HỘI NGHỊ TOÀN QUỐC KHOA HỌC TRÁI ĐẤT
VÀ TÀI NGUYÊN VỚI PHÁT TRIỂN BỀN VỮNG (ERSD 2018)

Simulation of propagation area triggered by debris flows using Flow-R: A case study at Ta Phoi watershed, Lao Cai province

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ABSTRACT

This research activity aimed at reducing risk of debris flows to infrastructure at Ta Phoi watershed by using Flow-R model. Hence, an inventory of debris flow deposits were compiled by previous researches and field surveys. The Flow-R model allows for automatic source area delineation, given user criteria, and for the assessment of the propagation extent based on various spreading algorithms and simple frictional laws. The debris flow map for Ta Phoi watershed provides a substantial basis for a preliminary susceptibility assessment at a regional scale. Field verification with known debris flow events helped define the parameters of source areas, spreading, and runout distance. Final result produces a map that captures most of the known events and displays debris flow susceptibility in smaller and steep channels that had not been previously documented.

Keywords: debris flows, Flow-R model, Ta Phoi watershed

1. Introduction

A debris flow is a moving mass of loose mud, sand, soil, rock, water and air that travels down a slope under the influence of gravity. Debris flow constitutes one of the most destructive geological hazards in the world today. One of the main reasons for this is because of the high speeds that slides can reach. A single flow is capable of burying entire small towns and communities, covering roads, causing death and injury, destroying property and bringing all transportation to a halt.

In Vietnam, most debris flows occurred at the end of the rainy season when soils and rocks were water-oversaturated thus mechanically weak; this is when pore water pressure decreases, lowering the strength from the soil. Debris flows like water-laden masses of soil and fragmented rock rush down mountainsides, funnel into stream channels, entrain objects in their paths, and form thick, muddy deposits on valley floors. The debris flow occurred in Muong Lay in August 1996 was the first to be witnessed by survivors and videotaped so that it was attracted greatly by society. Subsequently. debris flows were also recorded in Nam Coong (Sin Ho, Lai Chau) in October 2000, Tan Nam (Xin Man, Ha Giang) in July 2002, Du Tien (Yen Minh, Ha Giang) in July 2004, Khen Len (Pac Nam, Bac Kan) in July 2009, Nam Luc (Bac Ha, Lao Cai) in September 2012, and Ban Khoang (Sa Pa, Lao Cai) in September 2013 (Tran Van Tu et al., 2016). Besides the well-known places, debris flows occurred in many remote and isolate areas.

Debris flows are among the most devastating natural disasters in mountainous regions of Vietnam, especially in the northern part like Lao Cai province. The Ta Phoi watershed composed of mountainous range of Phan Si Pan (over 75% of total area) with average annual rainfall of ~2000mm. The typhoon season starts from June to September and maximum daily rainfall can reach up to 560mm/day. However, most of the debris flows were initiated by slope steepness as terrain differentiation define the potential energy of rock masses. These slopes are steep enough for flash floods to happen and it was found that, in Ta Phoi watershed, debris flows occurred in areas having slopes as steep as 25-35°.

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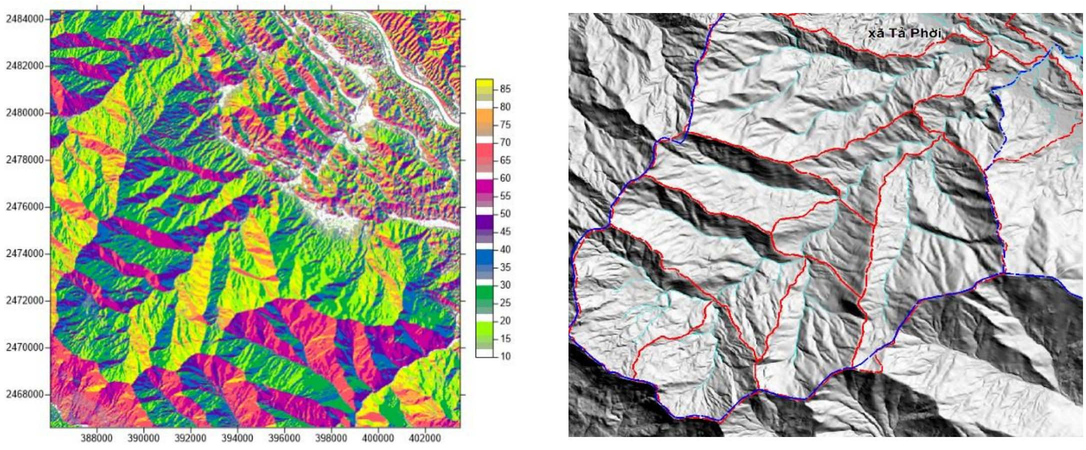


a) b)

