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ARTICLE

A study of rationality of slopeland use in view of land preservation

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Abstract In recent years, frequent attacks of heavy rain and typhoon have severely devastated the vulnerable mountains of Taiwan; slopelands are artificially disturbed by improper development and utilization. People are getting more aware of the importance of slopeland preservation as well as disaster prevention and mitigation. The government, realizing the criticality of gradually worsened land safety issues, has also set forth the "Draft of National Land Planning Act" and the "Draft of Regulations on Land Preservation Act" in the purposes of rehabilitating the excessively explored ecosystems and diminishing the development extent of environmentally susceptible areas, so as to effectively preserve soil, water, and organism resources and to achieve perpetual development of national lands. "Classification of Slopeland Utilization Limitations" is a critical link to national land preservation. The classification is based on four factors, namely average slope, effective soil depth, soil erosion, and parent rock, with different utilization zones defined as bases of landuse planning. However, current classification results of the environmentally susceptible and disaster-prone mountain lands are mostly defined as suitable for forestry or husbandry. Scattered allocation of these lands results in critical issues such as segmented landuse and impaired landscape and ecotype. It is necessary to re-adjust land resources planning and usage management. Therefore a review of the current standards for classifying slopeland utilization limitations is proposed to facilitate rational allocation of slopeland use. Jhuoshuei River is selected as the scope of the case study, with data of debris flows induced by the typhoon Toraji in 2001 as the training data. Eight susceptibility factors, which include form factor of watershed, integral hypsometric, slope of main stream, density of stream network, density of road network, area ratio of historical landslide, and area ratio of triggered landslide, together with the total rainfall of the storm event as the triggering factor, are selected for creating the debris flow susceptibility model by employing the logistic regression within the multivariate geostatistics analysis. This model interprets the curve of success ratio of debris flows triggered by typhoon Toraji, of which the area under the curve is as high as 74.3%. The debris flow susceptibility model created in the study takes the Feng-Chiu section of Sinyi Township, Nantou County, Taiwan within the Jhuoshuei River as the scope of research. GIS technology has been applied in the feasibility study of classification standards. New concepts have been further proposed in view of national land preservation addressing the medium and high elevation disaster-prone areas that are not suitable for agricultural use, for standard revision reference.

Keywords Slopeland utilization limitations · Logistic regression · Debris flow susceptibility · Land preservation · Geographic information system · Digital terrain model

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Introduction

With limited land and dense population, Taiwan has its slopeland occupying two-thirds of the total area. Due to restricted resource of plains, slopeland development has become a main subject in land development. In order to develop conservation and utilization of farmland businesses on the slopeland, the "Slopeland Conservation and Utilization Act" was enforced in 1976 (Council of Agriculture 1976, 1977), which stated in the Article 16 that "Slopeland which is available for agricultural purposes shall be classified by the limits on its permitted scope of use". Slopeland shall be defined by the central or special municipality regulatory authority as land suitable for agricultural, animal husbandry or forestry purposes or as land subject to strengthened conservation (Council of Agriculture 1995; Soil and Water Conservation Bureau 1995). "The land classification standards for permissible slopeland" are used as a referencing standards of farmland classifications setup by the United States Department of Agriculture over respective states (Doolittle et al. 2002; Dave and Nels 2003; David and Bill 2003; Keith 2008). Slopelands are categorized into six classes according to factors including average slope, soil effective depth, soil erosion, and parental rock. 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. Land use and management shall be implemented based on the specific classification, for achieving rational allocation of slopeland conservation and utilization.

In recent years, a number of the natural environment have been caused by the poor geographic environment and improper development of slopelands. Frequent calamities caused by frequent typhoons and torrential rains those attacked Taiwan have resulted in severe depletion of soil and water resources and become hidden threats to the land preservation mechanism. Among those, the land classification standards for permissible slopeland use have been an important issue in national land preservation. Current issues, e.g., on the impact of farmhouse construction to the agricultural production environment and the unbalanced soil and water conservation resulted from exceedingly utilizing the land, have all been closely connected to the classification of slopeland utilization limitations. Since the current regulations require that parcel lands to be classified as suitable for forestry or for agriculture or animal husbandry, this has resulted in scattered land-uses, especially a severely separated utilization of farmlands in the disaster-prone areas. In order to achieve perpetual development of national lands, the government has been continuously promoting to enhance public recognition and conceptual acceptance of the significance of national land preservation and setting forth relating policies regarding national land preservation at the same time.

