Practical Management of Debris-flow-prone Torrents in Taiwan

Hsiao-Yuan Yin, Ph.D.[1]; Chen-Yang Lee, Master[1]; Chyan-Deng Jan, Ph.D.[2]; Meei-Ling Lin, Ph.D.[3]

ABSTRACT
In Taiwan, owing to steep topography, weak geological structure, frequent earthquakes and severe rainfalls, especially brought by typhoons, debris flow has become one of the most serious disasters causing enormous losses of lives and properties. The Soil and Water Conservation Bureau (SWCB), Council of Agriculture is the national-level department for the preparedness on the reductions of debris flow disasters. To deal with debris flow hazards, the first step for mitigation works is to identify the locations of debris-flow-prone torrents (i.e., potential debris flow torrents). So far, there are 1,673 potential debris flow torrents in Taiwan, and about 48-thousand people living in the debris-flow endangered flooding areas. In this paper, we will introduce the practical management measures of debris flow hazards including the identification and evaluation of potential debris flow torrents, administrative operation process, watershed investigation, risk potential assessment, flooding zone mapping and evacuation route map. Good preparedness and management of potential debris flow torrents have been proved to be an effective measure in reducing debris flow hazards.

KEYWORDS
debris flow hazards; debris-flow-prone torrent; potential debris flow torrent; evacuation route map

INTRODUCTION
Debris flows are rapid, gravity-induced flows of mixtures of rocks, mud and water. Due to the steep topography, young and weak geological formations, earthquakes, erodible soils and heavy rainfall brought by typhoons, Taiwan is subject to debris flows and other sediment-related disasters, causing enormous losses of lives and properties in mountain areas (Jan and Chen, 2005). According to the "Disaster Prevention and Protection Act" of Taiwan, the SWCB is the national-level department for the preparedness and mitigation works of debris flow hazards. As we know that reliable and accurate debris-flow watches and warnings must be based on sound identification of areas susceptible to debris flows and recognition of the conditions that will result in their occurrence. Therefore, the first step for debris-flow hazards mitigation is to identify the locations of debris-flow-prone torrents. In this paper, we will introduce our practical experiences of debris-flow managements in Taiwan.

1 Soil and Water Conservation Bureau, Council of Agriculture, Nantou, TAIWAN, sammya@mail.swcb.gov.tw
2 National Cheng Kung University, Taiwan
3 National Taiwan University, Taiwan

POTENTIAL DEBRIS FLOW TORRENTS

Since1990, the SWCB has devoted to establish the inventory of potential debris flow torrents. Potential debris flow torrents are debris-flow-prone torrents (or gullies) associated with important targets to be protected, and are identified after comprehensive evaluation of the natural occurrence conditions and the on-site human activities. A debris-flow-prone torrent without any residents or infrastructures to be protected will not be classified as a potential debris flow torrent, because the zoning of potential debris flow torrents is for human-oriented disaster management. In 1996, there were 485 potential debris flow torrents recognized and managed. After a catastrophic Chi-Chi earthquake (magnitude 7.3 on the Richter scale) in 1999, the number of potential debris flow torrents increased to 722 due to significant landslides in mountainous areas. However, the number dramatically increased to 1,673 after severe actions of rainfalls, especially brought by typhoons during the last 15 years. In order to mitigate the possible debris flow hazards, it is crucial for the government to update the inventory database of potential debris flow torrents every year before the flood season from May to October in Taiwan.

IDENTIFICATION AND EVALUATION OF POTENTIAL DEBRIS FLOW TORRENTS

Lin et al. (2010) suggested that the potential degree of debris-flow-prone torrents can be determined primarily by watershed area, drainage slope, landslide ratio, and geological structure. The comprehensive identification and evaluation procedure of potential debris flow torrents used in Taiwan is summarized in an operation direction, named as "Zoning operation directions of potential debris flow torrents" published by SWCB in 2013. Two major processes of the operation direction are presented in detail as follows.

