DEBRIS FLOW RISK RANKING AND MANAGEMENT - A CASE STUDY IN TAIWAN

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ABSTRACT

This study conducted the debris flow quantitative risk analysis for 148 debris flow potential torrents in Taiwan following the concept of Risk=Hazard×Exposure×Vulnerability, the calculation result of economic losses and fatalities were generated into annual average loss to provide the same standard for risk ranking. For government or agencies, different types of ranking could be conducted and proper risk management strategies could further proposed. Also the current risk treatment options for debris flow hazard in Taiwan were listed and displayed with spatial and frequency distributions, together with the analysis result of 148 torrents a better management strategy could be suggested in the future.

Keywords: debris flow, risk analysis, risk management, risk ranking, risk treatment

INTRODUCTION

Taiwan is located in western Pacific, with earthquakes and Typhoons occurring frequently. After magnitude 7.3 Chi-Chi earthquake of 1999, debris flow hazard resulted in tremendous property losses and casualties in Taiwan. As of 2011 there were 1,578 debris flow potential torrents enlisted in Taiwan. Since 2006 the Soil and Water Conservation Bureau (SWCB), which is in charge of the mitigation and management of debris flow hazards, conducted extensive field investigation to collect information of individual torrents. With limited resources, authorities should establish a disaster management system to cope with debris flow or other slope disaster risks more effectively. This study following the management framework for debris flow risk, by breaking down the debris flow risk into Risk=Hazard×Exposure×Vulnerability, a debris flow quantitative risk analysis is applicable. Through risk analysis procedures, annual average loss could be calculated for each debris flow potential torrent. Risk ranking and risk classification could thus be conducted. Based on the results, central and local governments could implement different risk management strategies with different concerns.

DEBRIS FLOW RISK ANALYSIS AND MANAGEMENT CONCEPT

The natural hazard risk concept was first proposed by UNDRO in 1979 (UNDRO, 1979) and widely accepted around the world for all kinds of natural hazard risk analysis (Peduzzi *et al.*, 2002; Glade, 2003; Granger, 2003; Papathoma-Köhle *et al.*, 2007; Schmidt *et al.*, 2011; Mousavi *et al.*, 2011). For debris flow hazards in Taiwan, the Risk=Hazard×Exposure×Vulnerability combination could be defined as follows:
Risk: The possible consequences when debris flow hazard occurred.

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Hazard: Matters discussing triggering factors, return period, inundation area, depth, velocity, boulder size and impacted force of debris flow.

Exposure: Elements at risk, for example crops and other valuable infrastructures or utilities within the possible inundation area, types and numbers of buildings and their residents.

Vulnerability: The damage ratio under specific magnitude, deposition depth, velocity of debris flow to different types of elements at risk.

The risk management framework for natural hazard had been adopted in several nations or regions around the world (Australian Geomechanics Society, 2000; Fell *et al.*, 2005; Hufschmidt *et al.*, 2005), in Taiwan a debris flow risk management framework (Fig.1) and the 10 steps for quantitative debris flow risk analysis (Fig.2) were proposed in 2008 (Tsao *et al.*, 2010). For quantitative debris flow risk analysis the UNDRO risk concept could be further broke down as Eq. 1.

$$Risk = P_{H|T_M} \times P_{S|H} \times P_{T|S} \times V_{prop|S} \times E_{prop} \qquad (1)$$

Where $P_{H|TM}$: Probability of different magnitude debris flow to occur.

$P_{S|H}$: Probability of spatial impact of each element at risk. Within the debris flow inundation area, the value is 1, otherwise the value is 0.

$P_{T|S}$: Probability of temporal impact of each element at risk. For elements at risk which does not move, as buildings, roads or bridges, the value is 1. For residence house occupants, the value is 0.75 (18 hours per day), for schools students and faculties the value is 0.375 (9 hours per day).

$V_{prop|S}$: Vulnerability of each type of elements at risk, ranging from 0 to 1.

E_{prop}: The value of each element at risk in NT dollars or fatalities.

