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# THE CASE STUDY OF DEBRIS FLOW HAZARD CAUSED BY TYPHOON MORAKOT IN TAIWAN, 2009

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## ABSTRACT

Typhoon Morakot struck southern Taiwan on August, 8, 2009 with high rainfall intensity and accumulated rainfall as high as 2860 mm for 72 hours. Severe landslides and debris flow hazards were induced. The debris flow cases resulted in severe impacts to local communities were selected for case study, for which field investigation and analysis were conducted. Most severe landslide and debris flow cases originated from the rainfall center, which is Alishan mountain, and distributed with decreasing elevation. The analysis of debris cases were selected by category of watersheds including: Nanshalu, Maya, Dakanuwa villages of Namasha Township, Shinkai and Shinfa areas of Liugui Township, Kaohsiung County, and Chianghuangkern of Nanhua Township, Tainan County, Taiwan. Data analysis of the rainfall records suggested that a linear threshold for triggering of the debris flow could be defined, and the debris flow associated with low accumulated rainfall usually occurred at the high rainfall intensity, but involving smaller amount of debris transportation. While debris flow occurred at high rainfall accumulation with low intensity usually involved large amount of debris, which cause sever hazard.

**Key words:** *Typhoon Morakot; debris flow; case study; threshold rainfall*

## INTRODUCTION

Typhoon Morakot struck central and southern Taiwan on August 8, with the monsoon system drawn in by the Typhoon, continuous high-intensity rainfall resulted in accumulated rainfall as high as 2860 mm in three days. High accumulated rainfall was measured at Yushan and Alishan with the recorded rainfall of Alishan station as high as 3059.5mm from 0AM, 5, August to 11PM, 10, August, 2009. Typically the highest rainfall intensity appeared from 8 August to 9 August and resulted in severe hazards, especially the landslide and debris flow hazards in mountainous area. Most landslide hazards occurred during the period from the afternoon of 8 August to early morning of 9 August as the rainfall intensity rose. Soil and Water Conservation Bureau documented 1349 landslide hazards including 46 debris flow cases. The landslide area identified using FORMOSAT II satellite images by Central Geological Survey is more than 50000 hectares. Debris flow usually induces severe hazard due to direct impact to local communities, thus severe debris flow cases were selected for case study. Field investigation, rainfall records, damage records, hydrology data collection and analysis were conducted. Accordingly, the thematic map was generated and causal factors were discussed. Selected severe debris flow cases in this research include: Nanshalu, Maya, and Dakanuw villages of Namasha Township, Shinkai and Shinfa area of Liudui Township, Kaohsiung County, and Chianghuangkern of Nanhua Township, Tainan County. Results of this study can provide information for mitigation of secondary hazard and drafting of mitigation strategy.

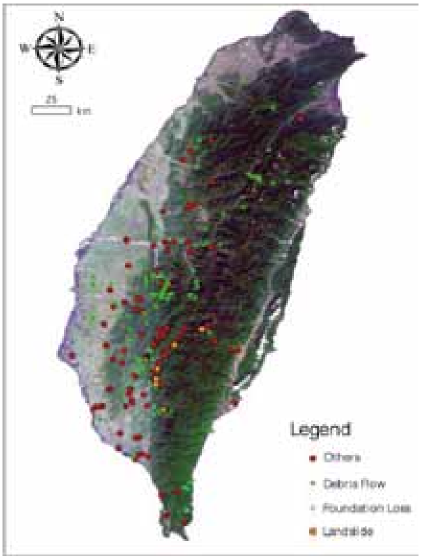


*Fig. 1 - Locations of different types of hazards (from DGH, 2009)*

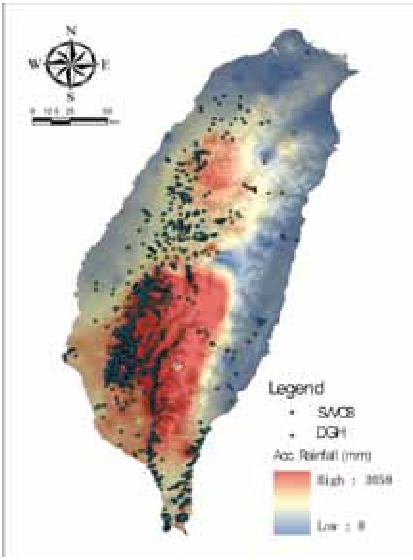


*Fig. 3 - The distribution of landslide hazards with rainfall from August 5 to 10, 2009 overlaid with topography*