Figure 1. Slope steepness (a) and small watershed (b) of Ta Phoi watershed

2. Geological settings

The geology of northern mountainous regions of Lao Cai where debris flows commonly occurred includes relatively soft formations, comprising mainly of Proterozoic to early Cambrian schists, early Proterozoic and Cenozoic granodiorite, diorite and granites. Late Cenozoic tectonic activities have created main characteristics of topography, distribution of rivers and streams network, as well as weathered activities in the north Vietnam (Ngo Van Liem et al., 2016).

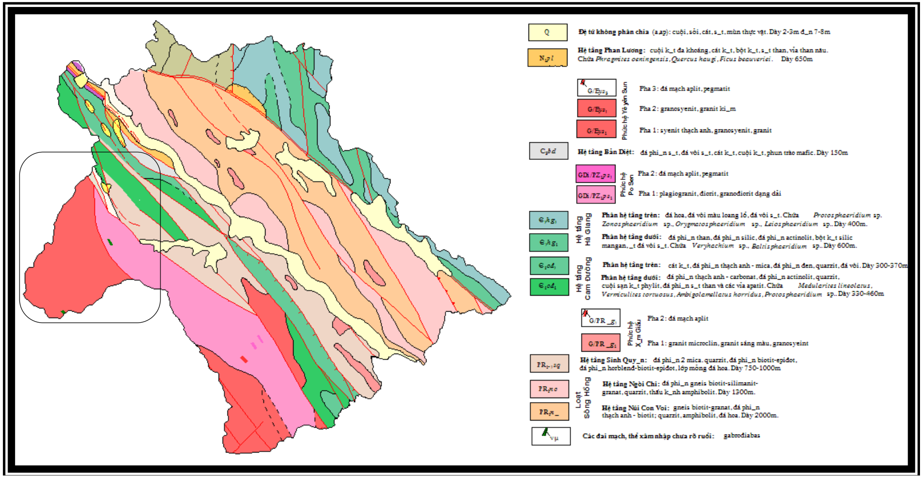


Figure 2. Geological map of study area

At Ta Phoi watershed, high elevation on the upstream part mostly composed of granosyenite, alkaline granite and quartz syenite of Yeyesun complex (Ɛ*ys*) and plagiogranite, diorite and banded granodiorite of Po Sen complex (PZ$_1$*ps*). Whether the downstream composed by two-mica schist, biotite-epidote schist of Sinh Quyen formation (PR$_{1\text{-}2}$*sq*) and quartz schist, silic schist, sandstone, limestone of Cam Duong formation (∈$_1$*cđ*). A geologically significant feature of these areas is the strong activity of recent geodynamics.

3. Flow-R model

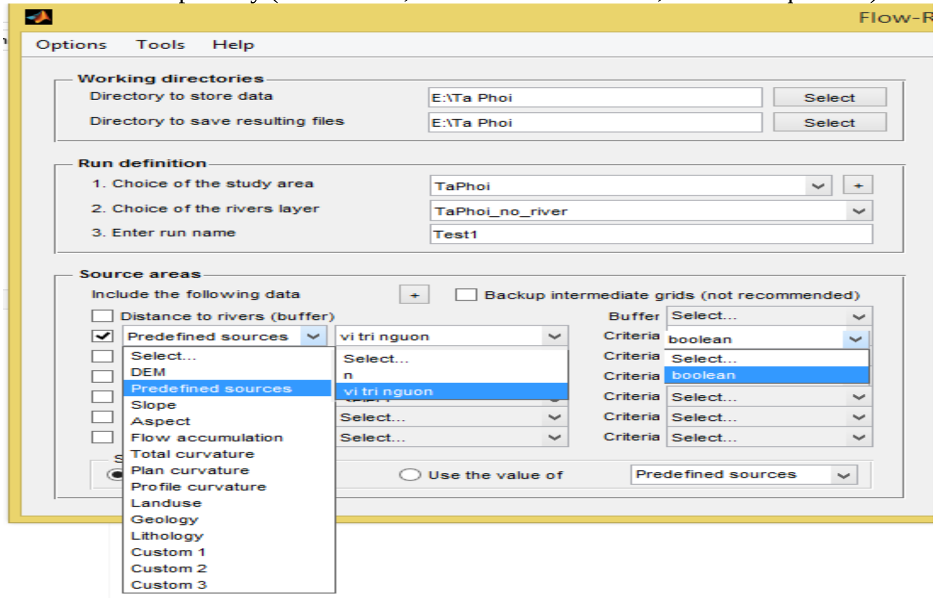
We used the Flow-R model developed by Horton et al. (2008, 2013) to assess debris flow susceptibility and focus on the area of Ta Phoi watershed. Flow-R, developed under Matlab® by Horton et al. (2013) stands for *Flow path assessment of gravitational hazards at a Regional scale* and can be freely downloaded from www.flow-r.org.

