A Rainfall-Based Warning Model for Shallow Landslides

Zeng, Y. C. (1); Wang, J. S.(2), Jan, C.D. (1) , Yin ,H.U. (3) Lo ,W.C. (3)

(1) Department of Hydraulic and Ocean Engineering, National Cheng Kung University, Taiwan (zengyichao@gmail.com).
(2) Ecological Soil and Water Conservation Research Center, National Cheng Kung University, Taiwan
(3) Debris-Flow Disaster Prevention Center, Soil and Water Conservation Bureau, Taiwan

1 Abstract

In recent decades, rainfall patterns have presented a more concentrated, high-intensity and long-duration trend in Taiwan. The most representative event is Typhoon Morakot which resulted in the heaviest casualties in southern Taiwan during August 7 to 10 in 2009. In addition, the nature of vulnerability results in more severe sediment-relative disasters, in which shallow landslides are widespread hazards in mountainous regions. This research aims to develop a model for predicting shallow landslides triggered by rainfall in mountainous area. Considering the feasibility of large-scale application and practical operation, the statistical techniques is adopted to form the landslide model. The 16 landslide inventory maps were interpreted and delineated since 2004 to 2011. Logit model is utilized for interpreting the relationship between rainfall characteristics and landslide events delineated from satellite. Based on the analysis results of logistic regression, a Landslide Rainfall Triggering Index (*LRTI*) proposed for assessing the occurrence potential of shallow landslides is defined as the product of I_3 (mm/hr) and R_t (mm) which are 3 hours rainfall intensity and the effective cumulative precipitation, respectively. A form of probability of shallow landslide triggered threshold is proposed to offer a measure of the likelihood of landslide occurrence. Two major critical lines which represent the lower ($LRTI_{10}$) and upper ($LRTI_{90}$) boundaries of the probability range must be defined. Further, the various probability of shallow landslide occurrence is analyzed between these two boundaries. Two assessing indexes are used for determining appropriate probability rainfall threshold which are the disaster-capture ratio and false-alarm ratio. The result shows that $LRTI_{70}$ is preferred adopted as the warning threshold of shallow landslides because of the higher disaster-capture ratio (95%) and lower false-alarm ratio (13%). By the proposed approach, the warning threshold can be determined more reliability and objectivity than the conventional methods.

Study area

The Gaoping River watershed, located in southern Taiwan, has a catchment area of 3,285 km2, a main stream length of 171 km and an average elevation about 3,400m. Almost half the total basin has an elevation greater than 1,000 meter. The annual rainfall in the watershed ranges from 2,000 mm to 3,400 mm with an average value of approximately 3,130 mm. About 80 percent of the precipitation occurs during the rainy season from May to October, especially during typhoons. Landslide hazards are common within the watershed owing to combination of weak geological conditions, large sediment yielding from hillside, and accompanying heavy rainfall.

