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How do valley head initiation, colluvial channel initiation, and headwater catchment extent change with relief?

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• Introduction

- Headwater catchment is a mass movement–dominated region (Gomi et al., 2002).

- Headwater catchments supply sediment, water, and nutrients for downstream channels (Figure 1).

- The area of the headwater catchment ranges from 10^4 to 10^6 m^2 (Swanson et al., 1998), but little is known about what factors affect its range.

- The headwater catchment includes hillslopes, valley heads, and colluvial channels (Figure 2).

- High elevation, steep slopes, frequent landslides, and substantial soil erosion.

- Surface processes (such as landslide and runoff) determine the hillslope sediment input into channels, thus affecting the extent of each part (hillslopes, valley heads, and the colluvial channels) in a headwater catchment.

- Such surface processes vary depending on the gradient of hillslopes, which is determined by the topographic relief.

- **How do (1) valley head initiation, (2) colluvial channel initiation, and (3) headwater catchment extent change with relief?**

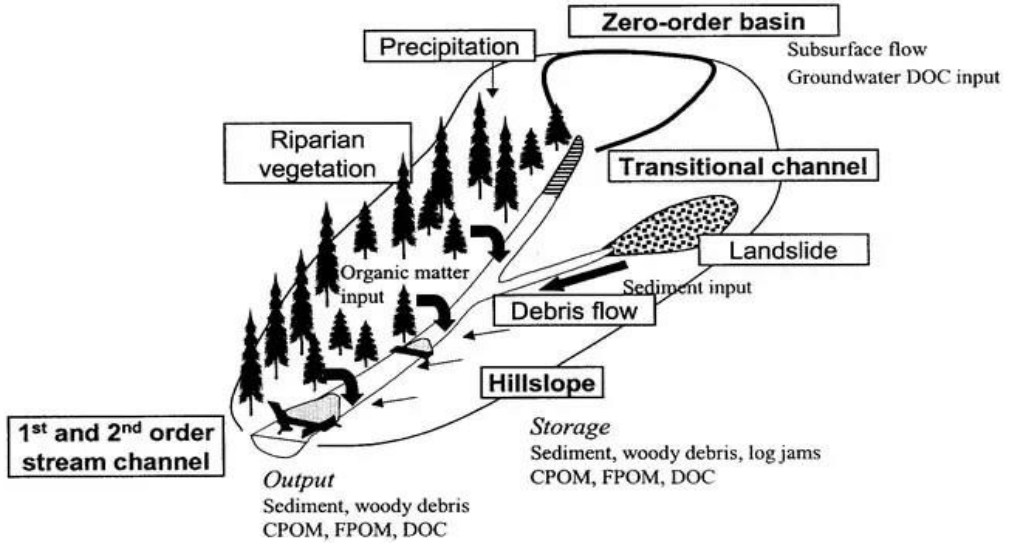


Figure 1. Processes and structures in headwater catchment (from Gomi et al., 2002). The processes in headwater catchments are different from those in downstream channels (mass movement-dominated versus fluvial process-dominated).

