An analysis on the characteristics of landslides induced by heavy rainfall associated with Typhoons Herb (1996) and Troaji (2001) in Nantou on Taiwan

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Abstract: Debris flows associated with landslides occur as one of the most devastating natural disasters that threat Taiwan. Typically, three essential factors are needed simultaneously to trigger debris flow, namely sufficient soils and rocks, favorable slope, and abundant water. Among the three essentials, the slope is natural and static without external forcing, while the landslide is generally induced by earthquake or rainfall events, and the water is produced by heavy rainfall events. In this study, we analyzed the landslides triggered by the typhoons Herb (1996) and typhoon Troaji (2001). It is concluded that the statistical data are useful to quantify the threshold of the potential landslide area. Then, the possibility to prevent the debris flow occurrence may be increased.
Keywords: landslide, debris flow, typhoon

1. Introduction

Taiwan is an island with two-thirds of its terrain covered by hills and mountains. Because of limited usable land, may apartments and housing units have been built at the hillsides and on the hills. During heavy rainfalls, the colluviums are easily weakened to induce debris flows [1]. It is a common agreement that knowledge of the causes associated with debris flows, areas of probable landslide events, and ways of preventing the loss resulting from the landslides is needed.

2. Methodology

1) The approach

We applied statistical analysis to the causes and characteristics for the landslides based on GIS techniques, and geomorphological and geological information contained in aerial photos, SPOT images maps, and digital elevation model (40*40 m DEMs). Two heavy rainfall events associated with Typhoons Herb (1996) and Troaji (2001) that caused severe damage to Taiwan were chosen as examples for detailed analysis. The factors of interest include near-surface geology, slope gradient, and slope aspect of the surface, and the contributing area. According to the statistical results, we can find the threshold of the potential landslide area, and even prevent the landslide damage.

2) Study area

The watershed of the Chen-Yu-Lan River “Fig. 1” was selected for this study because many destructive landslides and debris flows occurred in this watershed during the 1996 Typhoon Herb event and the 2001 Typhoon Troaji event. It shall be noted that a disastrous earthquake happened on Sep 21, 1999 in the central Taiwan, which will likely trigger more landslides in the study area. Therefore, it is interesting to study the landslides characteristics before and after the 921 earthquake.

3) Typhoon Herb

From 31 July to 1 August, 1996, Taiwan was severely struck by a strong typhoon named Herb. The wind produced by Typhoon Herb reached 60 m/s and the region under its influence covers an area with a radius of 320 km. Herb caused 1315 landslides, more than 20 debris flows, 73 deaths, and 463 wounded. In addition, there were 1383 houses destroyed or damaged and one billion USD in property losses [2].

4) Typhoon Troaji

In 2001, on 28 July to 31 July, typhoon Troaji was a medium typhoon with a wind speed up to 38 m/s and a radius of 250 km. There were 100 deaths, 103 disappeared, 189 wounded, and 2617 houses destroyed or damaged.

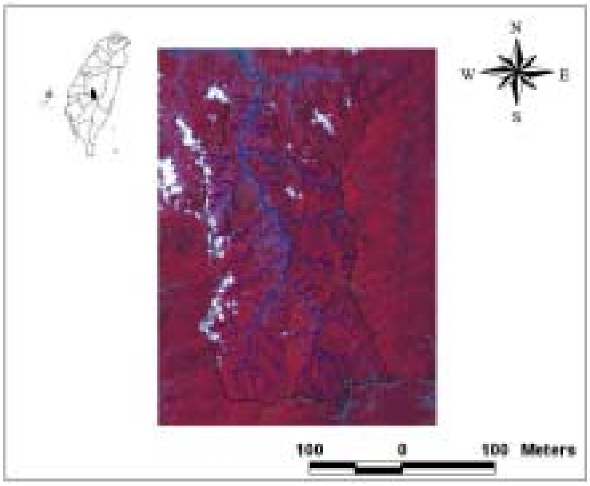

Fig. 1. The watershed of the Chen-Yu-Lan River [1]

3. Results

To examine the physical parameters contributing to the initiation of landslides, the landslides that occurred in the study area were correlated with those parameters considered to have influence on their occurrence. The physical parameters include lithology, slope gradient, slope aspect, elevation, and contributing area. The digital map of landslide classified by the aerial photos and the SPOT images was overlaid on the raster data layers of physical parameters retrieved from 40*40 m DTM. The results are described in the following:

1) Geology

Fig. 2 shows the numbers of the landslide cases in different lithological areas. The landslide triggered by the two typhoons showed very similar patterns but the total number of landslides in sedimentary rock area is larger than that in Metamorphic rock area.