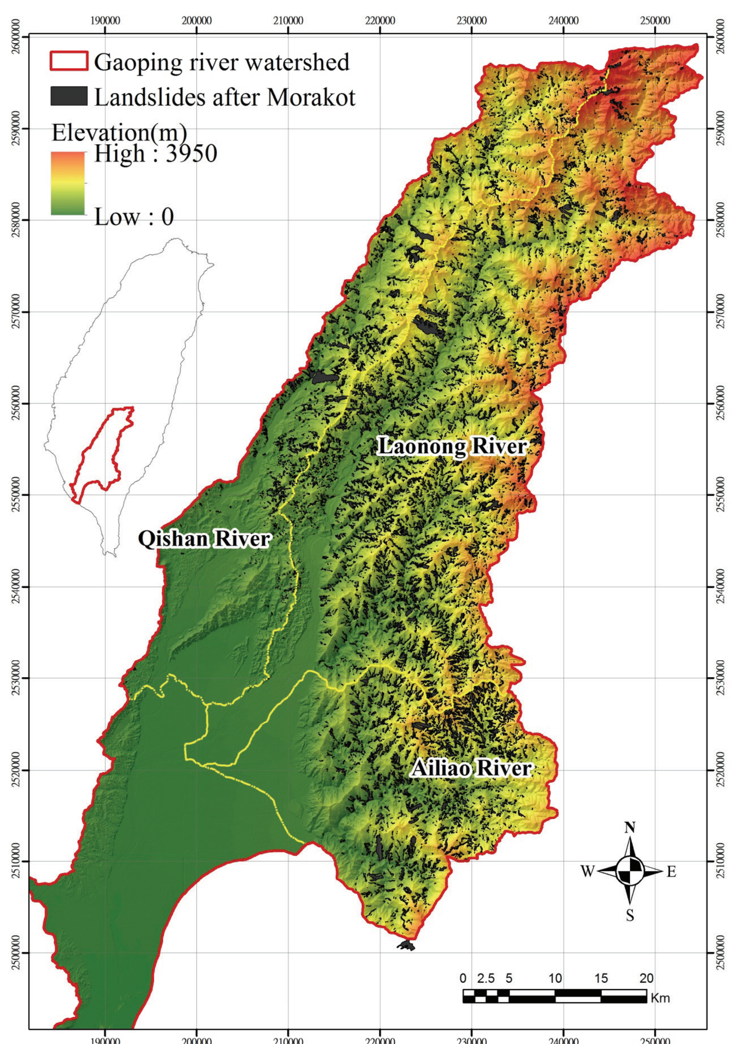


Fig. 1 Study area and landslides triggered by Typhoon Morakot.

2 Procedure for establishing a landslide triggering model

2.1 Rainfall data and landslide inventory

Landslide warning model must dependent on abundant rainfall data and landslide inventory. Precipitation records of the study area were obtained from the automatic rain-gage stations from 1987 to 2013. The landslide inventory was interpreted and delineated from FORMOSAT-2 images since 2004 to 2011. It includes 16 landslide inventory maps and 15 variation results by comparing satellite images taken before and after the rainfall event.

Tab. 1 Dates of images used in this study and trigger typhoon events.

Year	Event	Image date
2004	AERE	2004/9/19~2005/3/26
2005	0612 heavy rain	2005/7/1~2005/7/14
2005	HAITANG	2005/6/12~2005/9/2
2005	MATSA, TALIM	2005/9/4~2006/1/31
2006	0609 heavy rain, Bilis	2006/6/17~2006/7/2
2007	0604 heavy rain	2007/6/27~2007/7/24
2007	SEPAT, KROSA	2007/10/24~2007/11/4
2008	KALMAEGI, FUNG_WONG	2008/7/23~2008/8/24
2008	SINLAKU, JANGMI	2008/12/1~2008/12/20
2009	MORAKOT	2009/8/17~2009/9/3
2010	0725 heavy rain	2010/8/4~2010/8/27
2010	FANPI	2010/9/21~2010/10/10
2011	0719 heavy rain	2011/7/25~2011/7/30
2011	NANMADOL	2011/9/2~2011/9/15
2011	1001 heavy rain	2011/10/8~2011/10/17

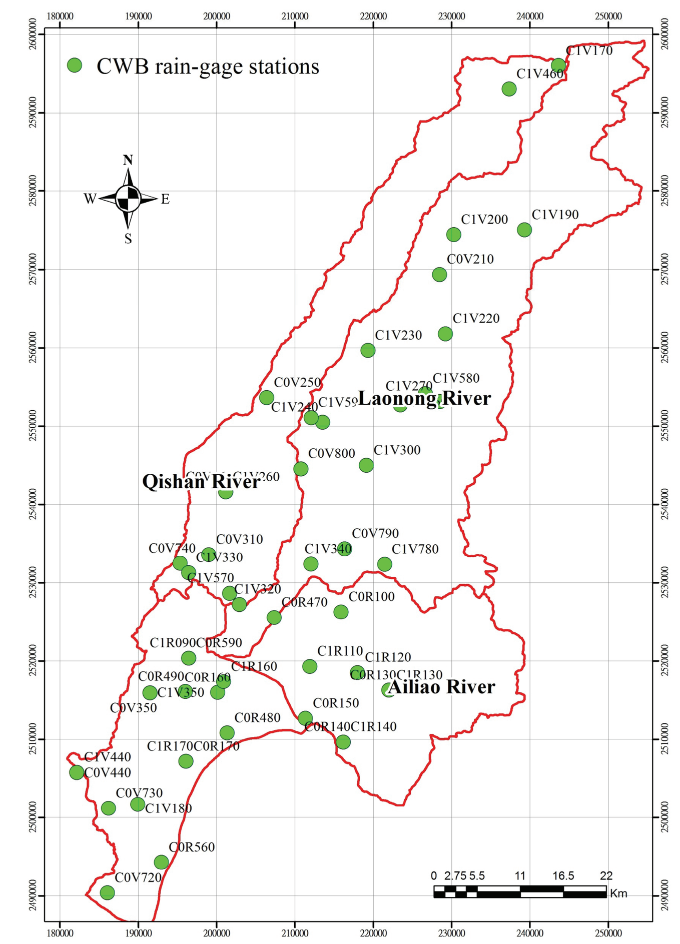


Fig. 2 Rain-gage stations within the study area.