Preliminary identification

In order to identify potential debris flow torrents, two preliminary conditions should be considered i.e., the existence of protected targets and the characteristics of valley landform. The possible protected targets contain the residents, buildings, roads and other infrastructures which are potentially endangered by debris flows, especially in or nearby the downstream area of debris-flow-prone torrents. The geomorphologic characteristics of valley landform are identified mainly by using aerial orthophoto base map and/or high resolution DTM (digital terrian model). It also has a further requirement with the catchment area (only considering the watershed areas above the 10 degree gradient point in the main channel) is larger than 3 hectares. After satisfying the above-mentioned two prerequisites, if the torrent also has historic debris flow events or geological disaster potential according to the geological map from the Central Geological Survey of Taiwan, then the torrent could be classified as the candidate of potential debris flow torrents.

Potential evaluation

Once a torrent has been considered as a potential debris flow torrent, the next step is to evaluate its potential level. The protected targets and the debris-flow occurrence potential are the two major factors used to evaluate and classify the degrees of potential debris flow torrents into three categories, i.e., high, medium and low potential debris flow torrents.

Protected targets

The vast majority of loss or damage occurs in the depositional zone of debris flows, which is referred to as the creek fan. Fans are preferred locations for urban development because they are well drained, gently sloping, and often provide good aquifers (Jakob 2005). Generally speaking, a torrent considered as the potential debris flow torrent has its downstream endangered fan area. From the historic events, people who live in the alluvial fan are vulnerable by debris flows meaning that the fan area roughly equates to the so-called affected area. The evaluation of protected targets is to estimate the vulnerability of those residents, buildings, roads, infrastructures and mitigation measures within the affected area as shown in Table 1. The mitigation measures mainly depend on the weighting of watershed management performance especially the levels of engineering constructions and ecological treatments through the field investigation. Three levels of the weighting values are applied consisting poor (weighting:1), fair (weighting:0.8) and good or unnecessary (weighting:0.6). The final score of protected targets evaluation is equal to the weighting times the sum scores of buildings and transportation facilities. Therefore, the degree of potential damage on protected targets can be classified into three risk grades as low (≤40 scores), medium(40~60 scores) and high(≥60 scores).

Table 1: Potential evaluation of protected targets.

Protected targets (100 scores)	Classifications	Scores
Buildings (65)	Public infrastructures relating to disaster mitigation (Schools, hospitals and public shelters)	65
	Above 5 houses	60
	1-4 houses	30
	None	0
Transportation facilities (35)	Bridges	35
	Roads	20
	None	0
Weighting		
Watershed management performance	Poor	1.0
	Fair	0.8
	Good or unnecessary	0.6
Final scores	Scores of (Buildings+ Transportation facilities)×Weighting	

Occurrence degree

The occurrence degree is referred to the probability of debris flow events. In this paper, the major factors relating to the debris flow occurrence comprise the landslide ratio, drainage slope, sedimentation amount, geological structure and vegetation condition as shown in Table 2. According to the evaluation scores in Table 2, the degree of potential damage on occurrence degree also can be classified into three risk grades as low (≤46 scores), medium (46~62 scores) and high(≥62 scores). Among them, the scores of 46 and 62 are the 30% and 70% probability of cumulative distribution diagram during statistic analysis respectively.
By using the potential damage evaluation on inhabitation including both protected targets and occurrence degree, the identified potential debris flow torrents in Taiwan can be classified into three risk grades as low, medium and high through the following risk matrix shown in Table 3. Those high risk torrents have the priority of hazards mitigation measures such as evacuation propaganda and drills, engineering construction and landuse replaning.

Table 2: Potential evaluation of occurrence degree.

