

## **Rainfall-induced Landslides: A Case study of Bharmour Tehsil of Chamba District in Himachal Pradesh**

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Received : 15-01-2026

Accepted : 16-02-2026

### **Abstract**

*Landslides and rainfall are closely associated. The landslides activities become prominent after the occurrences of the rainfall in hilly terrains. Rainfall induced landslides pose a substantial risk to the lives of the people and the infrastructure. There have been various studies to understand the rainfall and landslide associations' world over. All steep slopes experience landslides of smaller or grater magnitudes at one or other point of the time in the year after the rainfall. The present study area of Bharmour tehsil is worst landslide affected area in Chamba district and the problem becomes grave at the time of the monsoon rains. The only road connecting the study area to the district Chamba remains close for days together due to landslides at different locations. The present study recorded the landslides occurrences along the roads in Bharmour tehsil during the pre-monsoon and the post-monsoon surveys in the year 2018. The study revealed that there was a substantial increase in the landslide numbers after the monsoons. Field survey recorded the increase in the number of landslides from 212 to 309 during post monsoon period. Thus, with an increase of 97 new incidences the study proved that the landslides activities increase with the increase in the amount of rainfall.*

**Key words:** *Landslide, mass-movement, slope failure, correlation, slope stability.*

### **1. Introduction:**

Slope failures are influenced by a variety of natural and anthropogenic factors, with rainfall being one of the most significant triggers. Landslides are commonly observed during and after rainfall events across the world (Sato & Shuin, 2023). Their frequency and severity increase especially during prolonged periods of intense precipitation, as rainfall intensity and duration have a direct impact on the types and magnitudes of slope failures (Larsen & Simon, 1993; Sato & Shuin, 2022). Areas with steep slopes, loose soil, sparse vegetation, and prolonged heavy rainfall are particularly susceptible to landslide activity.

Rainfall-induced landslides can occur suddenly—within minutes or even seconds—yet the preparatory conditions for slope failure often build up over time. Extended rainfall contributes to slope instability through various mechanisms, including water loading, reduction in soil strength due to increased pore water pressure, and the erosion or weakening of slope materials (BGS, n.d.). Such processes are especially prevalent in tropical and monsoon-dominated regions. In countries like India, landslides are most frequent during the monsoon season from July to September, with August and September being particularly critical due to peak rainfall intensity and duration.

Increased soil moisture from rainfall elevates pore water pressure, which reduces the internal cohesion of slope-forming materials. This, in turn, decreases their shear strength and increases the likelihood of slope failure. Among the various forms of mass movement, landslides are distinct because they typically occur along a defined plane of failure. This movement involves the downslope displacement of rock, debris, or soil under the influence of gravity, setting landslides apart from other types of mass wasting events.

Landslides are typically defined as the downslope movement of rock, debris, or soil under the influence of gravity, though they may be triggered or accelerated by additional factors. These movements may include falls, slides, slumps, or flows—each varying in speed and material type (Cruden & Varnes, 1996). Gravity remains the primary driving force behind such events, displacing material and depositing it at lower elevations (Sharma, 1993). Importantly, Brabb (1993) emphasized that up to 90% of landslide-related losses can be mitigated if hazards are identified in advance, underlining the need for proactive assessment and planning.

Hydrological processes play a crucial role in triggering landslides. One of the key mechanisms is the reduction in shear strength of slope-forming materials caused by elevated pore water pressure—a process that often culminates in slope failure (Terlien, 1998). Groundwater is widely recognized as a major contributing factor in most landslide events. Consequently, understanding the source, movement, and volume of water within slopes is essential for landslide assessment and prevention (Bell, 2002). Among all climatic variables, rainfall is the most influential. When precipitation exceeds a critical threshold, it increases pore water pressure to a level that surpasses the shear strength of the material, initiating slope movement (Oliveira et al., 1994).