The main data set required for susceptibility assessment in Flow-R is a grid-based DEM. The quality of DEM is of great importance for the accuracy of the results. We used a 10×10m DEM in order to reduce the roughness and avoid the effect of channelization that can occur with very high resolution data so that a wider propagation could be captured within the fans. The following concepts of Flow-R and the implemented models are summarized from Horton et al. (2013). Susceptibility assessment using Flow-R involves two stages (Horton et al., 2013):

Step 1 - Delineation of debris flow source areas based on the geological, morphological, and hydrological criteria critical in debris flow occurrence. These controlling parameters are used in grid format and are classified according to their favourability in debris flow initiation. The data are classified as favourable if initiation is possible, excluded if the initiation is unlikely, and ignored if there is not enough evidence in favourability of the class. The classified input parameters are integrated based on the following rule: a grid cell is considered a source area if it was classified as favourable in at least one of the parameter maps, but was never classified as excluded.

Step 2 - Propagation of the source areas. The potential source areas are propagated using two types of algorithms: (1) spreading algorithms which determine the path and the way debris flows spread and (2) algorithms which are based on the friction laws and control the runout distance of debris.

The spreading algorithms address flow direction algorithms and persistence functions and describe downslope movement of material. We used the flow direction algorithm of Holmgren (1994) and applied the height factor added by Horton et al. (2013) in order to smooth the roughness of the DEM and obtain a more consistent spreading. Another influencing factor which is implemented in Flow-R is inertial parameter. The flow direction is weighted based on the change in direction according to the persistence function. The weights resulted from the persistence function and those from flow direction are combined to provide the overall susceptibility (see Gamma, 2000 and Horton et al., 2013 for equations).



Working directories
Directory to store data: E:\Ta Phoi
Directory to save resulting files: E:\Ta Phoi

Run definition
1. Choice of the study area: TaPhoi
2. Choice of the rivers layer: TaPhoi_no_river
3. Enter run name: Test1

Source areas
Include the following data
☐ Backup intermediate grids (not recommended)
☐ Distance to rivers (buffer) — Buffer: Select...
☑ Predefined sources: vi tri nguon — Criteria: boolean
○ Use the value of: Predefined sources

Figure 3. Screen capture of the main frame of the Flow-R software

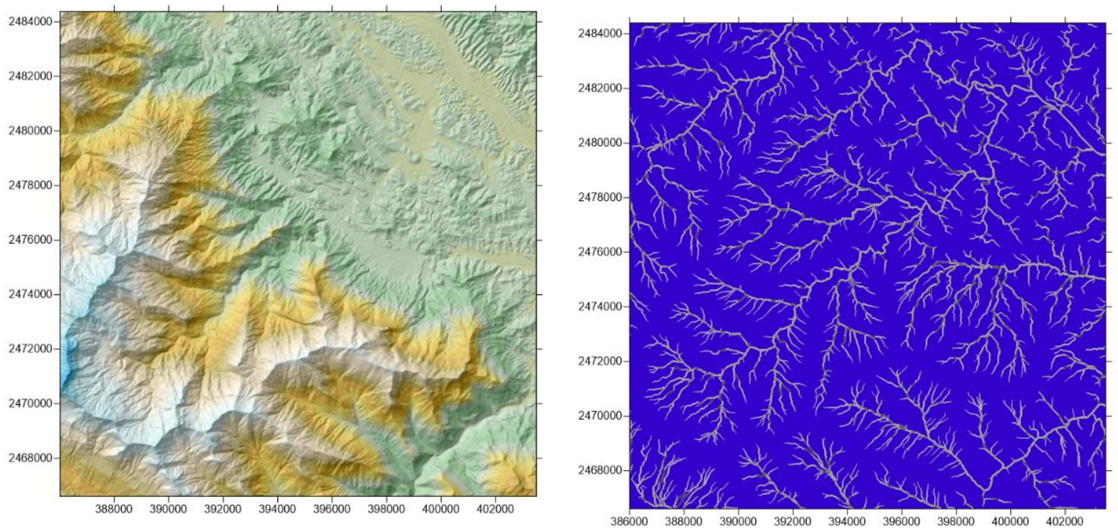
The runout distance algorithms control the distance which can be reached by debris flows. Two types of algorithms are available in Flow-R to assess the friction loss: a twoparameter friction model based on Perla et al. (1980) and a simplified friction model based on maximum possible runout distance. The Perla model, used in this study, is based on a non-linear friction law and calculates the velocity of the flow at the end of segment i. The model requires the value of friction coefficient μ and mass-to-drag ratio ω to be provided. In order to keep the energy within reasonable values, a maximum threshold is introduced to avoid achieving unrealistic velocities.