2.2 Determining high risk region of landslide influence

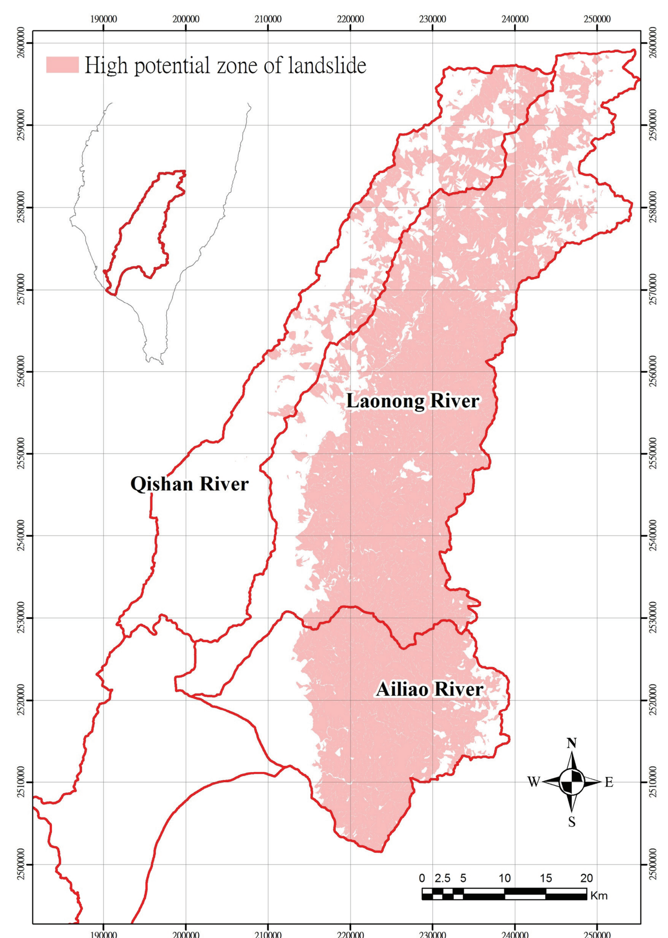
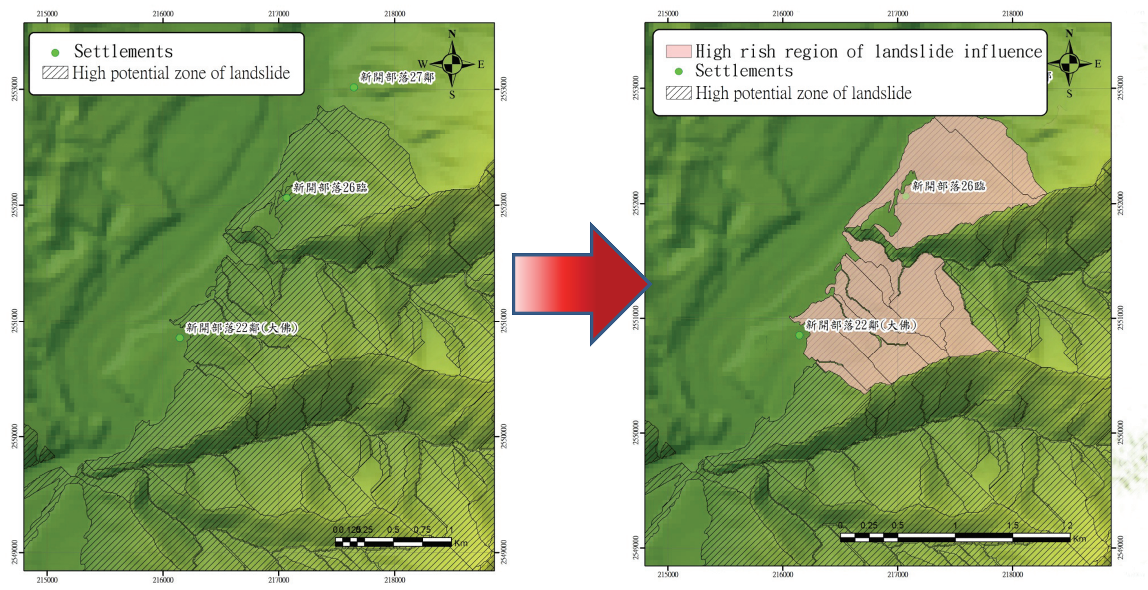


Fig. 3 The landslide-prone zone.

By overlaying maps of hillside settlements located on landslide susceptibility maps, we can identify which areas are at greatest risk from landslides.