The occurrence of rainfall-induced landslides is largely dependent on the duration and intensity of precipitation. While brief rainfall events may not lead to significant slope failure, prolonged or extremely intense rainfall can trigger both shallow and deep-seated landslides (Jahns, 1978). Substantial rainfall elevates pore water pressure, which in turn reduces the internal shear strength of soil and rock grains. The type and behavior of landslides also vary by climate. For

instance, frost action can trigger rockfalls in arctic regions, whereas thawing in permafrost zones often leads to debris slides and flows (Bell, 2002).

## 2. Hypothesis

Monsoon rainfall contributes to an increase in landslide occurrences along the roads in Bharmour tehsil.

## 3. Study area

The study area lies in the Bharmour tehsil of the Chamba district in Himachal Pradesh. The study area comprises NH-154A and all motorable roads in Bharmour tehsil. The total road length covered is 167 kilometres. The study area extends between 32°24'6 N to 32°32'40 N and 76°23'4 E to 76°41'34 E. It lies in the south-western part of the tehsil. It lies in a hilly terrain with Pir-Panjal range in its north and Dhaula-Dhar range towards its south. The climate of the study area is that of Dry-Temperate Alpine Highlands type. The great diversity in relief, variations in elevation and the geographical location of the study area gives the area unique climatic and topographical conditions.

## 4. Methodology

A systematic methodology was adopted to document landslides before and after the 2018 monsoon season.

**4.1 Data preparation:** A total of 167 km of roads were digitized using Google Earth imagery. Road layers were overlaid on a base map sourced from the District Census Handbook (2011). A 50-meter buffer was applied to delineate the survey corridor.

**4.2 Field surveys:** in order to collect the realtime landslide data in the study area. Two rounds of field surveys were conducted. A handheld GPS receiver was used to collect the landslide location coordinates in the area. The location of each landslide was recorded precisely and the pictures of the events were also clicked for reference. By using the empirical method each landslide was categorized by type (debris slide, debris fall, rockfall, soil creep, rock slide, debris flow, topple, slump).

- **Pre-monsoon:** 22 April – 22 May 2018
- **Post-monsoon:** 10 – 25 October 2018

