RISK ASSESSMENT OF DEBRIS FLOW DISASTER IN SONGHE COMMUNITY IN TAIWAN

Su-Chin Chen[1], Chun-Yi Wu[2], Yung-Chuan Ko[3], Bo-Tsung Huang[4]

ABSTRACT

The concept of risk management has been popular on the field of natural hazard mitigation in the world. In order to understand the distribution of risk around the potential debris flow torrents, this study established a model for assessing risk of debris flow disasters. Based on the concept from the International Strategy Disaster Reduction (ISDR), the definition of risk herein is an interaction of the hazard, vulnerability and capacity. Thus, risk has a close connection with humans' activities and could be expressed by the function of hazard, vulnerability and capacity. In this study, the risk level was calculated by multiplying the hazard grade, the value of vulnerability and the normalized index of capacity (i.e., the disaster-stricken degree). Taking Songhe community for example, the installation of measures can reduce the total maximum risk value by 72% and the total average risk value by 75%; the reduced total risk values could be treated as a part of the benefit of the measures.

Keywords: Risk assessment, hazard assessment, vulnerability, capacity, risk map.

INTRODUCTION

Because of the steep geographic and fragile geologic conditions as well as frequent earthquakes and typhoons in Taiwan, the human activities are often influenced by natural disasters. After the Chi-Chi earthquake, the susceptible geology is even weaker; every time when heavy rainfall comes due to the typhoon or the storm, large-scale floods and debris flows occur repeatedly. Although the debris flows mostly occur in mountain regions, it is still a severe threat to hundreds of settlements. Because of the disaster's uncertainty, adopting the traditional methods to prevent the debris flow disasters through the engineering treatment would cause the difficult problem to balance the disaster mitigation investment cost and benefit. Therefore, emphasizing the thoughts of risk management for the disaster prevention has been an inevitable trend. In view of this, this research has the purpose to establish a risk assessment method of debris flow disasters in order to be the reference for the choice among different risk treatment goals such as risk avoidance, risk mitigation, risk acceptance and risk transfer.

About the definition of "risk", according to the Department of Humanitarian Affairs of the

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United Nations (1991), “risk” means the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular natural phenomenon for a given area. According to Tobin and Montz (1997), “risk” is seen as the product of some probability of occurrence and expected loss. Deyle et al. (1998) believe that “risk” has two measurable components: (1) the magnitude of the harm that may result; (2) the likelihood or probability of the harm occurring in any particular location within any specified period of time. Because the consequence of disaster approaches the disaster losses, and the expected losses are similar to the definition of risk. Therefore, Liu and Mo (2003) consider that the definitions of Department of Humanitarian Affairs of the United Nations and Tobin et al. are the most suitable because the essence of risk is a probable prediction value and not a real value. According to the International Strategy for Disaster Reduction, UN (ISDR, 2002), “risk” means the probability of harmful consequence, or expected loss resulting from interactions between natural or human induced hazards and vulnerable/capable conditions. This function has included capacity into the components of risk; this explains that it is possible to reduce the risk through suitable management or disaster prevention education and drill.

There are many different methods to express the risk level; one of them is adding the natural hazard grade and the value of vulnerability into a total risk (Forte et al., 2005); another is using a mutually independent probability multiplication form (Ferrier and Haque, 2003; Bell and Glade, 2004); the other one is using a direct descriptive method (NC, Division of Emergency Management, 1998; Cardinali et al., 2002). The main purpose is to define a certain level of the risk in order to determine the priority order of the disaster prevention tasks, as well as a reference of the future risk management. It is to fulfill the demand of a zero risk when either a zero natural hazard grade or the value of vulnerability, and to consider that the resilience capacity could influence the assessment results of disaster risk. Therefore, this research defines the risk is function of hazard, vulnerability, and disaster-stricken degree. The hazard reflects the natural characteristics of the disaster, which means the harming grade of the disaster to the zone; the vulnerability reflects the social characteristics, which is related to the material, economics and society; and the disaster-stricken degree reflects the resilience capacity of the zone, the higher the resilience capacity, the lower the potentiality of the community stricken by disaster.

