Landslide Hazard Assessment & Mitigation

DML – 502 Lecture - 8

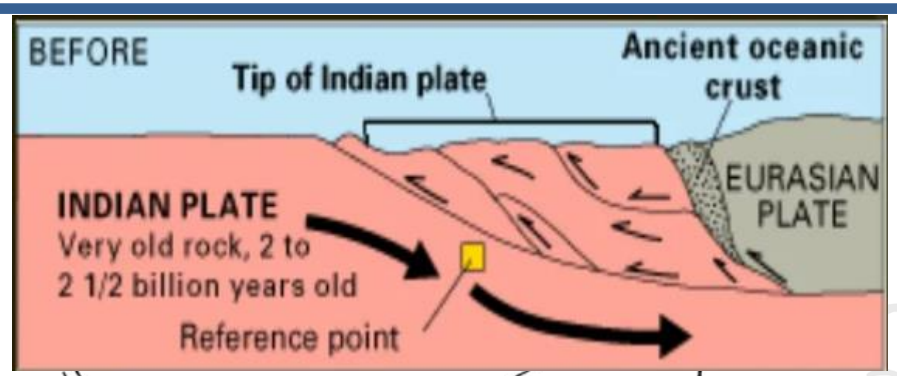
Subject Code: DML-502
Course Title: Landslide Hazard Assessment & Mitigation

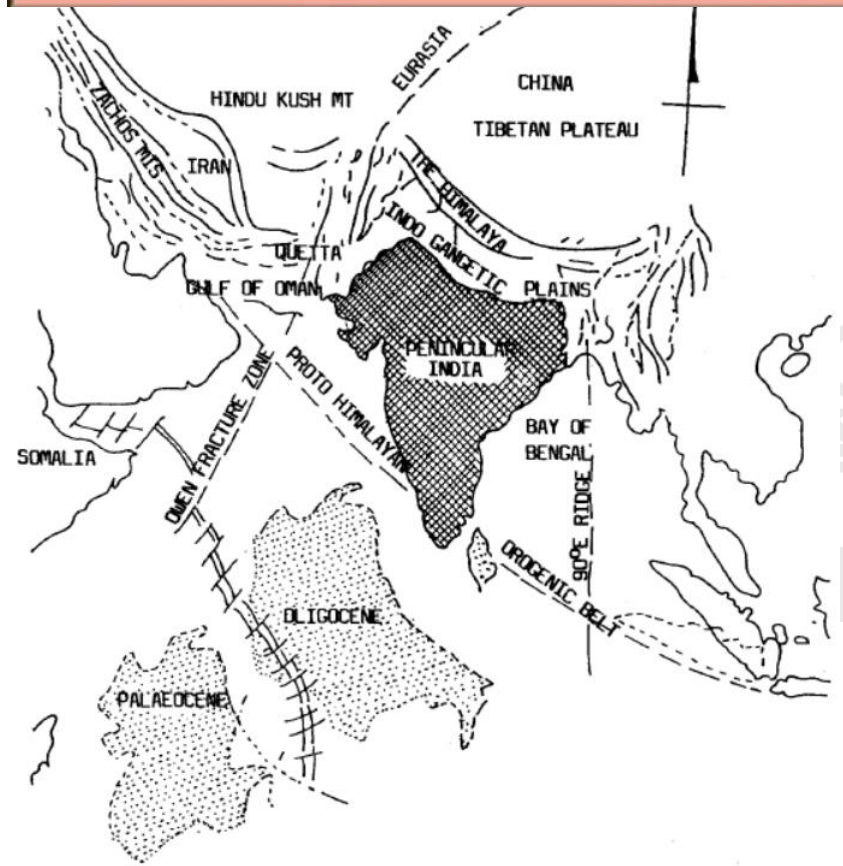
"To understand mapping and hazard assessment techniques of landslides and protection against landslide."

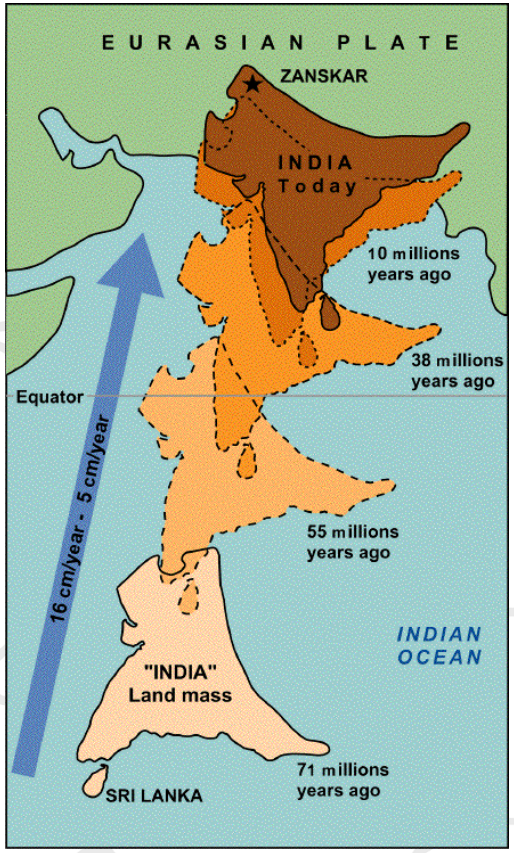
S. No 2

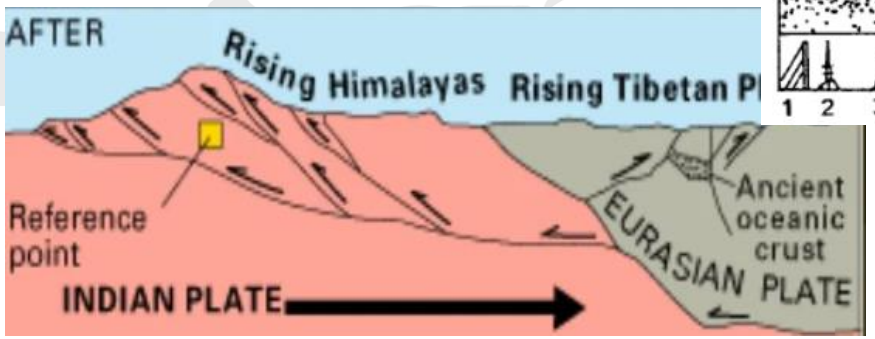
Causative factors of landslides – natural including inherent factors and external factors as well as anthropogenic factors; Impacts of natural causative factors like lithology, structure, slope morphometry, relative relief, hydrogeological conditions and land use and land cover on stability of slopes; Impacts of external factors like concentrated rainfall and earthquakes on slope stability; **Various causes of slope instability in the Himalayas and the Western Ghats;** extreme hydro-meteorological conditions leading to landslide dams and related damages;