Since the construction of Middle Transverse Highway in central Taiwan, the lacking of rational control and allocation of land utilization has resulted in various cases of impaired slope stability and spoiled landscaping. A pursuance of local economic development has pushed land development deeper into vulnerable mountains of high elevation. Whenever a typhoon or heavy rainfall attacks, multiple events of landslide and debris flow occurs, which cause substantial impact to the safety of local living and properties. A typical example is an event causing seven deaths on Sep 15, 2008 in a heavy rain during Typhoon Sinlaku. The incident took place when the potential debris flow (Nantou-028) (Jan 1993; Chen et al. 1999) burst out at the front of Feng-Chiu tunnel in Sinyi Township, Nantou County in central Taiwan, and the debris flow ran over Tai-#21 highway, the new Middle Transverse Highway. The landslide covered a range of about 110 m wide, 100 m long and 5 m depth, totaling a volume of approximately 45,000 m^3. Figures 1 and 2 show the location associated with three orthogonal images before and after the event, where the red color indicates range of landslide, green indicates range of debris flow, and blue indicates debris deposit.

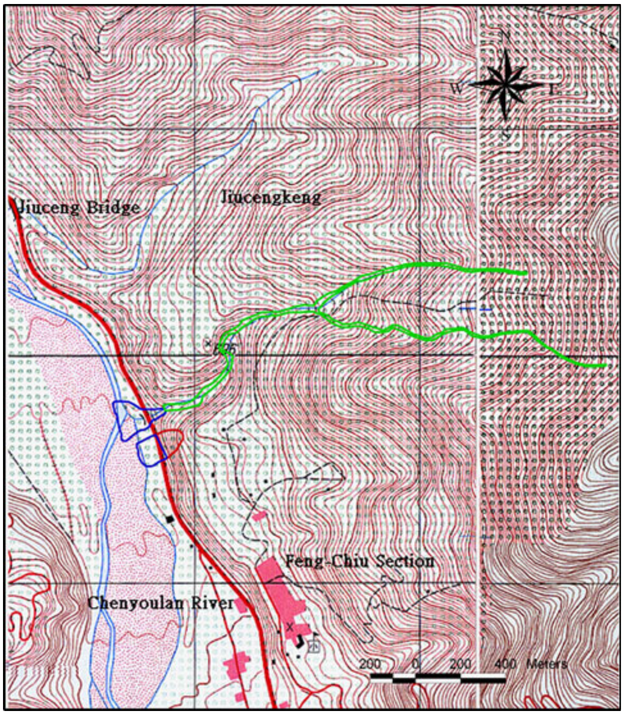

Fig. 1 The location of landslide and debris flow at Feng-Chiu, Sinyi Township, Nantou County, Taiwan

Fig. 2 Orthogonal image of Feng-Chiu section, Sinyi Township, Nantou County, Taiwan **a** before typhoon Sinlaku (taken in 2004). **b** after typhoon Sinlaku (taken in 2007). **c** after typhoon Sinlaku (taken in 2008)

Besides extensive injection of rehabilitation resources into the disaster area after events, the government has also paid great attention on slopeland conservation and crises management. Frequently pressing concerns on abusive and excessive uses of slopelands have since become critical issues after calamities. The "Classification of Slopeland Utilization Limitations" has also played a crucial role in all these activities. For example, the location of the landslide in front of Feng-Chiu tunnel was classified as forestry land, but the land situated above the forestry land was classified as agriculture land and used as orchards (Fig. 2c), means that agricultural activities have been taken place upon vulnerable slopelands. In view the entire land preservation policy from the hazard locations, it appears that regulations on classification of slopeland utilization are indeed requiring careful reviews. The motive of this study is mainly about discussions on the rationality of current slopeland and utilization limitations from the preservation view points of national lands; stressing that specific control measures by given overall localized considerations shall be taken on the scattered forestry and agriculture lands over disaster-prone areas.

For studying problems on the current classification and definition, the research takes Feng-Chiu section of Sinyi Township, Nantou County as the subject area. GIS technology is used for overlaying DTM (Wilson and Gallant 2000). Digital cadastre and relevant layers are used for problem analysis.

By the way of logistic regression within the multivariate geostatistics analysis, potential areas of debris flow are defined (Kobashi and Suzuki 1988; Koukis and Ziourkas 1991; Hearn 1995; Liu et al. 2002; Mark and Ellen 1995; Lee and Lin 2002; He et al. 2003; Cannon et al. 2003, 2004; Chang 2007; Dominguez-Cuesta et al. 2007; Griffiths et al. 2007; Carrara et al. 2008; Chen et al. 2008; Tunusluoglu et al. 2008). Besides suitability assessment of the current classification regulations, solutions regarding to disaster-prone areas in high mountains have been proposed based on new concepts of national land preservation. For the purpose of being referenced for revising statutory regulations of slopeland utilization limitations in the future.