In the part of assessment of the hazard grade caused by debris flow disasters, this research has realized simulation using the FLO-2D software. After determining the submerged areas as red and yellow hazard rating zones, the hazard grade of different elements at red or yellow zones are estimated according to the mode of the submerged elements. In the part of assessment of the value of vulnerability, this research has divided the land-use modes into six different element groups: house, farming land, forestry land, road, bridge and no-direct-loss. Assisted by the Geographical Information System (GIS), the represented values according to the diverse elements are given to realize the quantitative analysis of the vulnerability. In the part of assessment of resilience capacity, the community’s resilience capacity is composed by two parts established in this research: “the ability of residents to resist natural hazard” and “the resources of the community for preventing from disasters”. Using the Analytic Hierarchy Process (AHP) developed by Saaty (1980) to establish a hierarchical framework, the problems of the resilience capacity could be systemized and divided in five different hierarchies. Then the weightings among the diverse hierarchies are obtained through the professionals’ questionnaires, and furthermore an analysis of the results from the residents’ questionnaires and village’s check lists is realized. In synthesis, this research has combined the hazard grade, value of vulnerability and disaster-stricken degree to evaluate the risk level; then a risk map could be drawn to show the risk distribution. This assessment method, besides of possible to compare the risk map before and after the installation of mitigation measures in the same area in order to know the benefit of the measures and the distribution of the residual risk, is also possible to compare the total risk level in different areas in order to determine priority order of the disaster prevention tasks as a reference of the risk management afterwards.

In 2000, 2002, 2004 and 2005 debris flow disasters occurred in Songhe community, Taichung County; especially severe was the disaster caused by the Typhoon Mindulle in 2004, as a consequence 30 houses were buried in the debris flow, 1 person died and 1 got person injured. From 2001, this area has realized the integrated control projects of the watershed due to the disasters; the planning of many project facilities has been realized. In order to understand the risk change situation after installing the mitigation measures, this research used the complete information materials of Songhe community as an analysis case.

RESEARCH METHODS

Hazard assessment of debris flow

Normally speaking, at the analysis of the harming degree of a certain hazard, it is possible to predict rationally the occurrence frequency and the possible intensity through a certain amount of accumulated statistics information. But, most natural hazards do not necessarily have enough statistics data, and the hazard itself includes high uncertainties; therefore, it is necessary to use other accommodation methods. Taking the example of the debris flow disasters, the rainfall factor is the most important inducing factor of the debris flow; therefore, taking the concept of the rainfall frequency to represent diverse rainfall intensity to deduce different scales of debris flows, in certain level, could also reach the purpose of the relative occurrence probability. Besides, in the assessment of the flood risk of Forte et al. (2005), the nine indices with different hazard degrees were obtained by three classes of rainfall intensity and three classes of rainfall frequency. Cardinali et al. (2002) think that the landslide hazard depends on the frequency of landslide movements and on the landslide's intensity. Landslide frequency was estimated using four classes while landslide intensity was defined in four classes, based on the estimated volume and the expected velocity.

Therefore, this research takes the classification method of the Guidelines on Hazard Mapping of Austria (Fiebiger, 2004) as reference to classify the hazard rating zones of debris flows. The classification of the hazard degree is composed by the two parameters: intensity and occurrence probability; according to the harm to the people and the damage to the buildings, it is classified in red or yellow zone. Under different rainfall intensity, the submerged extent and the height of deposit of debris flow can be simulated by the FLO-2D software; then the results were used to classify the different hazard zones. Herewith the two parameters to classify the hazard degrees of debris flow are described:

A. Intensity

The criterion of the influence intensity is defined as the influence level to the human lives and the building's structure safety. The Guidelines on Hazard Mapping of Austria classify the intensity of debris flow according to the height of deposit; the height of over 0.7 m is considered as high intensity, and the height of below 0.7 m is considered as low intensity.

B. Occurrence probability

For the debris flow, the influence factors are complex; normally it is not easy to calculate the occurrence probability, and even more improbable to estimate its return period. Therefore, the probability of the debris flow within one year is selected as the criterion of high or low probability; and the occurrence probability of the events of 10 and 150 years return periods within one year are 10% and 0.7% respectively.