4. Assessment of the debris flows at Ta Phoi watershed

Recent debris flow occurred in August 2018 after heavy rainfall on saturated Quaternary deposits due to hydroelectric pipe leaking. It travelled almost 3-4km downslope and reached the Red river valley, next to the Coc 1 village of Lao Cai city. The event, transporting approximately 15,000m^3 and affected all the access roads, with at least a casualty and several missing. The propagation profile is fairly regular, but presents a brutal slope transition to the valley floor, which makes it a non-regular debris fan.

Figure 4. Debris materials at the downstream

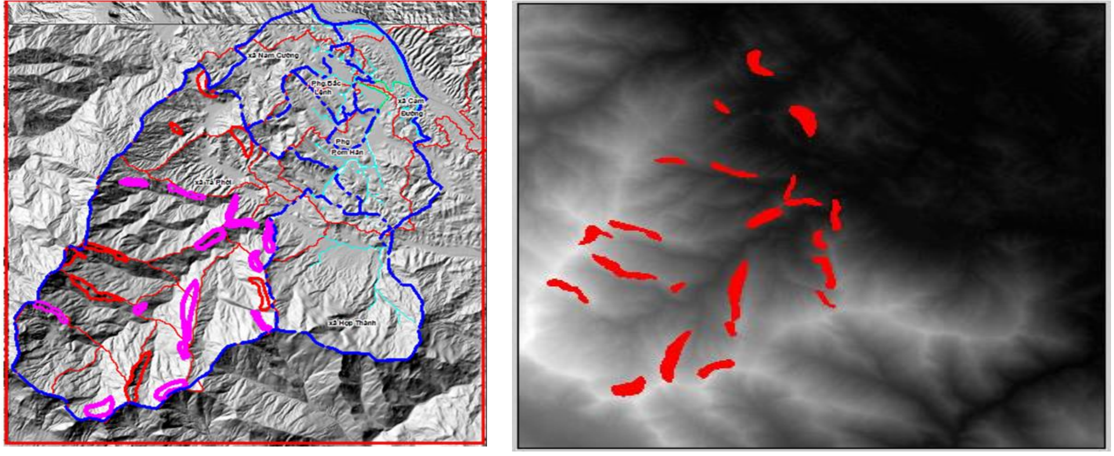
At the Ta Phoi watershed, the source material of debris flows originates either from surfacial deposit, colluvium, slope mass movement or/and fluvial deposits. Hydrologically, due to the fragmentation of the terrain, the river system in the study area is dense and unevenly distributed.



a) b)

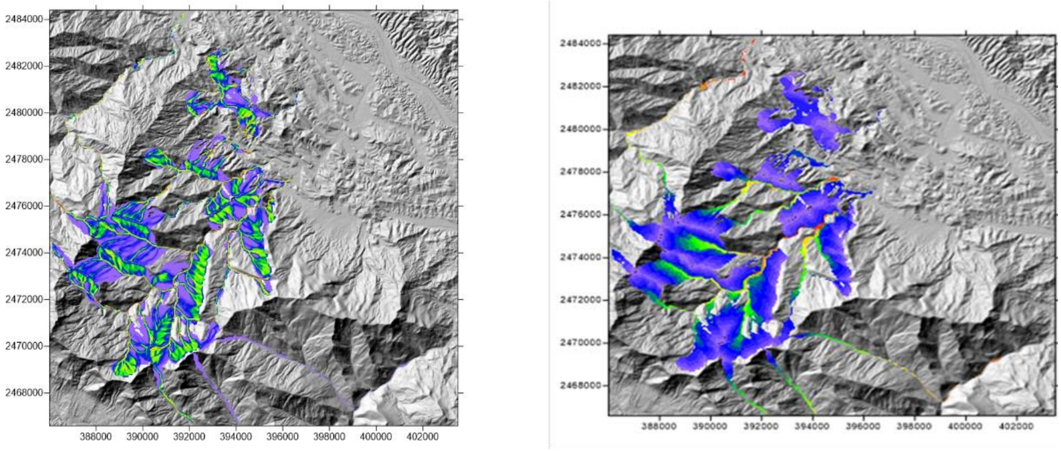
Figure 5. Areal view (b) and stream networks (b) of Ta Phoi watershed