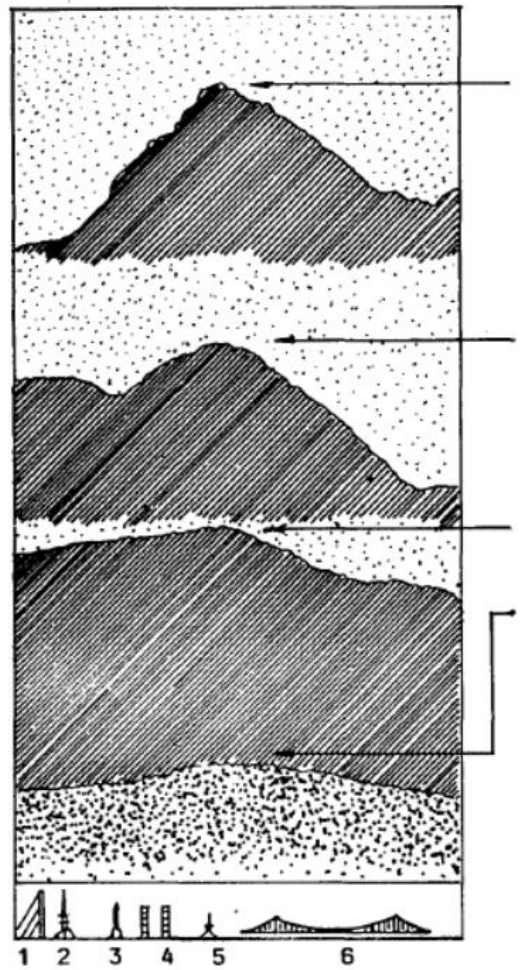
The Himalayas











Mount Everest
6840m

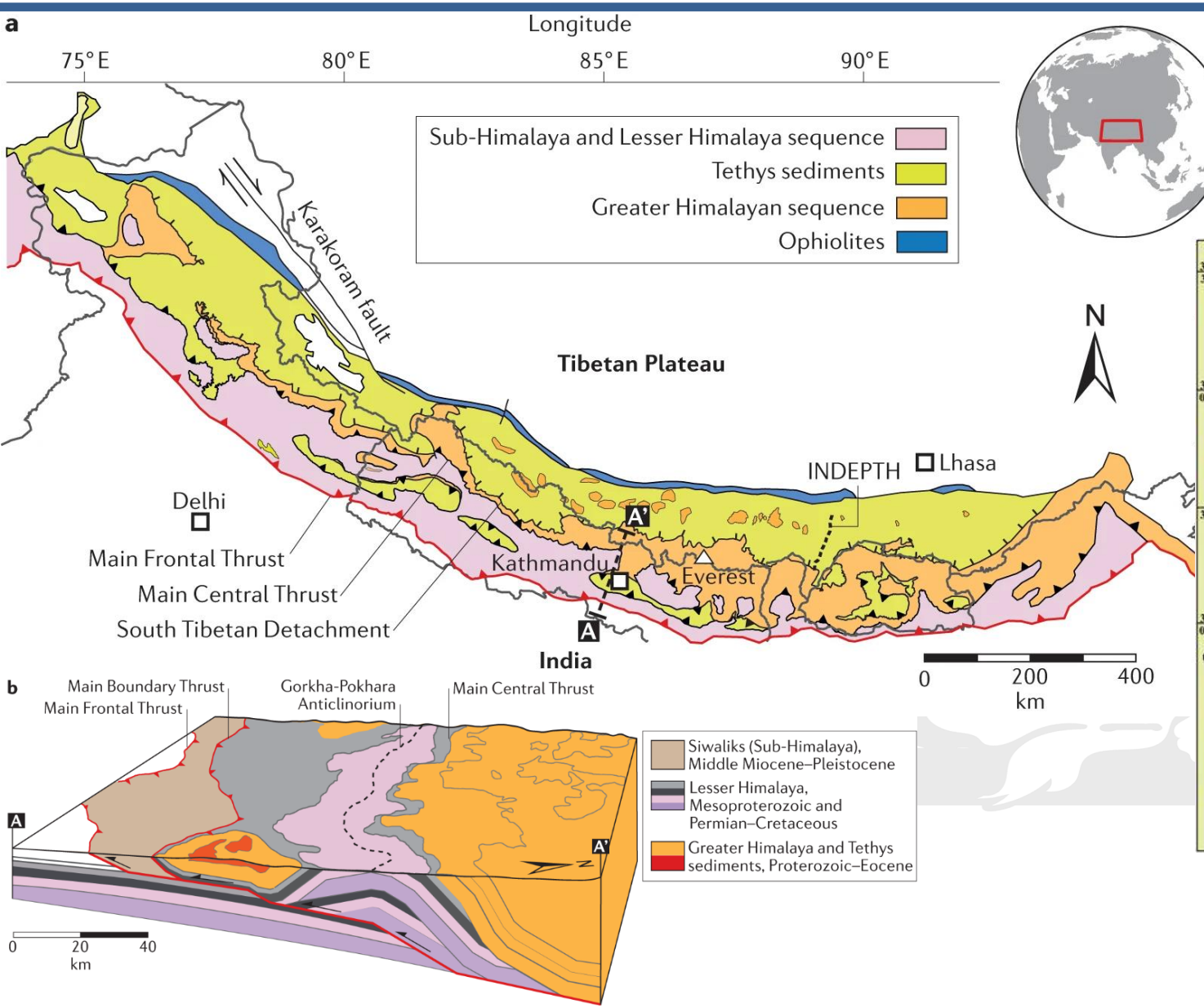
Mount McKinley
6187m

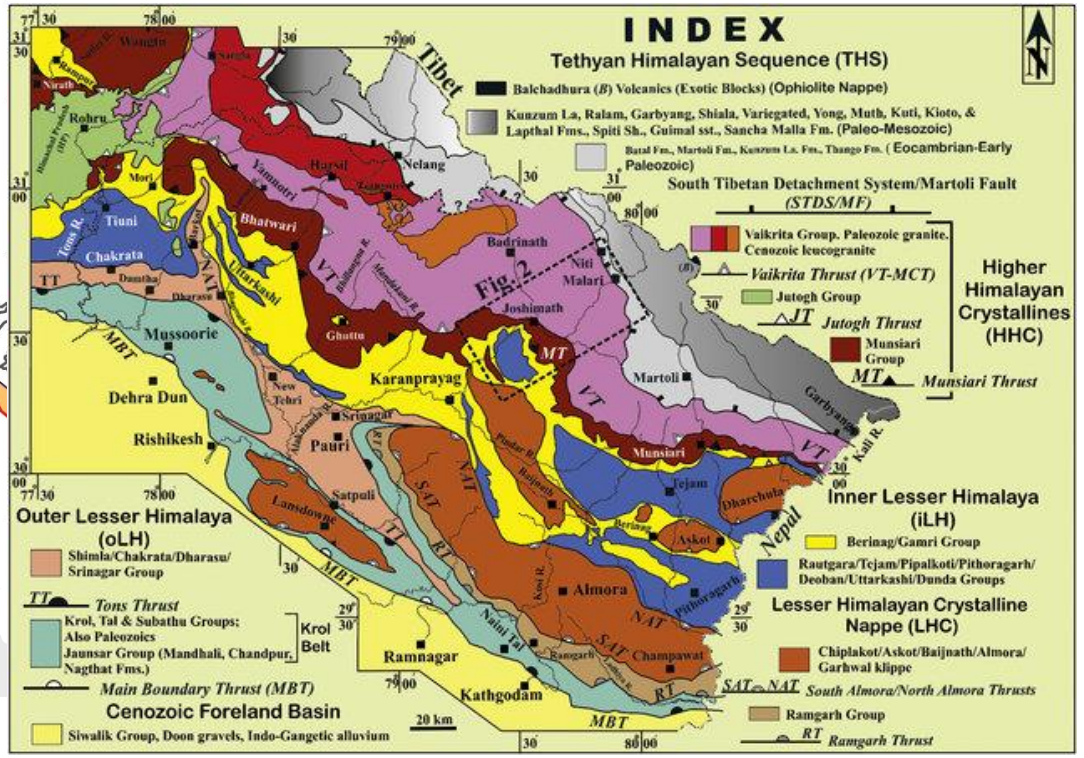
Pikes Peak
4301m

Mount Washington
1017m

1. TV Tower, Poland 850m
2. TV Tower, Moscow 550m
3. Empire State Bldg. New York, 480m
4. World Trade Centre Chicago. 410m
5. Eiffel Tower, Paris 320m
6. Golden Gate Bridge 230m

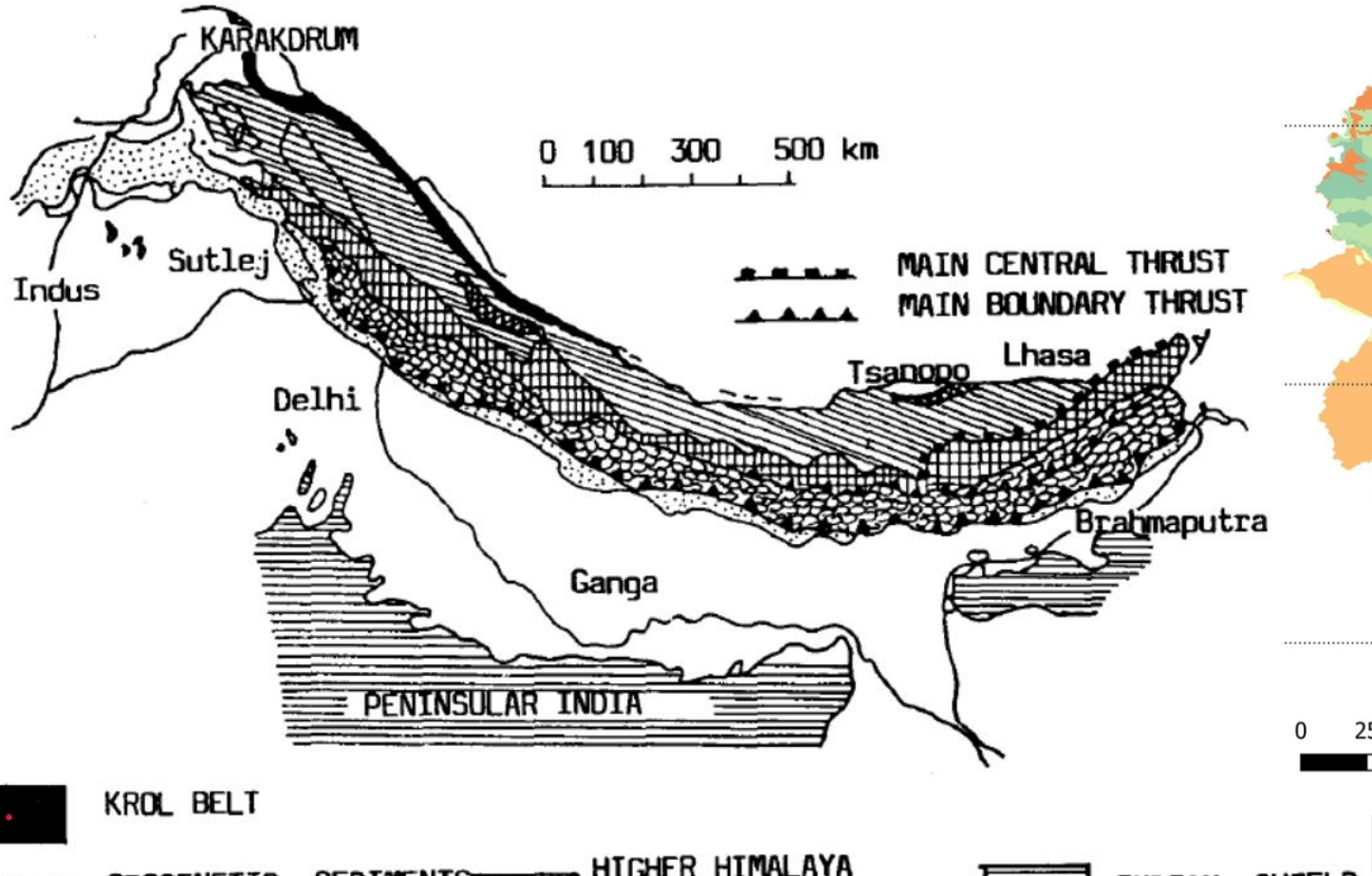
Litho-Tectonic map of the Himalaya: Uttarakhand