Combining both parameters of intensity and probability, it is possible to obtain the different hazard degrees of debris flow; when the intensity is high and the occurrence probability is high or low, it is classified as red zone; when the intensity is low and the occurrence probability is high or low, it is classified as yellow zone. On the assessment of hazard grade of debris flow, the submerged areas are classified as red or yellow zones using the results of FLO-2D software simulation. Based on the mode of the submerged elements at risk and the damage factor of Team KNU (2005), it is possible to estimate the hazard grade of different elements at red or yellow zones (as shown in table 1)

Tab. 1: Damage factor of diverse elements at risk

Element at risk	Average risk map		Maximum risk map	
	Yellow zone	Red zone	Yellow zone	Red zone
House	0.1	0.3	1.0	1.0
Farming land	1.0	1.0	1.0	1.0
Forestry land	0.1	0.5	1.0	1.0
Road	0.5	1.0	1.0	1.0
Bridge	0.5	1.0	1.0	1.0

The damage factor represents the average ratio of actual loss to the value of an element in the red and yellow zones when the disaster occurs. The hazard grade of each element equals the corresponding damage factor. Therefore, results of multiplication of the damage factor by the value of element are the average losses of the debris flow of 150 years return period; the obtained risk map is also called as average risk map. Besides of considering the average risk, estimating the possible maximum losses of the disaster is also very important. Taking all the damage factors as 1, the results are the possible maximum losses of the debris flow of 150 years return period; the obtained risk map is also known as the maximum risk map.

Vulnerability assessment

The vulnerability can be defined as the threat or harm to the people and property by the disasters. This means after predicting the hazard zones according to the scale of debris flows, all losses of lives and properties within the endangered extent when the disaster occurs shall be estimated. Because the vulnerability assessment, which involves the evaluation or estimation, is a complex process, it is necessary to simplify the assessment method in order to facilitate the analysis. For example, according to Forte et al. (2005), nine classes with different vulnerability degrees are represented for elements at risk. Each class has one fictitious multiple of three indices in order, so the vulnerability factor is numerically defined by values. Cardinali et al. (2002) estimate vulnerability based on the inferred relation between the intensity and type of the expected landslide, as well as the likely damage the landslide would cause to eleven types of elements at risk. The expected damage to the elements was classified as minor, medium and severe damage. Therefore, when it is impossible to realize an accurate analysis of the details of the possible losses, this research has selected some public or private properties such as house, farming land, forestry land, road, bridge as the main assessment elements, and analyzed the vulnerability; the indirect and intangible losses are not considered.

This research used the aerial photos and land-use maps to re-digitize the land-use layer of the nearby submerged areas. At the digitalization, the modes of land use were classified into six groups of elements at risk, i.e. house, farming land, forestry land, road, bridge and no-direct-loss (as shown in table 2). Assisted with the GIS and giving its represented value according to different elements, the quantitative analysis of vulnerability was realized.

In the calculation of unit value with different elements at risk, this research took the values used by National Science and Technology Center for Disaster Reduction (NCDR, 2005) as reference to realize the assessment of economic losses of debris flow disasters. The prices announced by the local authorities were used to assess the value of houses, farming and forestry lands; the values of roads and bridges were assessed with the minimum value of US\$ 909 / m^2 and 758 / m^2, respectively (Liu et al., 2006).

Tab. 2: Vulnerability assessment of different elements at risk

Element at risk	Land-use classification	Assessment method
House	House, school, etc.	The announced land price plus the value of the building itself
Farming land	Paddy field, dry farmland, betel nut farmland, orchard, etc.	The announced land price
Forestry land	Foliage forest, coniferous forest, etc.	The announced land price
Road	Road	US\$ 909 / m^2
Bridge	Bridge	US\$ 758 / m^2
No-direct-loss	River, dry river bed, etc.	US\$ 0 / m^2

Capacity assessment

The resilience capacity is defined as the capacity of individuals or communities to endure or resist the disasters. Chen et al. (2005b) considered the community resilience capacity as the combination of the community's legal capability, disaster prevention and response organization, communication capability, warning capability, payment capability of the mitigation fees and disaster prevention education, which means the community's preparedness capacity. Wang (2005) established an assessment model, using the check lists to interview the village heads, for the resilience capacity of slopeland communities in order to assess the community's preparedness of disaster prevention such as the responding system, monitoring system and communication system. Through questionnaires to the residents, Wu (2006) realized an assessment of the ability of residents to resist natural hazard such as responding capability, monitoring capability and communication capability, as well as then modified and combined the assessment model for the resilience capacity of slopeland communities to establish a model of resilience capacity for communities.

