ASSESSING THE AFFECTED AREA OF TYPHOON-INDUCED LANDSLIDES AND DEBRIS FLOWS

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ABSTRACT Typhoon events are often accompanied by short-duration intense rainfall. If the slopes are steep and rich in loose soil, rocks, or colluvium, it is prone to induce significant debris flows and landslides, causing heavy casualties and economic losses. The occurrence of debris flows and landslides is influenced by geology, topography, and the hydrological environment. To assess the affected area of the combined process, the landslide and debris flow requires an integrated modeling framework. This study proposed an integrated slope stability model which combines infinite slope stability analysis and debris flow simulation to predict the initiation of typhoon-induced shallow landslides and runout paths. The landslide event induced by Typhoon Saola in Heping Village, Xiulin Township, Hualien County on August 2, 2012, is selected as the study case. By investigating geological, hydrological parameters, and topographic characteristics, the model is expected to predict the affected area of landslides and debris flows in the study areas. Satellite imagery was used to effectively estimate regional parameters for the model application, including vegetation index and topographic variables. Preliminary modeling outcomes, including the landslide location and its runouts, will be validated by comparing with the high-resolution optical image and in-situ investigation data. The research results can be used as a reference for the assessment of the affected area of landslides and debris flows in the future.

1. INTRODUCTION

Taiwan is located in an active tectonic zone and mixed with the tropical and subtropical climate. The island covers an area of approximately 36,197 km^2, but more than half of the terrain is composed of hills and mountains. The typhoon season in Taiwan is summer which brings short-duration intense rainfall and causes the increase of soil water content, which affects the pore pressure and the increase of slope instability. Due to the geographical characteristics, such as small watersheds, rock formations, and steep river slopes, landslides and debris flow occur and result in casualties and heavy economic losses to the affected areas. Shallow landslides refer to failures on soil mantled slopes with depths generally less than 2 m (Chiang et al., 2012). Once a shallow landslide evolves into a debris flow, its sudden destruction and high speed make them quite destructive to downstream areas. Thus, more effective and objective assessment methods to find out the distribution of potential debris flow sources and run-out paths are necessary. There are many methods for assessing landslide and debris flow hazards, including predicting future unstable patterns based on the analysis of the landslide inventory (Wright et al., 1974; De Graf, 1985; De Graf and Kanuti, 1988); physically-based models, such as the critical rainfall model, which examine the impact of surface topography on hydrological response, and use a large number of terrain and soil parameters to calculate the critical rainfall rate that leads to slope failure (Montgomery and Dietrich, 1994). This study applies an integrated slope stability model that combines infinite slope stability analysis and debris flow simulation to predict the occurrence and path of shallow landslides induced by typhoons. The landslide hazard caused by Typhoon Saola in Heping Village, Xiulin Township, Hualien County of eastern Taiwan on August 2, 2012, is slected to perform the model in this study.

2. TYPHOON SAOLA AND STUDY CASE

2.1 Typhoon Saola

Typhoon Saola affected the island of Taiwan from July 30 to August 3, 2012. In just five days, it entrained abundant rainfall and caused debris flows, flooding, and road interruptions in lots of areas. According to data from The Central Weather Bureau (CWB) of Taiwan, there are eight rainfall measurement stations with a total accumulated rainfall of more than 1,000 mm, which are all in Yilan and northern Hualien. Short-duration intense rainfall occurred most in Yunlin’s Douliu (with hourly rainfall of 149 mm), followed by Hezhong Station at Hualien Xiulin Township (125 mm) in our study area. Eight rainfall measurement stations with rainfall exceeding 100 mm per hour in total.

2.2 Study Case

The landslide event induced by Typhoon Saola in Heping Village, Xiulin Township, Hualien County of eastern Taiwan on August 2, 2012, is selected as the study case located in eastern Taiwan where Typhoon Saola landed (Figure 1).