Table 1. The notations of lithology in the Chen-Yu-Lan watershed

Sedimentary rock		Metamorphic rock	
Q3	Alluvium	O2	Suichangliu Fm.
Q2	Terrace Deposits	M1	Paileng Fm.
Ms	NanchuaFm.& Kueichulin Fm.	E0	Chiayang Fm.
Mj	Nankang Fm.	E2	Tachien Fm.
		E1	Shipachungchi Fm.

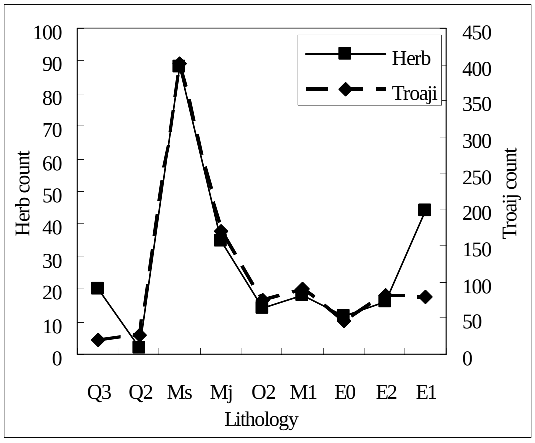

Fig. 2. Numbers of the landslide cases in different lithological areas

2) Slope gradient

According to the slope gradient of cumulative percentage of the two landslide cases "Fig. 3", we can find that the slope gradient for 60% (steeper slope from 30% to 90%) of landslides ranges from 27^{o} to 44^{o} for the Herb case and from 28^{o} to 46^{o} for the Troaji case. That is, the slope gradient of the landslides triggered by typhoon Troaji is 2 degree steeper than that by typhoon Herb.

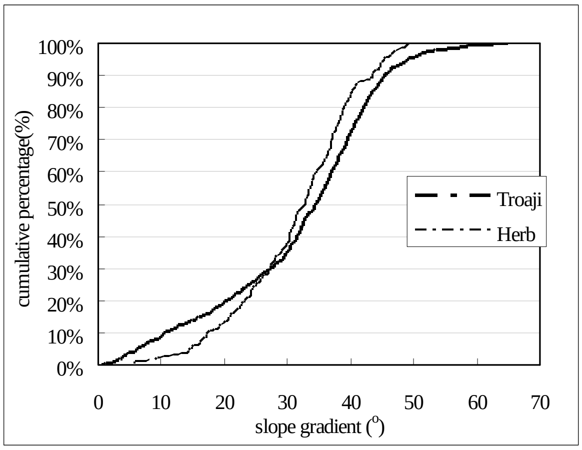

Fig. 3. The landslide slope gradient cumulative percentage

3) Slope aspect

The slope aspect in percentage for the two landslide cases shows three features. First, on north-facing slopes the percentage is relatively low. Second, the percentages reach their maximum on east-facing slopes for the Herb case, but on northeast-facing slopes for the Troaji case. Third, the landslides are distributed more on east-facing (NE-SE) than west-facing (NW-SW) slopes.