Therefore, the resilience capacity of the community is composed by two parts, including the ability of residents to resist natural hazard and the resources of the community for preventing from disasters. The problems of resilience capacity were systemized and divided into five different hierarchies (as shown in table 3) by the AHP. Then the weightings among the diverse hierarchies were obtained through the professionals' questionnaires, and furthermore an analysis of the results from the residents' questionnaires and village's check lists was realized. The assessment method of the community's resilience capacity is as follows:

- The "ability of residents to resist natural hazard" covers three capabilities that the residents have to resist the disasters like responding, monitoring and communication capabilities; the assessment was realized with the residents' questionnaires (Wu, 2006).

The design framework of the questionnaire is shown in table 3. Each question is given a grade mark from 0 to 60 points to realize the calculation.

- The “resources of the community for preventing from disasters” is based on the point of view of the disaster prevention system, and is divided in responding, monitoring and communication systems of the community; the assessment method is using the check lists (Wu, 2006) to interview the village heads. The design framework of the check list is shown in table 3. Each question is also given a grade mark from 0 to 60 points to realize the calculation.
- After obtaining the points of the “ability of residents to resist natural hazard” and the “resources of the community for preventing from disasters”, it is necessary to realize the weighting analysis on the grade mark obtained from the questionnaires and check lists because of the different importance among each item. According to the results of the questionnaires to professionals, investigated by Wu (2006), the distribution of weighting structure is shown in table 3. In the hierarchical weighting in the table, the sum of the items on the same hierarchy is 1; the whole weighting represents the importance of the item on whole resilience capacity of the community. Multiplying the number of points obtained in each question by the whole weighting respectively, the sum will be the assessment points of the “ability of residents to resist natural hazard” and the “resources of the community for preventing from disasters”.
- At the end, adding up the both points just mentioned above gets the community’s whole resilience capacity.

The community’s resilience capacity has a grading scale of 0-60 points; in order to combine with the analysis results of the above mentioned hazard and vulnerability, it is possible to use the formula (1) to transform the total points of the resilience capacity into a normalized index of a value between 0 and 1. This index can be considered as the disaster-stricken degree (D_s); the higher the resilience capacity, the lower the potentiality of the losses from the community due to disasters.

$$D_s = 1 - \frac{\textbf{the resilience capacity}}{\textbf{60 points}} \tag{1}$$

Risk assessment

According to the results from the analyses of debris flow hazard, vulnerability and resilience capacity, based on the risk function indicated by ISDR (2002), the risk level (R) can be calculated by multiplying the hazard grade (H), value of vulnerability (V) and disaster-stricken degree (D_s) as shown in formula (2); then the risk map can be drawn.

$$R = H \times V \times D_s \tag{2}$$

The risk map drawn in this research represents the risk distribution and extent when a disaster of 150 years return period occurs. Adding the above mentioned damage factors for analysis, it is possible to obtain the distribution of the average losses when a disaster of 150 years return period occurs, which means the average risk map; or the distribution of the most severe losses, which means the maximum risk map. Besides of showing the distribution of the high or low risk levels on the risk map, this research added up all the risk values within the submerged extent to obtain the total average losses of the whole area when the occurrence of debris flow, which means the total average risk value; or the total maximum losses, which means the total maximum risk value (as shown in tables 6 and 7).