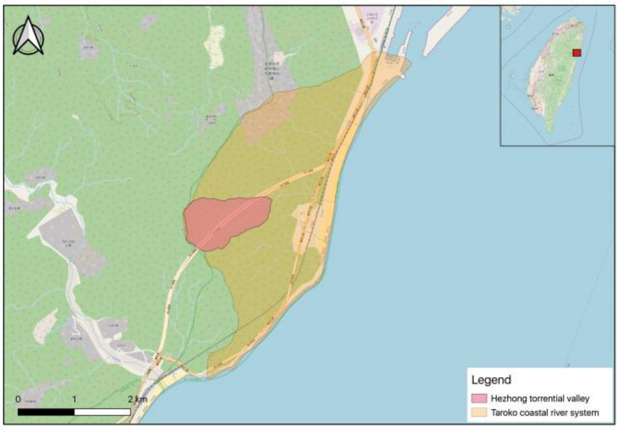

Figure 1. Study Area located in Heping Village, Xiulin Township, Hualien County

The short-duration intense rainfall of 130mm per hour caused debris flow disasters in the Hezhong tribe, Heping Village. According to the damage data investigated and recorded by Taiwan's Soil and Water Conservation Bureau (SWCB), the failure was caused by intensive rainfall over the north side of the Hezhong tribe. It belongs to the Taroko coastal river system. The upper geology of the catchment area is Nine Turns marble (Cu) that has been developed abundant joint. The lower part is Kainangang gneiss (Kg), and its surface is well weathered. The elevation difference from the source of the stream to the estuary exceeds 1000 m. The accumulation area is about 6,3000 m^2. According to the on-site investigation results of the National Science and Technology Center for Disaster Reduction (NCDR), the debris flow that occurred in Hezhong torrential valley from the upper reaches of the valley on the southwest side to the lower reaches of the northeast side. The length of the transport section reaches 1,100 m. The width of the river channel from upstream to downstream accumulation fan distribution is about 20 to 300 m. According to the measured values on-site, the sediment discharge in Hezhong torrential valley is shown in Table 1, the amount of sediment discharge in the first section is about 240,000 m^3, in the second section is about 618,000 m^3, and in the third section is about 86,400 m^3. The total amount of sediment discharge in the river channel of the Hezhong tribe is about 944,400 m^3. In addition, the fourth section (the lower right branch) has about 426,000 m^3 of sediment discharge. The final estimate is that the total amount of sediment discharge in Hezhong torrential valley is about 1,370,400 m^3.

Table 1. Sediment discharge in Hezhong torrential valley.

ID	Length (m)	Width (m)	Depth (m)	Sediment Discharge (m^3)
1	300+500+200+200	20	10	240,000
2	412	300	5	618,000
3	120	240	3	86,400
4	500	170	5	426,000
Total				1370,400

3. METHODOLOGY

3.1 Data Description

3.1.1 DEM data This study uses 20 m digital elevation model (DEM) data provided by the Ministry of the Interior in Taiwan and is produced by the airborne LiDAR (light detection and ranging) technology. Each grid point records the plane coordinates and elevation data of the point. To obtain the DEM data of our study case, Esri ArcGIS (geographic information system) software was used for editing and output (Figure 2).

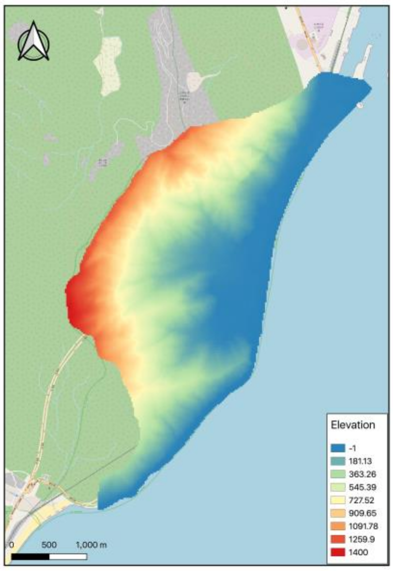

Figure 2. Digital elevation model data of study case

3.1.2 SWCB's Major Disaster Events Report The Major Disaster Events Report issued by SWCB in Taiwan provides on-site investigation data, including basic information on the disaster area, geographical location of the event, time of occurrence of the disaster, triggering event, and the size of the area affected by the debris flow. It also provides rainfall analysis, from which we can obtain the rainfall intensity at the time of the disaster for use in the model.

3.1.3 Geological map Our study case, located in eastern Taiwan, has steep topography and fragile geology properties. The geological structure, soil and rock characteristics affect the stability of the slope. Therefore, it is significant to obtain accurate geology and soil physics data such as soil density, soil cohesion, friction angle, and coefficient of permeability in simulating debris flow and runout path. Relevant geological data of this study case is provided by Central Geological Survey, MOEA's national geological data warehouse, and then digitized through GeologyCloud Map.