Research materials

Study area

The classification of slopeland utilization limitations is limited in the range of slopelands that are suitable for agricultural use. The study takes Feng-Chiu section of Sinyi Township, Nantou County as the study area. This section is located at Chen-You-Lan River, an upstream branch of the Jhuoshuei River, totaling an acreage of 11.46 km^2, including 1281 parcels in land categories of mountain and forest, prairie, road, dry field, and construction site, separated as national lands and private ones. The national lands are properties of National Property Administration, Ministry of Finance. Based on "The land classification standards for permissible slopeland use", 301 parcels in the Feng-Chiu section are excluded for being classified as range of undefinition. Therefore only 980 parcels in Feng-Chiu

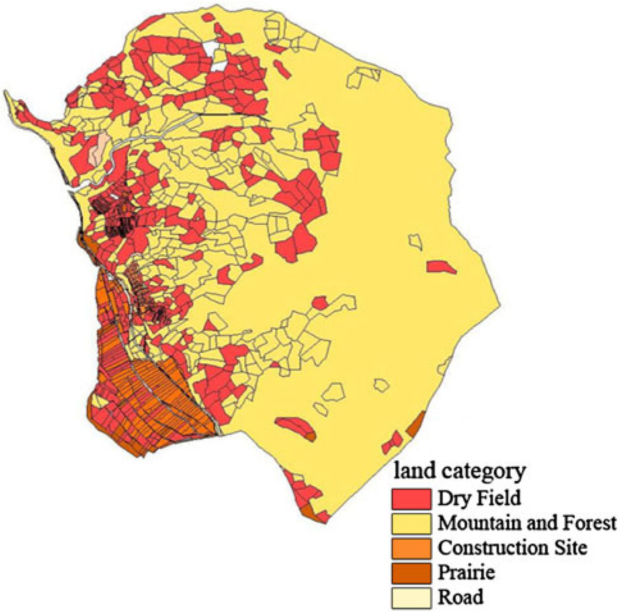

Fig. 3 Land category diagram of Feng-Chiu section, Sinyi Township, Taiwan

Table 1 Statistical list of land classification in Feng-Chiu section, Sinyi Township

Section	Feng-Chiu section		
Area	Acreage (m^2)	Percent	Parcel
Land classification			
Agriculture or animal husbandry	2,368,174	20.74	980
Forestry	8,872,937	77.36	
Range of undefinition	216,988	1.90	301
Total acreage (m^2)	11,458,099	100	1281

section can be analyzed for comparison (Hsu 2002). The distribution and the acreage statistical results are shown in Fig. 3 and Table 1.

Research materials

The most recent landslides and debris flows were chosen as the initial conditions. SPOT images were collected that included incidences such as the images after of Typhoon Herb in 1996, before and after images of Chi Chi Earthquake in 1999, before and after images of Typhoon Toraji in 2001 (Table 2). All SPOT images were received, processed, and rectified by the Center for Space and Remote Sensing Research, National Central University, Taiwan. Multispectral (XS) images and Panchromatic (PAN) images are merged via image fusion algorithm to obtain high resolution false color satellite images. By way of image processing for interpretation and review, together with spotted on-site surveys for re-check and confirmation, digital graphic files of landslides and debris flows have been established (Fig. 4). ArcGIS technique was further applied for overlapping a 5 × 5 m digital terrain model (DTM) with digitalized cadastral map files (Chen 2005; Sung 2006; Horng 2008), from which we found that the terrain rises gradually from the west to the east at an elevation in the range from 0 to 2,250 m. From the target section's cadastral data, classification and distribution of slopeland use may be obtained (Fig. 5).

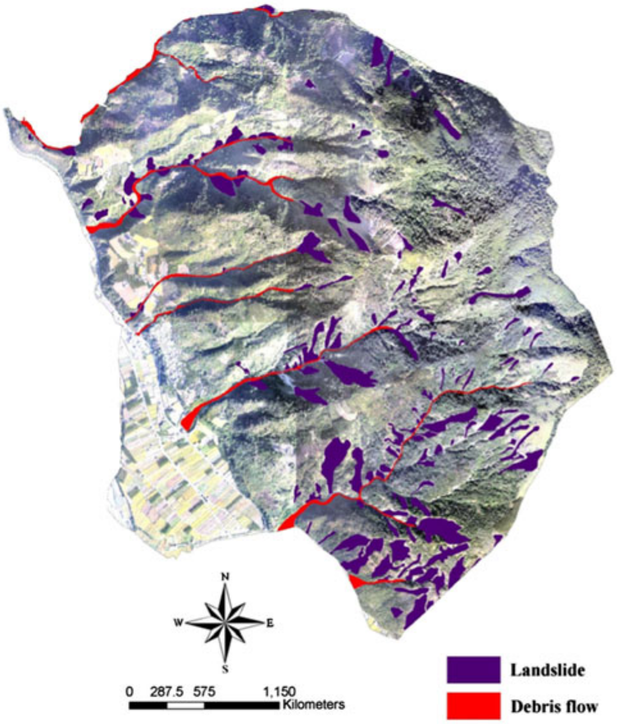

Fig. 4 Diagram of overlapped image of orthogonal projection of debris flow and landslides in Feng-Chiu section, Sinyi Township, Taiwan