When calculating the total average risk value in a region, the uncertainty of the submerged extent when the debris flow occurs shall be considered, which means whether all the areas in

Tab. 3: The framework and weighting distribution of the community’s resilience capacity

Hierarchy	Assessment items				Hierarchical weighting	Whole weighting
1	Community’s resilience capacity				1.000	1.000
2	Community’s resilience capacity	Ability of residents to resist natural hazard			0.498	0.498
		Resources of the community for preventing from disasters			0.502	0.502
3	Ability of residents to resist natural hazard	Responding capability			0.417	0.208
		Monitoring capability			0.272	0.135
		Communication capability			0.310	0.154
	Resources of the community for preventing from disasters	Responding system			0.406	0.204
		Monitoring system			0.271	0.136
		Communication system			0.323	0.162
4	Ability of residents to resist natural hazard	Responding capability	Understanding the community’s disaster prevention and response organization		0.207	0.043
			Preparing the disaster prevention resources of one’s own house		0.238	0.050
			Understanding the emergency evacuation route and shelter		0.323	0.067
			Acquiring disaster prevention experience		0.232	0.048
		Monitoring capability	Observing the one’s own rainfall gauge		0.616	0.083
			Experience principle		0.384	0.052
		Communication capability	Communicating with the supervisors		0.407	0.066
			Communicating with the relatives or neighbors		0.593	0.096
	Resources of the community for preventing from disasters	Responding system	Disaster prevention and response organization		0.279	0.057
			Disaster prevention and response resources		0.343	0.070
			The emergency evacuation planning		0.378	0.077
		Monitoring system	Observing the community’s rainfall gauge		0.546	0.074
			Real-time monitoring system		0.454	0.062
		Communication system	Communication feedback system		0.299	0.048
			Specialized personnel		0.429	0.069
			Communication equipment		0.272	0.044
5	Responding capability		Understanding the emergency evacuation route and shelter	Knowing the routes to shelters	0.432	0.029
				Active / passive evacuation	0.568	0.038
			Acquiring disaster prevention experience	Participation experience of disaster prevention drill	0.452	0.022
				Real disaster experience	0.548	0.026
	Responding system		Disaster prevention and response organization	Community’s rescue team	0.620	0.035
				Mobilization capacity	0.380	0.022
			Disaster prevention and response resources	Aid materials in the shelter	0.531	0.046
				Rescue equipments	0.469	0.041
			The emergency evacuation planning	Planning of the route and shelter	0.370	0.043
				Distribution of the residents	0.307	0.036
				List of the elders, minors and infirm patients	0.322	0.038
	Monitoring system		Observing the community’s rainfall gauge	Knowledge of the operation method	0.462	0.034
				Specialized personnel	0.236	0.017
				Device popularity	0.302	0.022
			Real-time monitoring system	Knowledge of the operation method	0.465	0.029
				Specialized personnel	0.250	0.016
				Device popularity	0.286	0.018

Source: Chen et al.(2006)

the red and yellow zones would be influenced by the same event. Therefore, this research used the process factor provided by Team KNU (2005) to represent the area proportion of hazard zones which could be influenced by the same event. It is necessary to know that when the debris flow of 150 years return period occurs, the process factor shall be 0.6 according to Team KNU. But this research established 1.0 for the process factor to calculate the total maximum risk value in a region.

CASE ANALYSIS

Environment outline of the Songhe community

The Songhe community is located in Taichung County, and is about 30 km of the Central Cross-Island Highway. It is at an elevation of about 700 meters; the annual average temperature is 22 degrees Celsius and the annual average rainfall is 2800 mm. The No. 1 and No. 2 Songhe Torrents are potential debris flow torrents; the watershed has a long form in east-west direction and narrow in north-south direction. The topography varies greatly; the lowest point is at 640 meters and the highest point is at 2870 meters elevation. The stratum structure of the Songhe community is complex; the joints have been well developed; the stratum is of argillites and sometimes sandstones; the naked parts of the stratum are often of debris. During the heavy or torrential rains, it can easily collapse and even cause debris flow disasters.

Risk assessment of debris flow disasters

A. Hazard analysis of the debris flow

This research used the FLO-2D software, together with the 10 m x 10 m DTM data and the peak discharge of rainfall of the 10 and 150 years return periods (as shown in table 4), to simulate the possible submerged areas of the No. 1 and No. 2 Songhe Torrents; then the heights of deposit were analyzed to decide the hazard degree caused by the debris flow and its distribution. After the classification of the simulation results, it is possible to obtain the red and yellow zones of the No. 1 and No. 2 Songhe Torrents, as shown in figure 1. The 30 houses buried in the debris flow caused by the Typhoon Mindulle in 2004 are almost within the red zones.