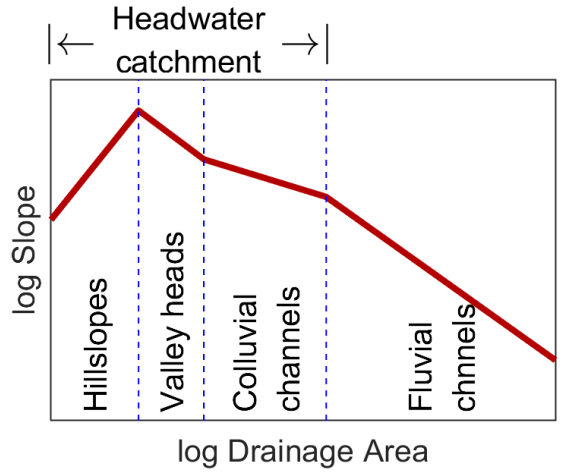
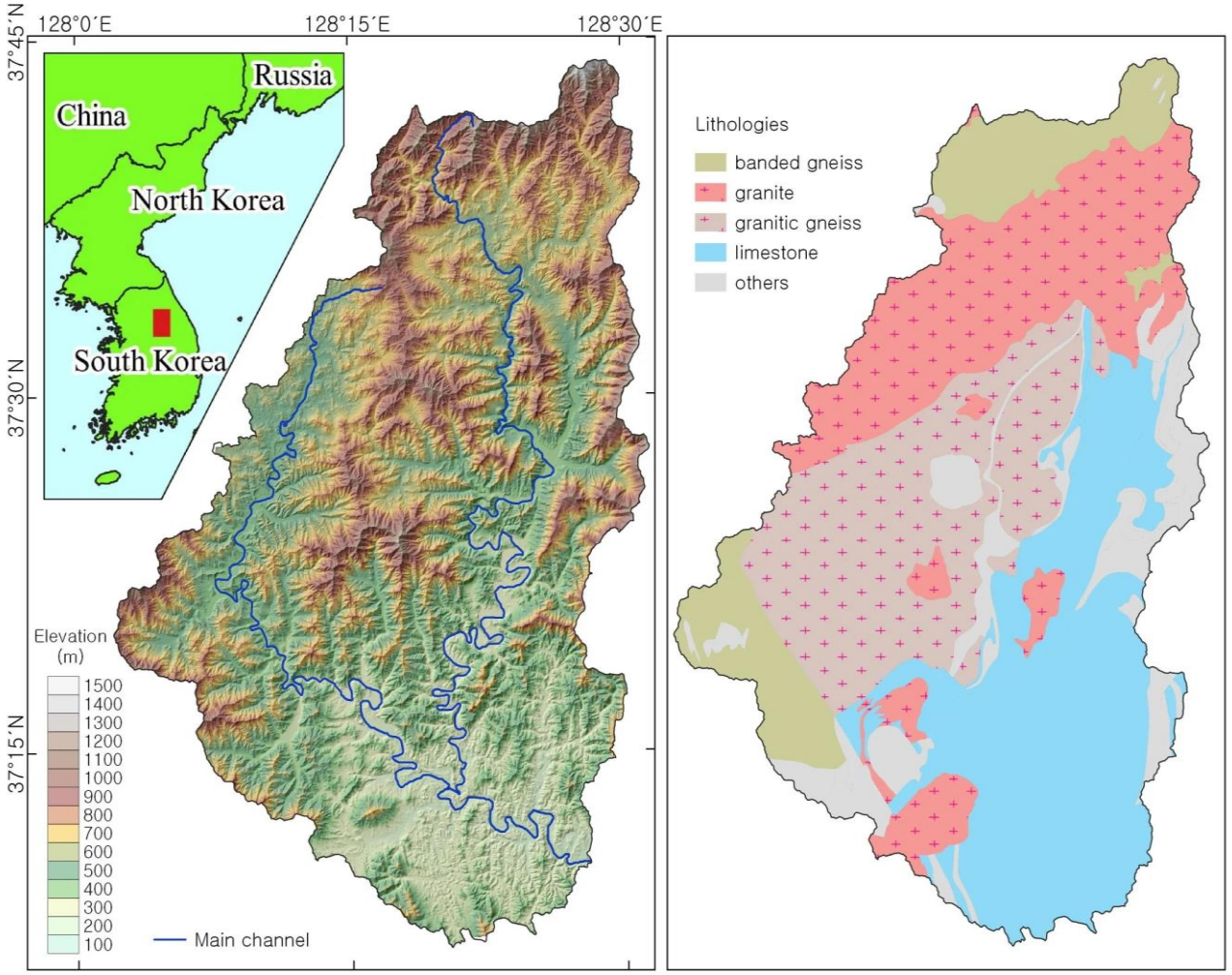


Figure 2. According to slope-area relations, the catchment can be distinguished into 4 zones (hillslopes, valley heads, colluvial and fluvial channels).

• Study area



- Seo River drainage
- Drainage area: 1770 km^2
- Range of elevation: 180 ~ 1577 m
- Topographic relief: decreased from north to south
- Rock type: banded gneiss, granite, granitic gneiss, and limestone

Figure 3. Topographic (left) and geological (right) maps of the Seo River drainage.

• Methods (1): slope-area analysis for finding valley heads initiation and headwater catchments extent

1. Extract sub-catchments (Figure 4) and calculate the relief of each sub-catchment (relief = Zmax – Zmin).
2. Find the initiation of valley heads and the extent of headwater catchments according to slope-area relationships (Figure 5).