The debris flow susceptibility map created using the propagation of source areas represents the present-day conditions. The mapped debris flow deposits were used to evaluate the susceptibility map although these deposits likely have been accumulating since Cenozoic deposits and spreading into large fans. Out of mapped 14 debris flow deposits, most are reached in terms of runout distance, but some of them are not completely covered in terms of lateral spreading. Nevertheless, debris can still flow, propagate, and block the highway even as relatively small fans.



a) b)

Figure 6. Source areas of debris flows on field map (a) and on DEM (b)



a) b)

Figure 7. The propagation of source areas (a) and maximum energy (b) of debris flows

Field verification at highly susceptibility areas was carried out in early October 2018 shows that the mose affected villages are Coc, Tram Thai and Cuoc of Ta Phoi commune, Lao Cai city. To mitigate the damage by debris flows, it is recommended that people should live far away from the mouth of stream containing proluvial or colluvial deposits. Communication means from remote residential areas to the nearest administrative headquarters must be established. Villages inhabited on colluvial deposits need to resettle to a more stable area.

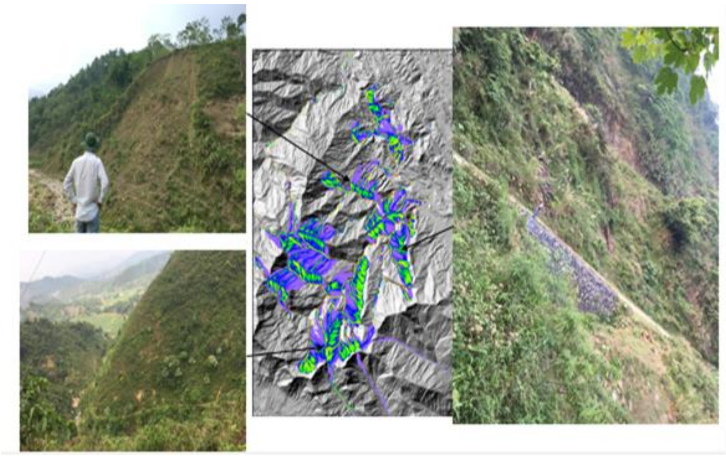


Figure 8. Field verification for highly susceptibility areas

Some noticeable features of the debris flows in Ta Phoi watershed are as follows (Tran Van Tu et al., 2016):

(1) Most debris flows occur in remote areas where transportation and communication systems are less developed, thus difficult to issue warning and help.

(2) Debris flows occur in areas where surface or temporary runoffs are channeled.

(3) Prior to debris flows' occurrence, it rains for a long time, causing soil wateroversaturated and become mechanically weak under the effect of pore water pressure. Debris flows often occur at the end of the rainy season, e.g., August, September, or even on October.

(4) Dense mud-rock flows run down to the mouth of a stream with enormous force. Downstream areas are favorable places for human settlement; therefore, the damages by debris flows are mostly effecting people.

(5) Large boulders with sizes up to several meters entrained by debris flows being pushed downward by flow currents appear to be a major factor in destroying houses, transportation and irrigation systems.

5. Conclusion

The quantitative Flow-R method was tested in order to define the potential source and debris flow susceptibility for the Ta Phoi watershed, Lao Cai province. The model allows for automatic source area delineation, given user criteria, and for the assessment of the propagation extent based on various spreading algorithms and simple frictional laws. Amongst the possible datasets, the DEM is the only one that is really needed for both the source area delineation and the propagation assessment. Correlation with known documented events helped produce a susceptibility map that captures most of the known events and displays debris flow potential in small and steep channels that had not been previously documented.

Debris flows in Ta Phoi watershed occur mainly in the proluvial and colluvial deposits or tectonic breccia zones. These soil-rocks mixed masses are weak and difficult to examine the geotechnical and engineering properties. They are stable during dry or suitable humidity condition, but become instable under watersaturated conditions, effected by fast surface flows or landslides.

The debris flow map for Ta Phoi watershed provides a substantial basis for a preliminary susceptibility assessment at a regional scale. This is a first step in assessing the debris flow hazard and risk in the future. Further quantitative hazard and risk assessments need site-specific investigations on magnitude and frequency of every events to have more reliable results.

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