Research method

The study employ the debris flow susceptibility analysis and disaster survey and drafting method developed by Central Geological Survey (CGS 2007) of Ministry of Economic Affairs; this method used logistic regression method in multivariate geostatistics for performing debris flow susceptibility analysis (Lee et al. 2007, 2008a, b). Since the said analysis mainly depends on terrain and geological and hydrological properties of the watershed, therefore the Jhuoshuei River is taken as an analysis unit including the study site (Fig. 6). First, Typhoon Toraji, which caused hazardous rainfall and wide range of rainfall variations within the rain-field, was used as the basic data

Table 2 SPOT images used in the Jhuoshuei River

Event	Event date	Image	Time	Type
Typhoon herb	July 29–Aug 1, 1996	After	March 13, 1997	XS PAN
Chi Chi earthquake	Sep 21, 1999	Before	April 1, 1999	XS
			April 1, 1999	PAN
		After	Oct 31, 1999	XS
			Oct 31, 1999	PAN
Typhoon Toraji	July 28–31, 2001	Before	July 2, 2001	XS
			July 2, 2001	PAN
		After	Nov 10, 2001	XS
			Nov 10, 2001	PAN

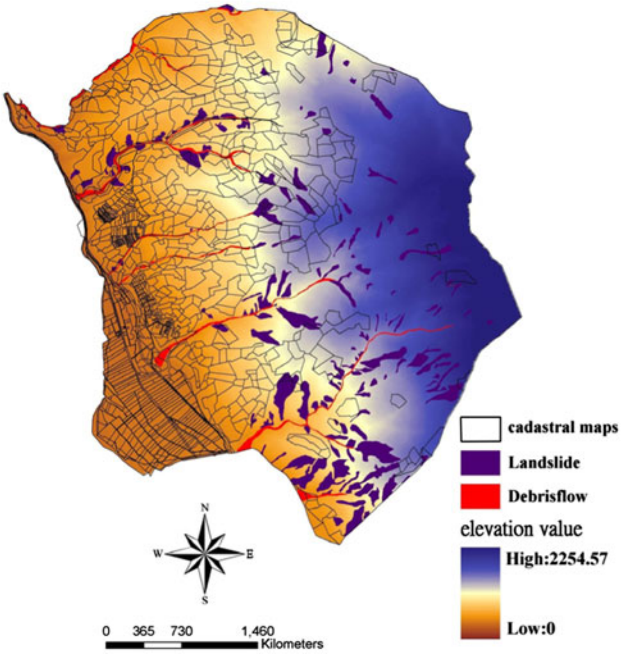

Fig. 5 Diagram of DTM overlay with cadastral maps of Feng-Chiu section, Sinyi Township, Taiwan

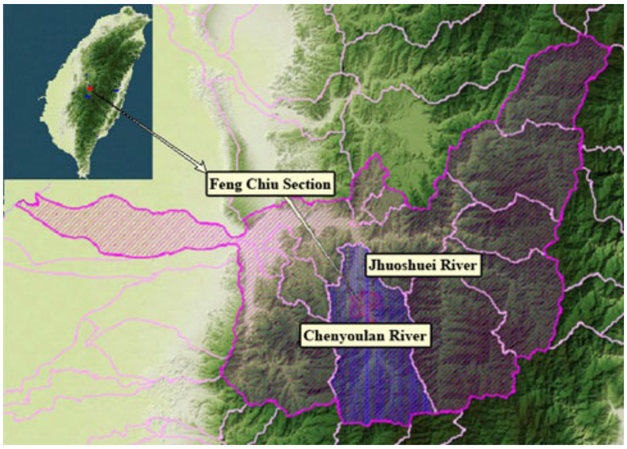

Fig. 6 Location of the study sites in Jhuoshuei River

of initial event that induced channelized debris flows (Fig. 7). Subsequently, based on topographic and geologic properties together with extents of availability and precision of data within the study area, eight debris flow susceptibility factors have been screened and identified. The eight factors are form factor of watershed, integral hypsometric, slope of main stream, area ratio of historical landslide, area ratio of the triggered landslide, density of stream network, and density of road network known as the susceptibility factors, and the total rainfall of the storm event known as the triggering factor. For the total rainfall, single-variate interpolation method was employed. Rainfall results estimated separately by Kriging, Inverse Distance Square, Thiesson polygons method, and Kriging with varying local means are compared for plotting a set of curves representing the probability of landslides caused by rainfall during the typhoon Toraji in the Jhuoshuei River. The area under this curve (AUC) represents the significance of the association between the rainfall and the landslide. Table 3 showed rainfall estimated using different ancillary factors, in which the estimation made by Kriging with varying local means has the largest AUC. Therefore this method was selected for the estimation of total rainfall (Hevesi et al. 1992; Daly et al. 1994; Goovaerts 2000; Buytaert et al. 2006).