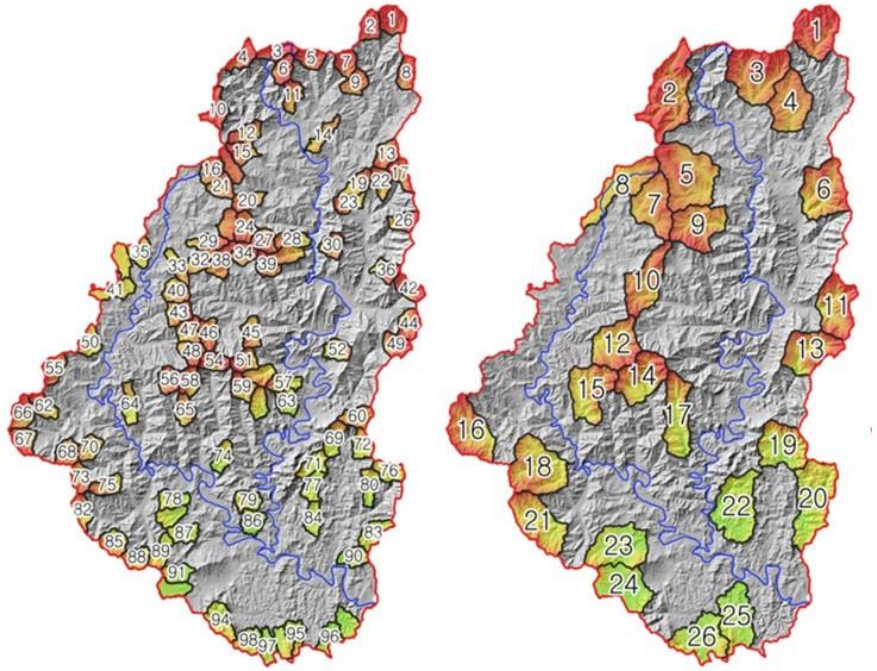


Figure 4. Location of sub-catchments for analyzing the relationship between slope and area. (Left) sub-catchments with an area of about 5 km² for finding the initiation of valley heads and colluvial channels; (Right) sub-catchments with an area of about 20 km² for finding the extent of headwater catchment.

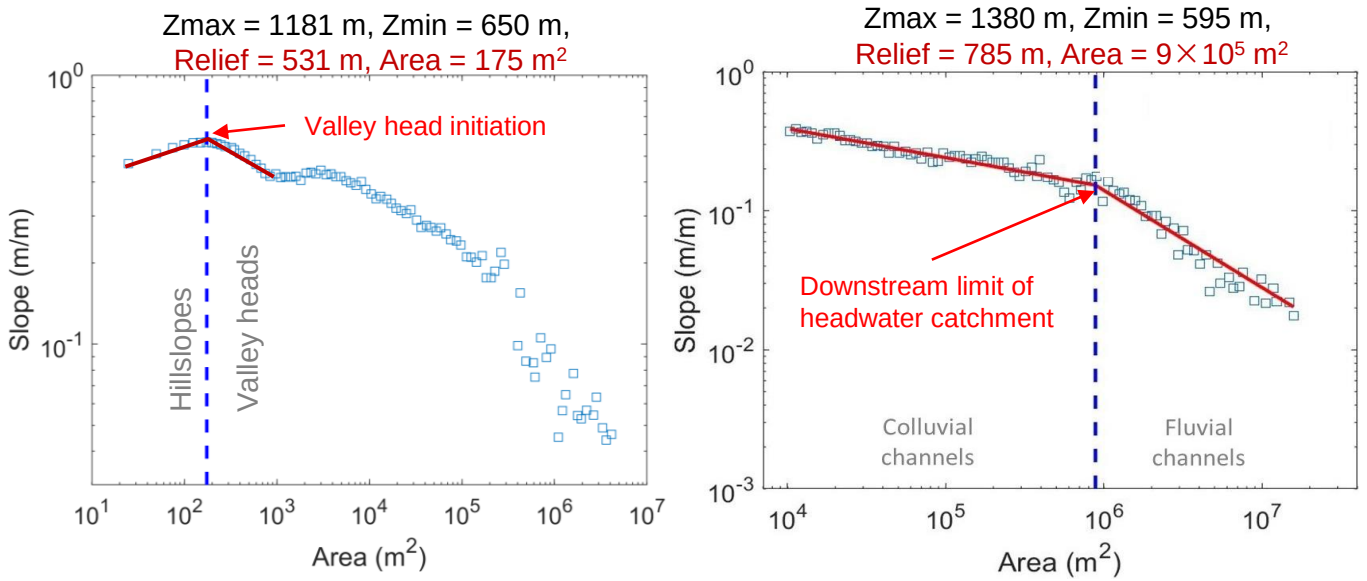


Figure 5. (Left) a sample plot derived from a sub-catchment with an area of 5 km² shows a transition from a positive trend for low drainage areas (hillslopes) to an inverse relation for larger drainage areas (valley heads). (Right) a sample derived from a sub-catchment with an area of 20 km² plot for finding the extent of the headwater catchment. It indicates a transition from the colluvial process–dominated to the fluvial process–dominated.

