Procds. of the 16th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering,
October 14-18, 2019, Taipei, Taiwan

On the rainfall induced landslides with the impact of climate change

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ABSTRACT

Climate change caused by global warming affects Taiwan significantly for the past decade. The increasing frequency of extreme rainfall events, in which concentrated and intensive rainfalls generally cause geohazards including landslides and debris flows. The extraordinary, such as 2004 Mindulle and 2009 Morakot, hit Taiwan and induced serious flooding and landslides. This study employs rainfall frequency analysis together with the atmospheric general circulation model (AGCM) downscaling estimation to understand the temporal rainfall trends, distributions, and intensities in the adopted Wu River watershed in Central Taiwan. To assess the spatial hazard of the landslides, landslide susceptibility analysis was also applied. Different types of rainfall factors were tested in the susceptibility models for a better accuracy. In addition, the routes of typhoons were also considered in the predictive analysis. The results of predictive analysis can be applied for risk prevention and management in the study area.

Keywords: landslide hazard; climate change; mountain highway; landslide susceptibility

1 INTRODUCTION

The climate change affects Taiwan significantly by an increasing frequency of extreme rainfall events, in which induced large scale landslides. Considering the existence of various types of large scale landslides and the protection targets, this study aims to analyze the landslide susceptibility along the Nantou County Road # 89 of Taiwan (see Fig.1). For the predictive analysis of landslide susceptibility, this study employed AGCM downscaling estimation. For the adopted large scale landslides (see Fig. 2), based on the information from boreholes, the temporal behavior and the complex mechanism of large scale landslides were analyzed in local scale. Based on the results, the pros and cons of the analysis in both scale were discussed, which could be applied for the risk assessment and management.

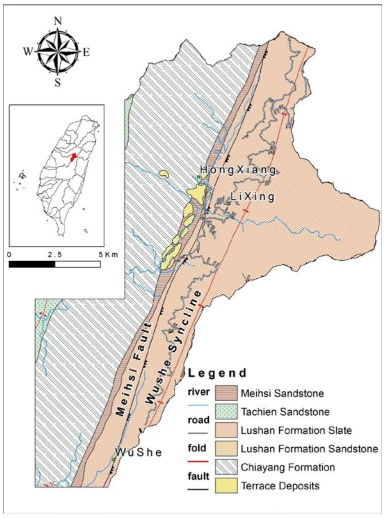
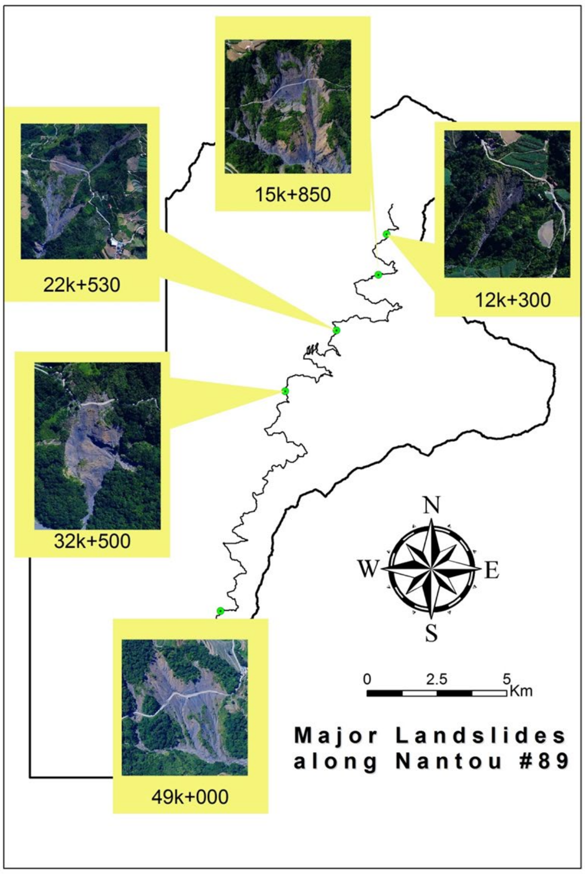


Fig. 1. Geology of the study area

Fig. 2. Large landslide along the Nantou County Road # 89



2 METHODOLOGIES

Landslide inventories, SPOT satellite images, borehole data were collected in the study area, including 5 major deep-seated landslides along the County Road #89. The obtain information and data were used for the shallow and deep-seated landslides in different scale.