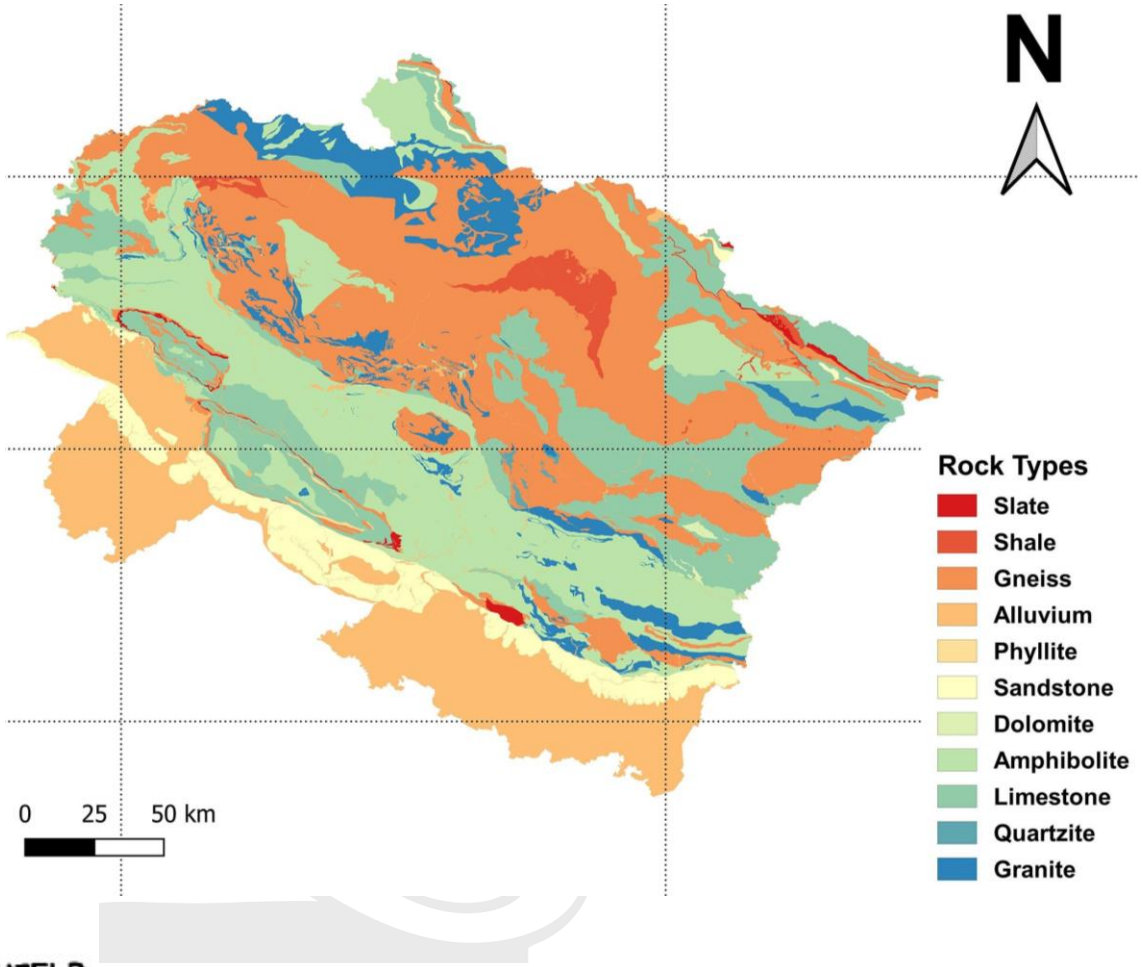




Mukherjee et, al., *Gondwana Research* 2019

The Himalayas



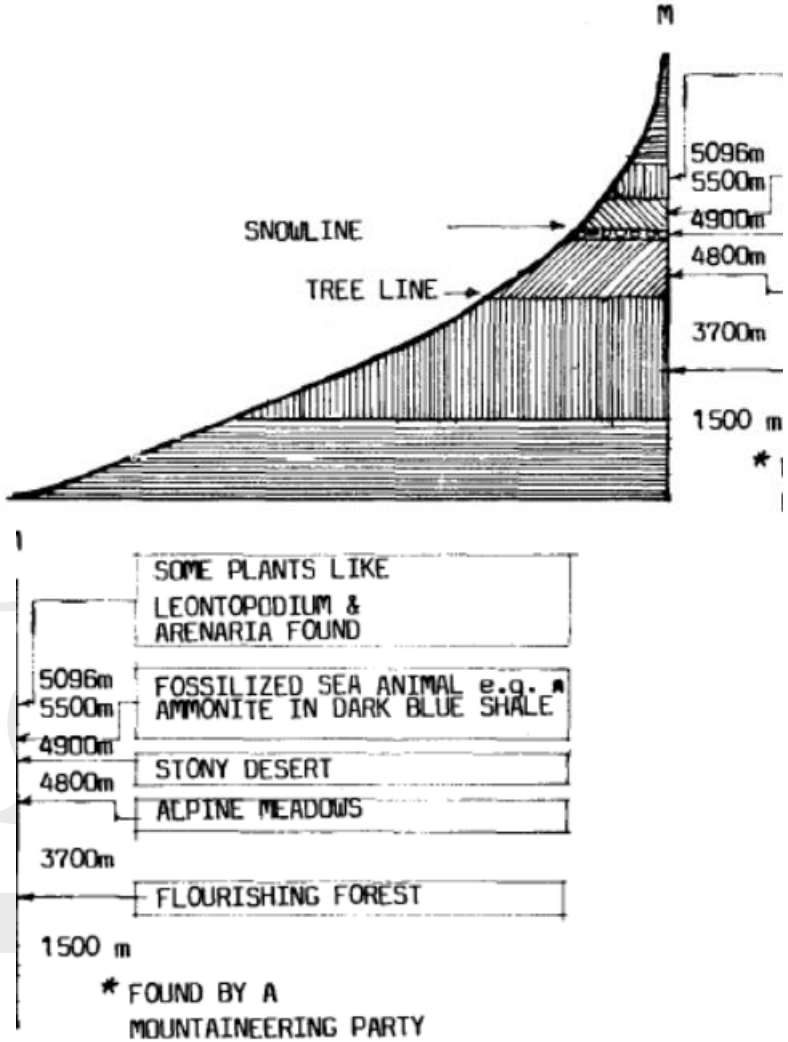


Gupta and Satyam, *Journal of Asian Earth Sciences: X* 2022

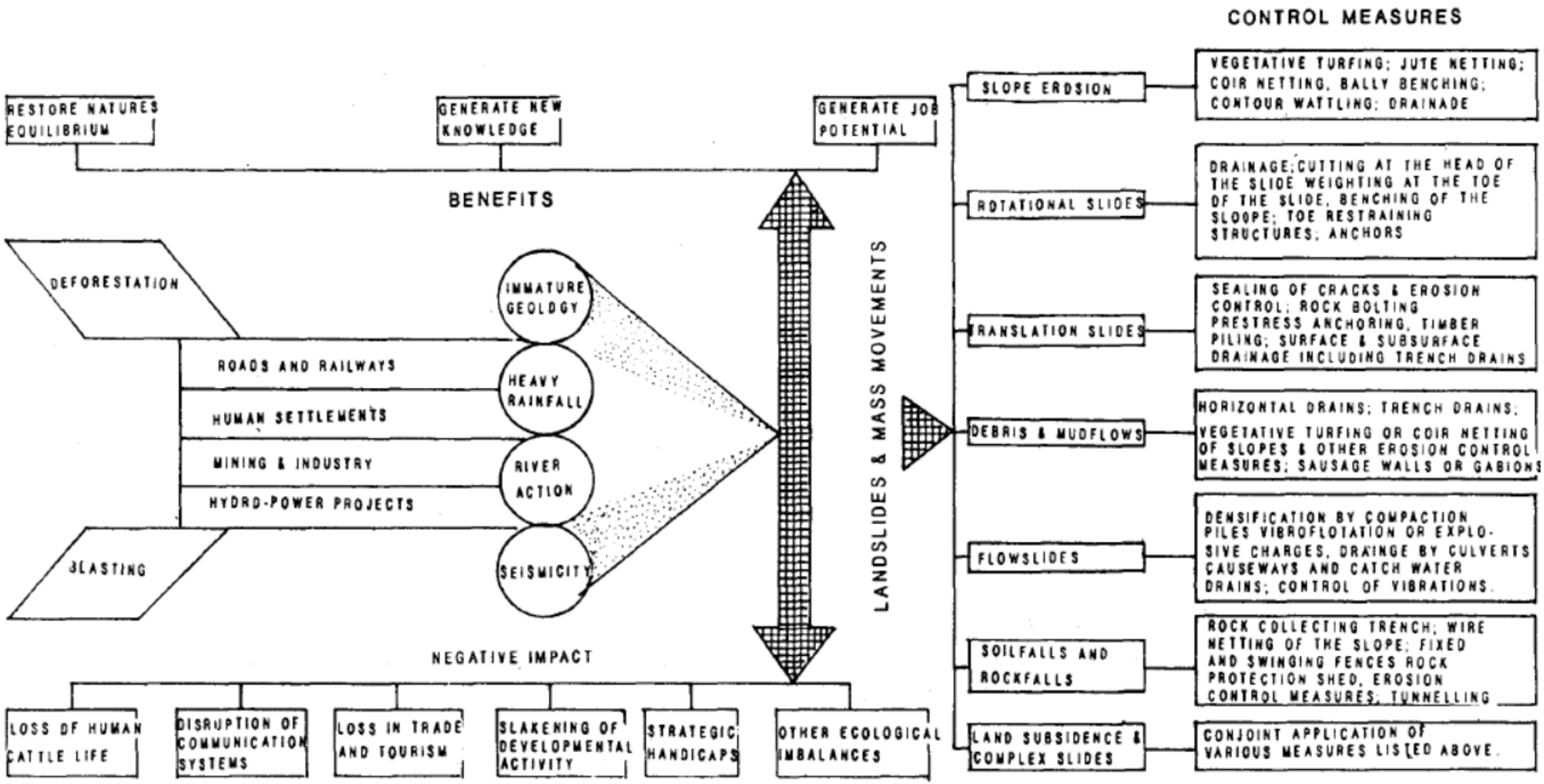
The Himalayas: Elevation

THE HIMALAYAN SYSTEM

Group	Relief	Descriprion
The sub-Himalaya or the Siwaliks (600 m t0 1200 m)	A succession of dissected hills largely with flat summits forming the southern-most part of foot hills. They are characterised by zone of intense landslides and mass wasting.	Comprise soft tertiary sediments, sand-stones silt stones, shales and clays prone to disintegration. It experi-ences full force of monsoon season Siwalik range is still thickly vegetated.
The Middle or Lower Himalaya (1200 m to 3000 m)	It is at angled mass of ranges and valleys, with major rivers cutting across it, some times in deep gorges. It lies immediately to the north of MBT where Siwalik belt ends and falls in medium to high relief zone.	This is para-autochthonus zone consisting largely of unfossiliferous rocks.The northern slopes are gentler, densely forested, colder and not much inhabited .The southern slopes are steep, bare and gullied, comprise essentially of sedimentary rocks subject to weathering Deforestation, over grazing and impact of monsoon are chief causes of denudation and mass wasting.
The Higher Himalaya (average height =5200 m-92 peaks over 8000 m high)	Lies north of MCT and is characterised by high relief zone of glaciation.	It is characterised by serrate nature of mountains with abundant sharp edged features and discordant drainage system. Comprise granitic gneisses and other crystalline rocks. Slopes are mostly bare with debricones and moraine walls at their base. Avalanches are recognised major hazard.
The trans Himalaya (average altitude 4500 m)	Tibetan marginal land High altitude passes between India & Tibet are located in this region.	It is composed of fossiliferous sediments of precambrian to cretaceous or even the tertiary periods. The principal rocks include slate, sandstone, conglomerater and limestone.



Factors Causing Slope Stability Problems in the Himalayas

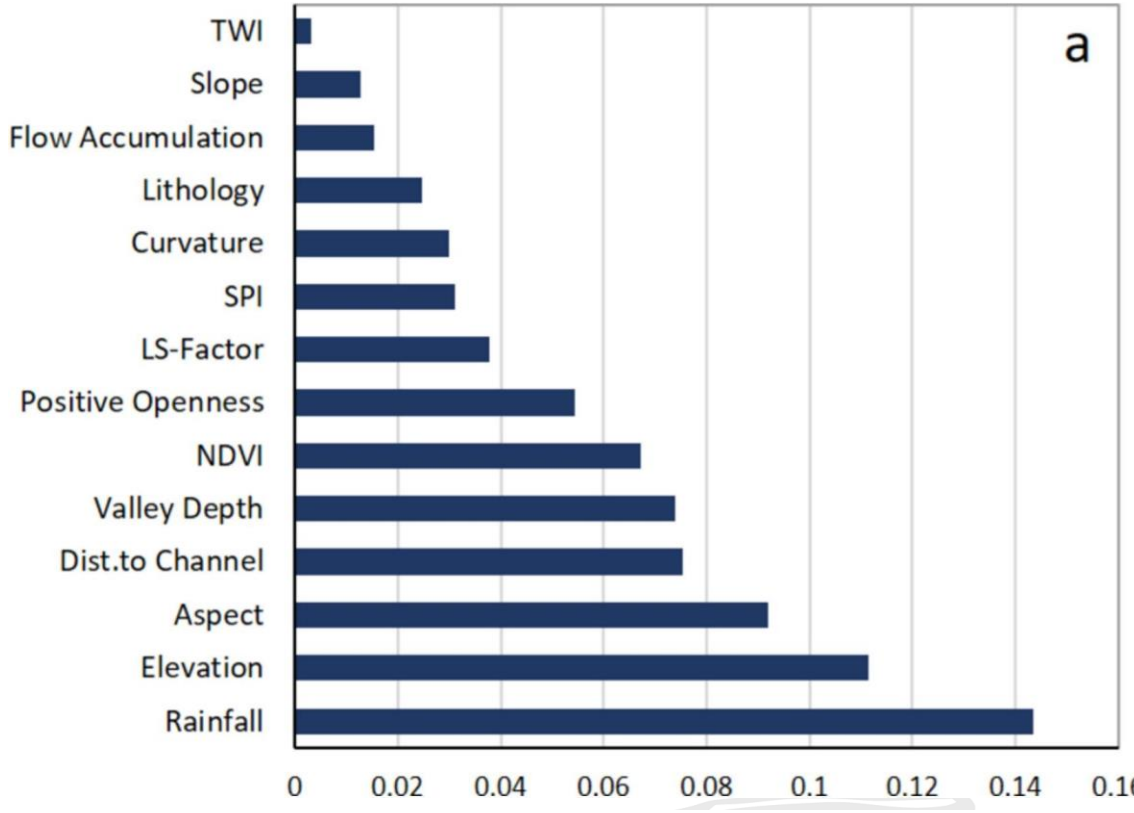


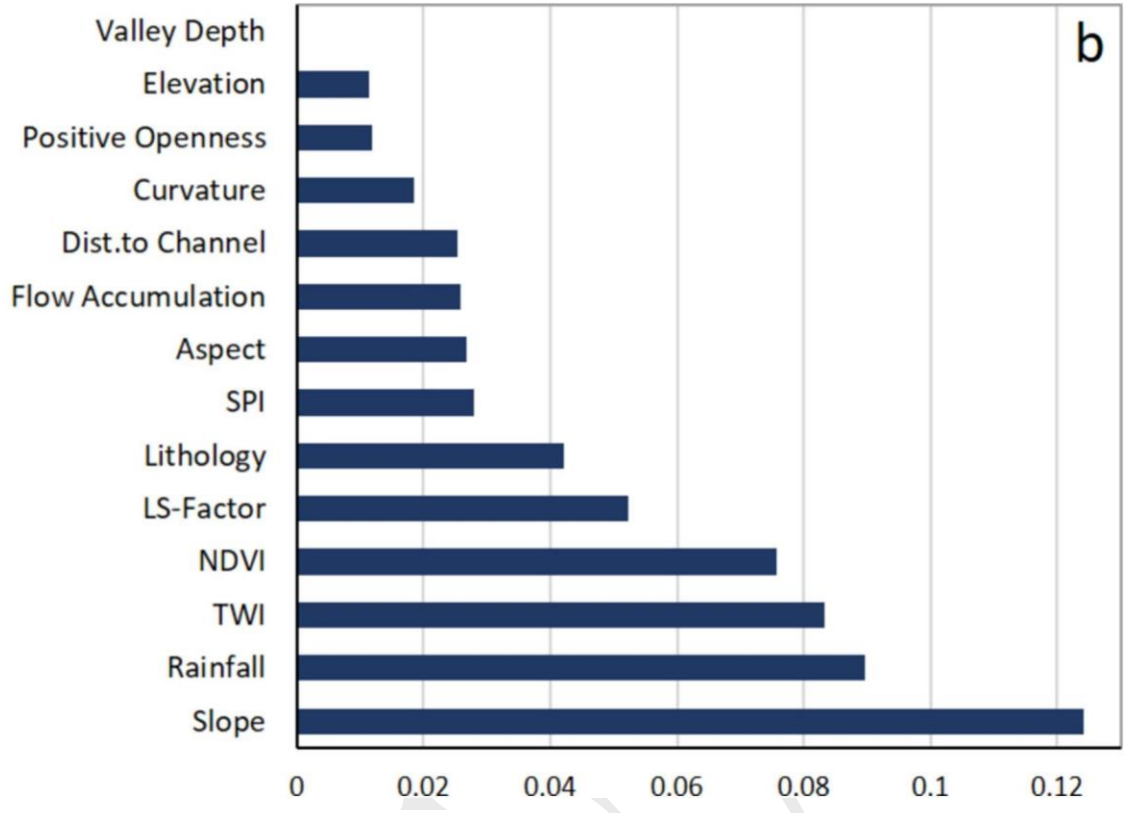
Classes of Slope Stability Problems in the Himalayas