• Methods (2): geomorphons analysis for finding colluvial channel initiation

1. Classify landforms using Geomorphons (Figure 6).
   Parameters used in geomorphons analysis: (i) lookup distance: 50 m; (ii) flatness threshold: 0.5.
2. Define hillslope as the slope pattern in geomorphons classification.
   Slope analysis: (1) percentage and (2) average gradient of the hillslopes.
3. Valley analysis: (1) valley density (total valley length / catchment area), (2) average valley width, (3) average valley length.
4. Define colluvial channel initiation as the starting point of the valley in geomorphons classification.
   Calculate stream power of colluvial channel initiation. ($\Omega = \rho g Q S$)

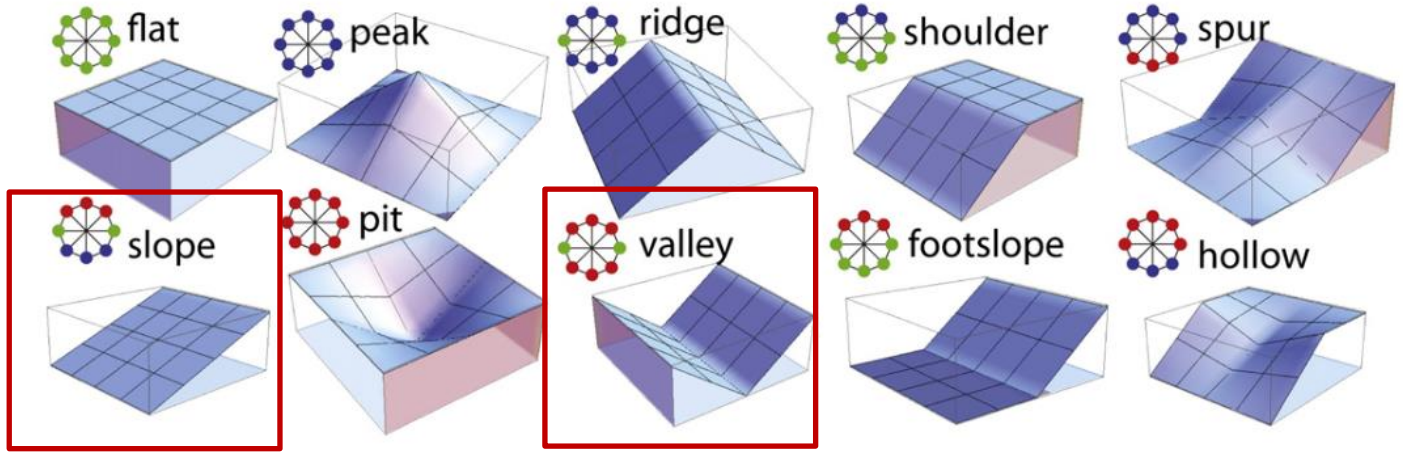


Figure 6. Geomorphons classification for the 10 most common landform elements (from Jasiewicz & Stepinski, 2013). The slope and the valley are used in this study.

• Results (1): valley head initiation and headwater catchment extent

• The valley head occurs at a drainage area of 50~225 m^2. The relationship between the drainage area of valley head initiation and topographic relief shows a weakly positive correlation (Figure 7).

• The area of the headwater catchment is from 1.7×10^5 to 2.03×10^6 m^2. The headwater catchment area increases exponentially with relief (Figure 8).