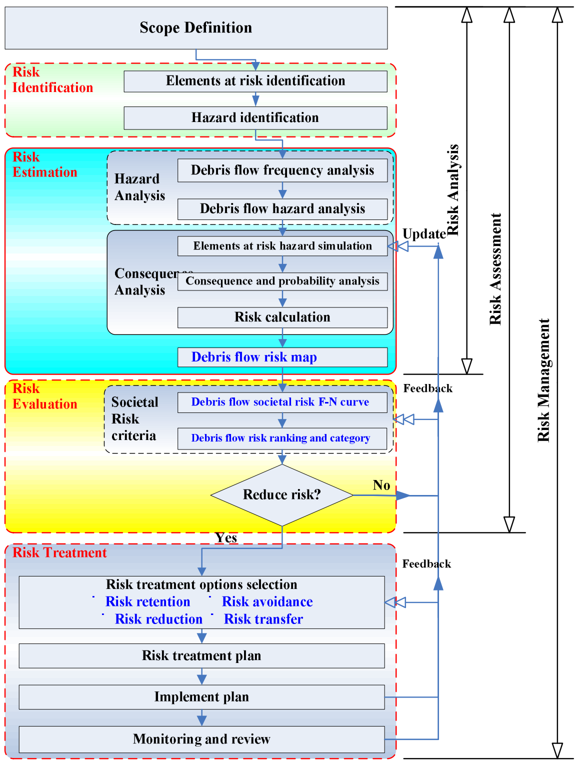

Fig. 1 Debris flow risk management framework (after Australian Geomechanics Society, 2000; Tsao *et al.*, 2010)

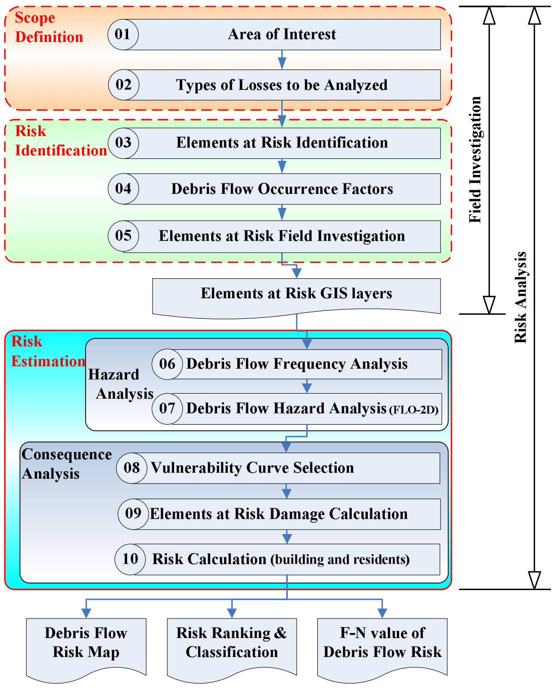

Fig. 2 Debris flow risk analysis procedure (after Tsao *et al.*, 2010)

The types of losses discussed in the quantitative analysis in the study of Tsao *et al.* (2010) were shown in Tab.1 (shaded area), mainly focusing on direct loss of the economic losses were calculated.

Tab. 1 Types of loss due to debris flow hazard

Type of loss	Economic loss	
	Tangible loss	Intangible loss
Direct loss	Property loss	● Fatalities
	● Building	● Health impact
	● Building interior	● Loss of species
	● Infrastructure	
	● Crops	
Indirect loss	● Production disruption	● Inconvenience during recovery
	● Transportation disruption	● Psychological effects
	● Emergency treatment cost	

Following the procedure of Fig.2, each of the 148 torrents went through the following procedure:
1. Risk identification
Field investigations were conducted to gather elements at risk information (including types and values), debris flow hazard history, triggering factors of debris flow. The information gathered from field was stored in GIS format.
2. Hazard analysis
In this study the two-dimensional commercial model FLO-2D, which was adopted in Taiwan for debris flow simulation (Hsu *et al.*, 2010; Lin *et al.*, 2011), was used for simulation. Rainfall data were gathered for input, several return periods of simulation were conducted (5, 10, 25, 50, 100, 200 years) to understand the flow velocity, inundation height and inundation area of each torrent.
3. Consequence analysis
The vulnerability curve for each type of elements at risk were selected. With experience from Alpin region (Fuchs, 2008) and Typhoon Morakot of 2009 building vulnerability curve were proposed for different types of buildings. Overlaying the simulation result with elements at risk GIS layer and calculate with vulnerability curve to determine the damage value, both economic losses and fatalities were generated to annual average loss. An example for losses of elements at risk of a torrent was

shown in Tab.2. The results of the 148 debris flow potential torrents are listed in Tab.3, and the spatial distribution of high and low risk torrents were shown in Fig.3.