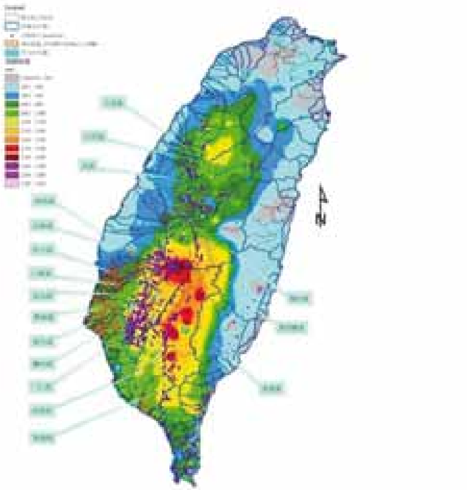

*Fig. 2 - The distribution of landslide hazards and watersheds with rainfall from August 5 to 10*

## CHARACTERISTICS OF DEBRIS FLOW HAZARD

Due to the rainfall carried by Typhoon Morakot, roads and bridges in the mountain area were severely damaged. According to the investigation of Directorate General Highway (DGH), damages were caused mainly by debris flow and landslides as shown in Figure 1. The rainfall concentrated at Yushan Mountain to Alishan Mountain and the effects radiated downstream for the basins originated from these mountains. The affected areas include Chenyulan river watershed of Juoshuei river watershed, Bazhang river watershed, Jenwen river watershed, Chishan river watershed, Laolun river watershed, Ailiao river watershed, and Taimali river watershed. Severe landslide, debris flow and flooding hazards occurred in each affected watershed; the distribution of landslide hazards and affected watersheds are as shown in Figure 2. Figure 2 illustrated the distribution of identified severe landslide cases with accumulated rainfall. Observing Figure 2, it was found that the locations of severe landslide and debris flow hazards are consistent with high accumulated rainfall area. Several sites located in Taitung county in the east part of Taiwan as shown in Figure 2 which appeared to be different from the trend of rainfall distribution.

Careful examinations revealed that those cases were debris flows originated from the landslides occurred upstream within the area of heavy rainfall. The results suggest that the major factor causing landslide hazards induced by typhoon Morakot is high accumulated rainfall. The distribution of high rainfall area and landslides were plotted along with topographic map as shown in Figure 3. In Figure 3, it appeared that the elevation increased rapidly in the high mountain areas, and such rugged terrain induced topographical effects which caused high rainfall on high elevation and steep slope. Significant number of severe debris flow hazards located at the west part of Central Mountain Range, and were mainly in Sanshia group formation, which included sandstone, shale, and interlayered sandstone and shale. The shale is poorly cemented with weak strength and easily crashed when weathered. Debris was often found filled with clayey materials during field investigation. These fractured materials with low shear strength could easily induce landslide hazards. Severe debris hazards located at the south and east parts of Central Mountain Range in Pingtung County and Taitung County are mainly in Lushan formation. Lushan formation is mainly slate with highly developed cleavages, which have significant effects on the strength of the material. The highly fractured geological condition is one of the major factors to result in severe landslide hazards

## DEBRIS FLOW IN NAMASHA TOWNSHIP, KAOHSIUNG COUNTY

Namasha township locates at the north of Kaoshiung county with Alishan township in north. Nanjishian river flows through the township connecting Kaoping river in the downstream. Three villages, i.e. Nanshalu, Maya, and Dakanuwa villages of Namasha township suffered severe debris flow hazard, and the distribution of villages in Namasha township is as shown in Figure 4.