Tab. 4: Peak discharge of the No. 1 and No. 2 Songhe Torrents

Potential debris flow torrents	**Rain station of the Central Weather Bureau**	**Annual average rainfall (mm)**	**Peak discharge of different return period (cms)**	
			10 years	**150 years**
No. 1 Songhe Torrent	Shangguguan	2807.0	112.1	158.9
No. 2 Songhe Torrent	Shangguguan	2807.0	16.4	23.2

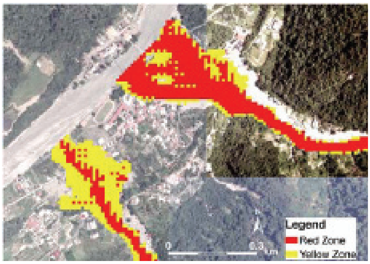

Fig. 1: The red and yellow zones of the No. 1 Songhe Torrent (right) and No. 2 Songhe Torrent (left)

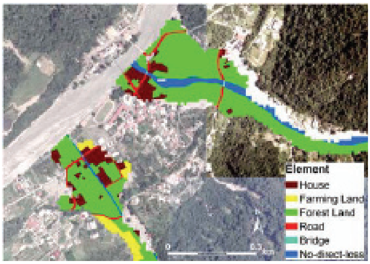

Fig. 2: Distribution of elements in the submerged areas of the No. 1 and No. 2 Songhe Torrents

B. Vulnerability analysis

In this research, the vulnerability analysis makes emphasis on the losses caused by the debris flow disasters in each land-use mode; thus, the land-use layer is the main assisting instrument. In order to make it more accurate, after obtaining the 1/5000 orthophotos, the land-use layer of the region was re-digitized using the ArcView software. At the digitalization, making a reference directly on the table 2, the land-use modes were classified into six groups of elements at risk like house, farming land, forestry land, road, bridge and no-direct-loss. The distribution of different elements in the submerged areas of the No. 1 and No. 2 Songhe Torrents is shown in figure 2.

In the assessment of average unit value of different elements, according to the land price announced by the Land Administration Bureau of Taichung County Government, the average value of construction lands of the Songhe community is US$ 3.9 / m^2; the value of farming lands is between US$ 2.0 – 3.6 /m^2, and the average is US$ 2.8 / m^2; the value of forestry lands is between US$ 2.0 – 3.6 / m^2, and the average is US$ 2.8 / m^2. About the value of the building itself, after the result of on site investigation of the buildings in Songhe community, the buildings in this region are mostly reinforced concrete residential houses and farmhouses, which belong to the third category of reinforced concrete houses in the "House Usage Classification List". Each building has 2 floors on average; from the "House Standard Unit Price List", the unit price of the first floor is US$ 72.7 / m^2, and the second floor is US$ 75.8 / m^2 in the third category of reinforced concrete houses. Therefore, for the element of the house in Songhe community, the unit value shall include the price of the construction land, the first and second floors, which amount to US$ 152.4 / m^2.

C. Analysis of the resilience capacity

In the calculation of the community's resilience capacity, scoring with the results of the residents' questionnaires and check list in Songhe community was realized, as well as the scores of the "ability of residents to resist natural hazard" and the "resources of the community for preventing from disasters" were recorded. After adding the weighting, the sum of both scores is the community's resilience capacity in Songhe community. Then, the resilience capacity can be transformed into the disaster-stricken degree (D_s); the calculation results are shown in table 5.

Tab. 5: Scoring table of each assessment item of the resilience capacity in Songhe community

Assessment items	Score	Assessment items	Score
Ability of residents to resist natural hazard	**18.89**	**Resources of the community for preventing from disasters**	**14.57**
Responding capability	**12.35**	**Responding system**	**11.53**
Understanding the community's disaster prevention and response organization	6.90	Disaster prevention and response organization	4.77
Preparing the disaster prevention resources of one's own house	7.99	Disaster prevention and response resources	7.24
Understanding the emergency evacuation route and shelter	9.34	The emergency evacuation planning	16.38
Acquiring disaster prevention experience	5.39	**Monitoring system**	**7.54**
Monitoring capability	**10.34**	Real-time monitoring system	0.00
Observing the one's own rainfall gauge	24.26	Observing the community's rainfall gauge	27.81
Experience principle	13.74	**Communication system**	**9.95**
Communication capability	**15.25**		
Communicating with the supervisors	49.21		
Community's resilience capacity	**33.46**	Disaster-stricken degree (D_s) *	0.44

