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# Multi-scale landslide susceptibility analysis along a mountain highway in Central Taiwan

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ABSTRACT

For the past decade, climate change has caused increasingly more frequent extreme rainfall events in Taiwan, during which concentrated and intense rainfall has induced large-scale flooding and landslides. Considering the urgency of protecting isolated villages and residential areas near highways from large-scale landslides, this study analyzed landslide susceptibility along Nantou County Road #89, in the upstream region of the Wu River in Taiwan. To assess landslide hazards spatially, landslide susceptibility analysis was implemented at the catchment scale. To predict landslide susceptibility, this study employed an atmospheric general circulation model with downscaling estimation. Information from boreholes was used to analyze the temporal behavior and complex mechanisms of large-scale landslides at the local scale. On the basis of the results, this paper discusses the different findings from the catchment- and local-scale analyses. For the major large-scale landslides, the rankings of landslide susceptibility values can be obtained to prioritize the remediation of the landslides. And the multiscale landslide susceptibility analysis could be applied to mountain highways with complex landslide hazard.



## 1. Introduction

Because of climate change, over the past decade, Taiwan has been affected by periods of concentrated rainfall with high rainfall intensities. The Climate Change in Taiwan Scientific Report (Hsu et al., 2011) systematically revealed relevant changes in Taiwan's precipitation. The average number of annual rain days in Taiwan has decreased significantly over the last 100 years; moreover, the number of days with heavy rain (>200 mm) has shown a significantly increasing trend in the last 50 years. Because of these climatic abnormalities, Taiwan has been affected by increasingly concentrated rainfall periods and higher rainfall intensities, which has increased the natural hazards.

Taiwan has geologically young formations fractured by plate tectonic activities, and it is therefore prone to landslides and debris flows during seasons of torrential rain, particularly in the country's mountain areas. The mountain highways of Taiwan are often affected by landslides and debris flows. The impact of the 1999 Chi-Chi earthquake increased the fractures of rock formations and changed the morphology of the mountain areas. Over the years, the visible evidences of the 1999 Chi-Chi earthquake have diminished as the fractured material and sediments in upstream locations have gradually been transported downstream (Lin et al., 2008; Shou et al., 2012). The effects of climatic abnormalities are becoming increasingly apparent, which makes the mountain highways difficult to maintain (Wu and Jou, 2006, Hsu et al., 2011, Liu et al., 2011). Nantou County Road #89, located in the upstream region of the Wu River, is a vital mountain road because it not only connects the major villages in this area, but also provides an alternative route to the important mountain city, Lishan. Focusing on the landslide hazard along this mountain highway, this study adopted the upstream region of the Wu River as the study area.

The Wu River watershed is one of the major watersheds that are prone to geohazards in Central Taiwan. The geology and the topography are strongly affected by geological structures that run along a north–south direction (Fig. 1). Although studies have analyzed landslides along highways with geology similar to that of the study area or at sites that are close to the study area (Lo and Feng, 2014; Chang et al., 2015), limited studies have presented detailed analyses of the study area, with or without consideration of the effects of climate change, which motivates this study. Chiang and Chang (2011) considered the potential impact of climate change in their analysis of typhoon-triggered landslides in Taiwan. However, their study was on a national scale and was based on rainfall predicted by a less mature climate model. Focusing on the Chingshui River watershed in Central Taiwan, Shou and Yang (2015) analyzed landslide susceptibility in extreme rainfall scenarios; they employed a rainfall frequency analysis and atmospheric general circulation model (AGCM) downscaling estimation.

Regarding multiscale landslide analysis, Guzzetti et al. (1999) tested the proficiency and limitations of multivariate statistical techniques; they examined various methodologies for dividing a territory into suitable areas for landslide hazard assessment at various scales. Their study

