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Towards a Policy Framework for Landslide Risk Management in the Western Himalaya: Site Specific Investigations from Ramban and Kishtwar Districts, Jammu and Kashmir, India

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Abstract

Mountainous terrain of the Himalayan region is inherently prone to different types of mass movements due to fragile lithology, steep slopes, active tectonics, high-intensity precipitation, and escalating anthropogenic disturbances. Here, we present the results of a comprehensive field-based site-specific investigation conducted at critical landslide-prone sites and to understand the hazard, vulnerability, and risk assessment (HVRA) in Ramban and Kishtwar districts in the Union Territory of Jammu and Kashmir. Systematic site-specific investigations were undertaken at critical hazard hotspots encompassing urban settlements, major road corridors, and river valley settings. The assessment integrates detailed field studies with analyses of geological, structural, hydrological aspects, and human-induced slope modifications to elucidate the dominant cause and modes of slope failures. The investigation suggests various dominant factors such as blocked and poorly managed drainage, rainfall-induced slope saturation, toe erosion along roads and riverbanks, and unfavourable litho-structural orientations as the principal triggers for slope instability and flash floods. Based on field evidences, the study proposes targeted, site-specific mitigation measures emphasizing improved surface and subsurface drainage, slope stabilization, debris-flow regulation, and land-use control. These measures are consolidated in a dedicated Policy Document on the basis of a robust scientific foundation for immediate risk reduction and support enhanced disaster preparedness and sustainable infrastructure planning in the region.

Keywords: Landslides, debris flows, flash floods, HVRA, drainage control, Ramban, Kishtwar, Northwestern Himalaya

1. Introduction

The Himalayan mountain system is recognized as one of the most tectonically active and environmentally fragile mountain systems in the world, where recurrent landslides and flash floods pose serious threat to human settlements, infrastructure, transportation corridors, hydropower projects, and ecological sustainability (Ramaya et al., 2023; Singh et al., 2024; Yadawa, 2024; Sain, 2026; Mir, et al., 2025a; Sati, 2026). The complex interplay of fragile lithology, active tectonics, steep relief, intense weathering, highly variable climatic conditions as well as anthropogenic disturbances including unscientific road widening, tunnel excavation, slope cutting, deforestation, poorly designed retaining structures, blockage of natural drainage,

and uncontrolled household wastewater discharge have substantially accelerated slope instability and flash flood vulnerability (Gerrard, 1994; Owen et al., 2008, 2026). Geological conditions determine the mechanical behavior and strength of slope materials, while geomorphological parameters such as slope gradient, aspect, elevation, valley morphology, and erosion patterns influence the spatial distribution of instability zones (Singh, 2018; Zou et al., 2026; Scaringi and Loche, 2022; Singh et al., 2024; Ul Haq et al., 2026; Sangra et al., 2026). The young and tectonically active orogen is characterized by highly fractured rock masses, pervasive shear zones, and deeply incised valleys, which collectively reduce slope stability and increase susceptibility to mass movements (Burbank et al., 2012). These inherent geological weaknesses are further exacerbated by frequent seismic activity and high rates of uplift, making the Himalaya particularly sensitive to both natural and anthropogenic disturbances (Shrestha et al., 2025; Mir et al., 2025b).

In the Northwestern Himalaya, landslides and flash floods constitute recurrent and destructive hazards, posing serious threat to human life, transportation networks, hydropower projects, and regional economic development (Singh et al., 2018, 2024; Mir et al., 2025; Khan et al., 2025). In the recent years, the road corridors constructed along steep valley flanks and river gorges are especially vulnerable, as slope cutting, toe erosion, and inadequate stabilization measures frequently trigger failures during the monsoon season (Sati et al., 2011; Shugar et al., 2021). Rapid urban expansion on unstable slopes, combined with deforestation and unregulated excavation, has further intensified landslide risk in recent decades (Singh et al., 2026a). Observational and reanalysis of data indicate an increase in the frequency and intensity of extreme rainfall events in the Himalaya, attributed to climate change driven alterations in monsoon dynamics and cloudburst occurrences (Dimri et al., 2017; Krishnan et al., 2019). Intense short-duration rainfall enhances pore-water pressure, reduces effective stress, and triggers shallow landslides, debris flows, and flash floods, particularly in weathered rock and unconsolidated colluvial deposits (Bazai et al., 2022; Amarasinghe et al., 2024; Habib et al., 2025). The impact of extreme precipitation is often magnified by poor surface and subsurface drainage infrastructure, which leads to uncontrolled infiltration and slope saturation (Archer et al., 2022; Mir et al., 2025b).