### *Debris Flow Hazards*

The heavy rainfall carried by typhoon Morakot resulted in debris flow at Nanshalu, Maya, and Dakanuwa villages. Several debris flows occurred in Nanshalu village since afternoon of August 8, according to SWCB (2009; b), which destroyed roads

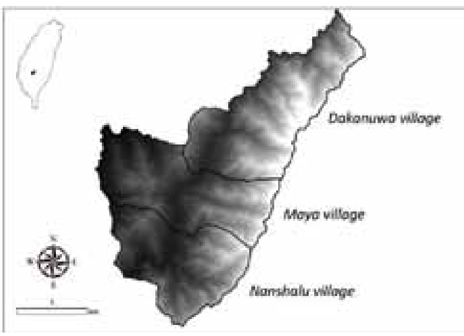


*Fig. 4 - The location of the three villages in Namasha township*

*Fig. 5 - Aerial photo of Nanshalu village after typhoon Morakot (provided by National Science and Technology Center for Disaster Reduction, NCDR)*

*Fig. 6 - Debris covered entire Nanshalu village (photo: Meei-Ling Lin)*

and buildings and resulted in 16 people dead, 25 people missing, and 80 buildings were damaged. Debris flow occurred in Maya village at 4 pm, 8, August and attacked buildings and Sanming junior high school. About 500 m of the road was covered with debris and 15-20 buildings were damaged. Another debris flow near Aboriginal Museum destroyed 3 buildings and about 400 m of road was covered with debris. Debris flow also occurred in Dakanuwa village and destroyed the access road to the village. Damages caused by debris flow were typically located at the lower river terrace. Communities situated at higher river terraces were not hit as severely. However, nine bridges in total along the Highway No. 21 were destroyed by debris flows, which blocked the access roads to the three villages and caused isolation and difficulties for emergency responses and mitigation efforts.

The aerial photo of the Nanshalu village after typhoon Morakot is as shown in Figure 5. Two debris flows hit the village. The buildings in the village were buried by debris and boulders as shown in Figure 6. The roads and riverbed are difficult to identify after being struck by debris flow especially for the debris

*Fig. 7 - Aerial photo of Maya village after typhoon Morakot*

*Fig. 8 - Debris flow occupied Minquan elementary school (photo: Meei-Ling Lin)*

flow torrent to the south of the village as observed in Figure 5. The significant change in terrain was caused by the landslides upstream of the river forming a dammed-up lake, and with the bursting of the lake at 5pm of August 9, huge amount of debris was flushed out and carried by the debris flow.

The aerial photo of the Maya village after typhoon Morakot is as shown in Figure 7. Two debris flows attacked the village from the north and south, and debris deposited in the Sanming junior high school and main resident area of this village. The Mingquan elementary school was filled with debris as shown in Figure 8. Moreover, the highway No. 21 was covered with debris about 3 meters thick.

The aerial photo of Dakanuwa village is as shown in Figure 9. Debris flows occurred at the north and south part of this village. The Markalung area at the right hand side of the Nanjishian River opposing the Dakanuwa village was also struck by severe debris flow. The roads and bridges connecting the Markalung area and the Dakanuwa village were destroyed by the debris flow and flood of the Nanjishian River.

*Fig. 9 - Aerial photo of Dakanuwa village after typhoon Morakot (provided by NCDR)*

*Fig. 10 - The location of Dakanuwa village and surrounding debris flow (photo: Kuo-Lung Wang)*

Dakanuwa village is consisted with two main resident areas as shown in Figure 10. The resident areas were not damaged by debris flow but the access roads were completely destroyed. The villagers were evacuated for more than a month due to the roads blockage.

## *HAZARDOUS FACTORS ANALYSIS OF DEBRIS FLOW*

The accumulated rainfall record of Minshen station in Namasha Township was 1778 mm and the maximum rainfall intensity is 96 mm/hr during typhoon Morakot as shown in Figure 11. The accumulated rainfall and intensity were high which induced landslide and followed by debris flow. The elevation varied as much as 1700 meter in the Namasha Township. Main geological formation of these villages is Sanshia group and formation of Nanjizian river is mainly Ruifang group. Sanshia group is mainly consisted with sandstone, shale, and inter-layered sandstone and shale. Ruifang formation in this area is formed by Nangang formation, which is consisted of dark grey shale. The upper part of Nangang formation is mainly structured by thin layered shale with thin sandstone. The geological condition in this area is easy to fracture which results in landslide after heavy rainfall. Most resident areas of these villages locate at lower river terrace nearby Nanjishian river except


*Fig. 11 - Rainfall chart of Minshen station during typhoon Morakot*

Dakanuwa village. Thus the communities were severely hit by debris flow.