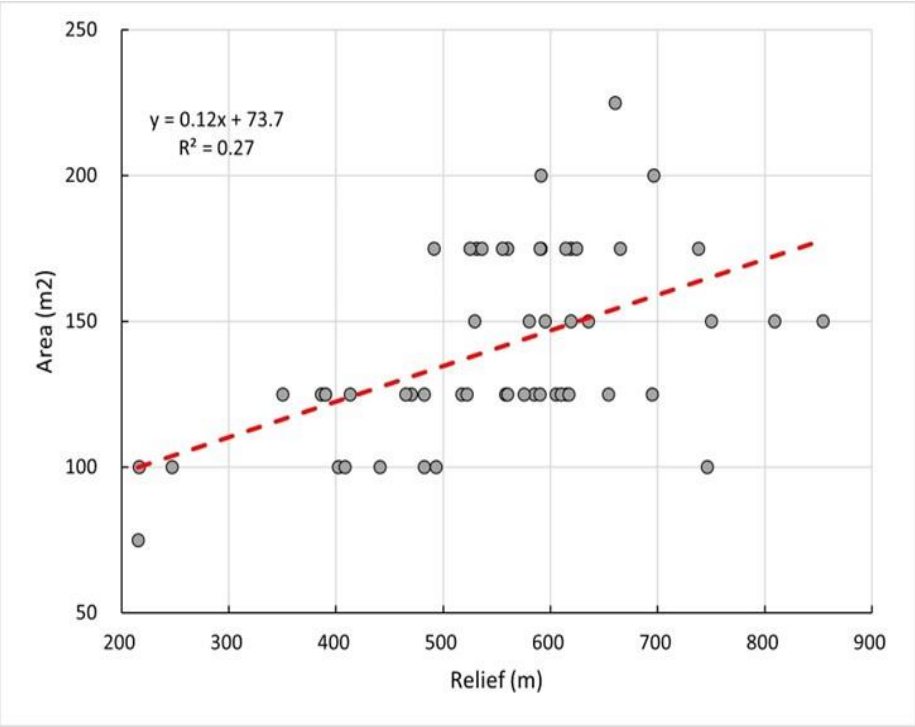


Figure 7. Relationship between area of valley head initiation and topographic relief.

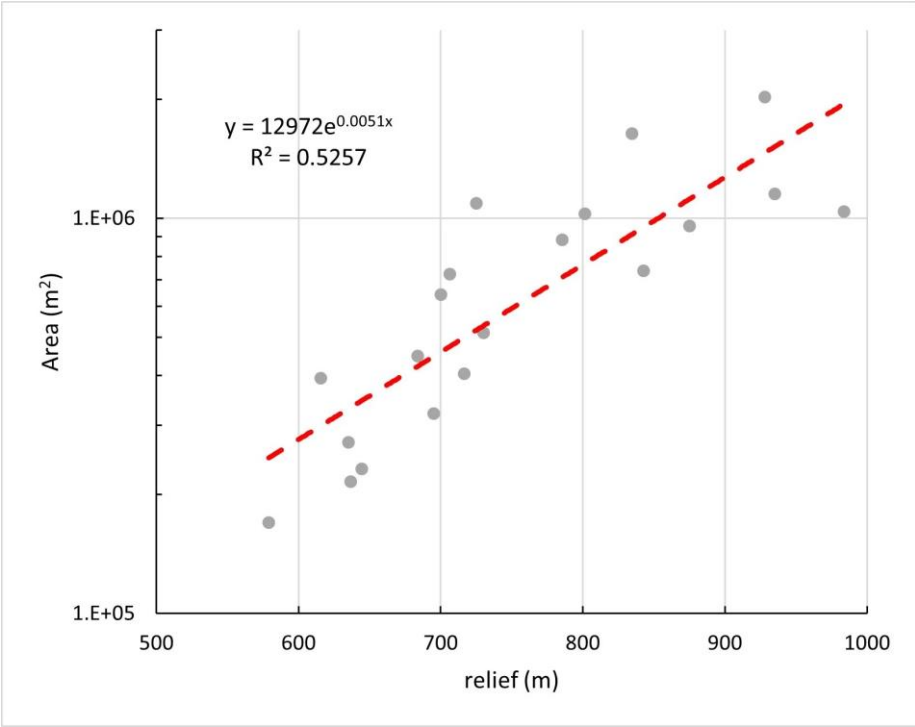


Figure 8. Relationship between headwater catchment area and topographic relief.

- **Results (2): hillslopes and valleys**

1. **Hillslopes:** As relief increases, the percentage of hillslope increases (i.e., hillslopes get longer) (Figure 9A), and the hillslopes get steeper (Figure 9B).

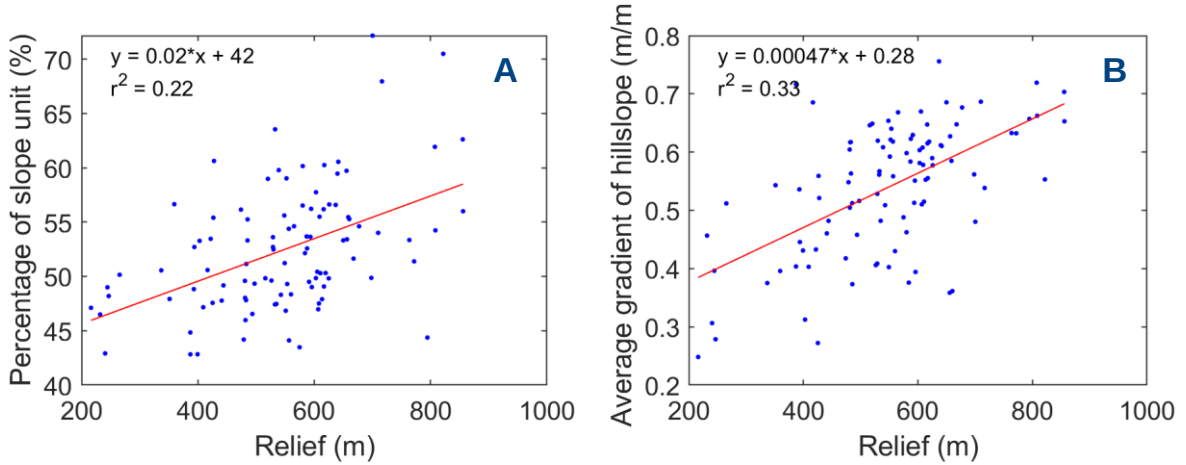


Figure 9. Slope analysis

2. **Valleys:** As relief increases, the valley density decreases(Figure 10A), and the valleys get narrower and longer (i.e., the valley continuity increases) (Figure 10B, C).