Occurrence degree (100 scores)	Classifications	Scores
Landslides ratio (25)	Obvious large landslide areas (landslide ratio≧5%)	25
	Small scale landslide areas (1%< landslide ratio <5%)	15
	No obvious landslide (landslide ratio≦1%)	5
Drainage slope (25)	Upstream drainage slope≧50 degrees	25
	Upstream drainage slope is between 30-50 degrees	15
	Upstream drainage slope≦30 degrees	5
Sedimentation (20)	Average grain size≧30cm	20
	Average grain size=8-30cm	13
	Average grain size≦8cm and no obvious sediments	2
Geology (15)	East rift valley, east coastal mountains range, sedimentary rock and igneous rock	15
	Meta sandstone and lateritic soils on tablelands	15
	Schist, gneiss, basin and plain	5
Vegetation (15)	Exposed bedrock, colluviums or poor vegetation	15
	Fair	6
	Good	3

Table 3: Risk matrix used in potential debris flow torrent classification.

<table>
<tr><th colspan="2" rowspan="2">Risk Degree</th><th colspan="3">Degree of Occurrence Potential</th></tr>
<tr><th>Low</th><th>Medium</th><th>High</th></tr>
<tr><td rowspan="3">Degree of Hazards on Protected Targets</td><td>Low</td><td>Low</td><td>Low</td><td>Medium</td></tr>
<tr><td>Medium</td><td>Low</td><td>Medium</td><td>High</td></tr>
<tr><td>High</td><td>Medium</td><td>High</td><td>High</td></tr>
</table>

PRACTICAL MANAGEMENT FOR DISASTERS MITIGATION

Every year before flood season, the information of potential debris flow torrents especially the affected areas and the inventory of affected targets will be released to local governments for proofreading and revision if necessary. So far in Taiwan, the 1,673 potential debris flow torrents are distributed among 17 cities (counties), 159 townships or 684 villages. The number of total protected people accumulates to 47,830. Based on the detailed name-list inventory information, local governments can easily help the residents to establish their own evacuation route maps as shown in Figure 1. Each map contains a lot of emergency response information such as important agencies (police station, fire department and hospital) and contact persons, shelter information (capacity, address, phone numbers), landing area of helicopter, evacuation directions and routes, and the allocation of potential debris flow torrents. During the ordinary times, people who live in the affected areas of debris flows will follow their own evacuation route maps to have drills and training activities. While during the emergency period of typhoons or torrential rains, they will be evacuated by local governments according to the debris flow warnings issued by the SWCB. The debris flow warning model is based on the rainfall criteria including the effective accumulated rainfall and rainfall intensity (Jan et al., 2013). During Typhoon Morakot in 2009 (caused 665 casualties and 34 missing in Taiwan), 9,100 residents who lived in the affected areas of potential debris flow torrents were evacuated. Among them, at least 1,046 people escaped from the possible casualties in terms of the post disaster investigation (Yin et al. 2014). Another successful evacuation example was in Holiu, Fuxing district, Taoyuan city during Typhoon Soudelor in August, 2015. Figure 2 shows the rainfall hyetograph progress of debris flow event. At 20:30 on Aug. 6, the Central Weather Bureau issued the Land and Sea typhoon warnings due to the threat of Typhoon Soudelor. At 12:00 on Aug. 7, the local government encouraged the residents to carry on autonomous evacuation according to the evacuation route map as shown in Figure 1. At 17:00, the SWCB issued the debris flow yellow warning for evacuation advisement and the local residents accomplished the evacuation of the whole village before 19:00. In the early morning at 5:00 on Aug. 8, the SWCB again issued the debris flow red warning for enforcement evacuation, two hours and 45 minutes earlier than the occurrence of debris flow at 7:45. The debris flow rushed down the Holiu village and buried 14 houses as shown in Figure 3. Due to autonomous evacuation in advance, all 48 residents were safely in the shelter. The preparedness management of potential debris flow torrents has been proved to make a good contribution to debris flow disaster mitigation, especially timely evacuation operation.

Figure 1: Evacuation route map of Holiu village near potential debris flow torrent (blue line, No. TaoyuanDF034). Shelters, moving directions, helicopter landing area, and other information of hospital, police station, fire department, emergency operation center, and emergency contact person are all indicated in the map.

