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Landslide and Debris Flow Characteristics during Extreme Rainfall in Taiwan

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***Abstract*—**As the global climate changes, the threat from landslides and debris flows increases. Learning how a watershed initiates landslides under abnormal rainfall conditions and predicting landslide magnitude and frequency distribution is thus important. Landslides show a power-law distribution in the frequency-area distribution. The distribution curve shows an exponent gradient 1.0 in the Sandpile model test. Will the landslide frequency-area statistics show a distribution similar to the Sandpile model under extreme rainfall conditions? The purpose of the study is to identify the extreme rainfall-induced landslide frequency-area distribution in the Laonong River Basin in southern Taiwan. Results of the analysis show that a lower gradient of landslide frequency-area distribution could be attributed to the transportation and deposition of debris flow areas that are included in the landslide area.

***Keywords*—**Landslide, power-law distribution, GIS.

I. Introduction

THE term "extreme rainfall" has no widely accepted definition. Extreme rainfall events could be defined in several ways. For example, the mean annual number of days on which daily (24hrs) rainfall amount exceeds a given amount, the value associated with a specific daily rainfall percentile, or the annual maximum daily rainfall associated with a specific return period [1]. Defining extreme rainfall events as the total of 24 hrs of precipitation at one or more stations exceeding the 50 yr recurrence amount is generally consistent with previous studies of heavy precipitation and flash floods from the United States in 1999-2003 [2].

Typhoon Morakot struck Taiwan on 7-10 August, 2009, bringing heavy rainfall and serious floods in southern Taiwan. These typhoon-induced disasters were attributed to its slow velocity, which led to long rainfall duration and high rainfall intensity [3]. The Alishan rain gauge station recorded historic highs in total cumulative rainfall, 1,624mm in 24hrs, 2,361mm in 48hrs, and a total amount of 2,884mm [4]. Typhoon Morakot was thus an extreme rainfall event (exceeding a 200yr recurrence amount at many rain gauge stations) causing severe floods, triggered landslides and debris flows throughout southern Taiwan [5].

Landslides show a power-law distribution [6]–[11]. The linear trend of the landslide frequency-area curve for larger landslides in a power law (log-log plot) can be found through least-squares regression:

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$$\log N(A) = \tau \log A + S \tag{1}$$

where N(A) is the number of landslides of area A, τ is the slope of the line defining the relationship, and S is the slope intercept.

The frequency-area distribution of historical landslides is calculated based on the derivative of the cumulative number (Nc) of landslides with an area greater than or equal to the value A and plotted as a function of the landslide area (A) [12]. The frequency density function is defined as [13]:

$$f(A) = dN_c/dA \tag{2}$$

The fitting is performed according to the ($-dNc/dA = bA^{-\beta}$) relationship, and the best-fit power-law model (log-log plot) is obtained by linear regression.

The purpose of the study is to identify the features of rainfall-induced landslides and debris flows and their frequency and area distribution under extreme rainfall conditions.

II. Rainfall Characteristics during Typhoon Morakot

Typhoon Morakot made landfall on August 7, 2009, causing severe flooding and landslides throughout southern Taiwan. The typhoon brought a maximum rainfall of 1,623mm/day during the 24 hours between 14:00, 8 August and 14:00, 9 August, and a cumulative rainfall of 2,361mm for the 48 hours between 18:00 on 7 August to 18:00 on 9 August at the Alishan rain gauge station. The heaviest rainfall was distributed across Chiayi, Tainan, Kaohsiung, and Pingdong counties in the mountainous areas of southern Taiwan (Fig. 1).

III. Study Area and Methodology

The Laonong River Basin, the study area, is located in Kaohsiung County in southern Taiwan. The Laonong River itself has a length of 137km with basin area of 1,373km^2, making it the second largest river watershed in Taiwan. The basin's elevation ranges from 27m to 3,941m and it is divided into 76 sub-basins (Fig. 2). The Laonong basin in southern Taiwan has been documented by numerous studies [14] [15]. The basin experienced 2,300mm of rainfall during Typhoon Morakot.

This study used SPOT 5 images. The river watershed was created using GIS and landslide and debris flow induced denuded areas were identified. The denuded areas were further separated into landslide- or debris flow-induced areas and their area calculated using GIS. A statistical analysis was conducted of the denuded areas and their frequency (number of landslides or debris flows) was modeled using power law distribution and its exponent calculated.

