

Empirical Intensity-Duration-based Rainfall Threshold for Landslides Initiation in Palpa District of Nepal

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Abstract: Landslides in the Lesser Himalaya are closely controlled by monsoon rainfall, fragile geology, and human disturbances. This study establishes practical rainfall thresholds for landslide initiation in Palpa District, west-central Nepal, using a district-wide inventory and rainfall records from 2009–2024. Intensity–duration (I–D) pairs were derived using observed and estimated sub-daily rainfall, and thresholds were developed following empirical methods used in Nepal. The preferred curve, $I = 58.67 D^{-0.84}$, indicates that around 97 mm of daily rainfall can trigger failures. Thresholds at multiple non-exceedance probabilities, along with spatial patterns of landslides and soil properties, support early warning and risk reduction efforts in Palpa.

Keywords: *Landslide, Rainfall threshold, Intensity-duration curve, Early warning.*

Introduction

Landslides are a frequent and destructive hazard in the Lesser Himalaya, where steep slopes, weak lithology, and intense monsoon rainfall combine to create highly unstable terrain. Palpa District in west-central Nepal represents one such region where rainfall-induced slope failures routinely affect rural communities, transportation networks, and agricultural land (Dahal, 2012). Understanding how rainfall triggers landslides in this physiographic zone is essential for forecasting hazardous conditions and developing early warning systems at the district level.

This study aims to define robust rainfall thresholds for landslide initiation in Palpa. By integrating multi-year landslide data, detailed rainfall records, soil characteristics, and terrain conditions, the research provides a scientifically grounded tool for operational landslide early warning and disaster risk reduction.

Data and methods

A district-wide landslide inventory was prepared from field observations, satellite imagery, and official reports. A total of 15 years of rainfall data (2009–2024) were obtained from the Department of Hydrology and Meteorology (DHM) stations near the landslide sites. Many stations recorded only daily rainfall, requiring estimation of sub-daily values to derive meaningful rainfall intensity–duration (I–D) pairs (Dahal and Hasegawa, 2008).

Where hourly data were unavailable, sub-daily rainfall was estimated using the method proposed by Shakya (2002). This approach generates hourly rainfall distribution patterns from daily totals. Spatial interpolation through ordinary kriging enabled assignment of rainfall values to each landslide location, ensuring spatial consistency across the district.

Two analytical procedures were tested:

1. CTRL-T approach, an exploratory method used for initial threshold derivation, and
2. Empirical intensity–duration modeling, following the methodology of Dahal & Hasegawa (2008), which has been successfully applied in several Himalayan regions.

The second method yielded more consistent and physically meaningful thresholds and was adopted as the preferred approach.

Preferred rainfall threshold

The final threshold curve for landslide initiation in Palpa District is expressed as:

$$I = 58.67 D^{-0.84}$$

where I is rainfall intensity (mm/h) and D is rainfall duration (hours).

This relationship indicates that short but intense storms as well as longer-duration moderate rainfall can trigger failures. As an example, the model shows that roughly 97 mm of rain in 24 hours is sufficient to initiate slope failures in the district.

Thresholds were also developed at different non-exceedance probabilities for early-warning operations. These curves provide flexible options for issuing alerts depending on desired sensitivity and acceptable levels of false alarms.

Comparison with regional and global thresholds

The Palpa threshold lies above global and mid-latitude baseline thresholds, indicating that stronger rainfall is needed to trigger failures in this Himalayan setting. However, it is slightly lower than thresholds reported

from other parts of Nepal and India, where geological conditions may be even more fragile or rainfall more extreme.

Conclusion

This study successfully developed a scientifically sound rainfall threshold for landslide initiation in Palpa District. The preferred curve,

$$I = 58.67 D^{-0.84}$$

Which represents the lower boundary of rainfall conditions capable of triggering failures in the region. It captures both high-intensity short storms and longer-duration rainfall events, illustrating the complex behavior of Himalayan slopes.

The threshold developed here forms a strong foundation for district-level early warning, improved land-use planning, and enhanced community resilience in this vulnerable Himalayan environment.

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