Tab. 2 Losses of elements at risk under different return periods of Chayi DF051 torrent

Return Period (year)	Annual Exceeding Probabilities	Losses of Buildings (NT $)	Losses of Bridges (NT $)	Losses of Roads (NT $)	Losses of Crops (NT $)	Total Losses (NT $)	Fatalities
-	100%	-	-	-	-	-	-
5	20%	1,369,863	2,024,007	573,413	64,819	4,032,102	-
10	10%	1,571,781	3,597,546	699,719	232,587	6,101,633	-
25	4%	2,221,755	4,734,081	944,135	573,066	8,473,037	0.0089894
50	2%	9,902,517	5,535,290	3,829,226	4,728,086	23,995,120	9.3299100
100	1%	22,889,237	9,671,976	12,565,199	20,802,955	65,929,368	33.7222000
200	0.5%	31,762,550	9,671,976	21,729,936	47,438,383	110,602,846	41.5282000
Annual Average Losses		1,230,665	1,567,719	557,781	416,237	3,772,402	0.4970457

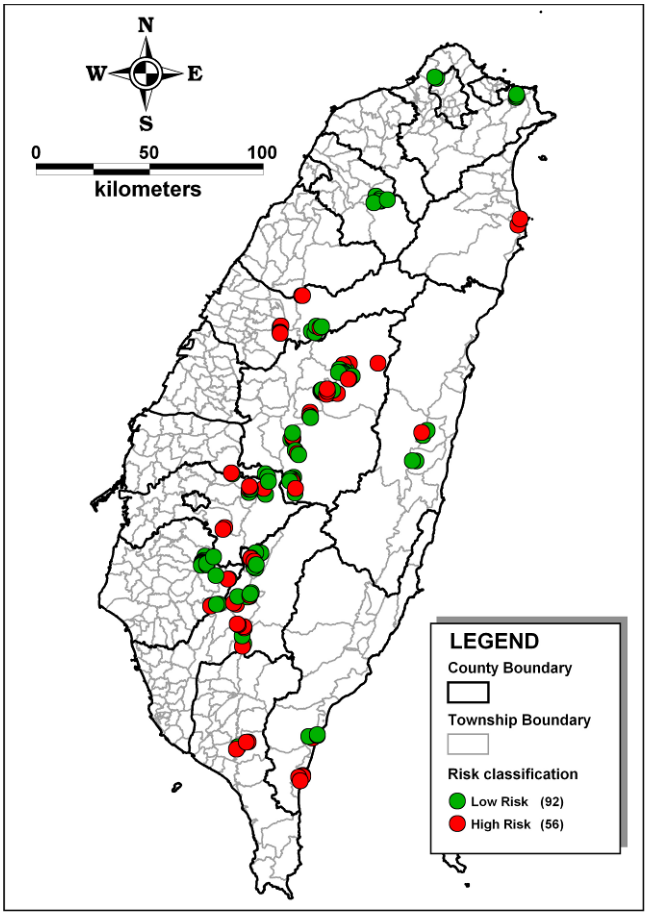

Fig. 3 Spatial distribution of the 148 high and low risk debris flow potential torrents

Tab. 3 Debris flow risk ranking result (ranked by fatalities)