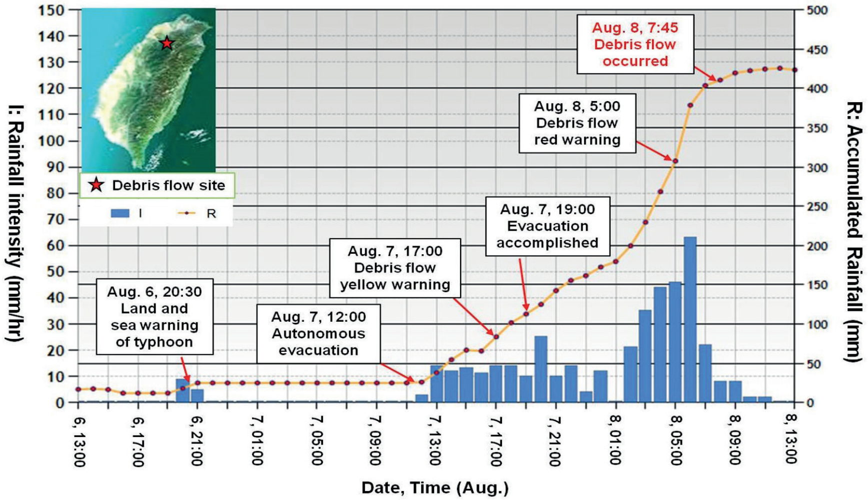

Figure 2: Hyetograph and warning time associated with the debris flow event in Holiu during Typhoon Soudelor on August 8, 2015.

Figure 3: Debris flow disasters in Holiu village.

CONCLUSIONS

Identification of potential debris flow torrents and their risk evaluation play important roles in hazards mitigation. Good management on debris flow torrents can effectively reducing debris flow hazards. The practical watershed management includes the identification procedure, evaluation measures, administrative operation process, watershed investigation, risk potential assessment, downstream fan area zoning, and evacuation route map. Through good management and annual review of the database of potential debris flow torrents as well as the real-time information update, protected people inventory, evacuation operation and public awareness, our government has effectively reduce debris flow hazards. After the challenges of severe rainfalls brought by tens of typhoon events in the last one and half decades, the preparedness management of potential debris flow torrents has been proved to make a good contribution to debris flow hazard mitigation.

REFERENCES

- Jakob M. (2005). Debris-flow hazard analysis, Chapter 17 in the book of Debris-Flow Hazards and Related Phenomena, edited by M. Jakob and O. Hungr, pp. 411-443, Springer, published by Praxis Publishing Ltd., UK.
- Jan, C.D., and Chen, C.L. (2005). Debris flow caused by Typhoon Herb in Taiwan, Chapter 21 in the book of Debris-Flow Hazards and Related Phenomena, edited by Matthias Jakob and Oldrich Hungr, pp. 539-563, Springer, published by Praxis Publishing Ltd., UK.
- Jan, C.D. Kuo, F.H., Wang, J.S. (2013). Early warning criteria for debris flows and their application in Taiwan, of ICL Landslide Teaching Tools, edited by Kyoji Sassa, Bin He Mauri McSaveney and Osamu Nagai, TXT-tool 2.886-1.3, published by International Consortium on Landslides, Japan.
- Lin M.L., Chen T.C. (2010). Zoning procedure modification of potential debris flow torrents, contract research report of Soil and Water Conservation Bureau, Council of Agriculture, in Chinese.
- Soil and Water Conservation Bureau, (2013). Zoning operation directions of potential debris flow torrents, Council of Agriculture, in Chinese.
- Yin H.Y., Lee C.Y., Jan C.D. (2014). A web-based decision support system for debris flow disaster management in Taiwan, 12th International IAEG Congress, Sep. 15-19, 2014, Torino, Italy, volume 3, pp. 109-113.