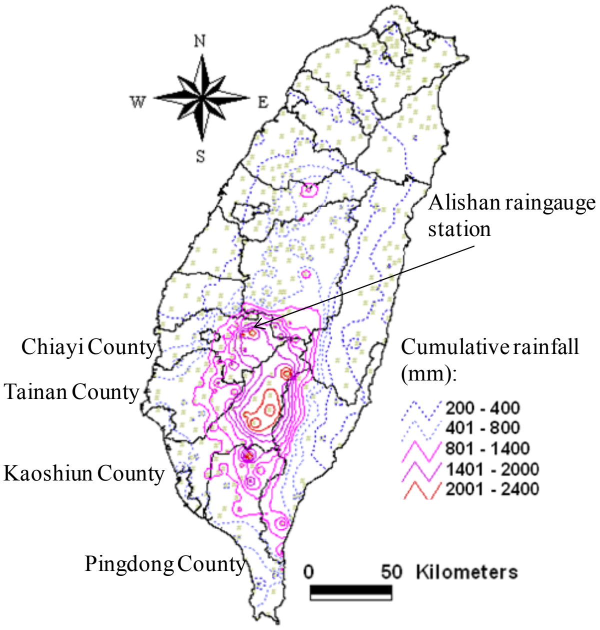

Fig. 1 Typhoon Morakot rainfall distribution in Taiwan, 7-10 August, 2009

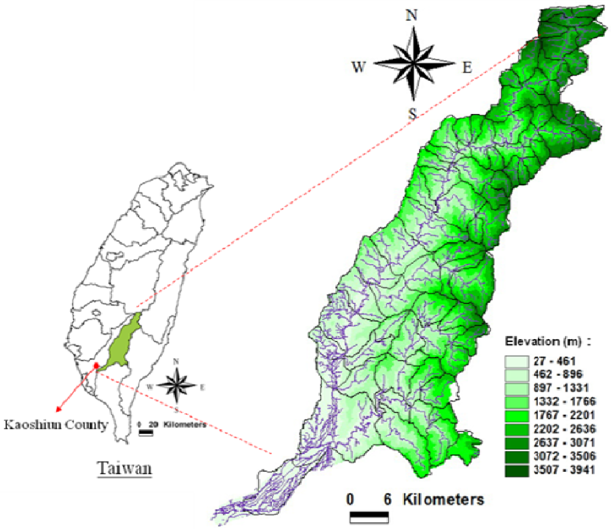

Fig. 2 Site location of the Laonong River Basin

IV. Landslides and Debris Flows during Typhoon Morakot

Debris flow and flash flood hazards were initiated in the study area during Typhoon Kalmegi in 2008. Kalmegi left 7 dead and 2 missing in the study area [16]. Debris flow hazards were also severe in Jiaxian, Liugui, and Taoyuan Villages in the study area during Typhoon Morakot in 2009. Debris flows in Liugui Township buried 38 residents (Fig. 3).

Fig. 3 Debris flow hazards in the Laonong River Basin during Typhoon Morakot (taken Po-lin Chi)

V. Geologic and Hydrologic Characteristics

The annual average rainfall is 3,360mm per year from 1982 to 2010 in the study area [17]. The maximum rainfall intensity was 106mm/hr and the accumulative rainfall reached 2,244mm over 7-12 August, 2009 (Fig. 4).

The main geologic formations in the basin are argillite, slate, and phyllite (Fig. 5). Landslide and debris flow hazards covered the entire study area. We believe that the geologic conditions were not as important a factor in the hazards as the extreme rainfall in the area.

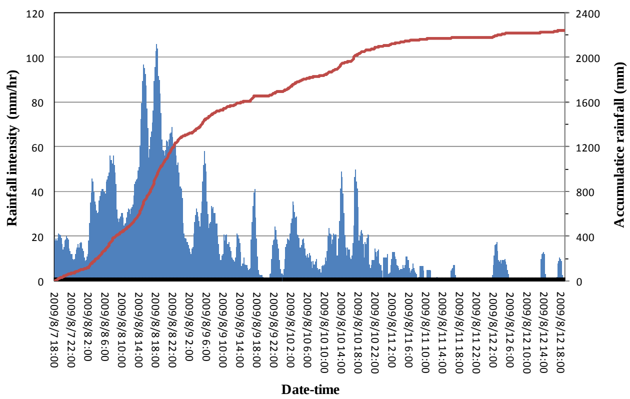

Fig. 4 The rainfall histogram at the nearest rain gauge station (C0R10) during Typhoon Morakot

