DATA RESOURCES

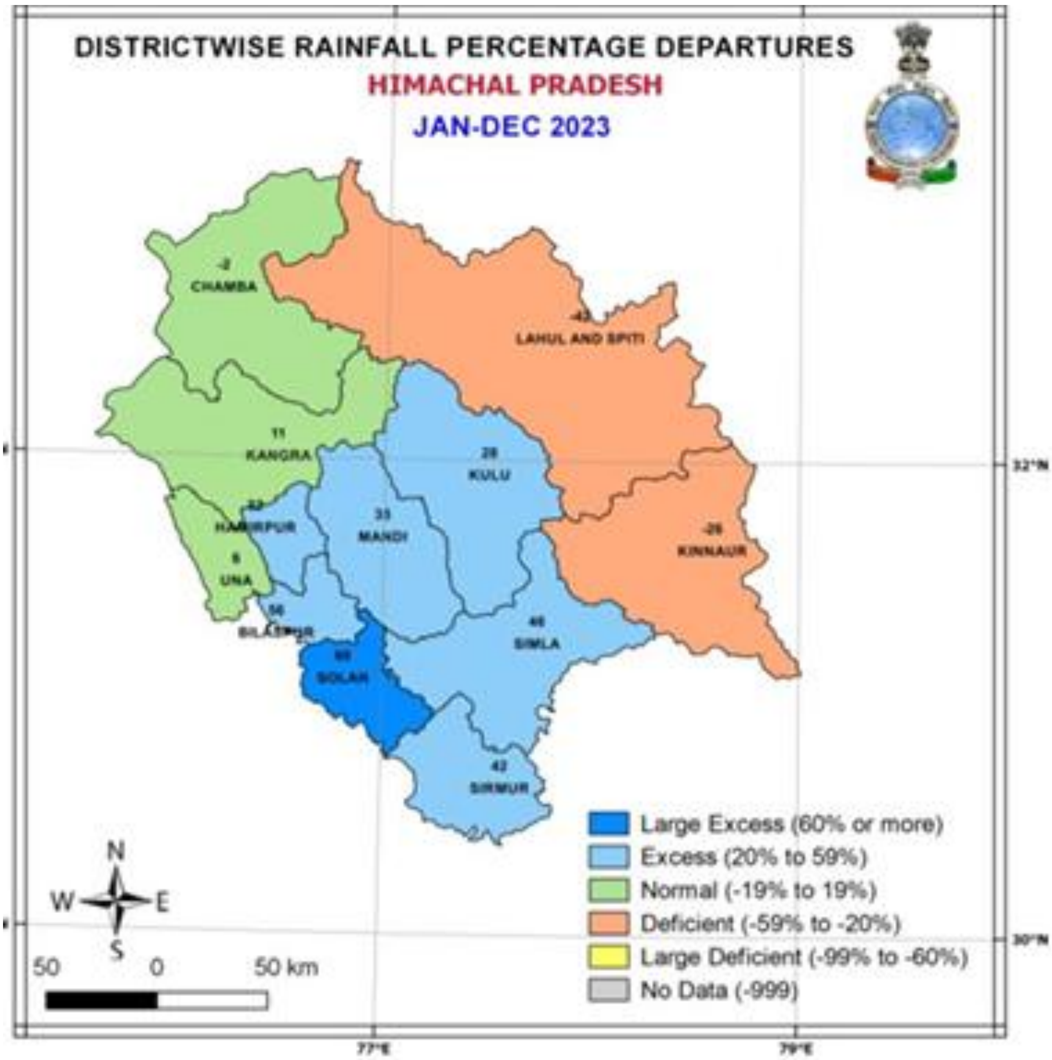
RAINFALL DATA

India Meteorological Department (IMD)

District-wise historical and near-real-time rainfall data used to model flood and landslide triggering conditions.

Years: **2022 & 2023**

1) [Statement on climate for the state of HIMACHAL PRADESH: 2023]
2) [IMD Mausam - India Meteorological Department]



5: District-wise annual rainfall percentage departures

Table 2

Extremely heavy rainfall (>= 204.5 mm) or Very heavy (115.6-204.4 mm) recorded over some stations of Himachal Pradesh during January – December 2023 #

DATE	STATION NAME	RAINFALL (mm)
24-JUN	KANGRA AERO	143.5
	KASAULI	145.0
9-JUL	BARTHIN	148.6
	KAHU	171.5
	NAINA DAVI	162.8
	R L BBMB	224.0
	CHUARI	160.1
	MEHRE (BARSAR)	170.2
	NADAUN	160.5
	DEHRA GOPIPUR	175.4
	GHAMROOR	166.0
	GULER	145.0
	NAGROTA SURIAN	154.2
	ROHRU	185.0
	SANGRAHA	180.0
	ARKI	150.0
	KASAULI	172.0
	BANGANA_R	172.0
	UNA	166.2
	UNA RAMPUR AWS	228.5
10-JUL	NAINA DAVI	198.4
	CHUARI	193.0
	MEHRE (BARSAR)	145.8
	ROHRU	160.0
	PACHHAD	220.3
	RENUKA / DADHAU	160.0
	SANGRAHA	150.0
	ARKI	170.0
	DHARAMPUR	140.4
	UNA	169.2
11-JUL	NAINA DAVI	188.2
	ROHRU	150.0
	JATTON BARRAGE	238.0
	NAHAN	250.0
	RAJGARH	117.0
	RENUKA / DADHAU	192.0
	SANGRAHA	190.0
	KASAULI	198.0