2.1 Landslides intepretation

This study adopts the NDVI-slope angel criterion, in which the normalized differential vegetation index (NDVI) is from satellite images and the slope angle is from digital elevation model (DEM). And improving the accuracy of landslide identification in shadow areas with different screening indexes, including brightness (BRI, Hsieh et al 2011), greenness (GI, Liu et al 2012; Lin et al 2013), and vegetation mask (Beumier and Idrissa 2014). The compare of landslides interpretation in different indexes as Table 1. A1 is the number of landslide cells interpreted as landslide, A3 is the number of landslide cells not interpreted as landslide, A2 is the number of non-landslide cells interpreted as non-landslide, A4 is the number of non-landslide cells interpreted as landslide.

Table 1. Comparison of the Criteria for Automatic Landslide Interpretation.

Criterion	Accuracy of Landslide Cells A1/ (A1+A3)	Accuracy of Non-landslide Cells A4/ (A2+A4)	Accuracy of Total Cells (A1+A4)/ (A1+A2+ A3+A4)
Slope=20%, NDVI=0, BRI=40	6.60	99.63	98.49
Slope=20%, NDVI=0, GI=0.25	7.11	99.62	98.49
Slope=20%, NDVI=0.2	21.02	97.79	96.86
Slope=20%, NDVI=0.2, BRI=40	18.81	97.87	96.90
Slope=20%, NDVI=0.2, GI=0.25	20.40	97.92	97.00
Slope=20%, NDVI=0.2, BRI=60	7.04	98.46	97.34

2.2 Landslide-rainfall index (Id)

For a specific typhoon event, by the overlapping function of GIS, the accumulated rainfall and rainfall intensity data at the landslide locations can be extracted and plotted in graph of accumulated rainfall and rainfall intensity (see Fig. 3).The landslide-rainfall index (Id) is defined by the distances d1 and d2 from the unknown point to the linear thresholds as d2/(d1+d2) (Shou et al, 2015).

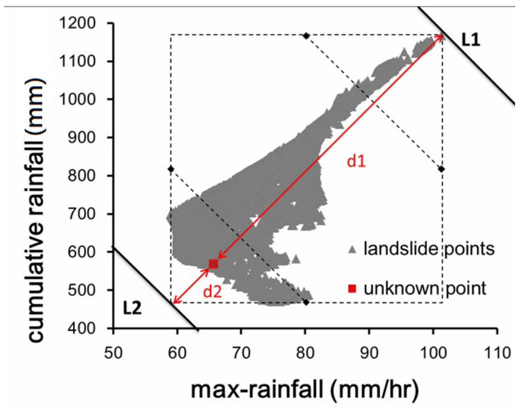


Fig. 3. The landslide-rainfall index (Id) is defined as d2/(d1+d2).

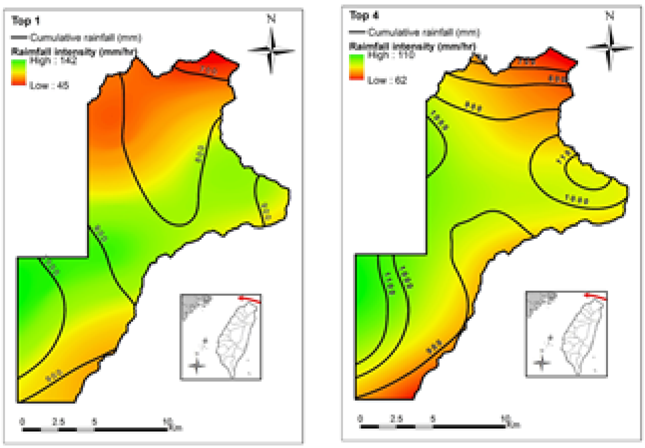
It ranges between 0 and 1. As Id approaches 1, the slope becomes increasingly susceptible to rainfall-induced landslide. On the contrary, as the point of the rainfall of potential landslide approaches the lower threshold, or as Id approaches 0, the slope becomes less susceptible to landslide.

