MJ\cdot mm\cdot ha^{-1}\cdot mm^{-1}\cdot h^{-1}$
	NDVI	First principle component	Dimensionless
	Soil erodibility index	Second principle component	$t\cdot ha\cdot h\cdot ha^{-1}\cdot MJ^{-1}\cdot mm^{-1}$
	Land cover and management index	Third principle component	Dimensionless
	Slope length factor	Fourth principle component	m

2.4. Method

The study adopted the linear discriminant analysis [37], with 95% confidence interval and desired accuracy of 75% or above. Analysis was done conducted on cadastral units with soil erosion degree examination dat. These samples for analysis were known as training samples (13,369 pieces). To streamline the procedure and increase efficiency, the study combined “slight erosion” with “medium erosion” into Group “slight to medium;” and “extremely severe erosion” with “severe erosion” into Group “severe”. This is to avoid low accuracy due to insufficient samples from excessive categories. After calculation, optimal linear functions were obtained for classification. Then the value in each linear function was substituted with the factor’s value corresponding to each cadastral unit, and each cadastral unit‘s discriminant score (*i.e.* Mahalanobis distance between groups) was calculated. Each cadastral unit was extinguished by the function with the highest score, as shown in the following equation.

$$\text{Category}= MAX\left(\begin{cases} y_1 = w_1x_{i_1} + w_2x_{i_2} + \cdots + w_jx_{i_j} + C_1)_1 \\ y_2 = w_1x_{i1} + w_2x_{i2} + \cdots + w_jx_{ij} + C_2)_2 \end{cases}\right) \quad (1)$$

in which x is a discriminant variable $x_j = (x_i, x_2, \cdots, x_i)$; w is a discriminant variable $w_j = (w_1, w_2, \cdots, w_j)$; C_1 is the constant in the discriminant linear equation of the first group; C_2 is the constant in the discriminant linear equation of the second group.

With discriminant analysis, we again obtained normalized canonical discriminant functions (NCDF) as a basis for calculating the discriminant scores of all cadastral units in the study area, so that a classification model of slopeland soil erosion degree may be established with these discriminant scores and examination data.

3. Results and Discussion

This study used the aforementioned 15 factors for soil erosion, analyzed Group "slight to medium" and Group "severe", and obtained linear discriminant functions, as shown in Table 2, where the soil erosion index with higher sensitivity is deemed a significant factor. To evaluate performance, a receiver operating characteristic curve (ROC) was created for prediction of accuracy; the area under curve (AUC) was estimated to be between 0 and 1; the larger the AUC is, the better performance the study achieves. Furthermore, a model not better than random would be characterized by an AUC value of 0.5 [38]. Therefore, the coefficient derived from the analysis is substituted in each cadastral unit to obtain the area under ROC curve (AUC=0.785), as shown in Figure 4.

Table 2: The result of coefficients of the discriminant function for classification of slopeland soil erosion degree

Soil erosion factor	Slight to medium	Severe
Standard deviation of slope	0.649	0.780
Standard deviation of aspect	0.079	0.079
Terrain roughness	-0.004	-0.004
Terrain curvature	6.703	4.734
Landslide ratio of Fanapi typhoon	0.033	0.084
Area ratio of badland	0.057	0.053
Area ratio of dip slope	0.015	0.035
Rockfall area ratio	-0.001	0.065
Debris slide area ratio	-0.054	0.023
Land slide flow area ratio	-0.023	-0.021
Rainfall erosivityindex	0.001	0.000
Soil erodibility index	209.408	219.744
Slope length factor	7.746	7.426
Land cover and management index	4.503	1.263
NDVI	2.447	4.946