CLASSIFICATION OF THE PROBLEMS OF MASS WASTING

Class	Problem	Effect	Economics of Control Measures and Efficiency
A Catastrophes	Simultaneous triggering of several landslides & other mass movements following 'cloudbursts', flash-floods' & tectonic activity. Includes fresh slides as well a reactivation of old ones.	Landslides and breaches often create river blockades, landslide dams and lakes. Damages are spectacular and ground movements extensive and large scale.	Problem often faced as it comes. Control measures require very heavy technoeconomic inputs rarely available. Palliative measures are only partially effective.
B Repetitive slides and mass movements	Major old landslides, particularly if left neglected, enlarge themselves to assume formidable proportions. The problem is less severe for slides already in treated state before reactivation.	Slope movements are sudden, extremely large and ensuing subsidences usually of a very high order. Drainage of area is severely impaired & susceptibility to erosion increases.	Massive haulage of earth and protection works essential and efficacy of the latter is intimately related to the appropriateness & adequecy of control measures and their timely execution.
C First time or fresh slides and mass movements	Problems on cuttings are more severe than those on natural slopes. Slides often involve subsidence at 'crown' & heave at the toe. Planer slides are also common in certain geological formations.	Virgin natural slopes usually retain cover of vegetation. Toe, rear scar and side shear boundaries can generally be identified. Mud flows cut across colluvium.	A 'stitch' in time can generally save the slope at a nominal cost. Drainage deserves special emphasis. Vegetation should be restored to contain surface erosion problem.
D Block slides and Rockfalls	Shooting boulders hurtle down the slopes, ensuing vibrations trigger mass movements.	Destroy bridges, roads and communication systems.	Often require detouring, tunnelling, anchoring etc. which are expensive.
E Creep Movement	Does not pose any serious problem.	Tilt trees, buildings etc.	No attempts are made to arrest creep movements.

Factors impacting landslides in the Himalayas



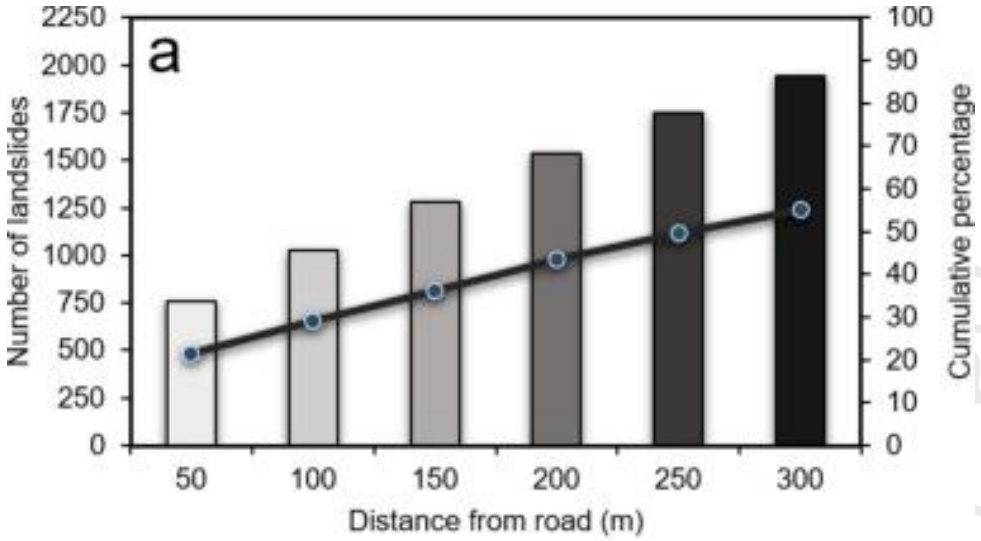


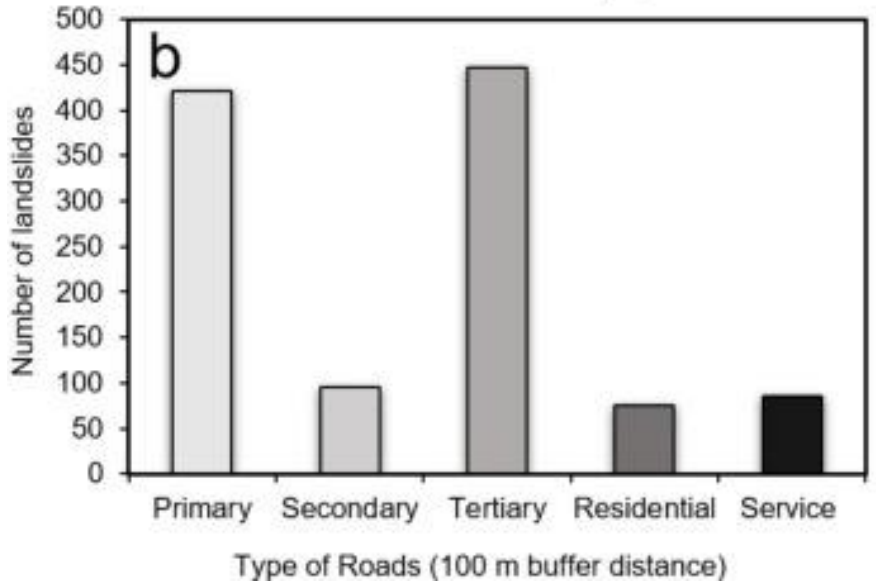
S. No.	Factors	Weightage	S. No.	Factors	Weightage
1	Elevation	0.35281	8	Lithology	0.08878
2	Distance to nearest road	0.33824	9	PGA	0.05467
3	Distance to nearest fault	0.1396	10	Slope	0.05181
4	Land use and land cover	0.1388	11	Aspect	0.05174
5	Distance to nearest river	0.128	12	Rainfall	0.04971
6	Geology	0.12787	13	Profile Curvature	0.01279
7	Soil Depth	0.09977	14	Curvature	0.00478

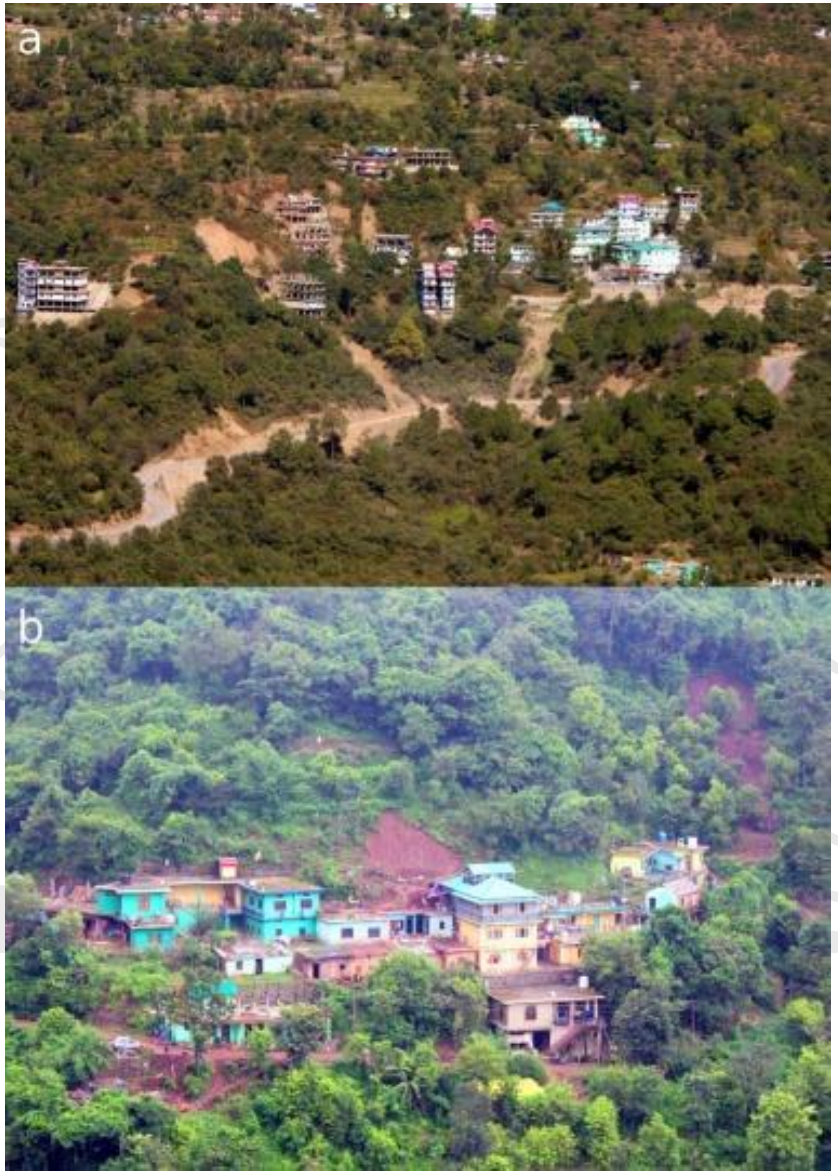
Kaushal et., al., *CATENA*
Volume 250, March 2025, 108771

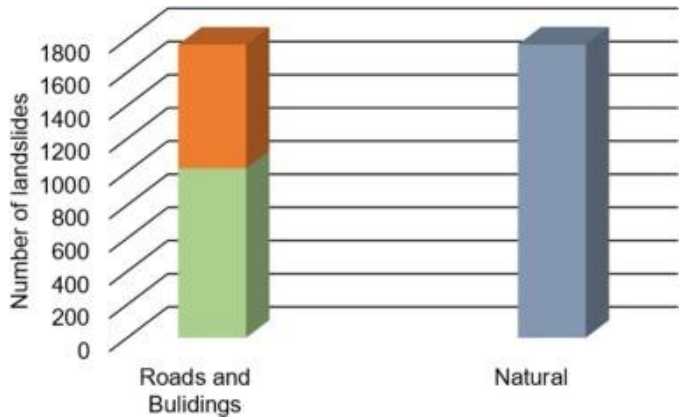
Dwivedi et., al., 2025 (*Unpublished*)

