Threshold Conditions for Channel Initiation in a Humid Forested Mountain: an Approach from Hydro-geomorphic Observations

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Abstract

One of the primary issues on landform evolution in mountainous terrains is what rainfall and topographic conditions affect the location of channel heads. Although many studies discussed channel initiation based on models or field observations, analysis filling the gap between models and observations is required for the better understanding of channel initiation mechanism. Many researchers focused on the conditions of shallow landsliding in humid forested mountains, while few studies discussed the role of bedload transport below channel heads. The aim of the present study is to analyze the thresholds for channel initiation by bedload transport based on the hydro-geomorphic observation in channel heads.

The investigated area is located in the eastern Ashio Mountains, eastern Japan (Awano Town, Tochigi Prefecture). The area is underlain by Triassic bedded chert, and characterized by dissected topography. Shallow landslides are rare in the investigated area. Mean annual air temperature is 12.5 °C, and average annual rainfall is 1,476 mm. Area-slope relationship in 24 channel heads shows an inverse correlation as $A = 747\ S_c^{-2.47}$ ($R^2 = 0.56$), where A is source area (m^2) and S_c is local channel gradient below a channel head.

Runoff observation was conducted in a third-order basin (CL basin) and two first-order watersheds (C1 and C3) in CL basin. Discharge was manually measured at 19 sites in CL basin for seven cases of base-flow condition and two cases of storm-flow condition. Flumes and water-depth probes for automatic runoff observation were installed at the downstream side of channel heads in C1 watershed (C1L), the downstream side of channel heads in C3 watershed (C3U), and the confluence with third-order stream in C3 (C3L). Tensiometers were

installed on a slope segment in C3 watershed. Hydrological observations were conducted mainly from June to October for three years (2000 – 2002). Bedload transport was simultaneously observed with the bedload traps installed at the three sites (C1L, C3U and C3L) from 11 June 2000.

Manual measurement of discharge at 12 springs in CL basin showed a strong correlation (R^2 = 0.79, p < 0.001) between drainage area and spring discharge during the largest storm flow. Observation of subsurface water in the slope segment revealed generation of subsurface storm flow. Since surface topography controls the flux of subsurface storm flow, the spring discharge, affected by subsurface storm flow, increases with increasing drainage area.

In the case that the peak discharge, Q_p, produced by a storm event is linearly proportional to the drainage area, A, and effective rainfall intensity, I_R, the rainfall-runoff equation is expressed by $Q_p = k_p I_R A$, where, k_p is a dimensionless coefficient on runoff peak generation. Relationship between rainfall intensity and peak specific discharge, Q_p/A, at the two channel-head sites (C1L and C3U) was analyzed with simple least squares linear regression. The maximum 4-hour rainfall, R_4, which maximizes the coefficient of determination (R^2 = 0.85), is suitable for the effective rainfall intensity in the investigated area. This analysis yielded the rainfall-runoff equation of $Q_p/A = 68.7 \times 10^{-6} (R_4 – 0.014)$.

Plots of bedload yield against peak discharge indicated that bedload yield abruptly increases when peak discharge exceeds a critical value, Q_{cr}. Critical discharges, Q_{cr}, were estimated to be 0.035 $m^3 s^{-1}$ at C1L site and 0.007 $m^3 s^{-1}$ at C3U site. These values of critical discharge satisfy a power function of channel gradient, that is $Q_{cr} = 0.0036 S_c^{-2.37}$.

In the condition that the peak discharge produced by a storm event, Q_p, is

equal to the critical discharge for bedload transport, Q_{cr}, thresholds for bedload transport is expressed by $AS_c^{2.37} = 52.4 / (R_4 - 0.014)$. In comparison with the observed area-slope data at 24 channel heads and the above thresholds for bedload transport, R_4 = 90 mm (equivalent to 3-year rain) appears to be the critical rainfall for bedload transport immediately below the channel heads. In most channel heads except for some steep channel heads, bedload transport occurs in relatively frequent rainfall (return periods of less than 30 years).

Key words: channel initiation, hydrogeomorphology, bedload transport, runoff generation, chert, humid forested mountain, return period

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