Rank	Debris flow ID	Total Economic Loss (NT$)	Total Loss (NT$) (Fatalaties & Economic)	Fatalities
1	Kaohsiung DF002	11,160,579	526,201,479	39.0182500
2	Kaohsiung DF071	15,989,706	122,461,032	8.0660095
3	Kaohsiung DF072	11,702,637	110,090,025	7.4535900
4	Kaohsiung DF050	22,916,469	113,359,662	6.8517570
5	Kaohsiung DF046	4,893,478	75,707,168	5.3646735
6	Nantou DF031	2,168,255	71,792,210	5.2745420
7	Miaoli DF057	4,841,566	71,379,886	5.0407818
8	Kaohsiung DF042	4,098,331	48,539,052	3.3667213
9	Taitung DF114	5,476,866	48,857,297	3.2863963
10	Hualian DF127	17,654,194	49,070,405	2.3800160
11	Chiayi DF061	4,018,192	33,546,552	2.2369970
12	Nantou DF052	2,605,309	29,560,515	2.0420610
13	Kaohsiung DF064	1,811,435	25,163,343	1.7690840
14	Chiayi DF055	6,235,740	27,744,773	1.6294722
15	Taitung DF098	4,377,775	25,183,171	1.5761664
16	Kaohsiung DF016	4,648,578	21,640,244	1.2872474
17	Taichung DF060	528,917	17,173,797	1.2609757
18	Yilan DF102	61,116,318	76,937,112	1.1985450
19	Taitung DF100	4,240,103	14,201,617	0.7546602
20	Taitung DF113	8,874,841	17,312,516	0.6392178
21	Nantou DF012	180,170	7,397,141	0.5467402
22	Tainan DF041	1,523,700	8,467,897	0.5260755
23	Taitung DF097	12,232,956	19,038,342	0.5155596
24	Chiayi DF051	3,772,402	10,333,405	0.4970457
25	Nantou DF178	259,901	5,737,218	0.4149483
26	Kaohsiung DF003	39,364,569	44,339,891	0.3769184
27	Taichung DF057	495,319	5,418,642	0.3729790
28	Pingtung DF025	3,211,595	8,012,258	0.3636866
29	Kaohsiung DF015	5,377,015	9,692,951	0.3269649
30	Nantou DF165	2,537,182	5,353,507	0.2133580
31	Miaoli DF058	4,940,614	7,720,878	0.2106261
32	Pingtung DF032	6,314,664	9,020,086	0.2049562
33	Kaohsiung DF049	3,326,274	5,637,040	0.1750580
34	Tainan DF045	794,065	2,712,156	0.1453099
35	Nantou DF010	248,383	1,739,817	0.1129874
36	Chiayi DF006	268,435	1,441,162	0.0888429
37	Yunlin DF002	1,889,236	3,054,081	0.0882458
38	Kaohsiung DF043	2,793,312	3,783,806	0.0750374
39	Nantou DF190	14,628,843	15,360,652	0.0554401
40	Taitung DF099	4,400,946	4,917,496	0.0391326
41	Yilan DF110	1,137,160	1,507,630	0.0280659
42	Nantou DF022	451,963	810,046	0.0271275
43	Chiayi DF004	3,687,231	4,017,235	0.0250003
44	Nantou DF200	409,520	585,999	0.0133696
45	Tainan DF044	5,190,803	5,286,533	0.0072523
46	Nantou DF050	760,105	805,881	0.0034678
47	Chiayi DF050	2,442,525	2,474,711	0.0024383
48	Pingtung DF026	508,400	535,003	0.0020154
49	Kaohsiung DF045	496,082	520,216	0.0018284
50	Kaohsiung DF065	6,006,450	6,019,309	0.0009742
51	Nantou DF051	1,469,783	1,480,506	0.0008123
52	Nantou DF177	279,295	285,360	0.0004595
53	Nantou DF167	4,835,429	4,841,285	0.0004436
54	Nantou DF197	654,711	660,221	0.0004175
55	Taichung DF024	1,473,235	1,476,724	0.0002643
56	Nantou DF028	2,847,065	2,848,367	0.0000986
57	Pingtung DF031	6,483,353	6,483,353	0.0000000
58	Hualian DF126	6,146,705	6,146,705	0.0000000
59	Kaohsiung DF048	3,704,600	3,704,600	0.0000000
60	Hualian DF118	3,539,656	3,539,656	0.0000000
61	Kaohsiung DF017	2,750,158	2,750,158	0.0000000
62	Kaohsiung DF062	2,712,297	2,712,297	0.0000000
63	Taitung DF115	2,671,481	2,671,481	0.0000000
64	Kaohsiung DF063	2,326,094	2,326,094	0.0000000
65	Hualian DF117	2,238,257	2,238,257	0.0000000
66	Tainan DF023	2,057,768	2,057,768	0.0000000
67	Nantou DF047	1,733,009	1,733,009	0.0000000
68	Nantou DF021	1,684,385	1,684,385	0.0000000
69	Chiayi DF003	1,595,647	1,595,647	0.0000000
70	Tainan DF040	1,421,370	1,421,370	0.0000000
71	Tainan DF048	1,397,201	1,397,201	0.0000000
72	Nantou DF164	1,253,296	1,253,296	0.0000000
73	Nantou DF166	1,139,931	1,139,931	0.0000000
74	Kaohsiung DF047	1,088,018	1,088,018	0.0000000
75	Kaohsiung DF067	1,069,481	1,069,481	0.0000000
76	Tainan DF017	1,015,610	1,015,610	0.0000000
77	Taipei DF010	992,405	992,405	0.0000000
78	Nantou DF195	985,800	985,800	0.0000000
79	Nantou DF191	959,868	959,868	0.0000000
80	Tainan DF024	925,289	925,289	0.0000000
81	Yunlin DF001	741,150	741,150	0.0000000
82	Nantou DF194	716,453	716,453	0.0000000
83	Taichung DF021	670,346	670,346	0.0000000
84	Tainan DF019	640,910	640,910	0.0000000
85	Chiayi DF005	603,627	603,627	0.0000000
86	Nantou DF019	560,198	560,198	0.0000000
87	Nantou DF045	546,692	546,692	0.0000000
88	Nantou DF048	535,095	535,095	0.0000000
89	Tainan DF015	533,902	533,902	0.0000000
90	Taipei DF174	527,211	527,211	0.0000000
91	Chiayi DF043	519,128	519,128	0.0000000
92	Nantou DF168	469,843	469,843	0.0000000
93	Tainan DF025	469,042	469,042	0.0000000
94	Taichung DF056	455,260	455,260	0.0000000
95	Tainan DF018	438,634	438,634	0.0000000
96	Nantou DF049	399,862	399,862	0.0000000
97	Kaohsiung DF004	378,986	378,986	0.0000000
98	Nantou DF046	366,945	366,945	0.0000000
99	Hsinchu DF060	317,021	317,021	0.0000000
100	Hualian DF125	310,537	310,537	0.0000000
101	Nantou DF011	277,708	277,708	0.0000000
102	Chiayi DF041	248,617	248,617	0.0000000
103	Kaohsiung DF001	239,338	239,338	0.0000000
104	Tainan DF020	237,045	237,045	0.0000000
105	Nantou DF180	226,933	226,933	0.0000000
106	Kaohsiung DF066	216,387	216,387	0.0000000
107	Tainan DF035	187,194	187,194	0.0000000
108	Chiayi DF042	185,931	185,931	0.0000000
109	Tainan DF021	175,683	175,683	0.0000000
110	Tainan DF016	153,241	153,241	0.0000000
111	Hsinchu DF056	150,157	150,157	0.0000000
112	Taichung DF022	118,210	118,210	0.0000000
113	Nantou DF020	116,846	116,846	0.0000000
114	Hsinchu DF058	116,515	116,515	0.0000000
115	Nantou DF017	113,464	113,464	0.0000000
116	Kaohsiung DF044	108,920	108,920	0.0000000
117	Nantou DF199	104,799	104,799	0.0000000
118	Kaohsiung DF061	104,297	104,297	0.0000000
119	Nantou DF016	99,603	99,603	0.0000000
120	Hsinchu DF062	93,438	93,438	0.0000000
121	Nantou DF014	92,061	92,061	0.0000000
122	Tainan DF022	90,194	90,194	0.0000000
123	Taichung DF025	89,616	89,616	0.0000000
124	Nantou DF196	83,119	83,119	0.0000000
125	Nantou DF189	79,326	79,326	0.0000000
126	Nantou DF013	70,218	70,218	0.0000000
127	Taitung DF116	67,804	67,804	0.0000000
128	Nantou DF179	62,675	62,675	0.0000000
129	Taichung DF059	60,263	60,263	0.0000000
130	Nantou DF026	46,603	46,603	0.0000000
131	Hsinchu DF057	46,066	46,066	0.0000000
132	Nantou DF018	43,143	43,143	0.0000000
133	Hsinchu DF059	42,874	42,874	0.0000000
134	Nantou DF027	40,677	40,677	0.0000000
135	Kaohsiung DF070	37,246	37,246	0.0000000
136	Nantou DF029	12,836	12,836	0.0000000
137	Taipei DF173	12,472	12,472	0.0000000
138	Taipei DF009	12,377	12,377	0.0000000
139	Taipei DF175	11,879	11,879	0.0000000
140	Hsinchu DF061	10,825	10,825	0.0000000
141	Taichung DF058	10,442	10,442	0.0000000
142	Chiayi DF039	6	6	0.0000000
143	Nantou DF015	0	0	0.0000000
144	Taichung DF020	0	0	0.0000000
145	Nantou DF198	0	0	0.0000000
146	Chiayi DF040	0	0	0.0000000
147	Taitung DF117	0	0	0.0000000
148	Tainan DF047	0	0	0.0000000