Remarks: * The disaster-stricken degree is calculated by the formula (1)

D. Result of the risk assessment

Using the results of the red and yellow zones, the distribution of the elements within the submerged areas as well as the disaster-stricken degree of Songhe community, the risk level of the debris flow disaster can be calculated with the formula (2), and then the risk map can be drawn. For example, figure 3 is the maximum risk map of the debris flow disaster in Songhe community, which represents the distribution of the most severe losses when the event of 150 years return period occurs; the figure 4 is the average risk map, which represents the distribution of the average losses when the event of 150 years return period occurs. Besides that the maps show the distribution of high or low risk levels, it is possible to obtain the total maximum risk value and total average risk value when the disaster occurs by adding up all the risk values within the submerged extent (as shown in tables 6, 7). From the analysis results, the total maximum risk value is about US$ 4.4 million and the total average risk value is US$ 1.4 million when the event of 150 years return period occurs.

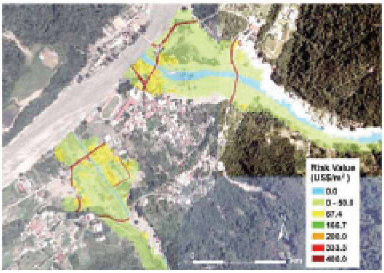

Fig. 3: Maximum risk map of the debris flow disaster in Songhe community

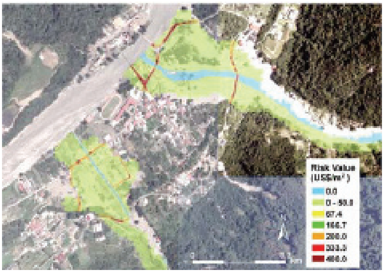

Fig. 4: Average risk map of the debris flow disaster in Songhe community

Tab. 6: Calculation of the total maximum risk value of the debris flow disaster in Songhe community

Element at risk	**Red zone**		**Yellow zone**		**Unit value (US$ / m²)**	**Loss value (US$)**
	Submerged amount (m²)	**Damage factor**	**Submerged amount (m²)**	**Damage factor**		
	(1)	(2)	(3)	(4)	(5)	(6)=[(1)*(2)+(3)*(4)]*(5)
House	9057	1.0	11440	1.0	152.4	3123743
Farming land	3030	1.0	5757	1.0	2.8	24604
Forestry land	119720	1.0	76971	1.0	2.8	550735
Road	3218	1.0	3547	1.0	909	6149385
Bridge	140	1.0	95	1.0	758	178130
No-direct-loss	14734	-	6490	-	0	0
Total risk value (7)						4,411,702
(7) = 1.0 * Σ(6) * 0.44						

Tab. 7: Calculation of the total average risk value of the debris flow disaster in Songhe community

Element at risk	**Red zone**		**Yellow zone**		**Unit value (US$ / m²)**	**Loss value (US$)**
	Submerged amount (m²)	**Damage factor**	**Submerged amount (m²)**	**Damage factor**		
	(1)	(2)	(3)	(4)	(5)	(6)=[(1)*(2)+(3)*(4)]*(5)
House	9057	0.3	11440	0.1	152.4	588432
Farming land	3030	1.0	5757	1.0	2.8	24604
Forestry land	119720	0.5	76971	0.1	2.8	189160
Road	3218	1.0	3547	0.5	909	4537274
Bridge	140	1.0	95	0.5	758	142125
No-direct-loss	14734	-	6490	-	0	0
Total risk value (7)						1,447,141
(7) = 0.6 * Σ(6) * 0.44						

Risk changes after the installation of mitigation measures

The Songhe community has been submitted for the integrated planning against debris flow disasters since 2001; the planned or finished mitigation measures are shown in table 8 (Soil and Water Conservation Bureau, SWCB, 2004). No. 5 comb dam is located most upstream; settling basin is located downstream. In order to understand the prevention effect of measures, FLO-2D software was used to simulate the submerged situation of the No. 1 and No. 2 Songhe Torrents under the condition of all measures installed, and then the risk map was drawn to determine the situation of risk changes.