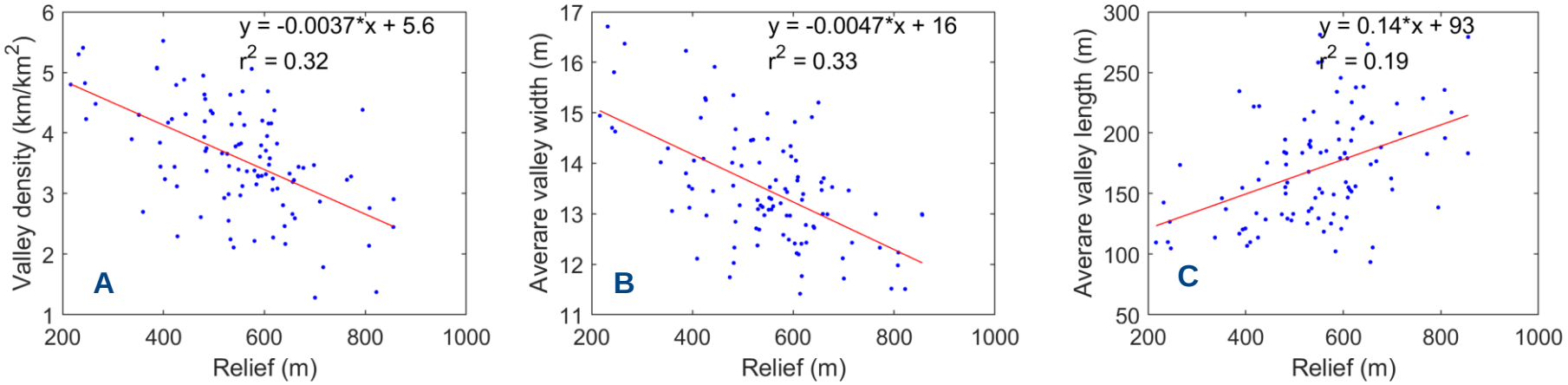


Figure 10. Valley analysis.

• Results (2): colluvial channel initiation

3. Colluvial channel initiation:
The stream power of colluvial channel initiation increased with relief (Figure 11).

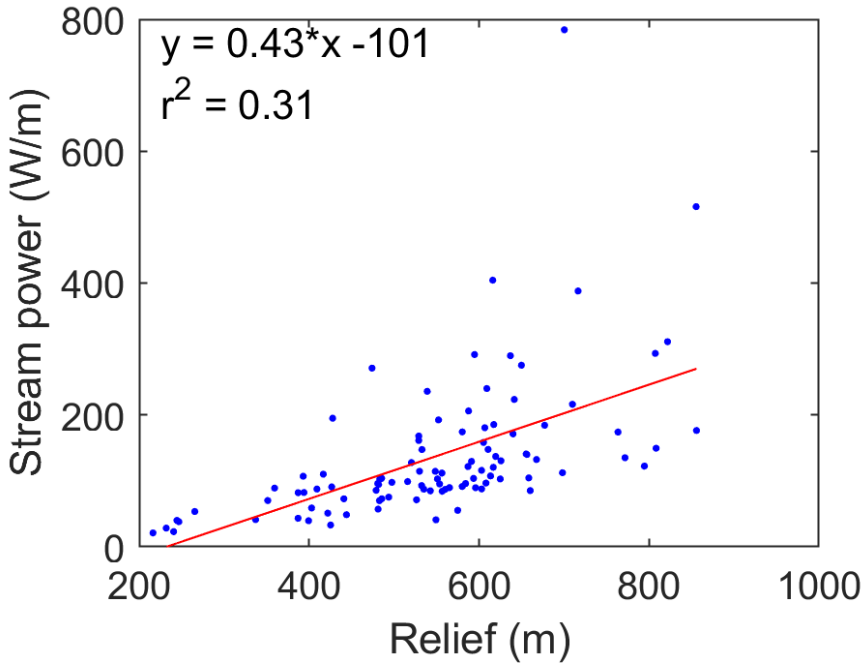


Figure 11. Relationship between the stream power of colluvial channel initiation and relief.