RISK RANKING OF DEBRIS FLOW TORRENTS

All analyzed results, both fatalities and economic losses, were generated into annual total risk, thus a debris flow risk ranking could be conducted with same standard. The ranking results, ranked by fatalities, are shown in Tab.3.

Although annual average fatalities and economic losses could be obtained through risk analysis procedure, the unit of measurement was different, by human life and currency respectively. To standardize the measurement this study takes 13.2 million NT-dollars (1 EU=41 NT$, as in 2011), which was suggested in some studies in Taiwan (Cheng, 2006; SWCB, 2008), as the approximately value of human life.

Different agencies or local governments might have different concerns about risk, from Tab.3 three different types or risk ranking could be conducted.

1. Ranked by fatalities: If the evacuation of residents was the main concern, the result could be ranked by annual average fatalities, thus to identify the priority settlements or torrents to hold evacuation drills more regularly or to enhance the risk awareness of residents.
2. Ranked by economic losses: If minimizing the economic losses was the main concern, the result could be ranked by annual average economic loss, thus to select the most beneficial investment in engineering options.
3. Ranked by combination of fatalities and economic loss: When both fatalities and economic losses should be considered, the ranking could be held by considering both values, thus both types of loss could be considered without bias.
4. Ranked by administrative divisions: Different counties, townships, or agencies (Soil & Water Conservation Bureau held 6 branch offices around Taiwan) could rank with three different categories and identify the most high risk region or torrents to frame out the mid or long term management strategies.