Table 2. The slope aspect of Herb and Troaji landslides

		N	NE	E	SE	S	SW	W	NW
Herb	No	14	31	54	39	39	21	24	20
	%	6	13	22	16	16	9	10	8
Troaji	No	92	194	153	128	123	118	149	80
	%	9	19	15	12	12	11	14	8

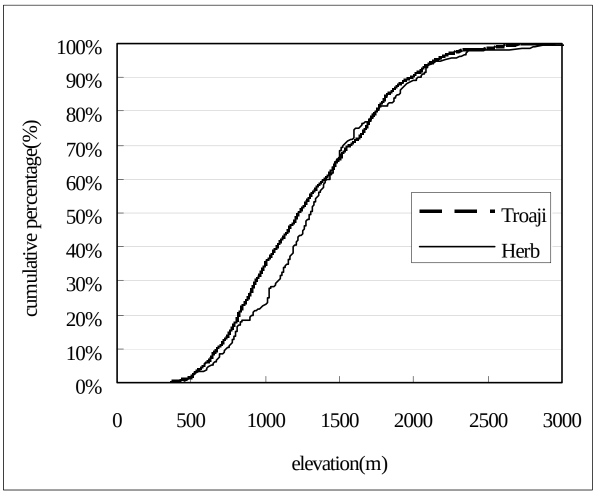

Fig. 4. The landslide elevation cumulative percentage

4) Elevation

The landslide elevation cumulative percentages for the two typhoons are shown in Fig. 4. They are almost the same for the two cases with 70% occurring at elevations from 830 m to 1970 m. The exception is in that the number of landslide cases is increased more quickly for the Herb case at elevations from 1000 m to 1500 m.

5) Contributing Area

Hsu (1995) indicated that the elevated pore pressure is critical in slope stability assessment and used the relationship between the pore pressure and geomorphology to estimate the contributing area of each landslide:

$$\mathbf{q_0 = (A / b)\, r_0} \quad (1)$$

where q_0 is the discharge rate per unit width of the discharging boundary; A is the upslope contributing area; b is the contour width; and A/b is called the specific catchment area; and r_0 is a steady average vertical recharge rate estimated from antecedent rainfall[3]. According to Eq.1, we know that A is proportional to q_0 and that the lager is the upslope contributing area, the higher becomes the pore pressure.

Fig. 5 shows that the percentages of landslides distributed in the contributing regions with areas larger than 1 ha are 70% and 40% for the Herb and Troaji cases, respectively. It was mentioned that landslides triggered by typhoon Troaji are caused at the higher hillsides than those caused by typhoon Herb. It may be affected by earthquake in 1999 (61.5% lower than 1 ha [4]).

4. Conclusions

By analyzing the geology, slope gradient, slope aspect, elevation, and contributing area of the landslides induced by typhoons Herb and Troaji, we can understand more about the spatial distribution of the landslides triggered by heavy rainfalls. In our study area, the statistics results show similar patterns of landslide characteristics for the geology, slope gradient, slope aspect, and elevation except that there is a larger difference for the contributing area. They indicate that threshold of the potential landslide area may be identified as shown in "Table.3.", which is very useful to the policy makers for preventing the landslide damage in advance.

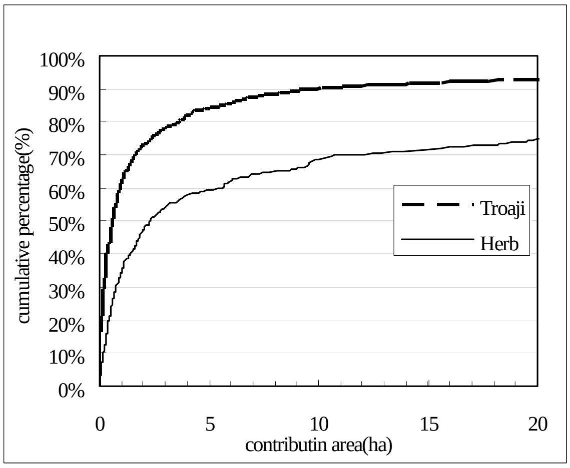

Fig. 5. The landslide contributing area cumulative percentage

Table 3. The favorable conditions for landslides triggered by heavy rainfall in the Chen-Yu-Lan watershed

	Favorable conditions for landslides
Geology	sedimentary rock
Slope gradient	$27^o \sim 46^o$
Slope aspect	NE to S
Elevation	830m ~ 1970m
Contributing area	>0.25 ha

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