In order to verify normal distribution of different factors that were introduced in the analysis mode, discriminators of respective factors (Davis 2002) and calculating correlation coefficients between any two factors (Table 4) were brought in to avoid excessive interdependence among factors or the effectiveness of subsequent analyses which may be impaired. At the end, eight factors were selected for the debris flow susceptibility analysis.

The 1031 sub-units have been defined in the Jhuoshuei River for the debris flow analysis, of which 190 are the debris-flow group and 841 are non-debris-flow group. Considering that the total area of every analysis sub-units in the two groups should not differ too much from each other, the sub-units are therefore classified based on the area size, they are 117, 48, and 25 units for the debris-flow group, and 80, 180, and 581 units for the non-debris-flow group (see Table 5).

The debris flow analysis model of Jhuoshuei River employ all the 190 units of the debris-flow group and just 190 units in the non-debris-flow group, i.e., 80, 85, and 25 units are randomly selected from the large, medium, and small classes, respectively. The program uses data of these 380 units for building a logistic regression model.

Logistic regression model is a special form of logarithm linear model (Feinberg 1985; Agresti 2002) when the dependent variable is a binary variable. The model has the following form:

$$\ln\left(\frac{p_i}{1-p_i}\right) = \alpha + \sum_{k=1}^{k} \beta_k x_{ki}, \tag{1}$$

where p_i is the event probability at the ith point with given values of independent variables $x_{1i}, x_{2i}, \ldots, x_{ki}$, and α, β_k are the coefficients. In the debris flow susceptibility analysis, x_{ki} is the factorial vector of an ith point if the point has a debris flow $p_i = 1$ rather than on debris flow $p_i = 0$. After regression of the training data we get coefficients α and β_k.

In order to assess the feasibility of the model, the study employs the Receiver Operating Characteristic (ROC) theory (Swets 1988) as the basis for verifying the result.

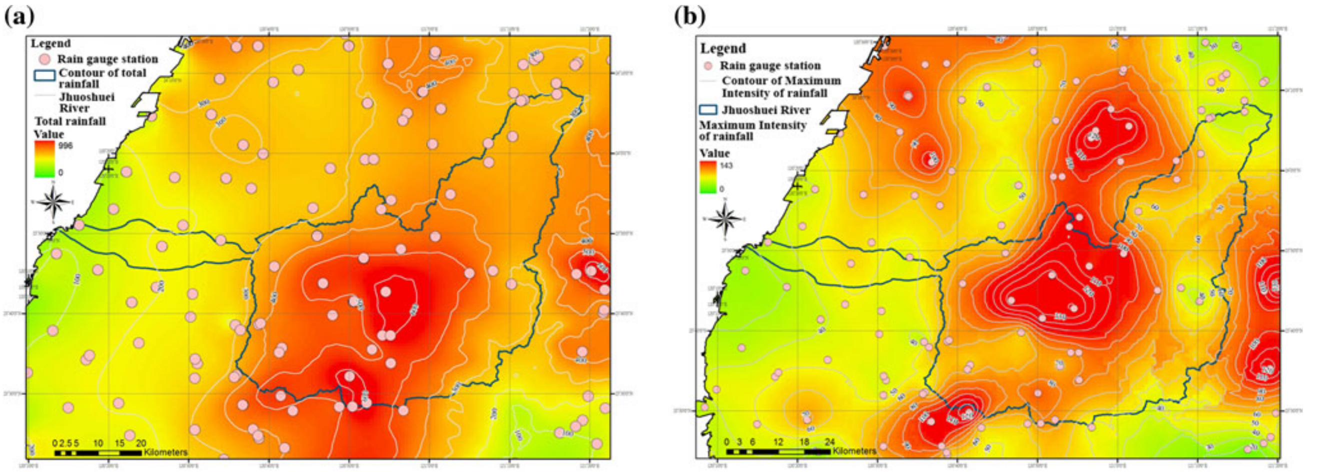

Fig. 7 Rainfalls in Jhuoshuei River during typhoon Toraji event **a** total rainfall **b** maximum intensity of rainfall

Table 3 Comparing success ratio curve for interpolation of total rainfall in Jhuoshuei River during typhoon Toraji event

Interpolation	Kriging	Inverse distance square	Thiesson polygons method	Kriging with varying local means
AUC	0.7377	0.7136	0.7105	0.7478