For example for the 18 torrents in Renai Township, Nantou County Government could rank by combination of fatalities and economic losses in order to propose a long-term risk management strategy, from Tab.4 we could identify that Nantou DF031 (Lushan hot spring area, where a debris flood event killed 1 people and damaged 50 buildings in 2008, as shown in Fig.4) ranked first in 18 torrents, thus the government should introduce risk treatment in this torrent, either engineering options or non-engineering options.

Fig. 4 Nantou DF031 (Lushan hot spring) of Renai Township, Nantou after Typhoon Sinlaku, 2008 (photo by Sinotech, Ltd.)

Tab. 4 Debris flow risk ranking result of Renai Township, Nantou County (ranked by combination of economic loss and fatalities)

Rank	County	Township	Village	Debris flow ID	Total Economic Loss (NT$)	Total Loss (NT$) (Fatalaties & Economic)	Fatalities
1	Nantou	Renai	Jingying	Nantou DF031	2,168,255	71,792,210	5.2745420
2	Nantou	Renai	Nanfong	Nantou DF012	180,170	7,397,141	0.5467402
3	Nantou	Renai	Fajhih	Nantou DF028	2,847,065	2,848,367	0.0000986
4	Nantou	Renai	Nanfong	Nantou DF010	248,383	1,739,817	0.1129874
5	Nantou	Renai	Cin-ai	Nantou DF021	1,684,385	1,684,385	0.0000000
6	Nantou	Renai	Cin-ai	Nantou DF022	451,963	810,046	0.0271275
7	Nantou	Renai	Nanfong	Nantou DF019	560,198	560,198	0.0000000
8	Nantou	Renai	Nanfong	Nantou DF011	277,708	277,708	0.0000000
9	Nantou	Renai	Cin-ai	Nantou DF020	116,846	116,846	0.0000000
10	Nantou	Renai	Nanfong	Nantou DF017	113,464	113,464	0.0000000
11	Nantou	Renai	Nanfong	Nantou DF016	99,603	99,603	0.0000000
12	Nantou	Renai	Nanfong	Nantou DF014	92,061	92,061	0.0000000
13	Nantou	Renai	Nanfong	Nantou DF013	70,218	70,218	0.0000000
14	Nantou	Renai	Fajhih	Nantou DF026	46,603	46,603	0.0000000
15	Nantou	Renai	Nanfong	Nantou DF018	43,143	43,143	0.0000000
16	Nantou	Renai	Fajhih	Nantou DF027	40,677	40,677	0.0000000
17	Nantou	Renai	Fajhih	Nantou DF029	12,836	12,836	0.0000000
18	Nantou	Renai	Nanfong	Nantou DF015	0	0	0.0000000

RISK TREATMENT OPTIONS

Through risk analysis and risk calculation the annual average loss of each torrent could be obtained. With annual average loss, the reasonable engineering project could be proposed, and the result could suggest the amount of disaster reserve which should be prepared. According to risk analysis and risk ranking results, proper risk treatments and frequency could be suggested for different classification. Possible risk treatment options could be analyzed through risk analysis procedures, and the difference before and after the application of each options could be estimated and recognized, and select the most effective risk treatment option with cost-benefit analysis. For example, if the invested amount was greater than possible loss, the cost-benefit ratio would be less than 1.0.

From debris flow risk management framework in Fig.1, risk treatment options should be applied after risk assessment to reduce risk. The risk treatment options could be categorized into risk avoidance, risk reduction, risk transfer and risk retention. While debris flow hazard management had been conducted for years with some promising results in Taiwan, debris flow risk management seems to be a new concept. However, several risk treatment options were already applied for years.

The current risk treatment options for debris flow hazard in Taiwan were shown in Tab.5. From the table it could be observed that most risk treatment options were concentrated on risk avoidance and risk reduction. While the other two (risk transfer, risk retention) had far less options, which implies that most debris flow risk treatment in Taiwan were conducted by governments and the entire risk treatment concept was still incomplete.