3.2 Integrated Slope Stability Model

The integrated slope stability model used in this study is based on the critical rainfall model proposed by Montgomery and Dietrich (1994). It is mentioned that topographic elements with the same critical rainfall are interpreted as having the same topographic control over the initiation of shallow landslides. Therefore, the spatial distribution of the critical rainfall value expresses the initiation potential of shallow landslides. In addition, in the literature, some researchers used a grid-based digital elevation model in the finite-difference model of shallow underground flow under steady rainfall. In the form of an infinite slope model, the predicted pore pressure value is used to calculate the stability of a single grid cell. Their model correctly identified most of the scars in a small (0.1 km^2) study watershed, although it predicted that there were more unstable cells than observed (Okimuraa and Ichikawa, 1985; Okimuraa and Nakagawa, 1988). To run the integrated slope stability model, we use a 20 m DEM to derive the local slope and the area of drainage contributed by the upslope. The assumption that there is a strong correlation between the physical properties of the soil and the lithological unit is used in this study. The model provides four typical land cover types to apply soil parameters include shrubland, settlement, water, and default (for any other types). Since our study case lacks detailed knowledge about the spatial variability of soil thickness, strength, and hydrological characteristics, we must use default values to set soil parameters, and simulate debris flow and runout paths from the predicted and investigated landslide data.

4. RESULT

The speed of the simulation process will base on the size of the DEM and the settings we establish. The simulation result contains an Unstable Map and Runout Map. Unstable Map shows the slope unstable cells with red color (Figure 3a). Based on this map we can modify the rainfall intensity value and control the scale of the landslide. When the rainfall intensity of the study area is 120mm/hr when the disaster occurs, the Unstable Map shows 0.39 km^2 of slope failure area. The red color in the Runout Map represents the affected area of the study site (Figure 3b).

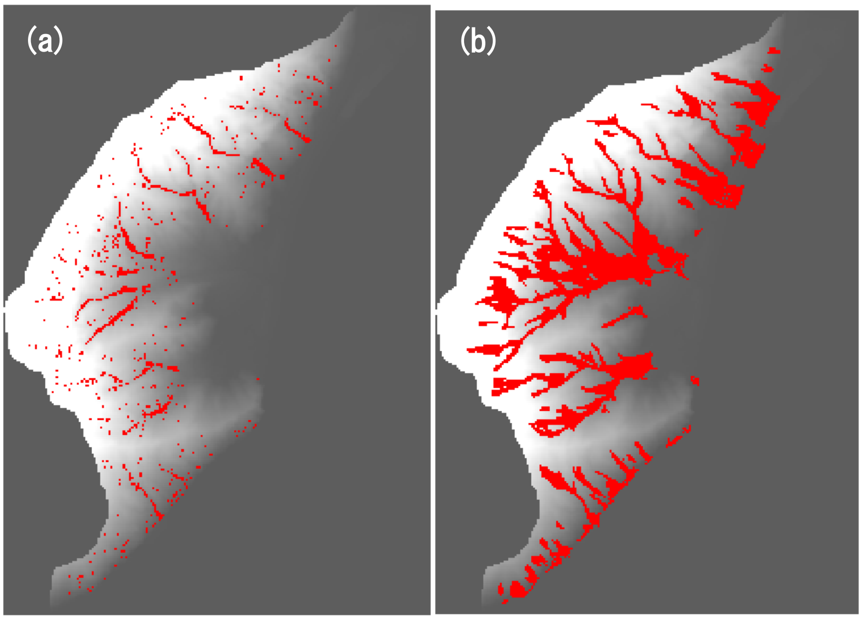

Figure 3. (a) Unstable Map. (b) Runout Map.

The preliminary modeling outcomes, including the landslide location and its runouts, will be validated by comparing with the digital aerial photo data provided by the Forestry Bureau Aerial Survey Office of Taiwan (Figure 4). The altitude distance between the aerial photos and the positioning point is 558.6m. The shooting date was 7 days after the disaster, August 9, 2012. The comparison result shows over-prediction of landslides and runout of the preliminary result. Regarding the limitation of model prediction, the accuracy of rainfall data and applied soil physics parameters should be improved. Because we still lack detailed geological data and soil parameters in the study area.

Figure 4. digital aerial photo data provided by the Forestry Bureau Aerial Survey Office of Taiwan.

5. CONCLUSION

This research proposes an integrated slope stability model that combines infinite slope stability analysis and debris flow simulation to predict the occurrence and path of shallow landslides induced by typhoons. We select landslide disasters caused by short-duration intense rainfall under typhoon events to simulate. The input parameters of the model include DEM data, geological map, and rainfall intensity. The adjustable soil parameters and rainfall intensity values are the relatively flexible part of this model. Although the results of over-prediction occurred due to insufficient soil physics data in our study case. However, the preliminary results can effectively simulate the location and runout paths of shallow landslides. The research results can provide references for future evaluation of landslide and debris flow affected areas.

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