Impact of changes in climate and land cover conditions in the application of TRIGRS model for landslide susceptibility in Northeast Vietnam

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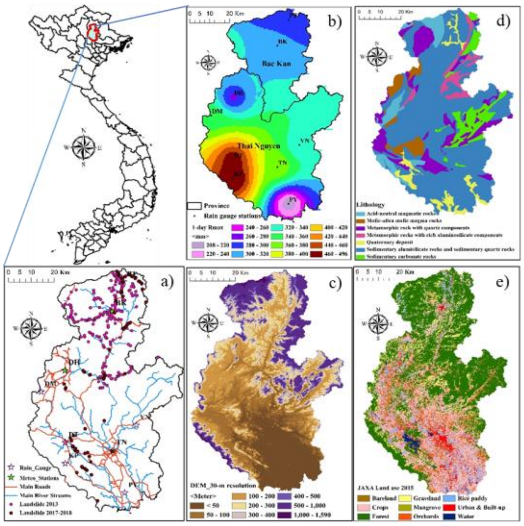
1. Introduction

Northeastern Vietnam is considered as one of the landslide-prone area, in which heavy rainfall, hydro-geological features, as well as human interferences in land-cover and natural slope condition are major contributors to the landfall occurrences. In fact, changes in natural slope conditions in relation to the higher and more frequencies of extreme precipitation due to climate change could bring about high risk of landfalls in this agricultural area. The expansion of poor-planning activities has resulted in high risk of slope failures especially under triggering events including prolonged-extreme rainfall; such failure has also borne catastrophic consequences to the society. It is crucially important to examine the potential impacts from anticipating changes to the climate regime on geotechnical properties, which control the slope stability. Therefore, main purpose of this study is to address landslide susceptibilities through application of the Transient Rainfall Infiltration and Grid-based Regional Slope stability (TRIGRS) model in a regional scale focusing the roles of a triggering parameter (rainfall) in relation to conditioning factors including changes land-use under the influence of climate change.

2. Study area

In this research, we examined the slope stability condition in the Cau River basin in the Northeast Vietnam. The catchment locates in the Northeast region, lying from 105.48° to 106.13° East longitude, and from 21.35° to 22.32° North latitude. The maximum 1-day precipitation in this basin varied from 208 to 496 mm (Fig. 1 b)). High rainfall often concentrates in the southwest area near the Tam Dao mountain ranges (peak elevation of above 1,500 m as shown in Fig. 1 c)). During the field investigation of the national project of landslide inventory in 2013, 141 landslide points were recorded in Bac Kan area belonging to the Cau River basin. In addition, an additional 57 slope-failure points were recorded during our filed-surveys in 2017-2018 (Fig. 1 a)). Based on the criteria of clay material components, estimated strength and density, and



a) Landslides in 2013 & 2017-2018 **b)** Maximum 1-day rainfall (1962-2016) **c)** 30m-DEM **d)** Lithology map **e)** Land use map 2015 (JAXA)

Fig. 1 Study area

weathering degree, there are seven lithology groups in this catchment as described in Fig. 1 d). According to the research of the Japan Aerospace Exploration Agency (JAXA), nine classes of land-use are shown in Fig. 1 e).

3. Methodology

In this study, the landslide susceptibility is analyzed based on the deterministic method using a Transient Rainfall Infiltration and Grid-Based Region Slope-Stability (TRIGRS) model. In this program, the pore-water pressure and the value of factor of safety (Fs) are calculated on a cell-by-cell basis and can be operated in the geographic information system [1)]:

$$Fs(Z,t)=\frac{\tan\varphi}{\tan\delta}+\frac{c-\Psi(Z,t)\gamma_w\tan\varphi}{\gamma_s Z\sin\delta\cos\delta} \qquad \text{(Eq. 1)}$$

In where Z is vertical coordinate direction (positive downward) and depth below surface (m); t represents time (second); φ is the soil friction angle (°); δ illustrates the slope angle (°); c refers to the cohesion (N/m^2); Ψ is ground-water pressure head (m); γ_s and γ_w refer to the unit weight of soil and unit weight of water (N/m^3). In order to set up simulating options in the assessment of slope stability state in the Cau basin, the authors considered five major components as illustrated in Table 1. Rainstorm