Table 4 Correlation coefficient between debris flow susceptibility factors

	Form factor of watershed	Integral hypsometric	Slope of main stream	Area ratio of the triggered landslide	Area ratio of historical landslide	Density of stream network	Density of road network	Total rainfall of the storm event
Form factor of watershed	1.00	−0.08	0.04	−0.05	−0.01	−0.32	−0.02	−0.05
Integral hypsometric	−0.08	1.00	0.34	0.00	0.03	0.12	−0.12	0.10
Slope of main stream	0.04	0.34	1.00	0.15	0.17	−0.19	−0.36	0.42
Area ratio of the triggered landslide	−0.05	0.00	0.15	1.00	0.01	0.02	−0.04	0.30
Area ratio of historical landslide	−0.01	0.03	0.17	0.01	1.00	−0.01	−0.10	0.03
Density of stream network	−0.32	0.12	−0.19	0.02	−0.01	1.00	0.13	0.01
Density of road network	−0.02	−0.12	−0.36	−0.04	−0.10	0.13	1.00	−0.06
Total rainfall of the storm event	−0.05	0.10	0.42	0.30	0.03	0.01	−0.06	1.00

For the ROC, a probability value of 0.5 is used in the logistic model to determine whether the model has made a correct prediction (>0.5) or not (<0.5). Thus a curve of success ratio is derived. Because the total area under the curve of success ratio, that is the AUC value, has a range of 0–1, a higher value indicates a higher prediction rate, whereas a value near 0.5 means the prediction is no better than a random guess (Chung and Fabbri 2003). In other word, the AUC value should be higher than 0.5 for a successful convergent prediction.

Curve of debris flow occurrence ratio was created using coefficients obtained from logistic regression model, for transferring susceptibility value into probability value according to a fitting equation so as to obtain the debris flow probability map. After that, streams with historical debris flow were overlain upon the debris flow probability map of 100-year return period for further estimate and establish the debris flow potential map. Select high and medium classes of debris flow potential areas from the debris flow potential map and overlay them onto the layer of classification of slopeland utilization limitations, to analyze, verify, and assess the impact resulting from land classification and its distribution within the debris flow potential areas.

Table 5 Class of analysis units of debris-flow in Jhuoshuei River

Class of analysis units	Debris-flow group		Non-debris-flow group	
	Number of data	Number selected	Number of data	Number selected
Large (>300 ha)	117	117	80	80
Medium (300–100 ha)	48	48	180	85
Small (<100 ha)	25	25	581	25
Total	190	190	841	190

Results and discussion

Before performing logistic regression, factors are normalized for eliminating domain differences between factor values and exhibiting relative weight differences between factors. Samples of debris-flow data and non-debris-flow data are then grouped based on the typhoon Toraji event, for the purpose of analysis and verification. After verification and assessment, an optimal fitting analysis is conducted by matching all the data of the debris-flow-group with a group of the same quantity of non-debris-flow data. Table 6 shows coefficients have been obtained. From coefficients obtained by logistic regression we find that the integral hypsometric and the total rainfall are the most significant factors, and the slope ratio of main stream, the area ratio of historical landslides, and the total rainfall are in positive relationship to debris flow susceptibility in all events. The regression analysis shows an accuracy of 70.5 and 69.5%, respectively, for the debris-flow group and the non-debris-flow group, with an overall accuracy of 70%. By substituting coefficients obtained by the logistic regression into the analysis units of the Jhuoshuei River, the AUC value of the success rate is 0.743 (as shown in Fig. 8). This indicates that the debris flow susceptibility model has a high tendency of causing a debris flow in the typhoon Toraji event. Within the classification of the debris flow susceptibility, one-variable multi-power regression formula is used for fitting the value of debris flow susceptibility and the distribution curve of the occurrence ratio (obtained by dividing the total count in each class of debris flow susceptibility by the event-count of the debris flow group in that class). Figure 9 shows the regression formula as the following optimal fitting equation:

Table 6 Result of coefficients of logistic regression and verification in the Jhuoshuei River

Analysis method	Data type	Logistic regression
Variable		
Form factor of watershed	Discrete	−1.658
Integral hypsometric	Discrete	−6.331
Slope of main stream	Discrete	1.423
Area ratio of the triggered landslide	Discrete	−0.776
Area ratio of historical landslide	Discrete	4.429
Density of stream network	Discrete	−2.895
Density of road network	Discrete	−0.898
Total rainfall of the storm event	Discrete	2.630
Constant	Discrete	1.957

$$p_{\mathrm{df}} = 0.1759\left(\frac{\lambda}{1-\lambda}\right)^{0.8506}. \qquad (2)$$

Where, p_{df} is debris flow ratio, or the spatial probability of debris flow; λ is debris flow susceptibility index. The probability of debris flow is in positive association with debris flow susceptibility and rises fast exponentially. This indicates that a location with a high susceptibility value will have a quick rise in the occurrence probability.

Based on the fitted equation of index distribution, debris flow susceptibilities can be converted into debris flow probabilities. Substituting the rainfall distribution of 1-h duration of 100-year return period interval into the model equation, the debris flow probability can be converted. Then, by overlapping streams with historical occurrence of debris flows for evaluation, debris flow probability is classified, and the debris flow probability map in the Jhuoshuei River is plotted (Fig. 10).