DATE	STATION NAME	RAINFALL (mm)
14-JUL	SALONI	124.0
16-JUL	PALAMPUR	151.0
21-JUL	PALAMPUR	147.0
22-JUL	JATTON BARRAGE	150.4
	RENUKA / DADHAU	195.0
23-JUL	NALAGARH	140.0
26-JUL	JATTON BARRAGE	156.0
7-AUG	NAINA DAVI	162.6
	R L BBMB	139.0
11-AUG	BILASPUR SADAR	160.8
	NADAUN	164.0
13-AUG	SUJANPUR TIRA	145.5
	SUNDARNAGAR	166.1
14-AUG	CHUARI	234.0
	SUJANPUR TIRA	254.0
	DHARMSALA	250.2
	GULER	191.0
	KANGRA AERO	273.4
	NAGROTA SURIAN	175.8
	PALAMPUR	220.0
	JOGINDARNAGAR	178.0
	PANDOH	166.0
	SARKAGHAT	180.8
	SUNDARNAGAR	168.4
	BANGANA_F	175.3
	BANGANA_R	174.3
23-AUG	BARTHIN	180.2
	BILASPUR SADAR	180.8
	KAHU	213.6
	BALDWARA	143.5
	PANDOH	178.0
	DHARAMPUR	162.4
	KANDAGHAT	159.0
	KASAULI	148.0
	BANGANA_F	151.3
	BANGANA_R	150.4
24-AUG	JOGINDARNAGAR	154.0
19-SEP	AMB	147.0

(#: Rainfall figures are for past 24 Hrs. ending on 8:30 Hrs. IST of the date)

Elevation & Slope (DEM)

SRTM 30 m Digital Elevation Model – USGS EarthExplorer

Used to derive elevation, slope angle, and terrain steepness for landslide susceptibility analysis.

Static terrain dataset

1. [EarthExplorer]

Soil Moisture Data

Bhuvan VIC Soil Moisture Dashboard (NRSC)

Daily gridded soil moisture estimates derived from hydrological models and satellite inputs, critical for slope stability analysis.

1. [Bhuvan 2D 2.0]

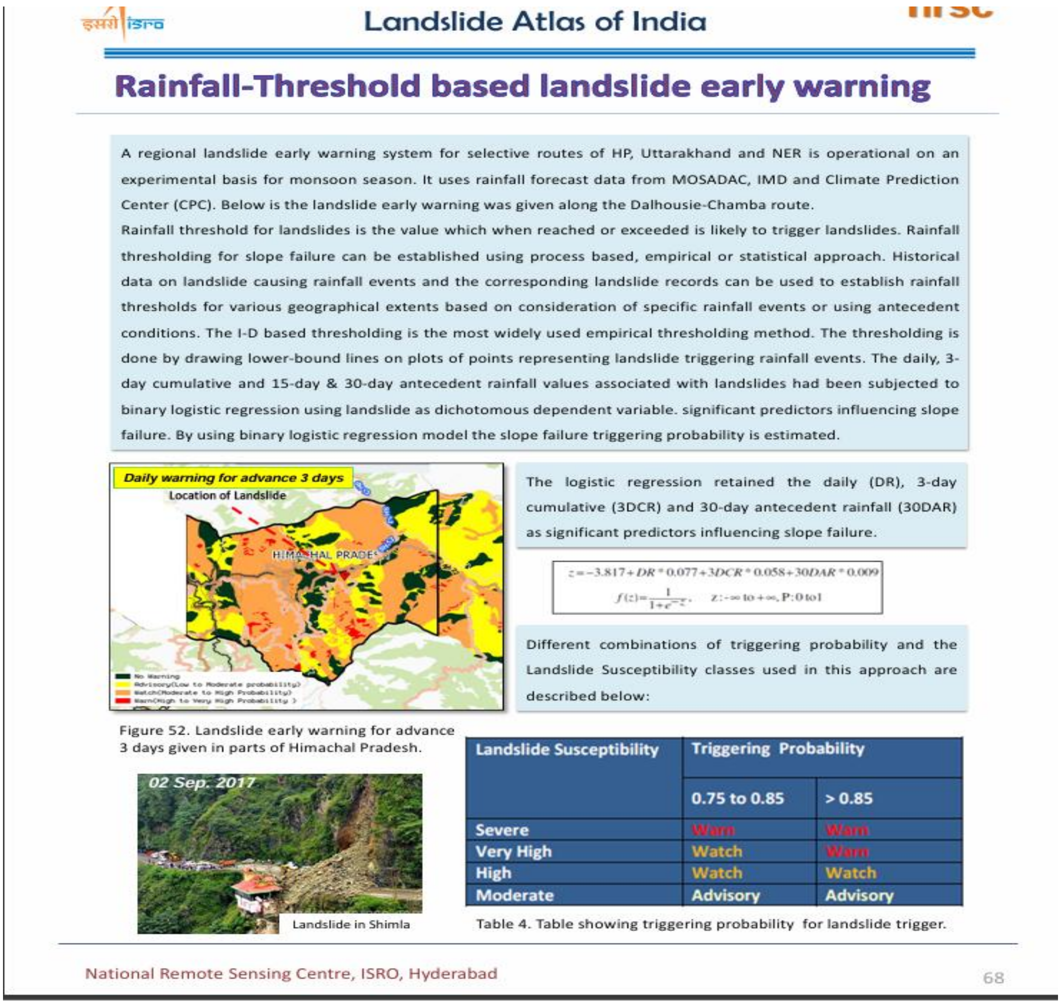
3) [mausam.imd.gov.in/imd_latest/contents/rainfall_statistics_4.php]
4) [Landslide Atlas_2023.pdf]