Tab. 5 Debris flow risk treatment options in Taiwan

Risk treatment types	Current options
Risk avoidance	1. Debris flow warning and evacuation 2. Restricted development of designated soil and water conservation area 3. Identification of hazardous areas
Risk reduction	1. Training of disaster resistant community and specialists 2. Debris flow warning signs 3. Debris flow disaster prevention drill 4. Field and mobile debris flow monitoring station 5. Heavy machinery standby 6. Landslide source area treatment in catchment 7. Torrent control and bottle neck section improvement 8. Dredging of torrents 9. Monitoring slope land use with satellite images
Risk transfer	1. Typhoon, flood and natural hazards insurance 2. Catastrophe bonds
Risk retention	1. Debris flow hazard support fund

The purpose of applying risk treatment options is to reduce the value of risk. From the equation of Eq.1, by reducing any of the components in the equation would effectively reduce the final output, through engineering treatments the possibility of occurrence could be reduced, or by reducing the possible exposures or enhance the vulnerability of the elements at risk would also result in the decreasing of risk. The concept of reducing risk and some of the corresponding risk treatment options was shown in Fig.5 (modified from Porter *et al.*, 2007).

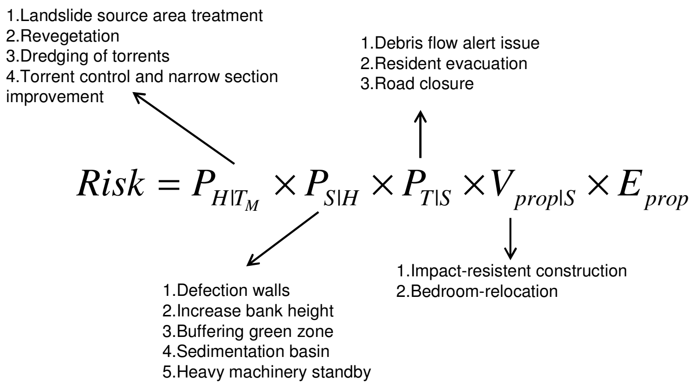

Fig. 5 Debris flow risk treatment option concept (modified from Porter *et al,* 2007)

After realizing the distribution and possible risk of debris flow torrents, Soil and Water Conservation Bureau could apply different types of risk treatment options to reduce the possible risk. The most common ones were shown as examples.

1. Debris flow disaster prevention and evacuation drill

The purpose of holding debris flow disaster prevention and evacuation drills (Fig.6) was to integrate resources from central government, local government, civilian organization and local residents to practice disaster prevention and response, evacuation and sheltering (SWCB, 2010). Since 2000 more than 486 drills had been held around Taiwan, numbers of drills held were categorized to three categories (1, 2 to 5, more than 5) and overlapped with the disaster area of Typhoon Morakot, which brought tremendous precipitation and hundreds of debris flow event in 2009. Fig.7 shows the spatial and frequency distribution of the drills, from the figure we could identify that not all these drills were evenly distributed around the island. This might be the result that the location of holding drills were proposed by local governments rather than central government, who should have a better image about risk management on a national scale.

2. Debris flow disaster resistant community

The goal of debris flow disaster resistant communities project (Fig.8) was to help local government to establish the disaster prevention system on community scale, through community organization to collaborate the strength of the residents, thus to improve the disaster prevention awareness of the community and thus reduce the threat from debris flow (SWCB, 2010; Chen and Wang, 2010). From 2004 to 2009, more than 108 communities had gone through the project. Fig.9 shows the three different frequency categories and the spatial distribution overlapping with disaster area of Typhoon Morakot. Again the proposed communities to join the project were from local government rather than central government.

3. Heavy machinery standby

For debris flow torrents it was usually the blockage of bottlenecks or low ceiling bridges that caused overflew. During typhoon or heavy rainfall event the heavy machinery would pre-deployed and standby at these areas to dredge the torrent during emergency situation. Fig.10 shows several excavators operating along a bridge during Typhoon Morakot event, the location was overflew by debris flow in 2008, and with the excavators the area was prevented from serious overflow and flooding in 2009 event.

Fig. 6 Debris flow disaster prevention and evacuation drill (photo provided by SWCB)