Factors impacting landslides in the Himalayas

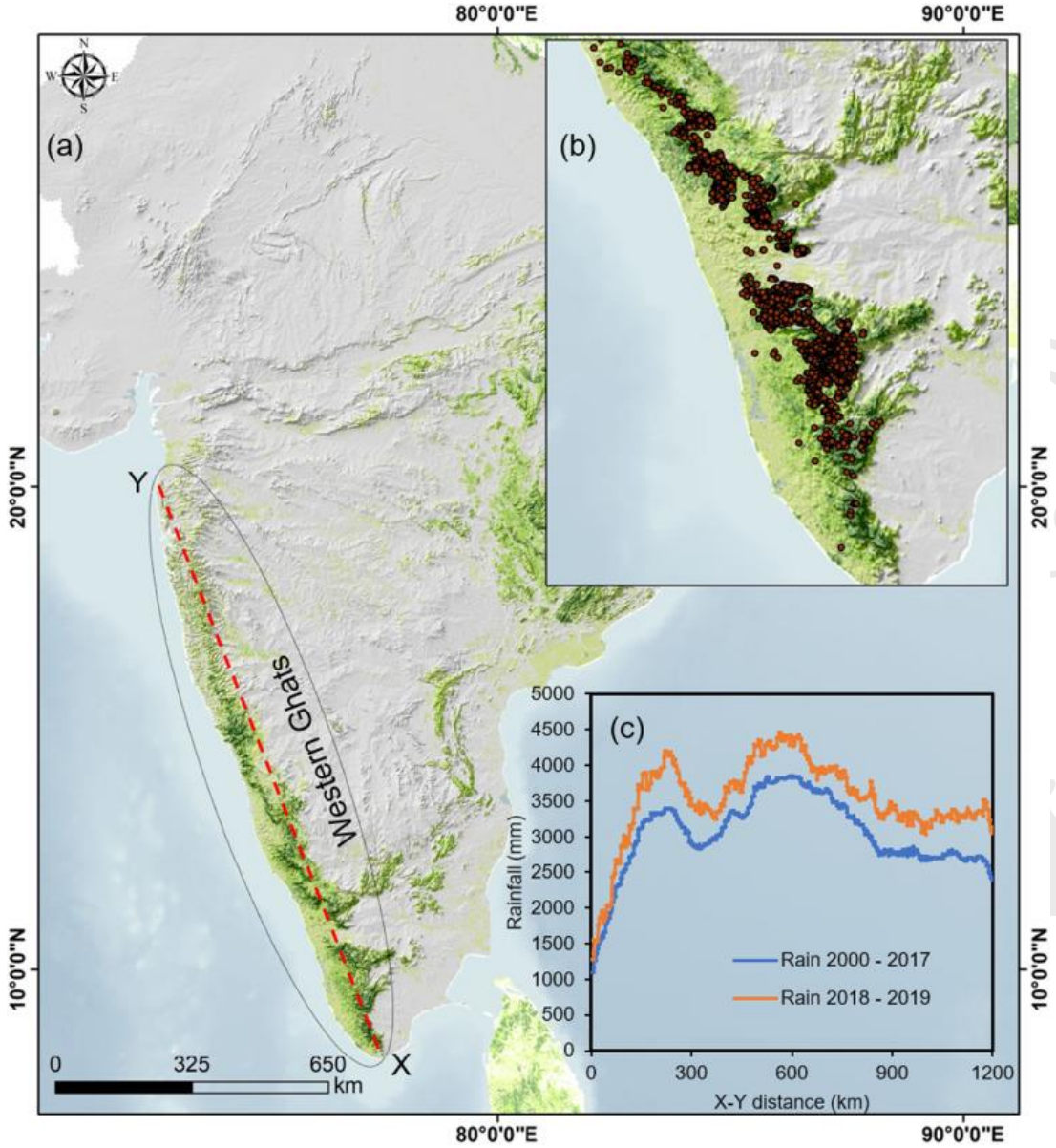








Drivers of Intensified Landslide Regimes in Western Ghats



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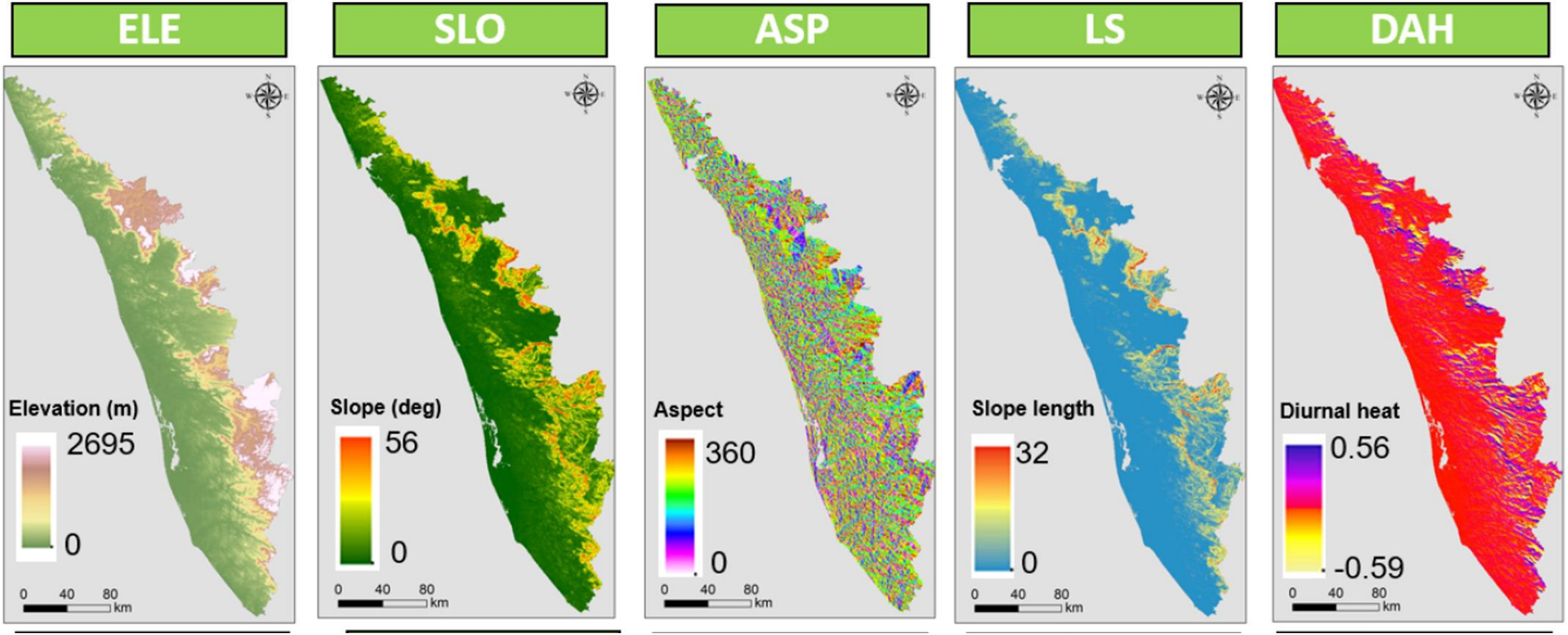

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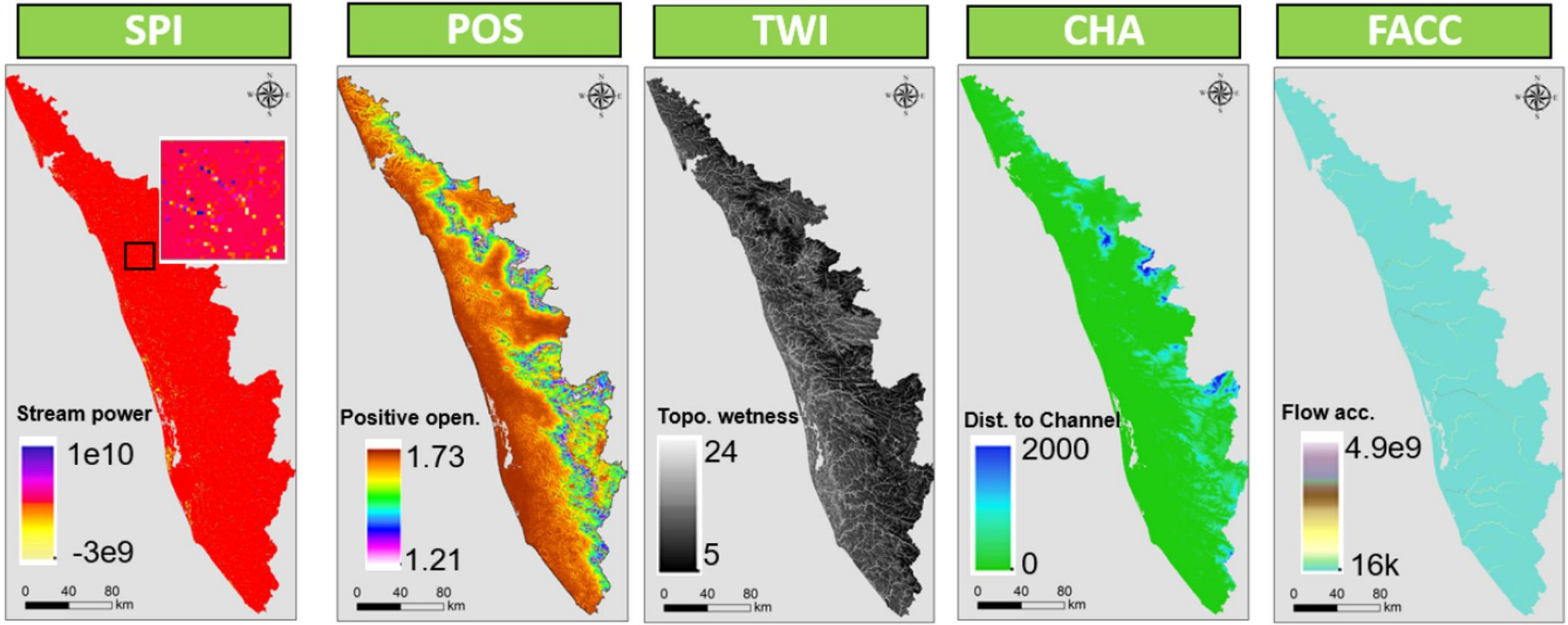

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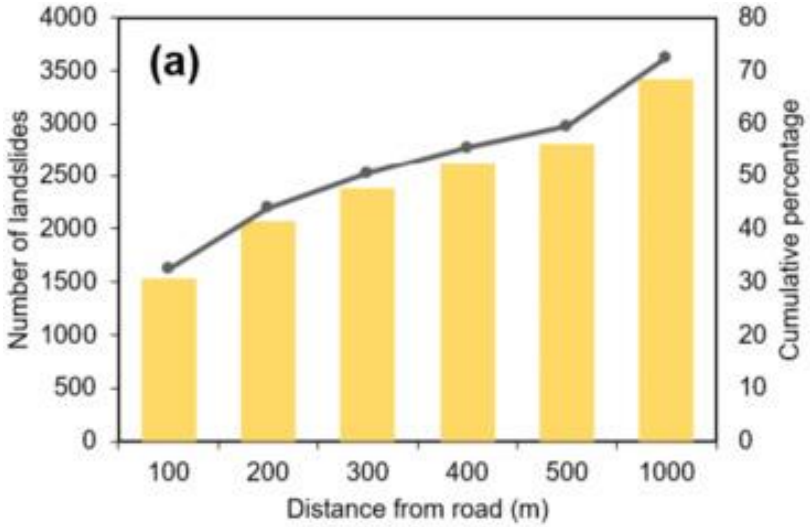