VI. Results and Discussion

The interpretations of denuded areas were separated into two categories, landslides and debris flows. A total of roughly 6,800 landslides and 166 debris flows were interpreted from the SPOT 5 images after Typhoon Morakot. The landslide area-frequency distribution may be expressed as:

$$\ln(f)=-1.53\ln(Ac)+4.42 \ (r^2 = 94\ \%) \quad \text{(Debris flows and landslides)} \qquad (3)$$

The frequency-area distribution for Chi-Chi earthquake-induced larger landslides can be expressed as:

$$\ln(f) = -2.06\ln(Ac)+5.79 \ (r^2 = 93\%) \quad \text{(Chi-Chi EQ)} \tag{4}$$

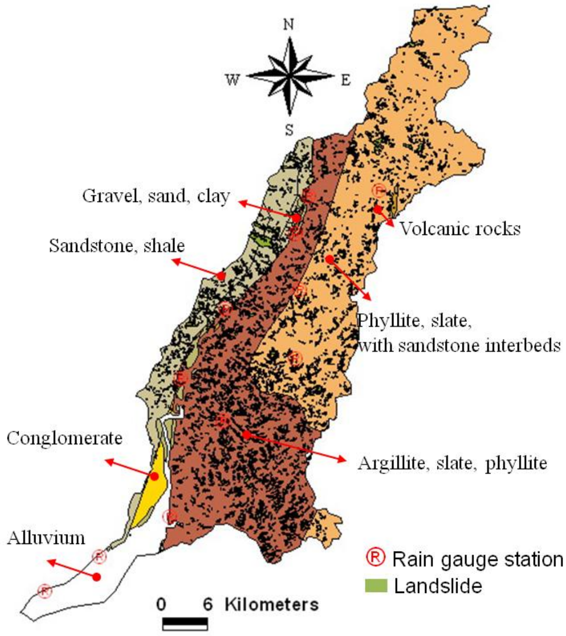

Fig. 5 Rain gauge stations, landslides, debris flows, and geologic conditions in the Laonong River Basin

The critical exponent for cumulative frequency-area distribution is 1.0 in the Sandpile model [18], [19]. The exponent of the coseismic landslide frequency-area distribution of the Chi-Chi earthquake is 2.06 for the non-cumulative form and 1.06 for the cumulative form, both of which exceed the critical exponent.

In general, a debris flow shows a larger denuded area than a landslide. The denuded areas interpreted from the SPOT image as debris flows include the source, transportation, and deposition areas. The debris flow areas displayed a lower gradient in the landslide frequency-area distribution. The lower gradient was affected by the debris flows (Fig. 6).

VII. Conclusion

Under extreme rainfall conditions, the landslide area-frequency distribution in a basin may be estimated by the Sandpile model with the critical slope of 1.0 for larger landslides in a power-law distribution. The lower gradient distribution is attributed to the compound area of the source landslides, transportation, and deposition areas in the debris flow affected areas. The type of land movement, landslide, debris flow, or rockfall, could affect the trend of the area-frequency distribution. The Sandpile model is used for landslides. It is thus necessary to separate landslide and debris flow areas for area-frequency distribution analysis. The landslide area-frequency under extreme rainfall conditions can be estimated by the Sandpile model with a critical slope 1.0 for larger landslides.

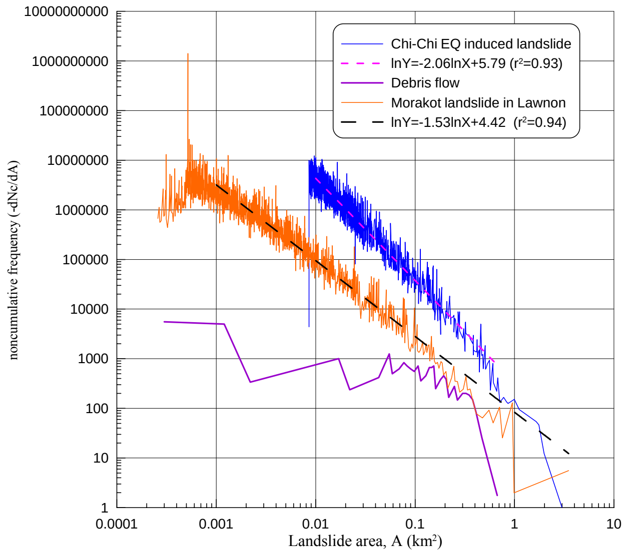

Fig. 6 Debris flow interpretation in the study area after Typhoon Morakot

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References

[1] P. S. Chu, X. Zhao, Y. Ruan, and G. Melodie, "Extreme rainfall events in the Hawaiian Islands," *Journal of Applied Meteorology and Climatology*, vol. 48, no3, pp. 502–516, 2009.