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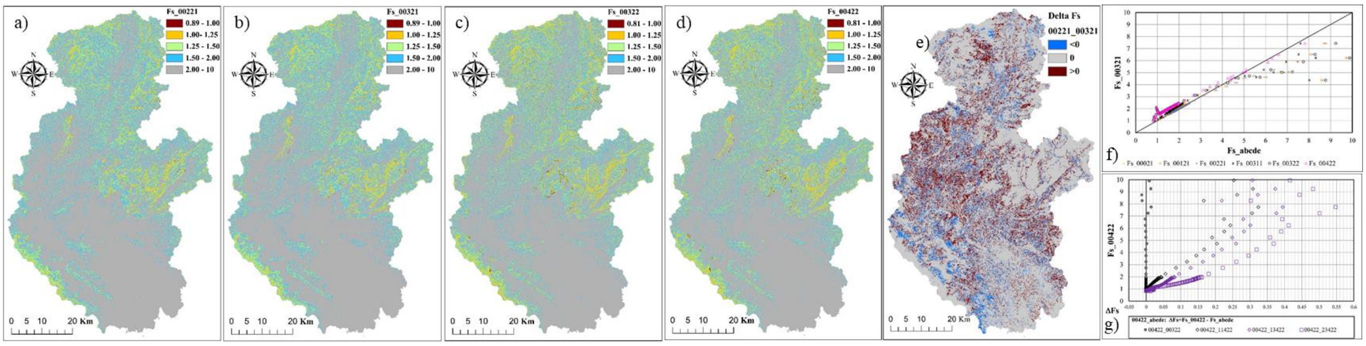

Fig. 2 Characteristics of Fs regarding to historical rainfall [a) to f)] and in case of 24-hr PMP and 48-hr PMP [g)]

Table 1. Summary of options [abcde]

	Rain event a	Rain distribution b	Land cover c	Soil depth d	DEM resolution e
0	Storm rain 2013	Actual distribution	Bared soil		
1	24-hour PMP	Type 1	USGS 2010	Case 1	30 meter
2	48-hour PMP	Type 2	JAXA 2007-50 m	Case 2	10 meter
3		Type 3	JAXA 2015-50 m		
4			JAXA 2015-30 m		

events included historical rainfall in 2013, and Probable Maximum Precipitation (PMP) using three distribution types regarding to the location of the peak-intensity in a storm. Land-cover data was collected from the USGS and JAXA. The spatial distribution of soil thickness based on the empirical relationship between topography attributes and soil thickness following the Saulnier method [2)].

4. Results

With regard to landslide susceptibility due the rainstorm events in 2013 using original DEM data of 30 meter (e=1), case 1 in soil depth estimation (00311) produced lower values of the factor of safety than the outputs from the soil-depth case 2 options (00021, 00121, 00221, and 00321). Under the same condition of soil depth (d=2), when the entire basin was covered by bare soil (00021), more unstable areas (Fs<1) were displayed, especially in the north, northwest, and southeast Bac Kan comparing to the Fs results from other options (00121, 00221, and 00321). Changes in land cover database such as USGS (2010) and JAXA (2007 & 2015) performed significant impact on the model simulation, as illustrated in difference between 00121 and 00221, as well as between 00121 and 00321. Such changes would be resulted from differences in resolution between two databases as well as some changes in land cover. When the same database of land-use was utilized, i.e. JAXA, changes in the land surface cover from 2007 (00221) to 2015 (00321 and 00421) resulted in changes in the value of factor of safety in many parts in the basin. When the data resolution changed, the slope obtain certain responses to the stability especially in case of changing DEM resolution from 30 meter (00321) to 10 meter (00322).

5. Discussion and conclusions

Despite the fact that the certain errors are revealed in the statistical interpolation from coarse-resolution to finer resolution, the model simulation using 10-m DEM shows the role of terrain condition to the slope stability. It indicates that the TRIGRS is sensitive to the DEM data input especially in case of changes in slope conditions; it also demonstrates the agreement with the risk of slope-failures in a relationship with destabilizing factors including slope-cutting activities. Differences in the resolution of input data also influence the output data as illustrated in scenarios 00322 (JAXA 2015 using 50-meter resolution) and 00422 (JAXA 2015 using 30-meter resolution). However, these changes are smaller than the change in DEM resolution. It is noted that under the same amount of the storm-rain and storm duration, landslide prone areas would expanse in case of changing the storm distribution from type 1 (11422) to type 3 (13422). Under the same rainfall distribution, the rise in rainstorm amount and duration leads to the decrease in the factor of safety. This reveals the importance of three major components of a storm event including rain-amount, rain-duration, and rain-distribution to the stability condition of hilly sites.

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