## DEBRIS FLOW IN LIUGUI TOWNSHIP, KAOHSIUNG COUNTY

The Shinkai and Shinfa areas are located in Shinfa village, Liugui township, Kaohsiung county. The main road across the area is Highway No. 27 (Shinfa road), which connects to Highway No. 20 and northbound toward South Trans-island Highway and southbound toward Pingtung county. The topographical map of Shinkai and Shinfa areas is as shown in Figure 12. The elevation in the area varies from 300m to 1350m. There is no severe landslide hazard in recent decades except some soil erosion and flooding conditions during typhoon Kalmaegi in 2008.

Debris Flow Hazards

Slope-type debris flow occurred at Upper-Shinkai, Lower-Shinkai, and Meilunshan stream, while stream-type debris flow occurred at Bashilan river and Bulau river during typhoon Morakot. Distribution of the debris flows and landslides of this area is as shown in Figure 13. The Sinfa community was struck by debris flow at 8:30 pm, August 8, and the Tsaihun temple was struck by debris flow at 8:50pm at the same date. The outlet of valley, deposition fan and buildings nearby river bank were damaged by debris flow. Four people were dead and 24 people were missing at Lower-Sinkai debris flow site. More than 10 buildings were buried by debris. Bridges connecting the areas including Sinbao bridge and Sinkai bridge were destroyed by debris flow. Moreover, Sinfa bridge was damaged by debris flowing from Bashilan river to Launon river. Sinfa village was separated into several smaller isolated areas and lost connections to these areas.

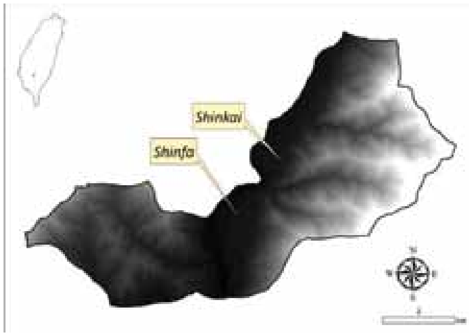


*Fig. 12 - Location and topography of Shinkai and Shinfa*

*Fig. 13 - Landslide and debris flow conditions of Sinkai area (photo: Tien-Chien Chen)*

The Tsaihun Temple in the Upper-Sinkai was struck by debris at about 8:50 pm, August 8. The in-situ debris flow condition is as shown in Figure 14. The height of landslide is about 250m and travelling distance is about 350 m. The debris flow was blocked by a big Budda statute and then redirected into the local community. The length of debris deposition is about 150m covering an area of about 0.5 hectare. Local residents were evacuated before debris flow occurred.

Lower-Sinkai was struck by debris flow at about 8:30pm, August 8. Four people were killed and 24 people were missing during this event. The travelling velocity of debris flow in this event is too fast to react. The resident area of Lower-Sinkai is an old deposition fan and the elevation is 20 m lower than Upper-Sinkai. The height and width of landslide are 450m and 1200m, respectively. The length of debris deposition is about 300 m and covering an area of about 20 hectares. The width of the stream increased to 200 m and the width of deposition fan is about 600 m. More than 10 buildings were buried by the debris deposition as shown in Figure 15. The deposited material flowed into Launon river and pushed the river channel, which resulted in erosion of embankment across the river.



 

*Fig. 14 - Debris behind Tsaihun temple (photo: Tien-Chien Chen)*

*Fig 15 - Deposition condition of lower Sinkai debris flow (photo: Tien-Chien Chen)*

### *HAZARDOUS FACTORS ANALYSIS OF DEBRIS FLOW*

The total rainfall in this area is 2418 mm during typhoon Morakot. The highest rainfall intensity occurred at 1pm, August 8, is 103 mm/hr. The rainfall record in this area is as show in Figure 16. The rainfall intensity higher than 50 mm/hr has lasted up to 10 hours.

The Tulunwan fault passed through the Sinfa village with lightly metamorphic rock in the east side and sedimentary rock in the west side of the fault. The lightly metamorphic rock belongs to lower part of Changshan formation which consists of slate and thin sandstone. The fissures and joints are well developed due to the fault and the material strength is weak. The main dip of the stratum is 30~50 degrees north to west with the dip direction along the slope sliding direction. The valley is eroded and the topography is mostly steep slope. The river terrace is deposited right next to the steep slate slope and the deposition materials are transported from upstream areas. Deposition

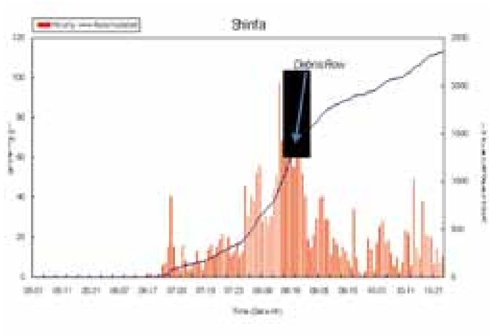


*Fig. 16 - Rainfall chart of Shinfa station during typhoon Morakot*

fans are very common at the outlet of each stream.