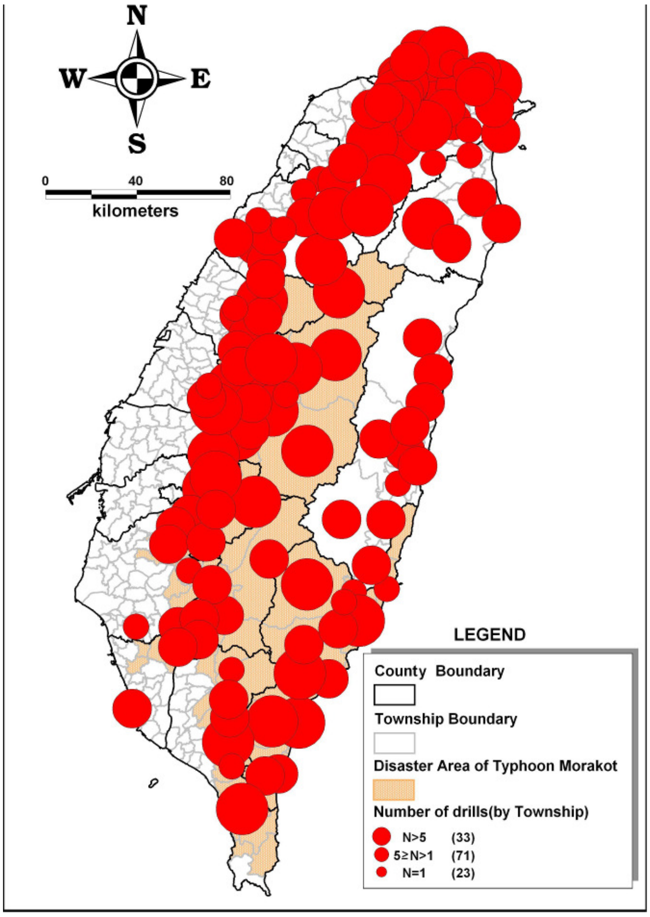

Fig. 7 Spatial and frequency distribution of number of debris flow disaster prevention and evacuation drills, from 2000 to 2009

Fig. 8 Debris flow disaster resistant community (photo provided by SWCB)

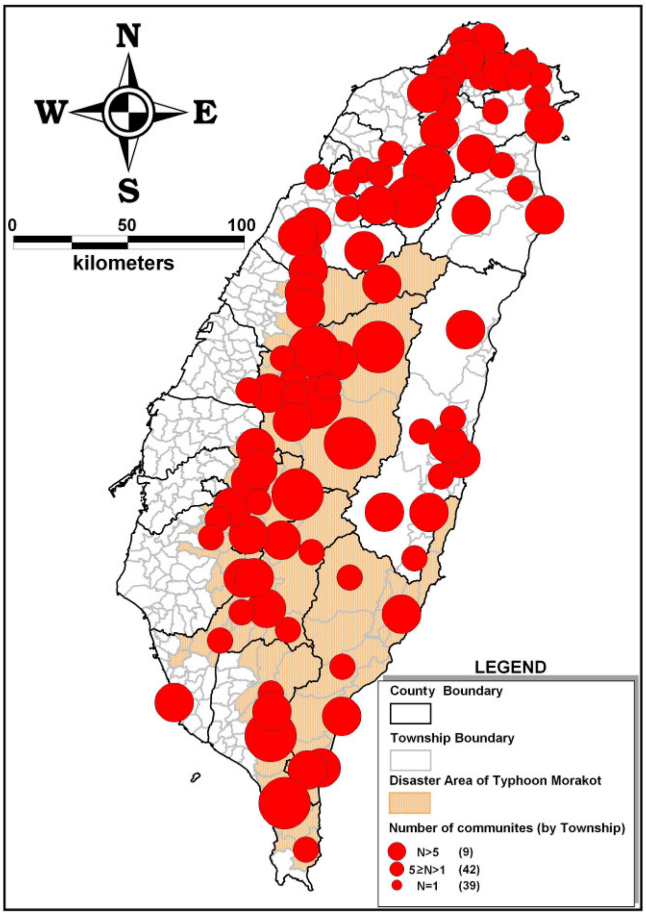

Fig. 9 Spatial and frequency distribution of number of debris flow disaster resistant community, from 2004 to 2009

Fig. 10 Heavy machinery standby along Nantou DF012 torrent during Typhoon Morakot, 2009 (photo by Sinotech, INC.)

The selection of risk treatment options should be based on the understanding of total risk distribution, possible options would be applied more effectiveness after the identification of high risk torrents or settlements. Although several risk treatment options were applied for sometime already in Taiwan, as the three examples mentioned above, the proposed locations were not from central government but from local governments, thus the concept of risk management was not fully applied. In the future the result from Tab.3 and Fig.3 could be overlapped with Fig.7 and Fig.9 to identified if any high risk torrents or settlements were not included with proper risk treatment options, thus a more effectiveness "from top to down" risk management could be put into practice.

CONCLUSIONS

- Following the debris flow risk analysis procedure, 148 torrents were analyzed with same process to provide average annual loss, and a risk ranking of different types of losses were conducted.
- Although the concept of debris flow risk management was new in Taiwan, already several risk treatment options were applied in the past decade with some results.
- Currently most debris flow risk treatments were government predominant, non-government treatments such as insurance were still in infant stage.
- A debris flow risk management strategy in a national level was still lacking in Taiwan, with the location of applying most risk treatment options were proposed by local governments, which might not have a better overview of risk compare to central government.

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