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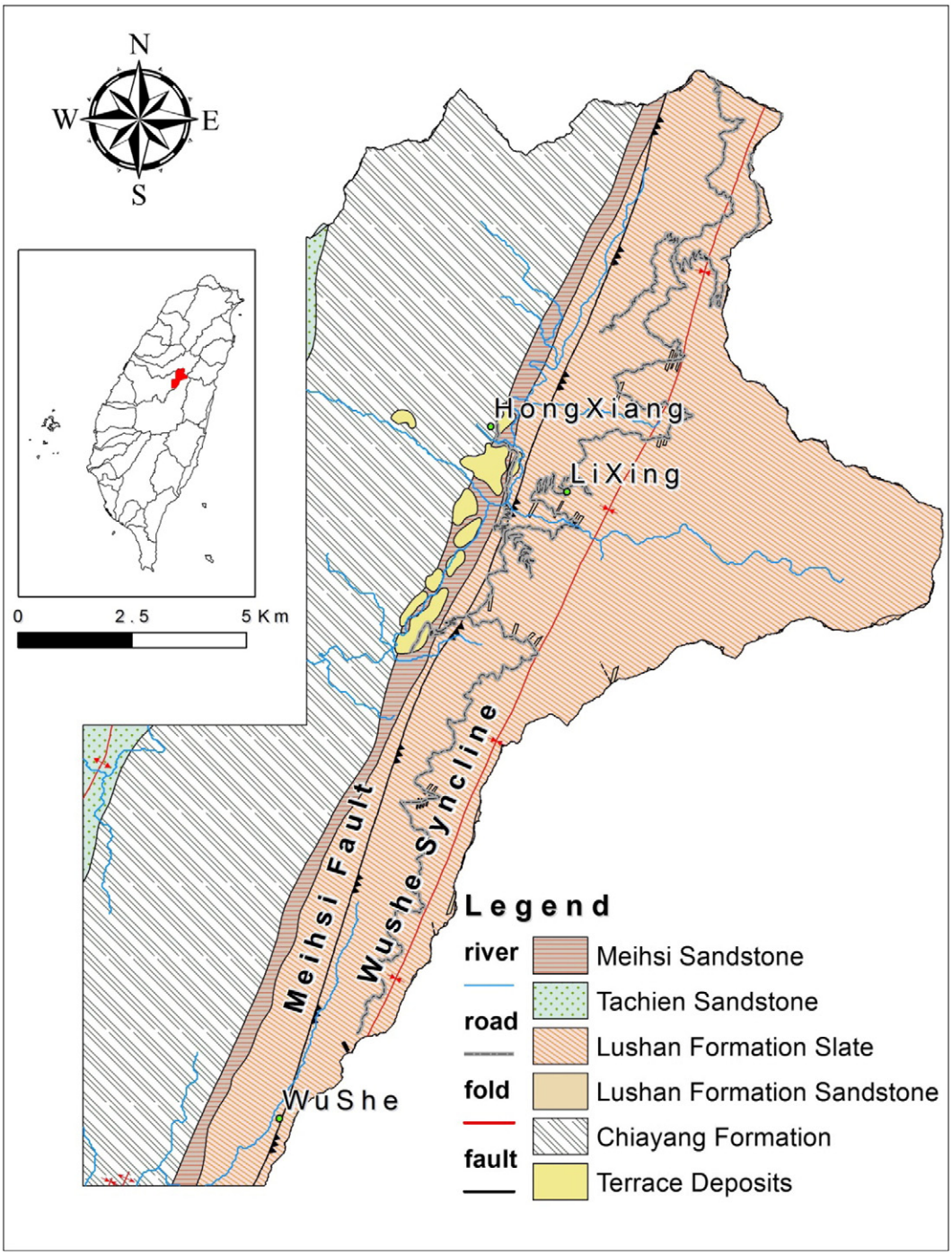


**Fig. 1.** The geology along the Nantou County Road #89 in the Upper Wu River watershed.

showed that landslide hazard assessment may constitute a suitable and cost-effective aid to land-use planning, and engineering geomorphology may facilitate assessing areas with high landslide hazard. Glade and Crozier (2005) reviewed the scale dependency in landslide hazard and risk analysis, and indicated that spatial landslide assessments require scale-dependent analysis to mitigate damage and other negative consequences at the various scales of occurrence. Lahousse et al. (2011) developed a multiscale object-based image analysis landslide detection technique for mapping shallow landslides. Their semiautomated detection method involved selecting multiple scales by analyzing landslide size statistics over successive classification rounds, and this method is expected to be useful for mapping shallow landslides. Kirschbaum et al. (2012) presented a modeling approach for landslide prediction, and found the algorithm for the scenario is critical for landslide hazard assessments.

According to the study of landslides in the French Alps, Lopez-Saez et al. (2013) found the evidence of the shift of landslide from snowmelt induced to spring temperature controlled. And their finding also suggests that climate change could further enhance landslide activity in the 21st century. For the areas with seasonal monsoons and tropical cyclones, the study of Southeast Asia (Loo et al., 2015) suggests a shift of the Indian summer monsoon and a delay of about 15 days; the study of the tropical cyclones in the North Pacific Ocean (Mori and Takemi, 2016) suggests changes in both tropical cyclone intensity and track. Collison et al. (2000) combined slope stability model with a down scaled general circulation model (GCM), and assessed the impact of climate change on