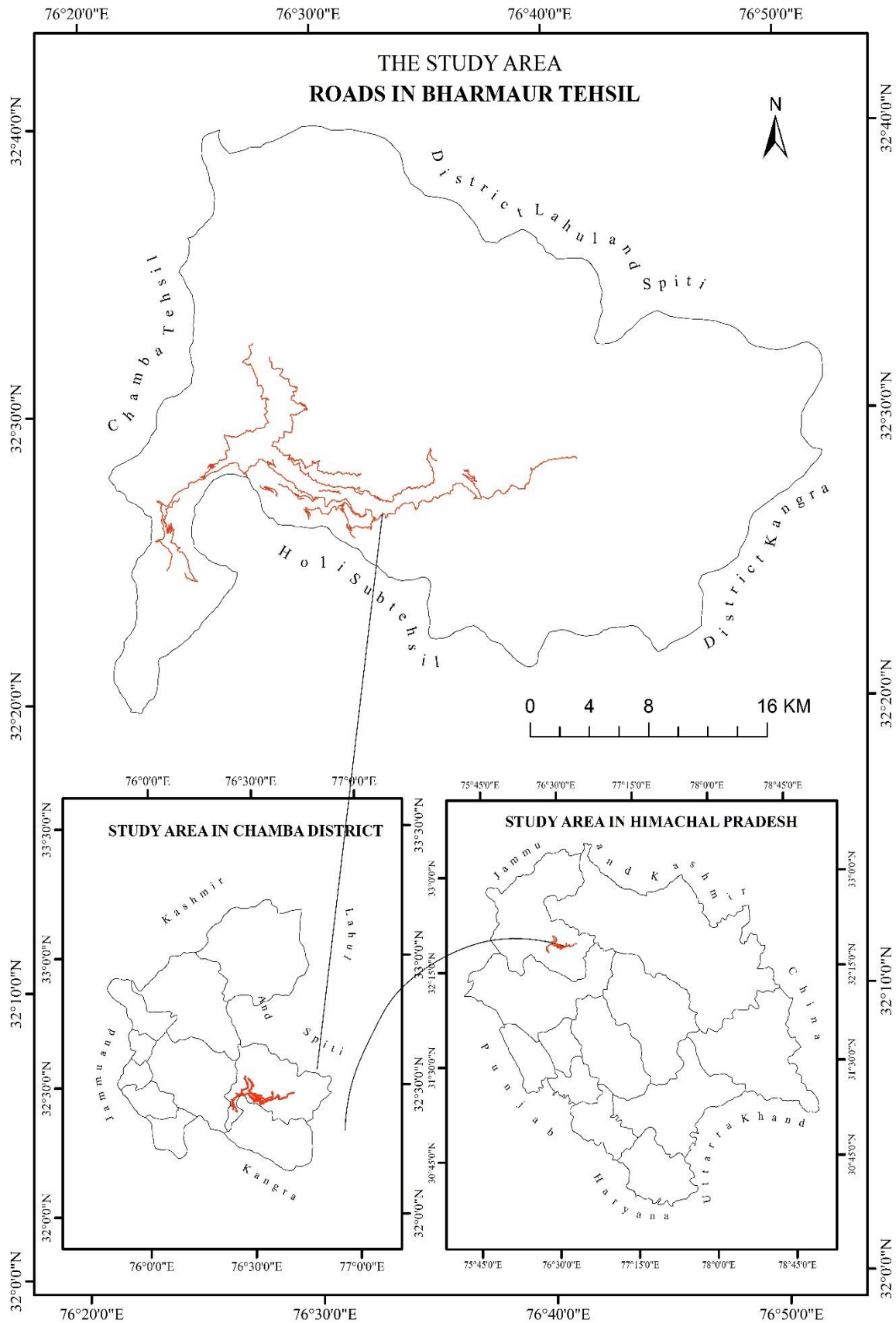


Figure. 1: Location of the Study Area

**4.3 Rainfall data:** Rainfall data for pre- and post-monsoon periods (for the mentioned time period) were obtained from the Indian Meteorological Department (IMD), Shimla. Due to the unavailability of daily rainfall data, statistical correlation tests could not be conducted. Instead, a descriptive comparison was used to assess the relationship between rainfall and landslide occurrences. This approach allowed for a preliminary assessment of the potential relationship between rainfall and landslide frequency based on observed increases.

## 5. Results and Discussions

### 5.1 Landslide inventory:

During the pre-monsoon survey a total of 212 landslides were recorded in the area belonging to 8 different landslide types namely: debris slide, debris fall, rock fall, soil creep, rock slide, debris flow, topple and slump. However, during the post-monsoon registered a total of 309 incidences indicating an increase of 97 incidences (Table-2).

According to the rainfall data collected from the Indian Meteorological Department, Shimla there was an increase in the amount of the rainfall during the same period i.e. from 190 mm before the pre-monsoon survey to 258 mm during the 2018 monsoon season (Table-1).

Table-1: Rainfall before Pre-monsoon and Post-monsoon Surveys

Period 2018	Rainfall (MM)
January, February, March	190
June, July, August, September	258