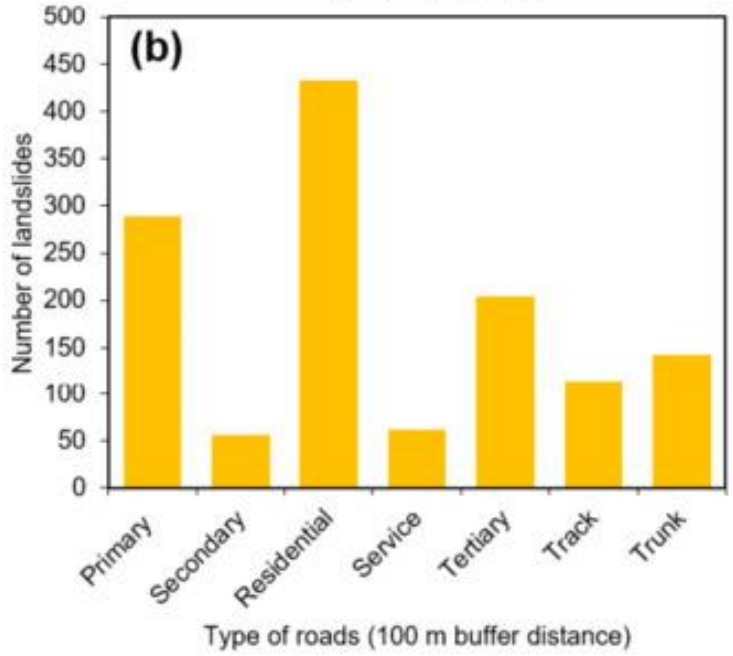

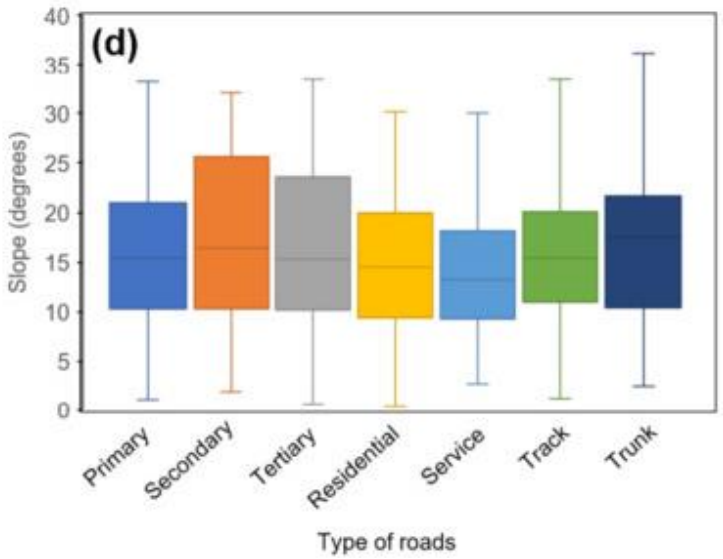

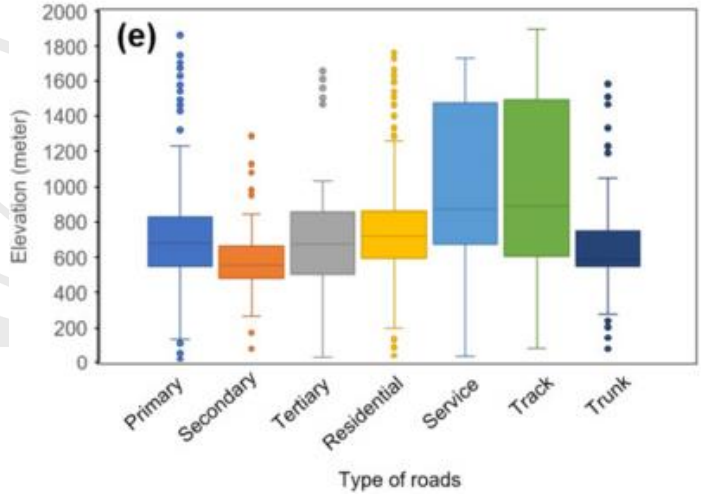

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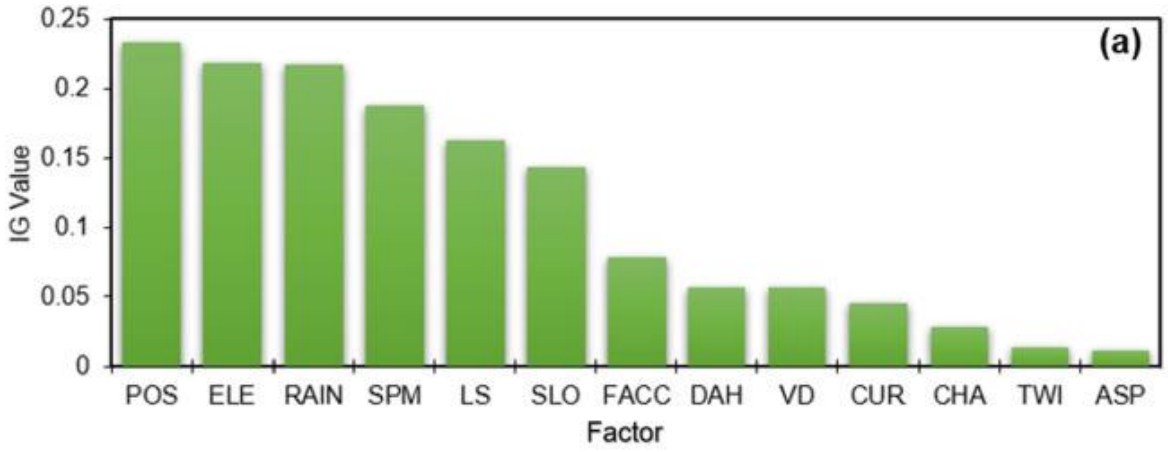
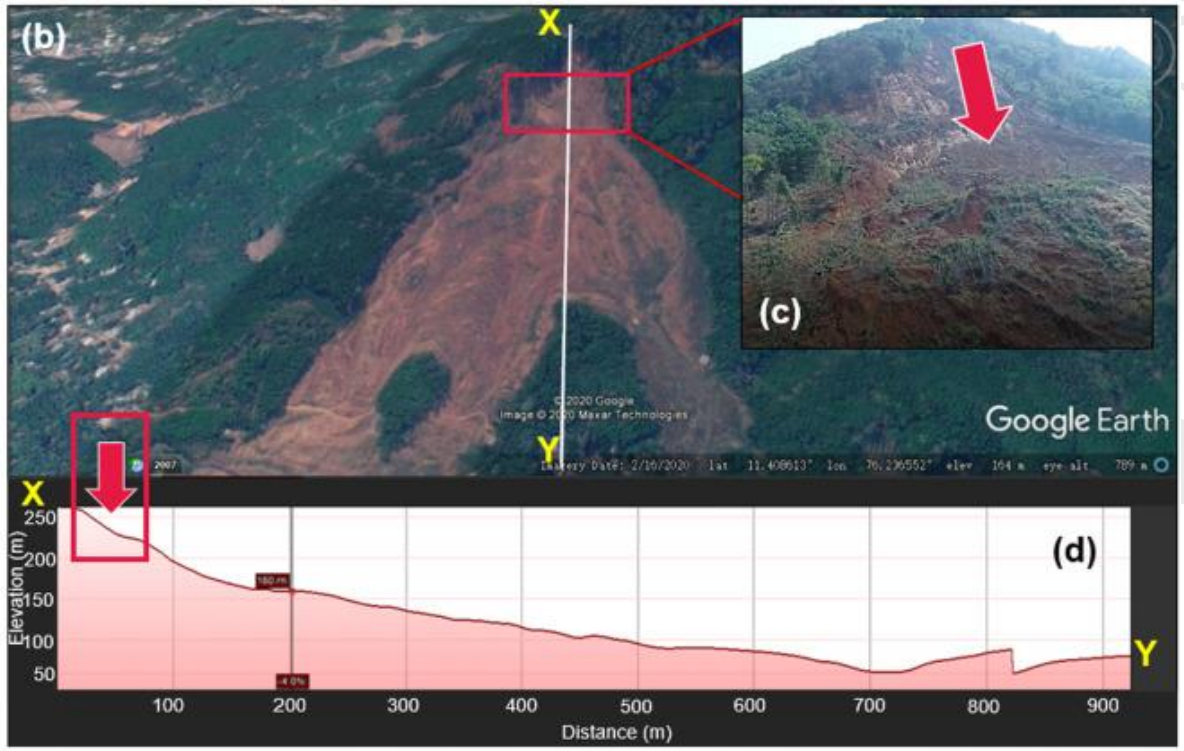
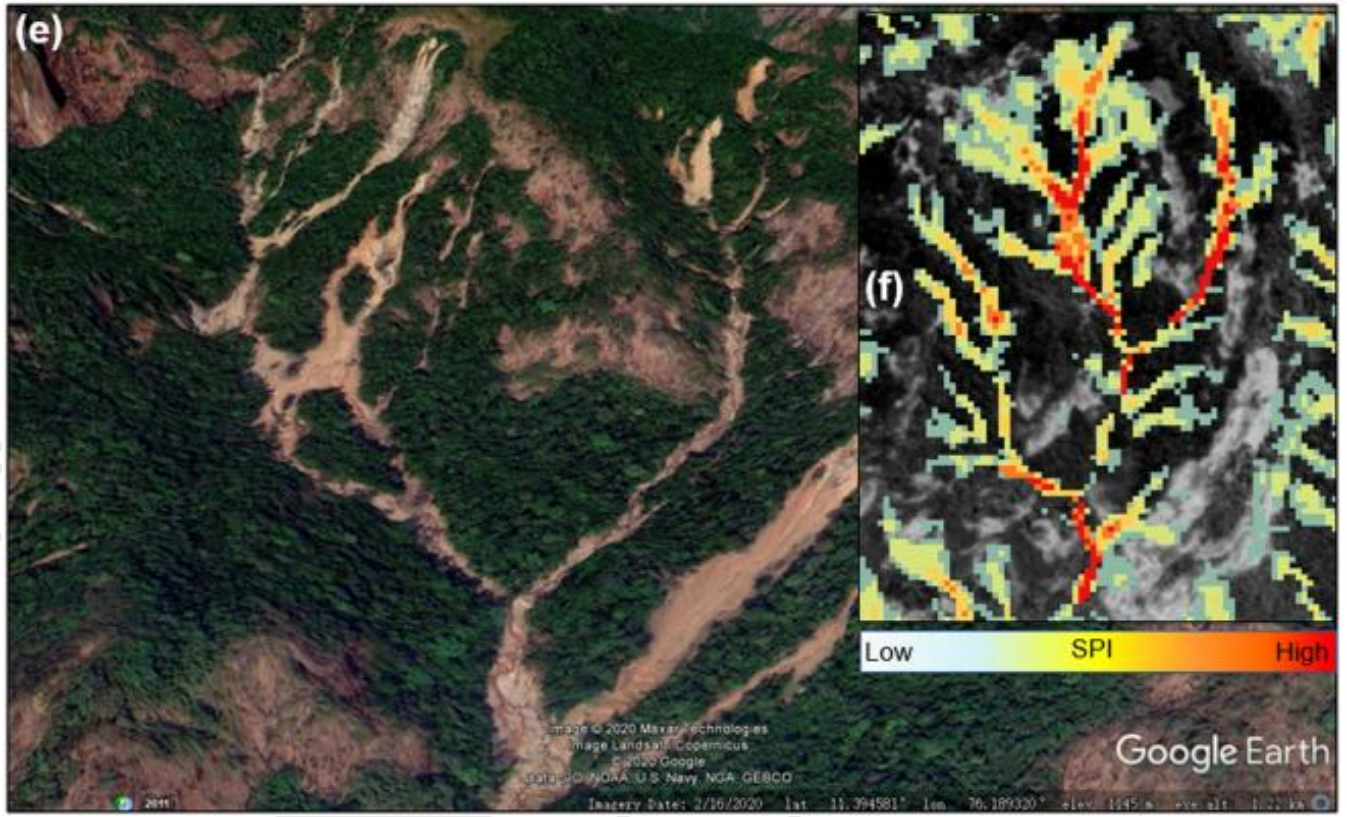