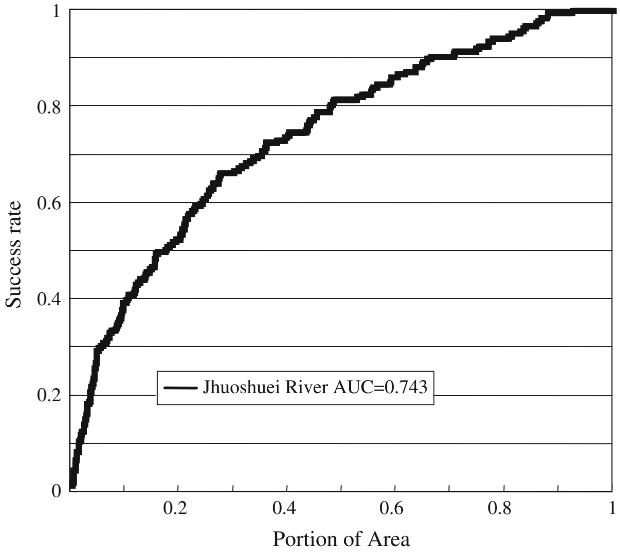

Fig. 8 ROC curve in Jhuoshuei River for Toraji Typhoon event

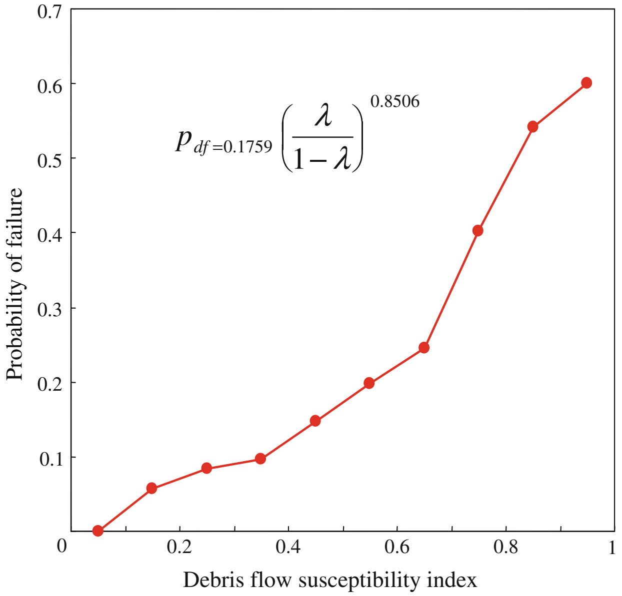

Fig. 9 Distribution of probability of failure with respect to debris flow susceptibility index in Jhuoshuei River

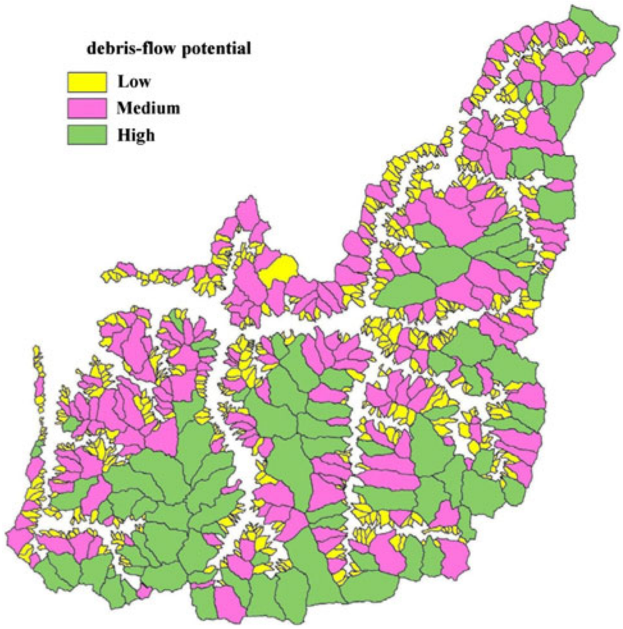

Fig. 10 Map of debris flow potential in the Jhuoshuei River

From the selected study area, Feng-Chiu section of Sinyi Township of Nantou County, Taiwan, we learn that there are four debris flow potential areas of medium to high hazard classes (Fig. 11), indicating that the section is geologically fractured. By overlaying the classification map, the statistical results show that farmlands of the medium to high debris flow potential in the Feng-Chiu section occupy around 116.34 ha, a ratio of 49.1% to the total agriculture or animal husbandry land of the entire section; and forestry lands of the same potential are 841.25 ha (Table 7), a ratio of 94.8% to the total forestry lands in the entire section. This means that almost 50% of the land being suitable for cultivation or pasturage and being used for agricultural activities in the Feng-Chiu section are within the debris flow potential area, and that multiple scattered agriculture land are distributed in the origins or debris flow potential areas. For the purpose to restrict scattered land explorations, it is necessary to enforce strict land use limitations in the medium to high debris flow potential areas. However, according to the current status of classification, doing so will surely affect the rights of land owners, especially to those of lands used for agriculture or animal husbandry. Therefore, a corresponding rational and adequate compensation mechanism must be provided.