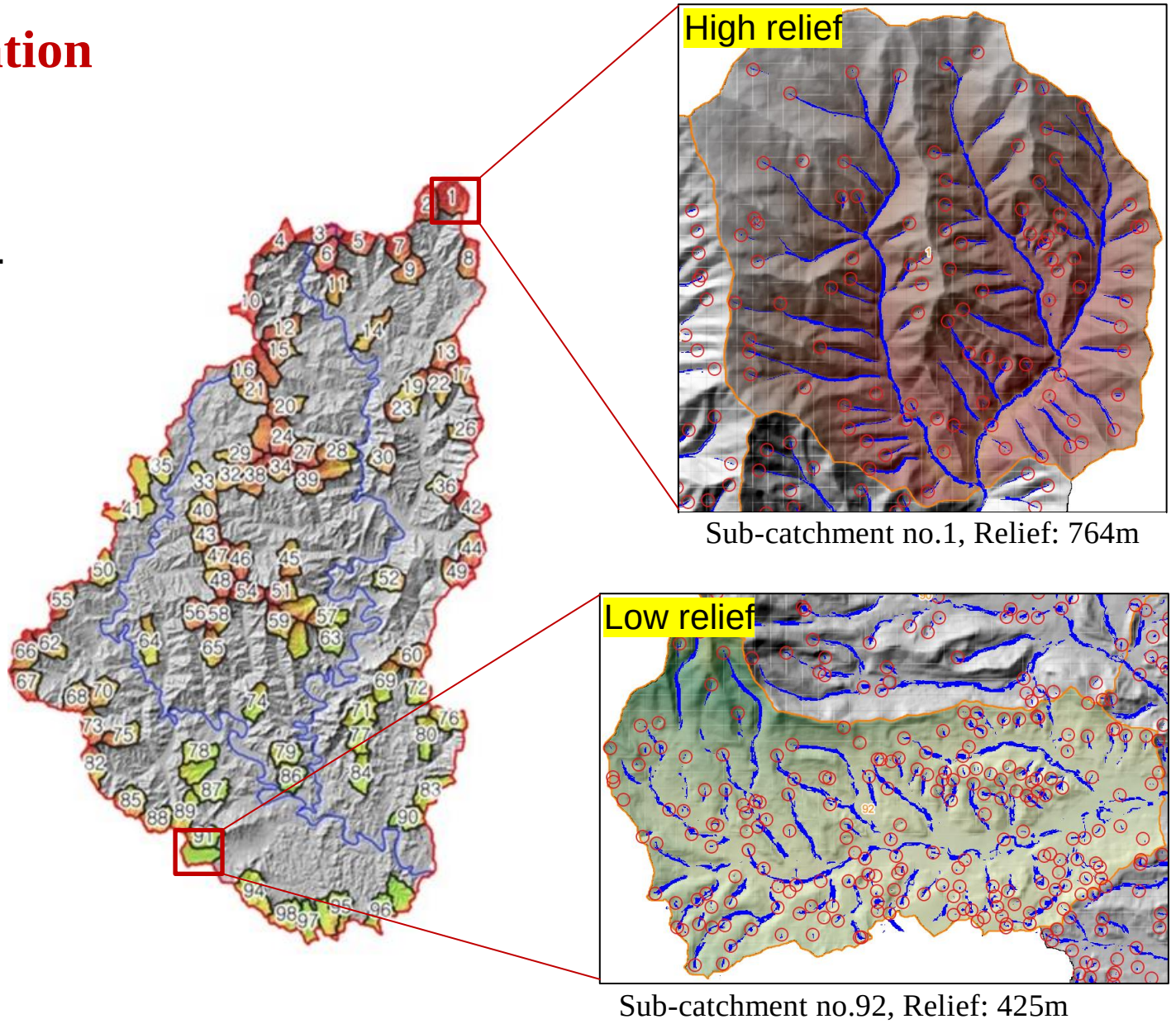


Figure 12. Sample sub-catchments in high and low relief regions. The red circles indicate the positions of colluvial channel initiation.

- **Results**

High relief

Clast size： boulder, cobble

Low relief

Clast size： pebble, sand

Figure 13. Photos of the colluvial valley in a high relief region (left) and a low relief region (right).

• Summary and conclusions

1. **Valley head initiation:** the area of valley head initiation shows a positive correlation with relief.
   High relief -> longer and steeper slopes -> more hillslope materials filling valley heads -> Valley heads initiate at more downstream locations.