The original resident area located at higher river terrace. Lower river terrace area was developed after hot spring was found. The new residences and hotels were located on the deposition fan of stream including Lower-Sinkai and Chinshan hot spring hotel. The location is originally hazardous area of debris flow deposition fan. The flooding of Launon river and debris flow destroyed connecting bridges including Sinbao, Sinkai and Sinfa bridges. The isolated condition of each resident areas resulted in more severe conditions.

## DEBRIS FLOW IN NANHUA TOWNSHIP, TAINAN COUNTY

Nanhua township locates at the east part of Tainan county with Kaohsiung county to the east and south. Chianghuankern is located in Yushan village of Nanhua township. The elevation in the watershed varies from 210m to 668m. The major road connecting the site is Highway No. 20. The location and topography of this area is as shown in Figure 17

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### *DEBRIS FLOW HAZARDS*

Landslide area in this event covers an area of about 1.9 hectares according to SWCB (2009a; b). The stream bed was eroded and the deposition started at the middle part of stream. The debris flow destroyed several buildings in the evening of August 8. Local residents were evacuated before debris flow struck. 15 buildings were damaged and 5 buildings were severely destroyed. The length of road covered with debris was about 170m. The width and length of deposition area were 110m and 150m, respectively. Figure 18 and

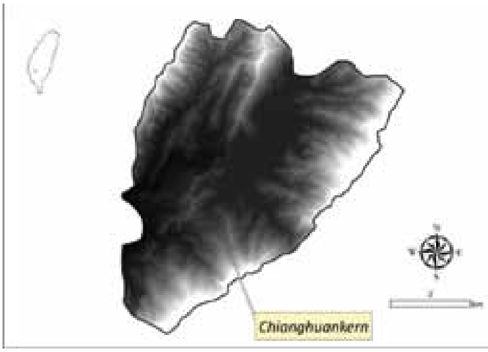


*Fig. 17 - Location and topography of Chianghuankern, Yushan Village, NanhuaTtownship*

*Fig. 18 - Building was damaged by debris flow (photo: Meei-Ling Lin)*

*Fig. 19 - Downstream of overflow position (photo: Meei-Ling Lin)*

Figure 19 illustrate the overflow position of debris flow and the buildings destroyed. The original stream channel of the debris flow path is as shown in Figure 18. However, after the channel was filled with debris, the debris overflowed in the trajectory direction and flowed downward in a straight-line direction toward the lower elevation area as illustrated in Figure 19.

### *HAZARDOUS FACTORS ANALYSIS OF DEBRIS FLOW*

The total rainfall during Typhoon Morakot is 1326 mm and the highest rainfall intensity is 93 mm/hr as recorded by the nearby Beiliao station shown in Figure 20. The elevation of the area decreases from south-east to north-west. The average slope angle in this watershed is about 22.5 degrees, which implies steep slope in the up-stream area. The geological formations in this watershed are mainly consisted with Tangen sandstone and Beiliao shale. Pingshi fault passes through the watershed, resulting in fractured materials and weak strength of rocks. According to the field investigation, there are some large rocks and thick debris deposit located within the resident area before the debris flow occurrence, which suggests that the resident area has been on an old debris deposition area of debris flow.

## DISCUSSIONS

Due to the high precipitation of Typhoon Morakot, the accumulated rainfall as high as 2000 mm was observed in many areas, which corresponded to a return period of more than 300 years according to the available weather records. The magnitude of hazards caused by such huge rainfall was larger than many other events in the past 10 years after Chi-Chi earthquake. The total affected area is more than 50000 hectares, which is more than the 30000 hectares of affected area induced directly by the Chi-Chi earthquake. The regions struck severely by Typhoon Morak mainly located in southern Taiwan, which were not significantly affected by the Chi-Chi Earthquake in 1999. Some hazardous area of Chi-Chi Earthquake such as the Chenyulan River watershed and upstream of Chinsuei River watershed were severely struck comparing with other hazardous areas of Chi-Chi earthquake. It was observed that some severe hazardous areas in Typhoon Morakot event were recurring after Typhoons Haitang in 2005, Kalmaegi, and Sinlaku in 2008. Still most of the hazards caused by typhoon Morakot did not have previous hazard history in the past decades.