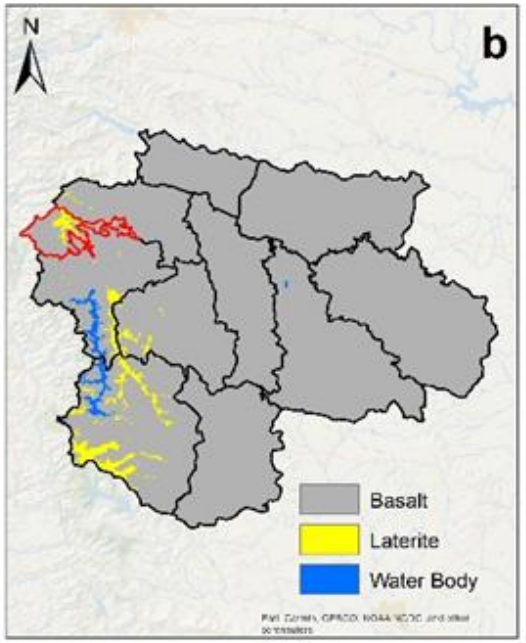


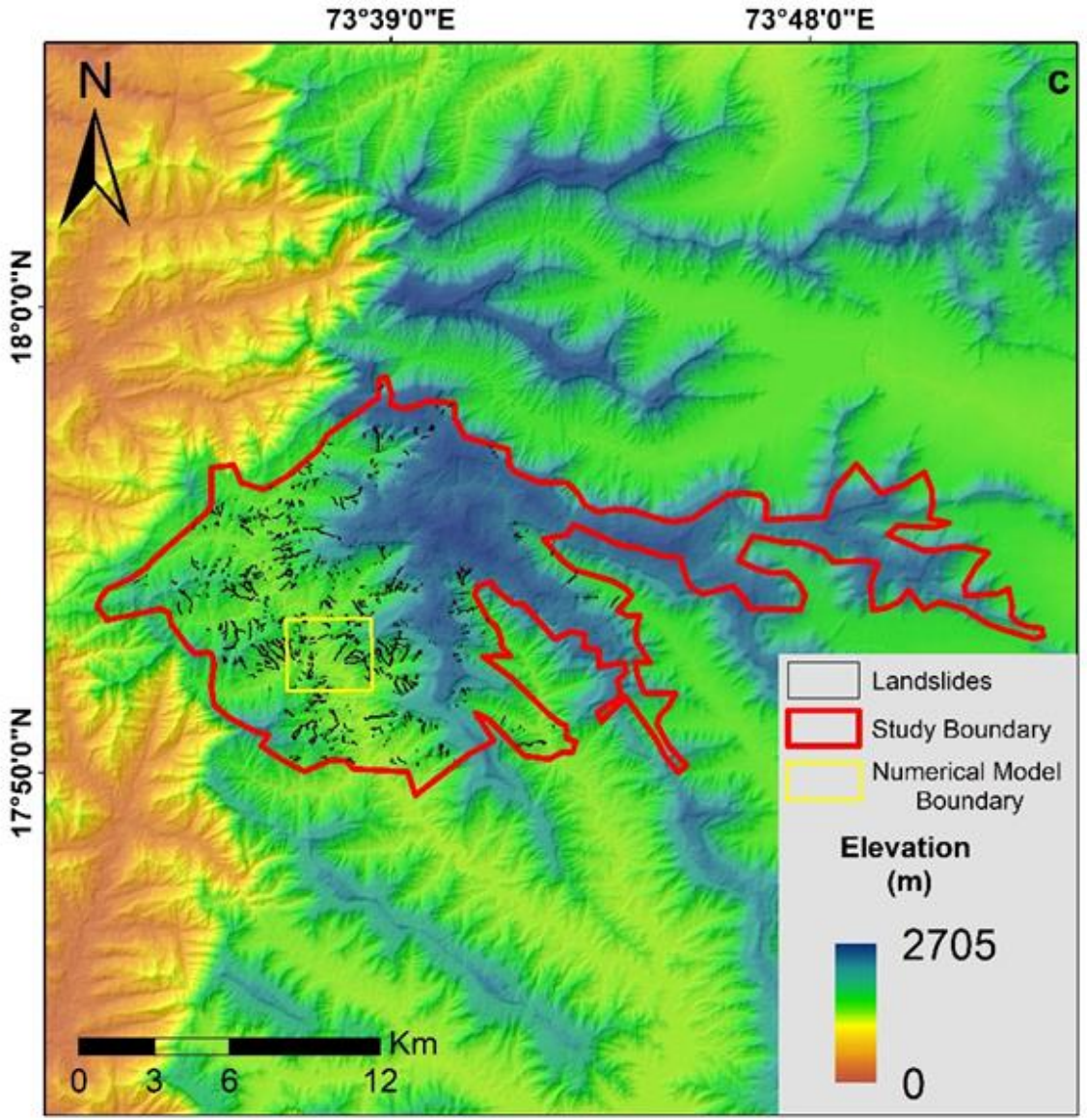


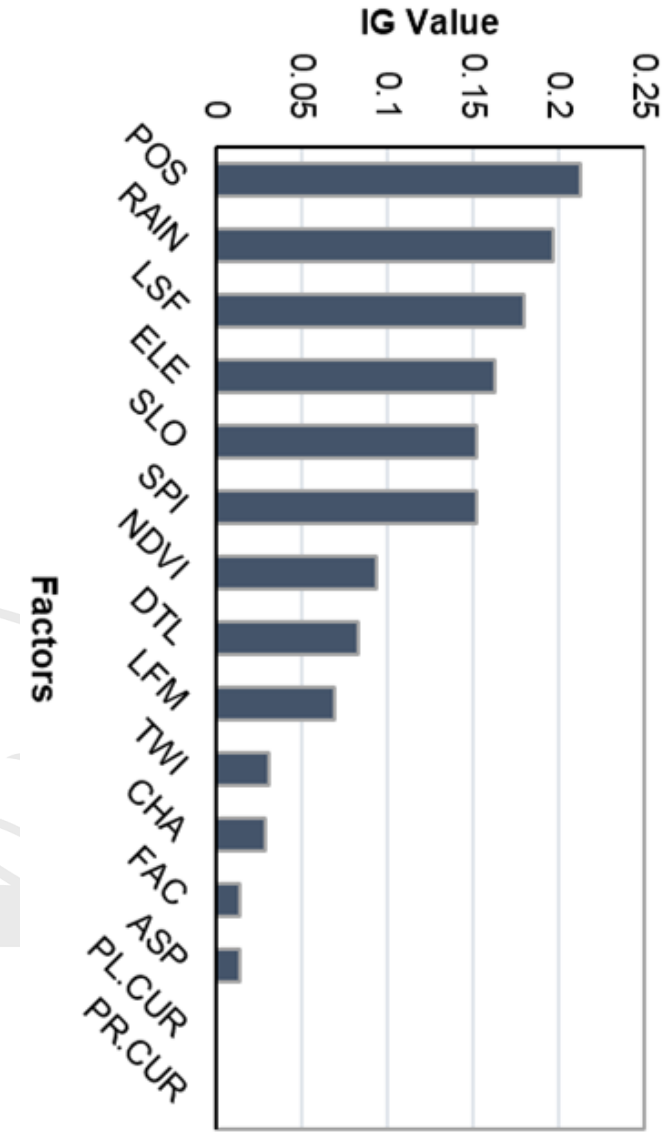
Drivers of Intensified Landslide Regimes in Western Ghats

S No	Factors	Description, Data Source and Resolution
1	Elevation (ELE)	30 m gridded elevation data taken from ALOS AW3D
2	Slope (SLO)	Rate of change of elevation for the 30 m grid (in degrees)
3	Aspect (ASP)	The slope's orientation defined as 0° for north and 360°, and 180° for south
4	Curvature (CUR)	The second derivative of the elevation surface, indicating the slope's shape, aiding in the understanding erosion and runoff mechanisms
5	LS-Factor (LSF)	Calculation of slope length (LS) is based on slope and specific catchment area. And it describes the effect of topography on erosion
6	Stream Power Index (SPI)	Calculation based on slope and specific catchment area (SCA). SPI = SCA * tan(Slope). This describe potential flow erosion in the watershed
7	Distance to Channels (DTC)	Distance from the channel network extracted using 0.5 km^2 as threshold contributing area
8	Topographic Position Index (TPI)	Index of grid cell position relative to ridges and valleys. Positive TPI represents cell is closer to ridges
9	Topographic Wetness Index (TWI)	This quantifies the impact of terrain on hydrological phenomena within a watershed
10	Valley Depth (VDF)	Vertical distance to a channel network base level
11	Positive Openness (POS)	A factor that expresses surface concavity and convexity (Yokoyama et al., 2002)
12	Normalized Difference Vegetation Index (NDVI)	A proxy of vegetation dynamics, obrtained from Sentinel-2
13	Distance to Lineament (DTL)	Distance from the faults and lineaments, obtained from Bhukosh Portal (1:250000)
14	Rainfall (RAIN)	CHIRPS rainfall data, resampled to 30 m

Drivers of Intensified Landslide Regimes in Western Ghats







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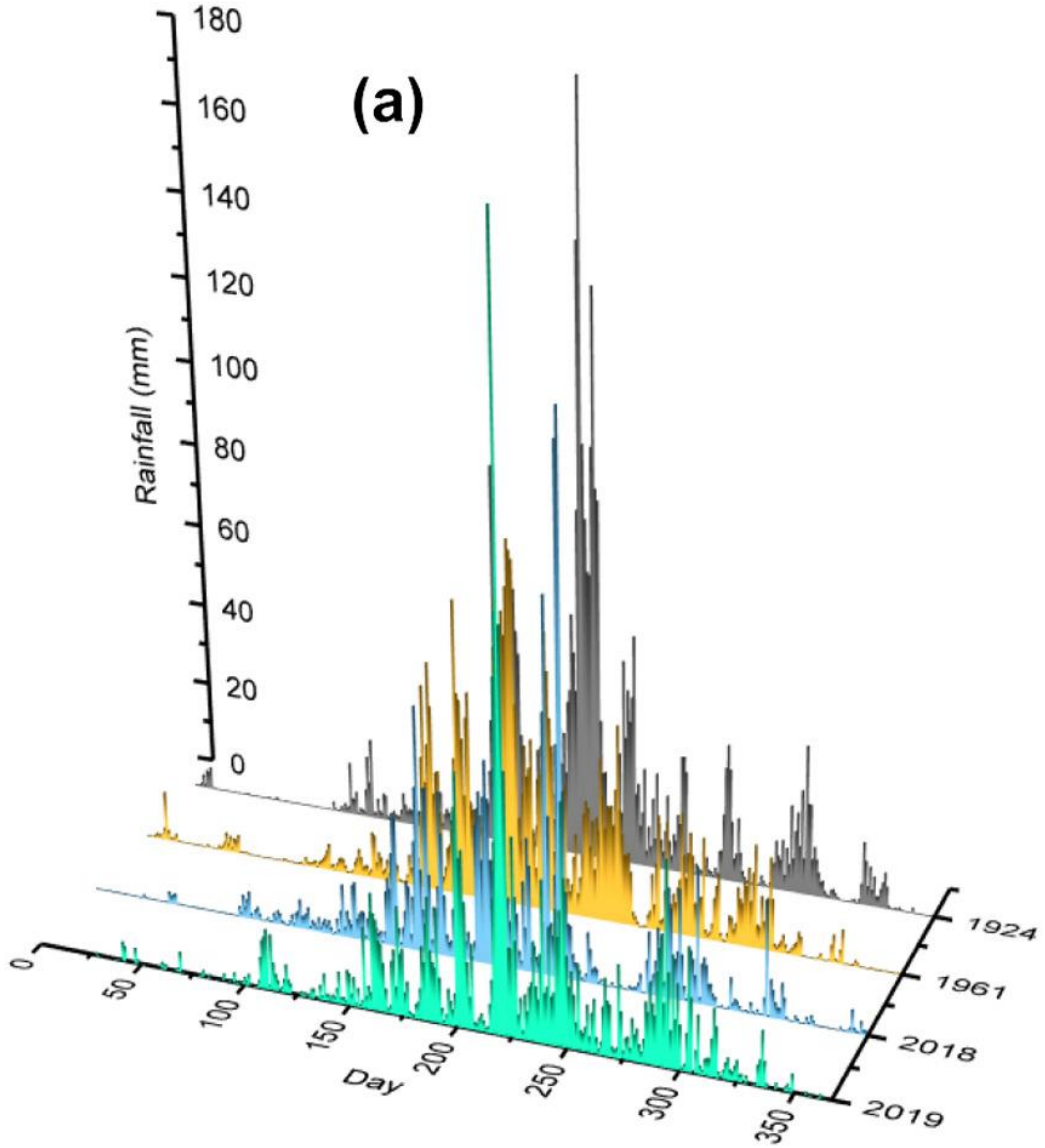