2.3 Landslide susceptibility models

This study adopts the In Logistic Regression Method for the landslide susceptibility analysis. Its performance was compared for the analyses of 2004 Mindulle, 2009 Morakot, and 2012 Saola. Based on the training samples, which comprised a group of data points or data locations, categorized as landslide and non-landslide. The data layer of each factor was then placed upon the landslide and non-landslide layers, and the correlation between each factor and landslides was used to conduct binary logistic regression. For the susceptibility model obtained by logistic regression, this study employed the receiver operating characteristic (ROC) curve (Swets 1988), in which the area under the curve (AUC) of the ROC curve was used to evaluate the prediction accuracy. Generally, the larger the AUC values the better. As the area approaches 0.5, the result may not necessarily be superior to that of a random selection. AUC values of less than 0.5 are not worth employing.

2.4 Rainfall predictions

This study employs rainfall frequency analysis together with the atmospheric general circulation model (AGCM) downscaling estimation to understand the temporal rainfall trends (see Fig. 4), distributions, and intensities in the adopted study area in Central Taiwan.



(a) near future (b) far future

Fig. 4. The predicted rainfall distributions in the upper Wu River watershed for the near future (2017~2036) and far future (2075~2099), based on the MRI-WRF dynamical downscaling data provided by TCCIP.

To assess the spatial hazard of the landslides along the mountain highways, landslide susceptibility analysis was applied. Landslide susceptibility model established by logistic regression method was applied and discussed. The results of predictive analysis can be applied for risk prevention and management in the study area.

3 LANDSLIDE SUSCEPTIBILITY ANALYSIS

This study adopts the Logistic Regression Method for the landslide susceptibility analysis. The model based on 2004 Mindulle can be expressed as

$$P=0.663F1+0.055F2-0.317F3-0.062F4-0.301F5-0.216F6-0.093F7+0.081F8-2.451F9+0.295 \quad (1)$$

where P is the logistic function, F1 is the slope angle, F2 is the elevation, F3 is the aspect, F4 is the distance to fault, F5 is the distance to river, F6 is the distance to road, F7 is the dip slope index (Ids), F8 is the landslide-rainfall index (Id), and F9 is the normalized differential vegetation index (NDVI). Eq. (1) can be used to calculate the landslide susceptibility based on the predicted rainfalls, including various extreme weather scenarios as below.

By using Eq. (1), we can estimate the landslide susceptibility of 2009 Morakot and 2012 Saola based on their specific rainfalls. The ROC curves for these estimations shows the AUC values are 0.806 for 2009 Morakot and 0.717 for 2012 Saola, which also reveal an acceptable performance of the 2004 Mindulle model.

For the predictive analysis, the rainfall in the future was estimated by the climate change model introduced as below. The Taiwan Climate Change Projection and Information Platform Project (TCCIP), analyzes the results from the assessment reports of the United Nations Intergovernmental Panel on Climate Change (IPCC), results of 2004Mindulle and Top1 Typhoon show as Figs. 5~6, and compare of cells number as Table 2.