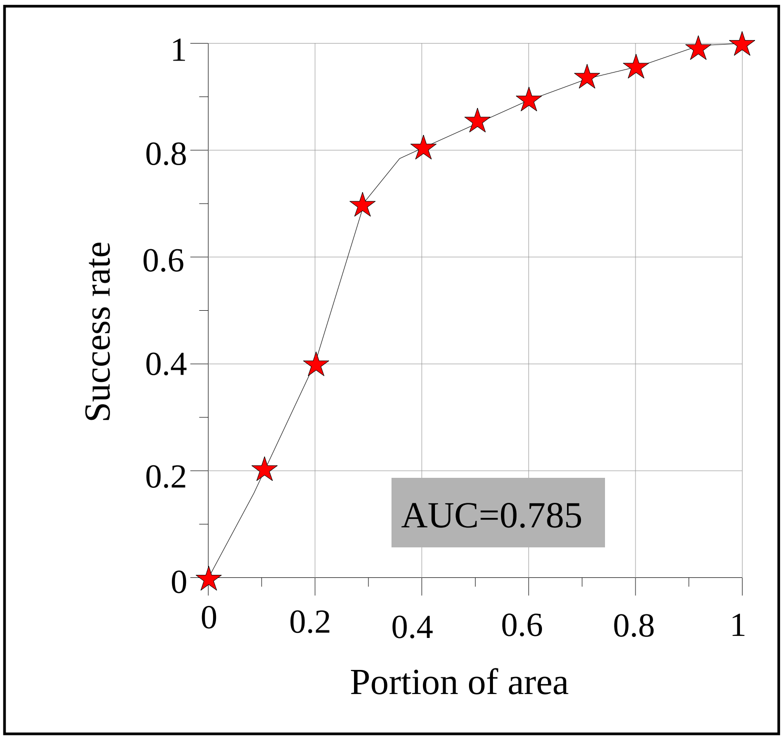


Figure 4: ROC curve of soil erosion classification model

The NCDF obtained from discriminant analysis yield the score of each cadastral unit; the distribution of the results is shown in Figure 5. An error bar chart was then created based on discriminant scores for soil erosion with descriptive statistics, as demonstrated in Figure 6, which shows standard error and confidence interval. An error bar chart can visually give discrete features of data. In this chart, the little circle showing the average and whiskers stretched from the bottom to the top indicates the confidence interval, standard error of the mean or standard deviation. According to this chart, the average of slight erosion is 0.110, the average of medium erosion is 0.765, and the average of severe (and above) erosion is 1.245. The study obtained two threshold values by computing an average of another two values. The suggested threshold values based on discriminant scores are listed in Table 3. This completes the study on the classification of slopeland soil erosion degree with the results shown in Figure 7.