After the installation of mitigation measures in No. 1 and No. 2 Songhe Torrents, the assessment methods of the hazard zones, different elements within the submerged areas and the disaster-stricken degree are the same as above mentioned; the obtained maximum risk map and average risk map are shown as figures 5 and 6. Besides of showing the risk change situation on the maps after the installation of the measures, it is possible to obtain the total maximum risk value of US$ 1.3 million and total average risk value of US$ 0.4 million at the occurrence of debris flow by adding up all the risk values in the submerged areas. Comparing with the total risk value without installation of the measures, the total maximum risk value can be reduced by US$ 3.1 million (a reduction of 72%) and the total average risk value by US$ 1.0 million (a reduction of 75%) when the debris flow of 150 years return period occurs in Songhe community.

Tab. 8: The planning of the mitigation measures of the Songhe watershed (SWCB, 2004)

	Type of measure	Height of the dam (m)	Torrent's average width (m)	Cost (US$)
No. 1 Songhe Torrent	No. 1 Comb Dam	5	40	81,000
	No. 2 Comb Dam	5	24	49,000
	Restoration of the Comb Dam	5	24	49,000
	No. 3 Comb Dam	5	24	49,000
	No. 4 Comb Dam	5	24	49,000
	Restoration of the Comb Dam	5	24	49,000
	No. 5 Comb Dam	6	30	97,000
	Settling basin	Area: 2.6 hectares; Average depth: 5 m; Width: 24 m – 175 m		1,500,000
No. 2 Songhe Torrent	Settling basin	Area: 1.1 hectares; Average depth: 3 m; Width: 16 m – 64 m		528,000

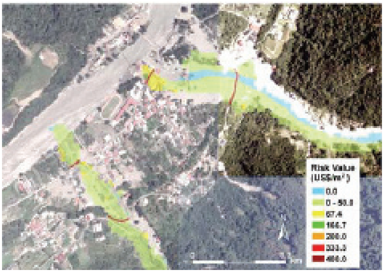

Fig. 5: Maximum risk map of the debris flow disaster (with mitigation measures)

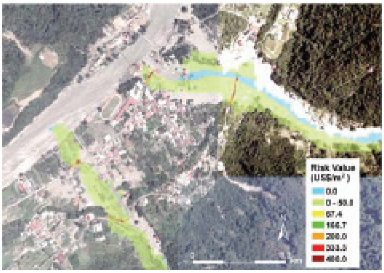

Fig. 6: Average risk map of the debris flow disaster (with mitigation measures)

CONCLUSION

This research has realized a risk assessment of debris flow disaster in No. 1 and No. 2 Songhe Torrents through using the product of the hazard grade (*H*), value of vulnerability (*V*) and disaster-stricken degree (D_s) to calculate the risk level (R), as well as drawing the risk maps; then the maximum risk map and average risk map before and after the installation of mitigation measures can be obtained. The installation of measures can reduce the total maximum risk value by 72% and the total average risk value by 75% when the debris flow of 150 years return period occurs. These reduced risk values can be considered as a part of direct benefit; it is possible to be included in the analysis when realizing the cost-benefit analysis of the mitigation measures in the future.

Hundreds of settlements under the threat of debris flow disasters often have the difficult problem of the balance between the disaster mitigation investment cost and benefit, especially when facing the disaster's uncertainty. Using the risk assessment method in this research to compare the risk maps before and after the installation of mitigation measures in the same area, it is possible to know the benefit of the measures and the distribution of the residual risk. Also, comparing the total risk value in different areas can determine the priority order of the disaster prevention tasks and be as a reference of the risk management in the future.

The related factors and parameters of the risk assessment model established in this research can be modified in the future according to the real needs. For example, the damage factor and process factor are from the data of Austria due to the insufficient information materials in Taiwan; once when the related data become more complete in Taiwan in the future; these can be modified in order to approach more the situation in Taiwan.

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