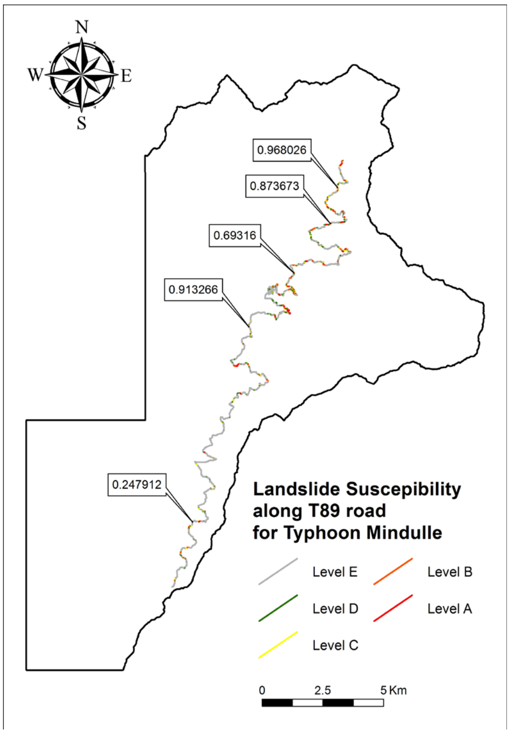


Figure 4. The landslide susceptibility along Nantou County Road #89 estimated by 2004 Mindulle model

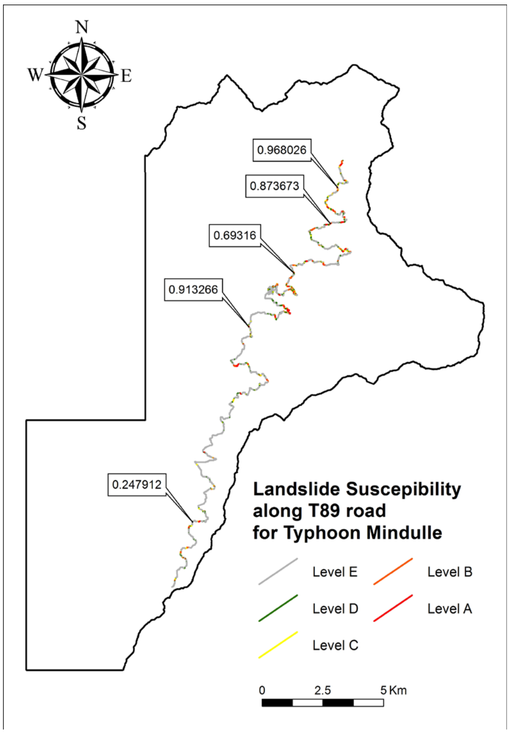


Figure 5. The landslide susceptibility along Nantou County Road #89 estimated by the TCCIP Top1 Typhoon

Table 2 Comparison of the Landslide Susceptibility and Risk Ranking of the Large Scale Landslides

Site	Mindulle Landslide Susceptibility		Predict Top1 Typhoon(2075-2099) Landslide Susceptibility	
	Value	Ranking	Value	Ranking
12k+300	0.968026	1	0.966557	1
15k+850	0.873673	3	0.8683	3
22k+530	0.69316	4	0.688009	4
32k+500	0.913266	2	0.914724	2
49k+000	0.247912	5	0.271284	5

4 CONCLUSIONS

In this study, rainfall frequency analysis and the atmospheric general circulation model (AGCM) downscaling estimation were applied to understand the temporal rainfall trends and distributions in the study area. The susceptibility analysis in catchment scale and local scale were performed for the hazard assessment of the mountain highway, i.e., Nantou County Road # 89 in Central Taiwan. The hazard of the major landslides can be ranked to prioritize the hazard mitigation. It is worth noting that the results of local scale analysis also suggest a similar hazard ranking of these landslides, i.e. the sites 15k+850 and 12k+300 are the most dangerous.

ACKNOWLEDGEMENTS

This research was made possible by the financial support of the Ministry of Science and Technology (Project No. 107-2625-M-005-005-005) of Taiwan. We also deeply appreciate the databases and support from the research groups conducting the Central Geological Survey project (Project No. 97-5826901000-05).

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