# Soil Moisture analysis during a landslide event over India's Himalayan region

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## Background

Landslides during the monsoon season in the Indian Himalayan region are significant natural disasters that cause extensive destruction and loss of life. Key factors contributing to these landslides include local topography, geology, steep relief, and low shear strength in hillslope materials. Heavy rainfall is the primary trigger for slope failure, especially when increased soil water content reduces friction at the shear plane and adds soil weight. Based on past rainfall intensity and duration, the rainfall threshold method is often inadequate, as initial soil moisture also significantly impacts landslides (Brocca et al. 2012). The Himalayan region's unique hydrometeorological and geological conditions and human activities contribute to its landslide susceptibility. Recent interest in hydrometeorological thresholds focuses on integrating rainfall characteristics and subsurface hydrological variables. This study examines soil moisture conditions at Mandi during the landslide event on August 14, 2023.

## Methodology

The JULES land surface model is a community model from the UK Met Office that simulates the exchange of water, energy, and carbon between the land surface and the atmosphere. It can function as a standalone or part of the Coupled model. JULES calculates land-atmosphere heat and moisture exchanges for each grid through area-weighted averaging of the tile fluxes, requiring a time series of meteorological data such as radiation, temperature, humidity, wind speed, precipitation, and surface pressure. JULES uses 4 soil layers of 0.1, 0.25, 0.65 and 2 m thicknesses. The model ran from August 9 to August 17, 2023, to assess the JULES model's ability to predict soil moisture (Fatima et al. 2021) variations for early slope failure warnings. A landslide occurred on August 14, 2023. Meteorological data for JULES was sourced from NCUM (Unified Global model from UK Met Office adopted at National Centre for Medium Range Weather Forecasting) output, and the model was initialized with conditions from August 9 to 13. Soil moisture forecasts were analyzed based on these initial conditions, with all simulations concluding on August 17.

## Results

The variation in soil moisture at Mandi for the top four soil layers is illustrated in Figure 1. An increase in soil moisture is evident up to the third soil layer on the day of the landslide occurrence. Based on the different initial conditions, the model forecast indicates an increase in soil moisture for the upper three soil layers. However, the fourth soil layer forecast only shows an increase one day before the event. This delay is due to the time it takes for rainwater to infiltrate and reach the deeper layers of soil.

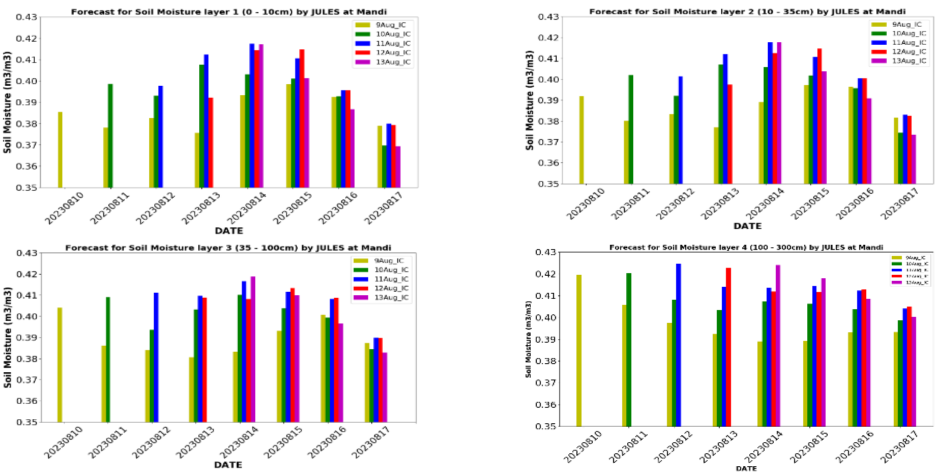


**Fig 1: Soil Moisture Forecast trend at Mandi from August 10, 2023 to August 17, 2023**

The model was initialized under different conditions on August 9-13, 2023, and we calculated the correlation coefficients between rainfall and soil moisture, as shown in Table I. Mandi shows a strong correlation between rainfall and top-layer soil moisture from day -3 onwards. Mandi receives significantly heavy rain and has an elevation of 760 meters. Its sandy loam to clay loam soil has good water-holding capacity (Source: Himachal Pradesh State Biodiversity Board), likely contributing to this strong correlation.

**Table -1: (Correlation between rainfall and Soil Moisture level-1 at Mandi)**

| Initial Conditions Based on | Forecast valid for August 14, 2023 | Pearson Correlation Coefficient |
|---|---|---|
| August 9, 2023 | Day -5 | 0.79 |
| August 10, 2023 | Day -4 | 0.77 |
| August 11, 2023 | Day -3 | 0.94 |
| August 12, 2023 | Day -2 | **0.95** |

Rainfall and runoff could contribute to the risk of landslides, so these variables have been plotted together to analyze their sensitivity to one another. In Figure 2, based on the initial conditions from August 11, 2023, the JULES model forecasted significant rainfall and surface runoff at Mandi three days later for August 14, 2023. The magnitude of the runoff is also high, and some part of the remaining rainwater evaporates, and the rest of it contributes to increased soil moisture in the area.

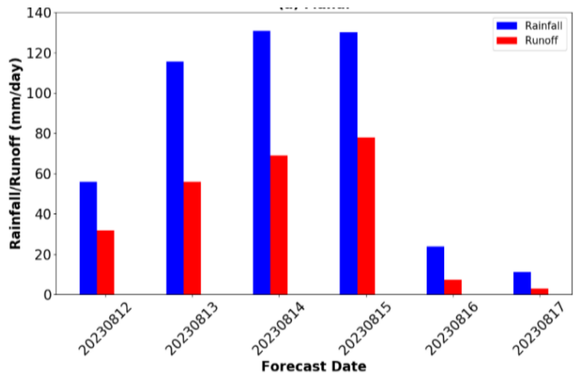


**Fig 2: Rainfall and Runoff at Mandi based on August 11, 2023 initial conditions**

This study examined how model-derived soil moisture forecasts can aid in predicting landslides. Soil moisture reflects hydrological processes influenced by meteorological conditions and topography. While the significance of soil moisture and rainfall variability in landslide occurrence is well recognized (Boggard and Greco 2018), the scarcity of soil moisture data in complex terrains has shifted focus to more readily available rainfall data. However, using rainfall characteristics—such as duration, intensity, and antecedent rainfall—has limitations in landslide prediction. Identifying the rainfall events and soil moisture conditions associated with landslides is often subjective. Soil moisture is influenced by current and antecedent rainfall, evapotranspiration, and topography. Thus, incorporating soil moisture data is essential for accurately predicting slope failures. We can reduce false alarms and missed warnings in landslide forecasts by considering soil moisture, rainfall, and other parameters.

**References**

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