2. **Colluvial channel initiation:** with the increase of relief, the colluvial channel initiates more downstream.
   The colluvial channel initiates where a stream can transport the channel materials. In high relief regions, more hillslope materials input requires higher stream power for colluvial channel initiation.

3. **Headwater catchment extent** increased exponentially with relief.
   High relief and steeper slopes -> frequent debris flow (high flux and coarse materials) and longer moving distance (Figure 15) -> longer colluvial channels and larger headwater catchment.

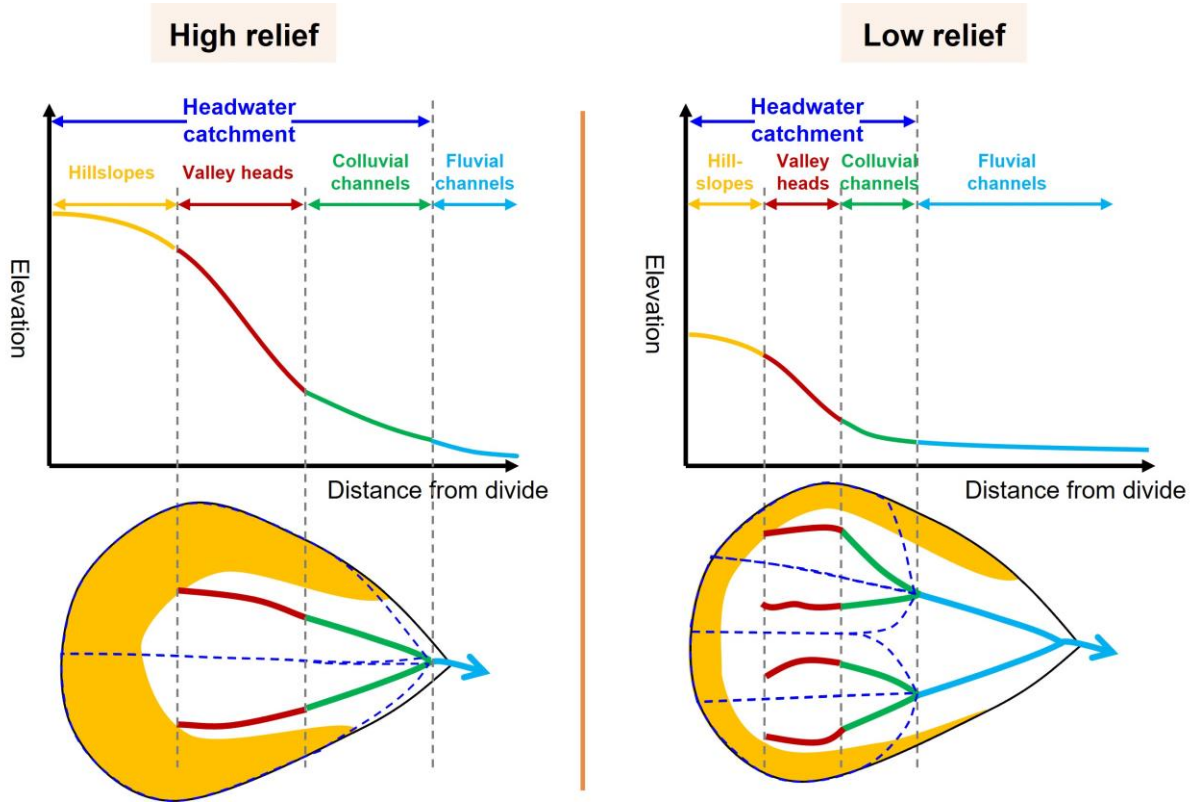


Figure 14. Comparison of the extent of headwater catchment between high and low relief regions.

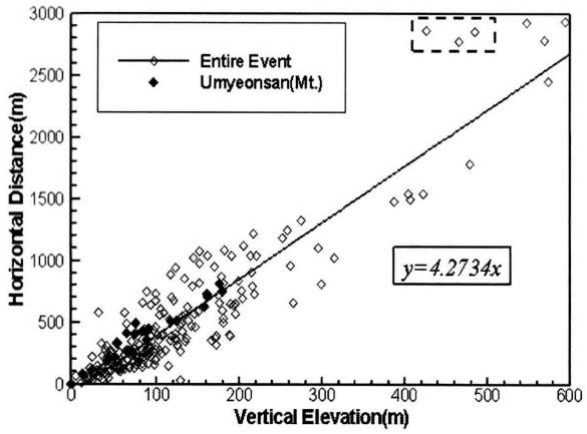


Figure 15. Relationship between vertical elevation and horizontal runout distance for debris flows (Choi & Paik, 2012).