[2] R. S. Schumacher and R. H. Johnson, "Characteristics of U.S. extreme rain events during 1999–2003," *Weather Forecasting*, vol. no. 21, pp. 69–85, 2006.

[3] J. D. Ben Jou, Y. C. Yu, L. Feng, Y. M. Chen, C. S. Lee, and M. D. Cheng, "Synoptic environment and rainfall characteristics of Typhoon Morakot," *Atmospheric Science*, vol. 38, no. 1, pp.21–38, 2012. (in Chinese)

[4] CWB, Central Weather Bureau, http://www.cwb.gov.tw, 2010.

[5] C. H. Juang, "Reconnaissance of extreme natural disasters of Morakot Typhoon, Taiwan," *Engineering Geology*, vol. 123, pp. 1–2, 2011.

[6] C. P. Stark and N. Hovius, "The characterization of landslide size distributions," *Geophysical Research Letters*, vol. 28, pp. 1091–1094, 2011.

[7] F. Guzzetti, B. D. Malamud, D. L. Turcotte, and P. Reichenbach, "Power-law correlations of landslide areas in central Italy," *Earth and Planetary Science Letters*, vol. 195, pp. 169–183, 2002.

[8] C. Y. Chen, F. C. Yu, S. C. Lin, and K. W. Cheung, "Discussion of landslide self-organized criticality and the initiation of debris flow," *Earth Surface Processes and Landform*, vol. 32, pp. 197–209, 2007.

[9] M. Van Den Eeckhaut, J. Poesena, G. Goversa, G. Verstraetena, and A. Demoulin, "Characteristics of the size distribution of recent and historical landslides in a populated hilly region," *Earth Surface Processes and Landform*, vol. 256, pp. 588–603, 2007.

[10] C. Y. Chen, "Sedimentary impacts from landslides in the Tachia River Basin, Taiwan," *Geomorphology*, vol. 105, pp. 355–365, 2009.

[11] C. Y. Chen, "Landslide and self-organized criticality in the Lushan hot spring area," *Journal of Mountain Science*, vol. 9, no. 4, pp. 463–471, 2012.

[12] G. B. Crosta, P. D. Negro, and P. Frattini, "Soil slips and debris flows on terraced slopes," *Natural Hazards and Earth System Sciences*, vol. 3, pp. 31–42, 2003.

[13] B. D. Malamud, D. L. Turcotte, F. Guzzetti, and P. Reichenbach, "Landslide inventories and their statistical properties," *Earth Surface Process & Landform*, vol. 29, pp. 687–711, 2004.
[14] M. C. Weng, M. H. Wu, S. K. Ning, and Y. W. Jou, "Evaluating triggering and causative factors of landslides in Lawnon River Basin, Taiwan," *Engineering Geology*, vol. 123, Iss. 1–2, pp. 72–82, 2011.
[15] C. H. Wu, S. C. Chen, and H. T. Chou, "Geomorphologic characteristics of catastrophic landslides during typhoon Morakot in the Kaoping Watershed, Taiwan," *Engineering Geology*, vol. 123, Iss. 1–2, pp. 13–21, 2011.
[16] NFA, National Fire Agency, Ministry of the Interior, Typhoon Kalmegi emergency response report, http://www.nfa.gov.tw/, 2008.
[17] WRA, 2010. Water Resources Agency, Ministry of Economic Affairs, Hydrological Year Book of Taiwan Republic of China 2010, http://gweb.wra.gov.tw/wrhygis/, 2010.
[18] P. Bak, C. Tang, and K. Wiesenfeld, "Self-organized criticality: an explanation of 1/f noise," Physical Review Letters, vol. 59, no. 4, pp. 381–384, 1987.
[19] P. Bak, C. Tang, and K. Wiesenfeld, "Self organized criticality," *Physical Review A*, vol. 38, pp. 364–374, 1988.