Source: *Indian Meteorological Department, Shimla, 2018.*

Table-2: Landslides registered during the Pre-monsoon and Post-monsoon Surveys

Survey Period	Total Landslides
Pre-Monsoon	212
Post-Monsoon	309

Source: *Field Surveys, 2018.*

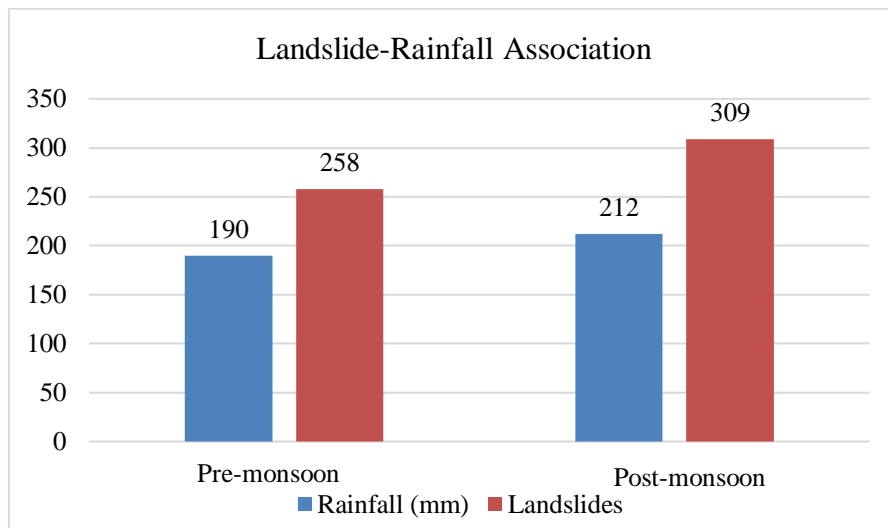


Figure-2: Landslide and Rainfall Association

**5.2 Spatial Distribution of Landslides:**

The analysis of the pre-monsoon and post-monsoon landslides shows that the landslide occurrences and rainfall are positively related as the study revealed that the landslides numbers increased with the increase in the amount of rainfall. The landslide distribution exhibited a predominantly linear distribution along road corridors. Several slope failures occurred away from the road—particularly in the northeast zone—due to natural processes such as river-induced toe erosion, including one event that destroyed a water mill in Upper Kugti village.

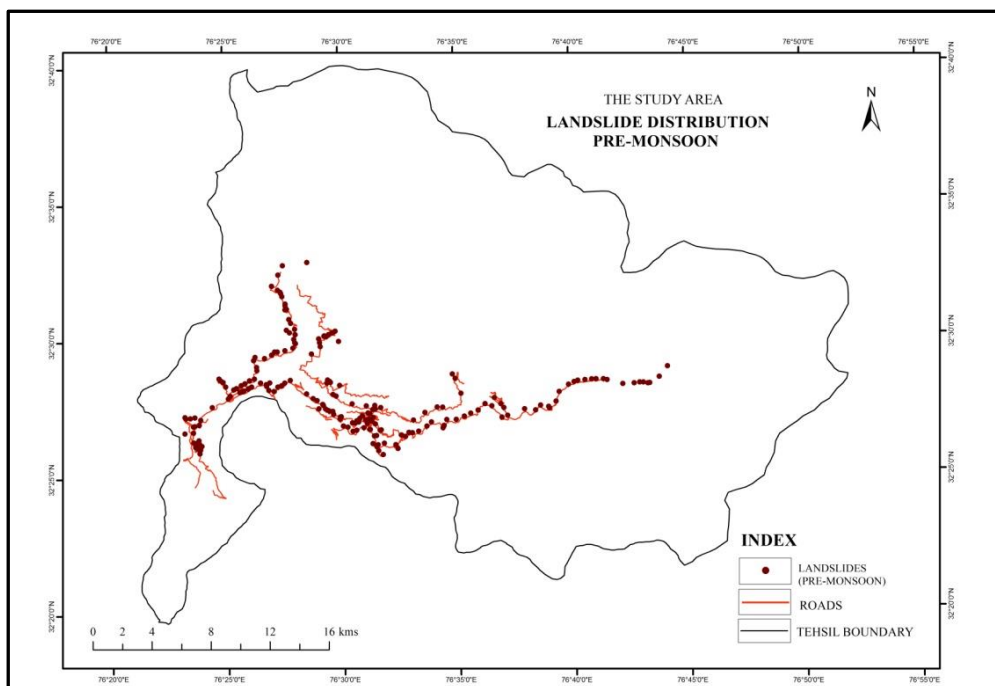


Figure-3: Spatial Distribution of Landslides (Pre-Monsoon)

Post-monsoon mapping (figure-4) revealed a substantial increase in landslide density in the study area. Several road segments were inaccessible due to large debris accumulations, preventing a complete survey. Despite this limitation, the surveyed areas showed a marked rise in both the frequency and spatial spread of slope failures.