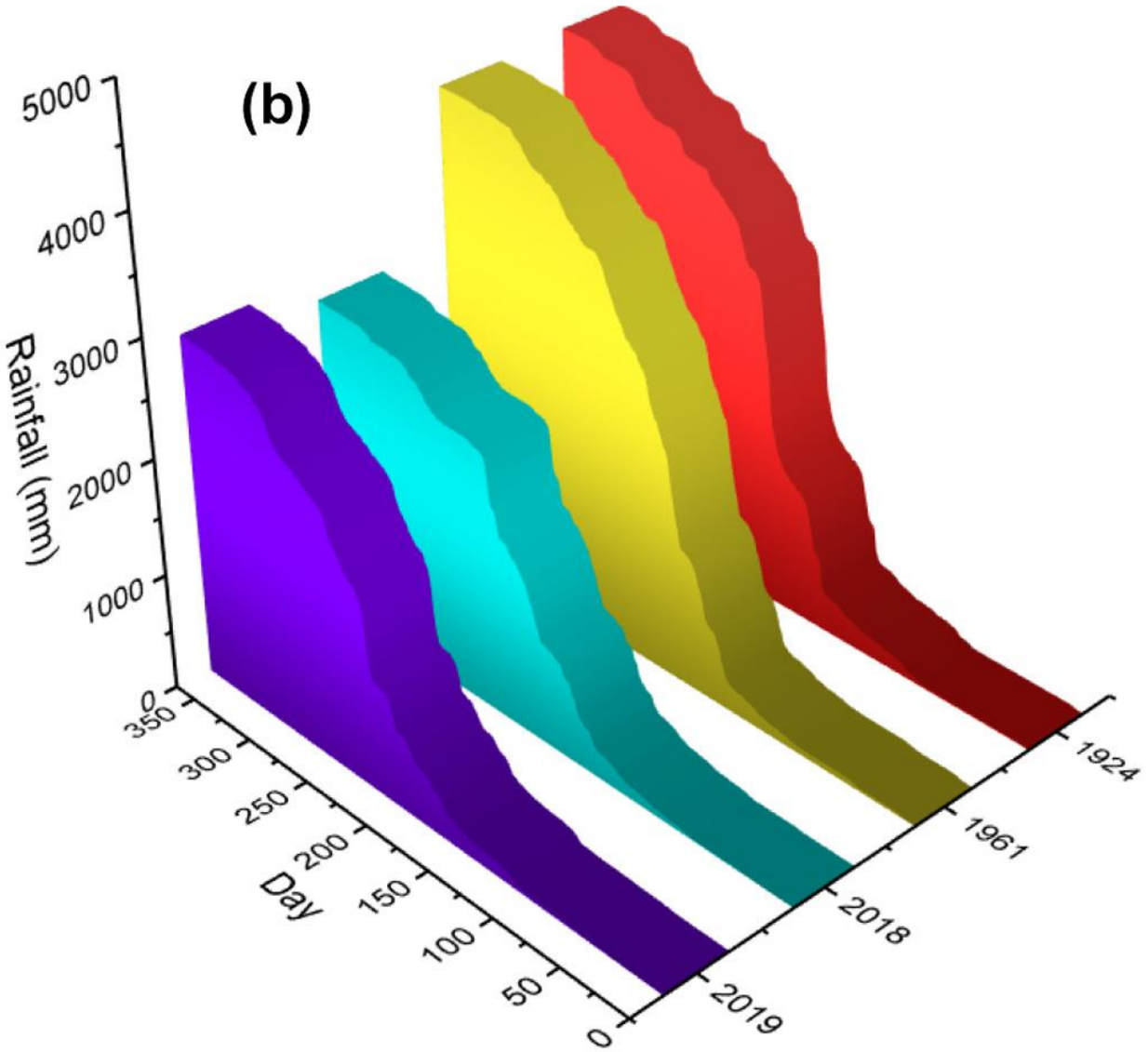

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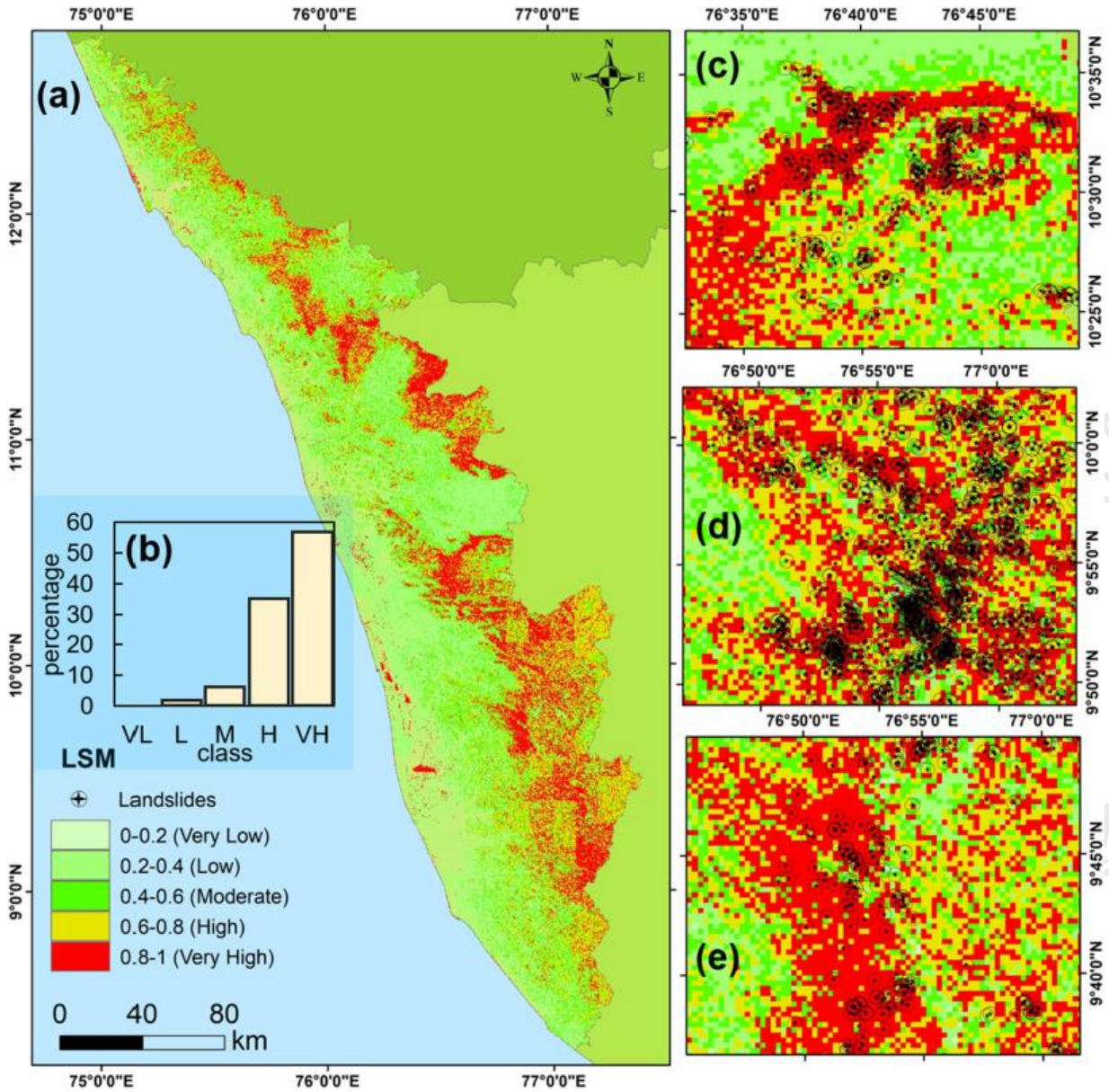
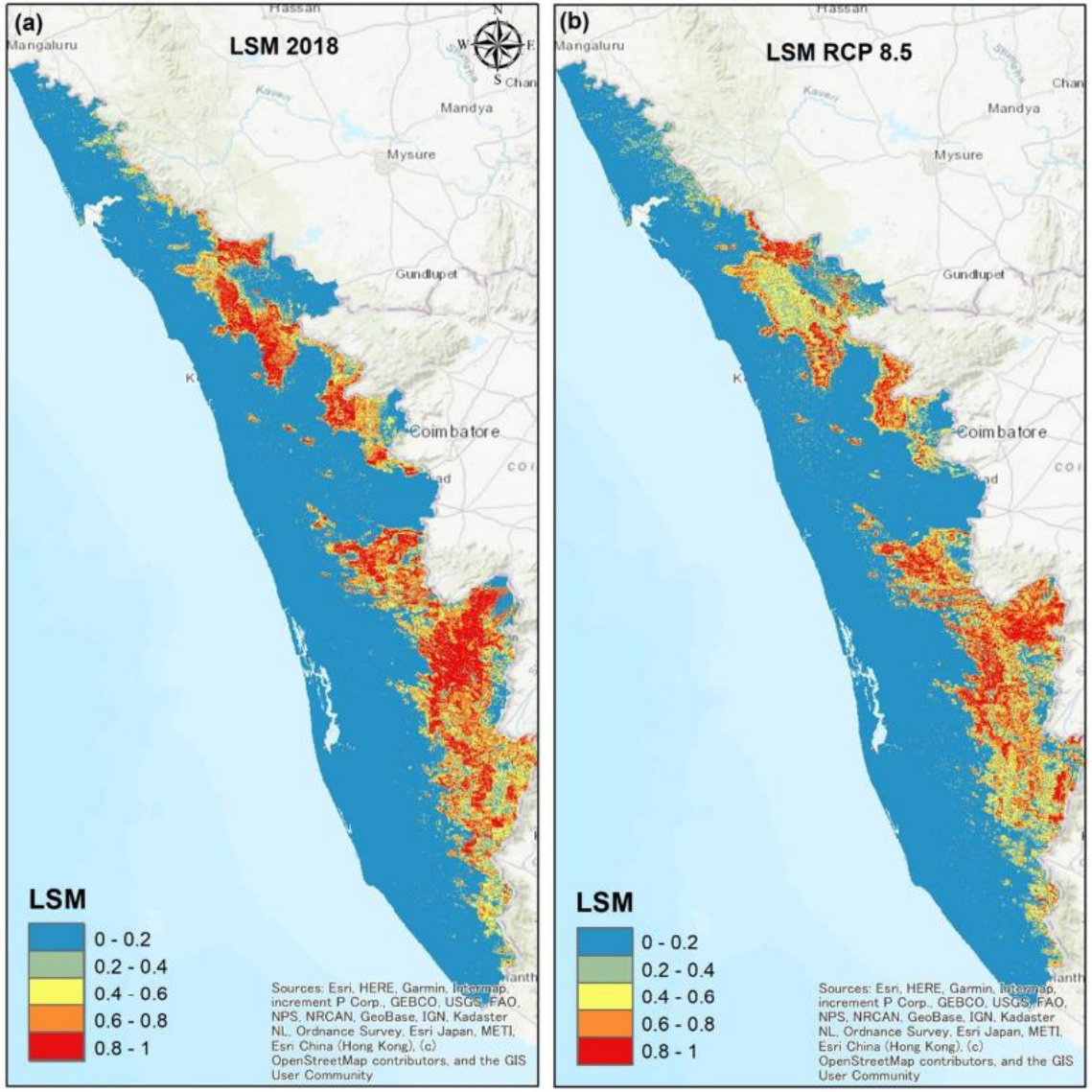




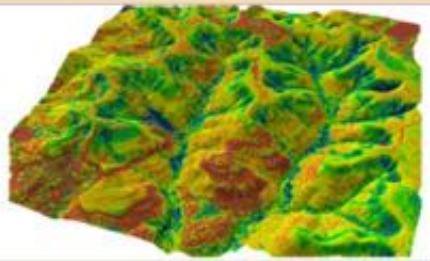
Drivers of Intensified Landslide Regimes in Western Ghats

Triggering Mechanism of Landslides in WG

Drivers of Landslides in WG

Unplanned Road Construction

Land cover dynamics Forest-to-Plantation



Topography (POS, SPI)

Key Risks

- ❑ Rock falls,
- ❑ Shallow landslides,
- ❑ Typically low casualties

- ❑ Shallow and Deep Landslides,
- ❑ Debris flows,
- ❑ High causalities

- ❑ Shallow and Deep Landslides,
- ❑ Debris flows,
- ❑ Low-Moderate causalities

Drivers of Intensified Landslide Regimes in Western Ghats

Mitigation Strategies

Mountain Roads

- Improved road designs
- Stabilize slope above and below the road cut
- Drainage management
- Adequate paving
- Vegetative filter strips

Plantation Slopes

- Alter agricultural practices & diversify crops
- Step terrace farming
- Smoothen concave surface
- Design drainage systems

Stream power

- Contour bunding, check dams
- Conservation ponds, and trenches
- Avoid constructions in riparian zones
- Smoothen undulating surface

Thank you very much for your kind attention and time!

Question time