2.3 Landslide Rainfall Triggering Index (LRTI)

Logit model is utilized for interpreting the relationship between rainfall characteristics and landslide events. Based on the analysis results of logistic regression, the rainfall factors that are highly related to shallow landslide occurrence are selected which are 3 hours rainfall intensity I_3 (mm/hr) and the effective cumulative precipitation R_t (mm). The Landslide Rainfall Triggering Index (*LRTI*) for assessing the occurrence potential of shallow landslides is defined as the product of I_3 and R_t .

$$LRTI = I_3 \times R_t$$

The larger *LRTI*-value is represented the higher probability for triggering landslide.

$$R_t(t) = R(t) + \sum_{i=1}^{7} \alpha^i R_i$$

R_i is the amount of the antecedent *i* day's rainfall; α is a weighting factor and set to be 0.7

3 The rainfall thresholds for landslide occurrences

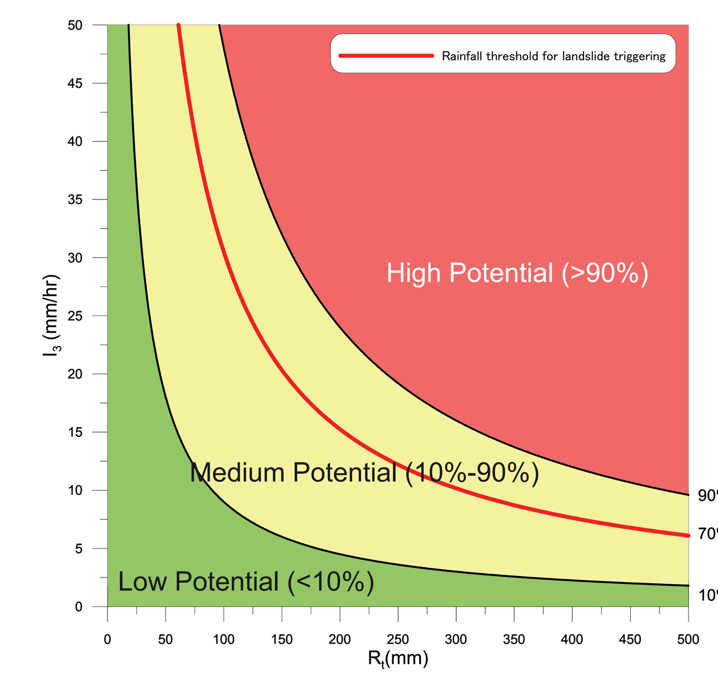


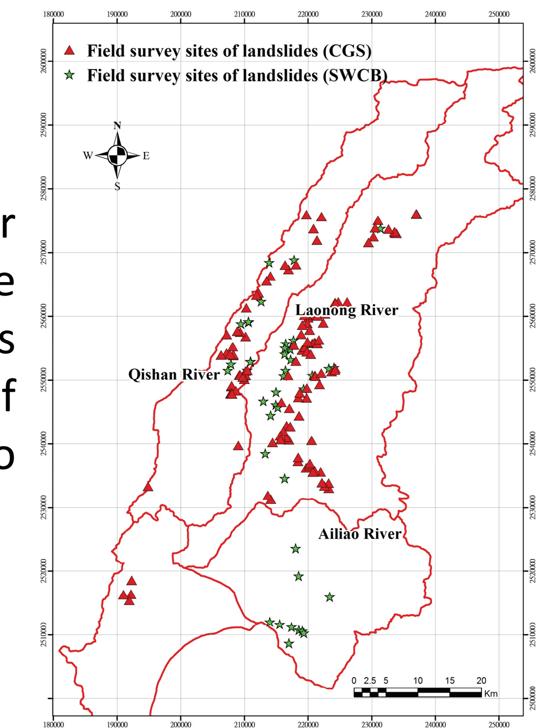
Fig. 4 The illustration of rainfall thresholds.

(a).The lower critical line (RTI_{10}) is defined as 10% of rainfall values for the historical rainfall events no matter triggering or not.

(b).The upper critical line is defined as 90 % of rainfall values for all rainfall events exceeded the lower critical line.

(c).If rainfall value is in between these two boundaries, the associated probability of landslide occurrence is estimated by linear interpolation.

The disaster-capture ratio and false-alarm ratio are used for determining appropriate probability rainfall threshold. The analysis result of historical landslide-triggering records shows that $LRTI_{70}$ is preferred adopted as the warning threshold of shallow landslides because of the higher disaster-capture ratio (95%) and lower false-alarm ratio (13%).



4 Conclusions

1. The rainfall-based statistical models are more suitable for the development of landslide rainfall thresholds at regional scale.
2. The disaster-capture ratio and false-alarm ratio will help decision maker to determine appropriate rainfall threshold.
3. The application of the Gaoping River watershed in southern Taiwan was proved that the proposed method can effectively provide early warning before landslides occurred.