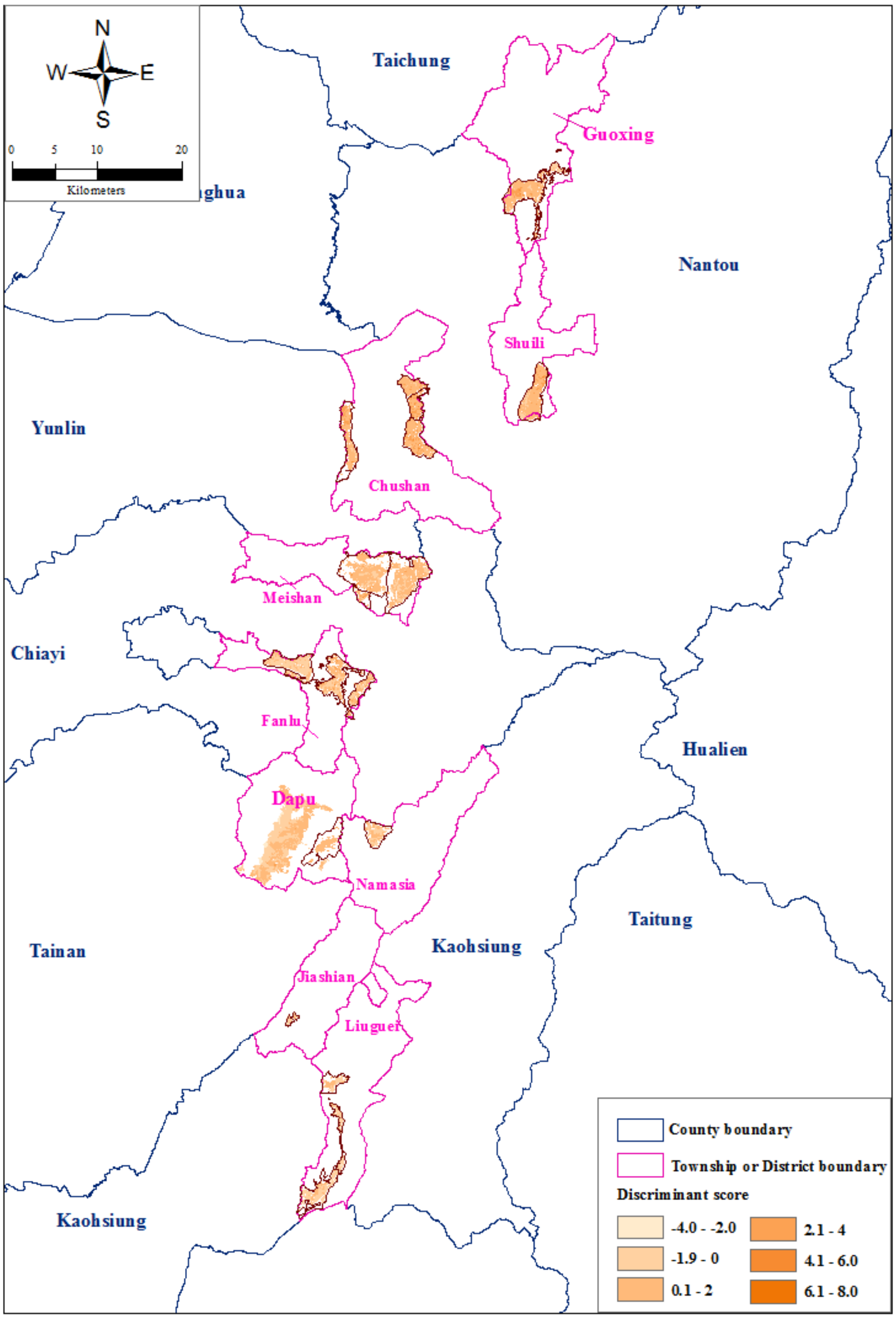


Figure 5: *The results of NCDF of each cadastral unit in the study area*

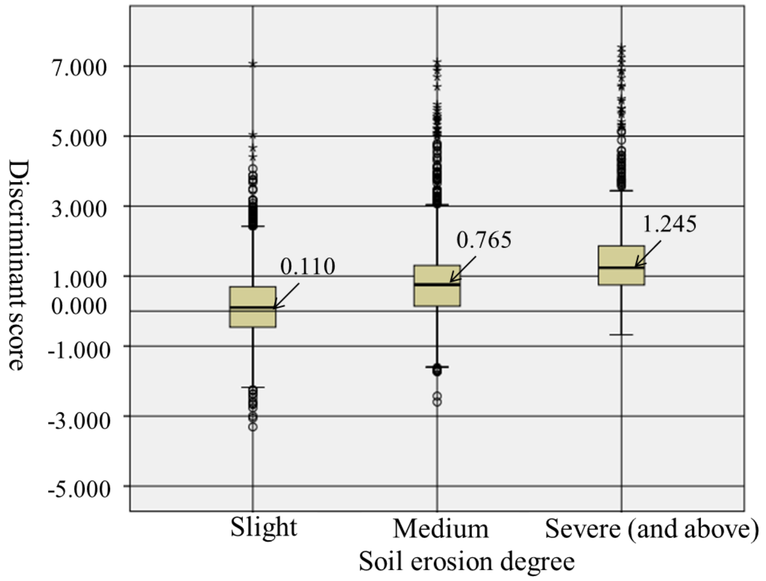


Figure 6: Error Bar of discriminant scores for soil erosion degree

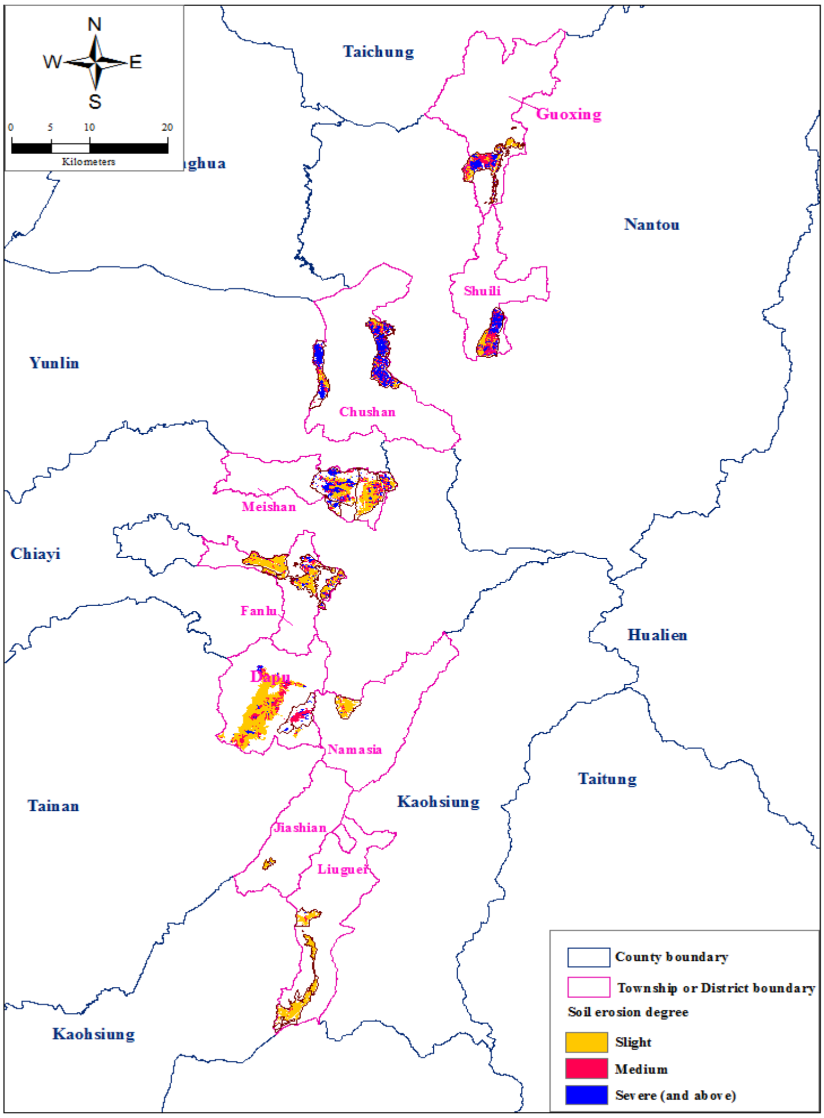


Figure 7: Result of soil erosion degree map in the study area

4. Conclusions and Suggestions

This study selected 15 factors using principle component analysis and correlation analysis. It then used applied linear discriminant analysis to develop a classification model for slopeland soil erosion degree (distinguished into slight, medium and severe). This model's area under ROC curve reached 0.785, suggesting the classification functions feature high classification performance and may provide good reference points to investigators in their examination of data on-site, thereby enhancing administrative efficiency.

During the study, we found that, not only are cadastral units are irregular but also the accuracy for analysis of factors such as slope, aspect, and terrain curvatures at 5m×5m high altitude terrain is lower for a cadastral unit with less area or a slender cadastral unit. It is suggested that LiDAR technology, which feature higher resolution and sharper precision, to be used in the future for analysis of terrain data; this technology may be helpful in improving the overall accuracy for model determination. Furthermore, as soil erosion factors are highly uncertain, the impact of physiographic conditions on soil erosion degree is more obvious if a classification model of soil erosion degree based on terrain variability is created.

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