Seismic Activity Data

National Center for Seismology (NCS), India

Earthquake magnitude and frequency data used to account for seismic triggering of landslides in the Himalayan region.

1.[Official Website of National Center of Seismology]



Landslide Atlas of India

Rainfall-Threshold based landslide early warning

A regional landslide early warning system for selective routes of HP, Uttarakhand and NER is operational on an experimental basis for monsoon season. It uses rainfall forecast data from MOSADAC, IMD and Climate Prediction Center (CPC). Below is the landslide early warning was given along the Dalhousie-Chamba route.

Rainfall threshold for landslides is the value which when reached or exceeded is likely to trigger landslides. Rainfall thresholding for slope failure can be established using process based, empirical or statistical approach. Historical data on landslide causing rainfall events and the corresponding landslide records can be used to establish rainfall thresholds for various geographical extents based on consideration of specific rainfall events or using antecedent conditions. The I-D based thresholding is the most widely used empirical thresholding method. The thresholding is done by drawing lower-bound lines on plots of points representing landslide triggering rainfall events. The daily, 3-day cumulative and 15-day & 30-day antecedent rainfall values associated with landslides had been subjected to binary logistic regression using landslide as dichotomous dependent variable. significant predictors influencing slope failure. By using binary logistic regression model the slope failure triggering probability is estimated.

Figure 52. Landslide early warning for advance 3 days given in parts of Himachal Pradesh.

Landslide in Shimla

The logistic regression retained the daily (DR), 3-day cumulative (3DCR) and 30-day antecedent rainfall (30DAR) as significant predictors influencing slope failure.

$$z = -3.817 + DR * 0.077 + 3DCR * 0.058 + 30DAR * 0.009$$

$$f(z) = \frac{1}{1+e^{-z}}, \quad z: -\infty \text{ to } +\infty, \text{P:0 to 1}$$

Different combinations of triggering probability and the Landslide Susceptibility classes used in this approach are described below:

Landslide Susceptibility	Triggering Probability	
	0.75 to 0.85	> 0.85
Severe	Warn	Warn
Very High	Watch	Warn
High	Watch	Watch
Moderate	Advisory	Advisory

Table 4. Table showing triggering probability for landslide trigger.

Vegetation / Land Cover

ISRO Bhuvan – Land Use & Vegetation Layers
Vegetation cover data used to estimate slope reinforcement and surface runoff reduction.

1. Bhuvan | NRSC Open EO Data Archive | NOEDA | Ortho | DEM | Elevation | AWiFS | LISSIII | HySI | TCHP | OHC | Free GIS Data | Download

CASE STUDIES

1) Landslide Atlas of India
2) nhess-21-3767-2021.pdf
3) LandslideAtlas_2023.pdf
4) Press Release: Press Information Bureau

FORMULAS

1) Richards Equation

$$\boxed{\theta = \theta_r + \alpha_r(\theta_s - \theta_r)}$$

Where (for gravel, sand, and silt):

- θ→ volumetric soil moisture after rainfall
- θ_r→ residual water content *(soil-type dependent)*
- θ_s→ saturated water content *(soil-type dependent)*
- $\alpha_r \in [0,1]$→ relative saturation caused by rainfall infiltration

2) Mohr–Coulomb Failure Criterion

$$\boxed{\tau = c + \sigma_n \tan\ \phi}$$

Where:

- $\tau \longrightarrow$ **shear stress at failure**
- $c \longrightarrow$ **cohesion** of soil
- $\sigma_n \longrightarrow$ **normal stress** on the failure plane
- $\phi \longrightarrow$ **angle of internal friction**