The rainfall records of the debris flow cases in this study were obtained as discussed previously. Based on the reported time of debris flow occurrence, the accumulated rainfall and rainfall intensity at the time of occurrence was determined for each case and plotted in Figure 21. A good linear correlation of data distribution was observed and a linear regression line was plotted as shown in Figure 21. Such linear relationship could serve as the triggering threshold

 

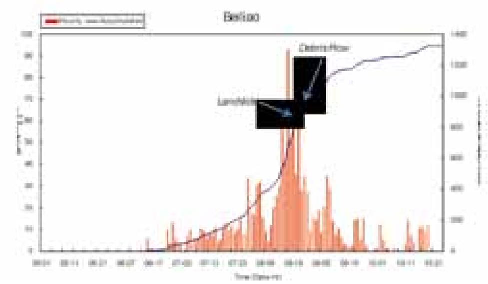


*Fig. 20 - Rainfall record of Beiliao station during Typhoon Morakot*

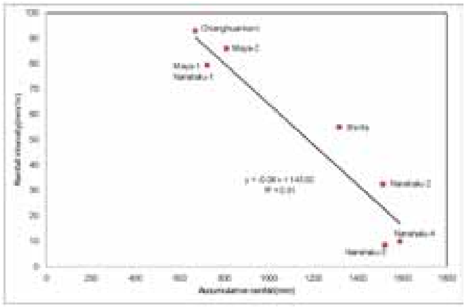

*Fig 21 - Accumulated rainfall and rainfall intensity triggering debris flows*

rainfall for the debris flows in the study area (Hong *et alii*, 2005, Brand, *et alii*. 1984, Wieczorek, 1987). Observing the data, it was found that the debris flows occurred with large rainfall intensity usually occurred at the earlier stage of rainfall record, and with smaller amount of debris transportation. While the debris flows occurred at the later stage of the rainfall record, large amount of rainfall accumulated with not so large rainfall intensity. In this stage, the total rainfall accumulation in the watershed is high and often induced large scale landslides, which lead to large amount of debris deposition in the upstream area of the basin. In such cases, the debris flow ended up involving large amount of debris, which caused a very severe hazard. The data point of Nanshalu-4 corresponds to the large scale debris flow triggered by the upstream landslides which dammed-up the river, and the dammed-up lake burst subsequently and caused the large-scale debris flow as discussed previously. The debris flowed downstream and overflowed to the community located near the outlet of stream. Some landslide debris still deposit in the upstream area, and which could be triggered to cause the secondary hazard.

## CONCLUDING REMARKS

Typhoon Morakot struck southern Taiwan and caused severe landslides and debris flow hazards in 2009. Case study of debris flow resulting into severe impacts to local communities was conducted. Most severe landslide and debris flow cases originated from regions close to the center of high rainfall area, i.e. the Alishan Mountain, and distributed at the front face with decreasing elevation. The cases selected for analysis were by category of watersheds including: Nanshalu, Maya, Dakanuwa villages of Namasha Township, Shinkai and Shinfa areas of Liugui Township, Kaohsiung County, and Chianghuangkern of Nanhua Township, Tainan County. Data analysis of the rainfall records suggested that a linear threshold for triggering of the debris flow could be defined, and the debris flow associated with low accumulated rainfall usually occurred at the high rainfall intensity, but involving smaller amount of debris transportation. While debris flow occurred at high rainfall accumulation with low intensity usually involved large amount of debris, which cause severe hazard.

The communities struck by debris flows were mostly located at low river terrace near the debris deposition area. Moreover, the roads and bridges connecting the residential areas also passed through the low river terrace. Both factors caused the risks and damages to increase during this event. For the comprehensive mitigation strategy, detailed investigation of the potential hazardous areas is required for relocation of communities and connecting roads and bridges.

## ACKNOWLEDGEMENT

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