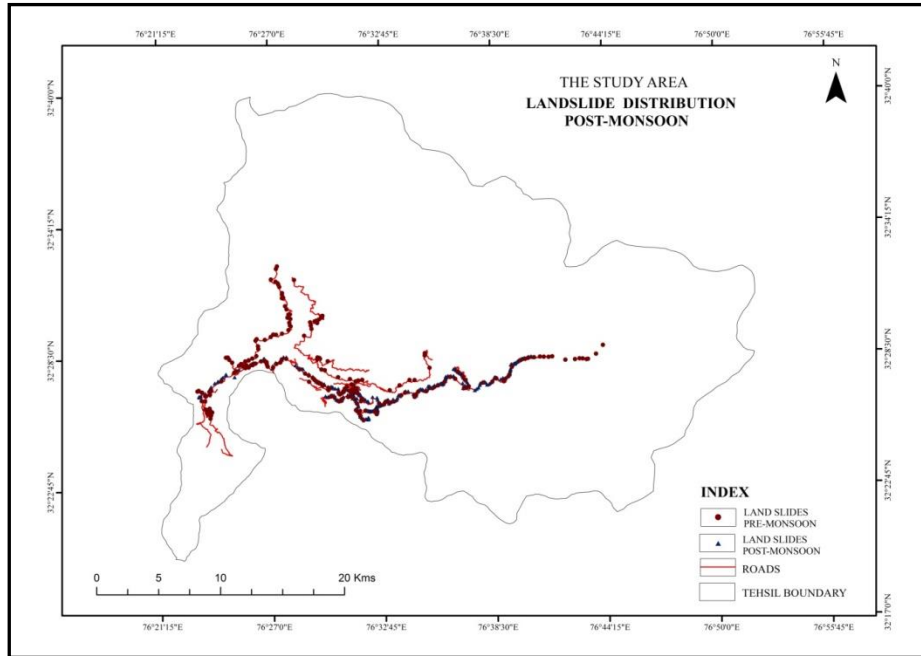


Figure-4: Spatial Distribution of Landslides (Post-monsoon)





Photo plates (1 and 2): Landslides in the Study Area (Source: Field Survey, 2018)

### 5.3 Interpretation

The findings of the present study indicate that

- The increased rainfall during the monsoon rains increased the soil moisture which in return increased the pore water pressure in the soils.
- Weak geological structure and the slope morphology further made the slope vulnerable for failures.
- The anthropogenic activities like road construction, slope under cutting and illegal quarrying further destabilized the slope.

While the study revealed that rainfall occurrences initiated the actual slope failure but the human alterations of the slope profile further amplified the vulnerability of the slopes in the area.

### 6. Conclusions and Policy Imperatives

The study documented over 300 hundred landslides occurrences across eight different categories in the study area during pre and post-monsoon surveys. A descriptive comparison of rainfall and landslide occurrence suggests a positive association between increased monsoon rainfall and the rise in landslide frequency in the area. Thus, the study establishes a positive relationship between landslides and rainfall. The observed data validates the hypothesis proposed at the outset, indicating that an increase in rainfall corresponds with a rise in landslide events.

However, the rainfall is not the sole factor driving the slope instability in the area. Human interventions like road construction without adequate engineering safeguards, hydroelectric development, unregulated excavation and the near absence of the protective structures like breast walls and retaining walls have further aggravated the problem.

### **Key policy recommendations**

- Construction of breast walls and retaining walls along the roads to stabilize slopes.
- Provision of roadside drains to reduce the infiltration of water during the rainfall spells.
- Slope afforestation and other bio-engineering measures for long term slope stability.
- Regulation of illegal slope quarrying activities along the roads through strict rules.
- Continuous rainfall data monitoring for early warning and risk forecasting.
- Detailed geotechnical mapping for the creation of the hazard profile of the area.

Future studies in the area should employ daily rainfall data, soil moisture analysis, and geotechnical investigations to statistically validate rainfall–landslide thresholds in the region.

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