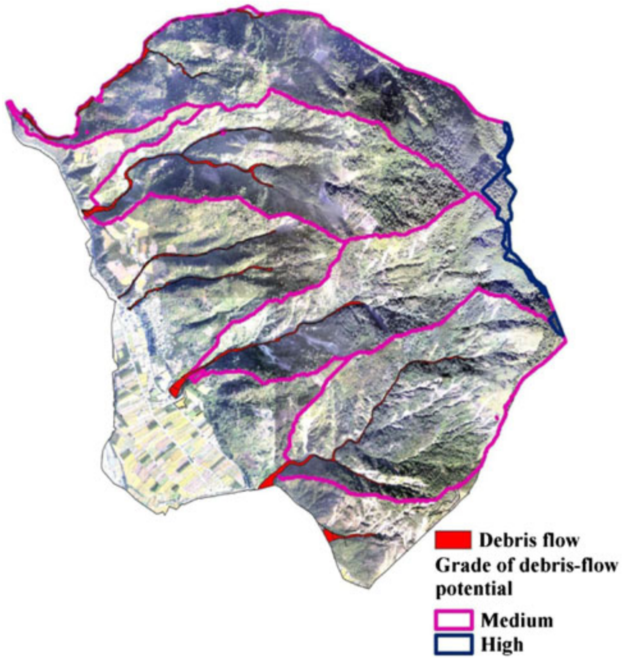

Fig. 11 Diagram of debris flow potential at Feng-Chiu section, Sinyi Township, Nantou County, Taiwan

Conclusions and suggestions

In recent years, drastic changes in slopeland development and utilization have caused alterations of policy in environmental preservation of slopelands. The early stage targets mainly aiming at eliminating soil scouring and increasing farmland productivity has been gradually adjusted into multiple applications for the conservation of soil and water resources as well as for ecological and landscaping protections. Correspondingly, the government has been forced to take special emphasis on the safety issue of

Table 7 Statistical analysis of land classification of debris flow potential areas in Feng-Chiu section, Sinyi Township, and Nantou County

Section	Feng-Chiu section		Debris flow potential area within the Feng-Chiu section	
Lots and area	No. of lots	Area (Hectare)	No. of lots	Area (Hectare)
Land classification				
Agriculture or animal husbandry	716	236.82	146	116.34
Forestry	264	887.29	198	841.25
Total	980	1124.11	344	957.59

national lands. The Executive Yuan has therefore compiled the Draft of National Land Planning Act in 2004 (The Executive Yuan 2004, 2005), the Article 22 of which states that "National Land Preservation areas, agricultural development, and urban–rural development shall be re-classified according to actual needs". Particularly, "National Land Preservation Areas" shall be mainly subdivided into national parks, ecological reserves, and national security zones. Then, re-classification and categorized control shall be implemented according to limitations defined by the existing statutes. However, the classification results are prone to cause problems such as overlapped functions or ranges, and inconsistency in managing methods.

The study mainly targets on resolving potential debris flow hazard sources in cultivating the slopelands in the hazard-prone areas. Regarding lands within the debris flow potential areas of medium to high risks, the four factors based on the standard for classifying slopeland utilization limitations are not suitable for being used as their classification criteria. Instead, special district areas shall be defined based on national land preservation concepts for enforcing particular control measures, with comprehensive compensation mechanism established at the same time. Furthermore, based on the existing regulations, it is also not appropriate to define the land classification factors for classifying lands outside the hazard-potential zones. That is, regulations on "The land classification standards for permissible slopeland use" specify that, under conditions of shallow or extremely shallow soil depth, slopelands are classified as suitable for forestry for those having a 30–55% slope with severe erosion, and those having a slope of more than 55% without soil erosion. It is evident that in classifying forestry and agriculture or animal husbandry land, the average slope factor is of decisive importance. The current land classification results in a way being prone to cause issues of fragmentized land use and damaged integrity of the ecological environment.

Climate changes in recent years have severely impacted our national land, especially with the destructions brought by Typhoon Morakot. Therefore, national land planning shall start with the concept of land preservation and utilization. However, current regulations on the classification of slopeland utilization limitation are merely based on land properties for the categorization and classification without specifying a land utilization control or land preservation measure in accordance with respective classifications. It is therefore necessary to amend the statutory regulations for reaching the goals for environmental protection and sustainable development in the future.

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