Ramban and Kishtwar districts, located within the Chenab River basin in the Union Territory of Jammu and Kashmir, India, experience repeated slope failures during high precipitation, resulting in frequent road blockages, infrastructure damage, and loss of livelihood. These districts are characterized by complex litho-tectonic settings, including highly jointed metasedimentary and crystalline rocks, major thrusts and faults, and thick mantles of colluvium and debris along valley sides (Thakur et al., 2010; Haq et al., 2019; Mir et al., 2022). In Ramban, landslides are commonly associated with road widening, slope undercutting, and inadequate drainage, while in Kishtwar, steep slopes, deep river incision, and localized cloudburst events play a dominant role in triggering mass movements (Khan et al., 2022; Singh et al., 2026b). Despite the implementation of several site-specific remedial measures such as retaining walls, gabion structures, and slope trimming the recurrence of landslides in these districts underscores the limitations of isolated engineering solutions. Many interventions fail to adequately account for slope-scale geological controls, groundwater conditions, and evolving anthropogenic pressures, resulting in repeated failures at the same locations. This highlights the urgent need for integrated, field-based assessments that explicitly link landslide failure mechanisms with geomorphology, hydrology, and land-use practices (Aleotti & Chowdhury, 1999; Glastonbury & Fell, 2008; Mir et al., 2021). In recent decades, several policy frameworks, disaster management

plans, and technical guidelines for landslide and flash flood risk reduction have been introduced in the Indian Himalayan Region through agencies such as the National Disaster Management Authority (NDMA), Geological Survey of India (GSI), National Institute of Disaster Management (NIDM), and state disaster management authorities. However, the implementation of these measures remains inconsistent even in the highly vulnerable mountain districts where developmental activities often proceed without adequate geological and geomorphological assessment. The reason for this include the lack of comprehensive short term mitigation measures on geologically fragile zones wherein the engineering capabilities need to consider the geological inputs for holistic safety of the region and its economic growth. It has been observed that most of the existing and ongoing studies focus on hazard zonation or disaster events individually, with limited comparative assessment of how policy guidelines are translated into practice across vulnerable Himalayan regions at district level. Despite growing research on Himalayan hazards, significant gaps still exist in integrating geomorphic processes, anthropogenic slope modification, local drainage mismanagement, and policy implementation within a unified risk reduction framework. Most existing studies focus either on hazard zonation or disaster events individually, with limited comparative assessment of how policy guidelines are translated into practice across vulnerable Himalayan areas. The present study therefore aims to critically evaluate existing policies, plans, and guidelines for landslide and flash flood risk reduction in the Northwestern Himalaya through comparative case studies of highly vulnerable districts. The study seeks to identify the gaps scientific recommendations and ground-level implementation, assess the influence of anthropogenic slope disturbances and drainage mismanagement on hazard occurrence, and propose integrated geo-environmental strategies for sustainable mountain development and disaster resilience in the Himalayan region of Jammu and Kashmir.

Against this background, the present study aims to: (i) assess landslide hazard and vulnerability at critical locations through detailed field investigations and engineering geological classification in Ramban and Kishtwar districts; (ii) identify the key geological, geomorphological, hydrological, and human-induced factors that control slope instability at selected landslide-prone sites; (iii) propose scientifically sound and practical short-term mitigation measures for disaster risk reduction; and (iv) develop general mitigation guidelines that are cost-effective, adaptable, and suitable for similar complex Himalayan terrain. The findings of this study are expected to support evidence-based disaster risk reduction strategies and contribute to safer infrastructure planning in the Northwestern Himalaya.

2. Study Area

The study area comprises Ramban and Kishtwar districts in the Union Territory of Jammu and Kashmir, situated within the Chenab Valley of the Northwestern Himalaya (Fig.1). The region represents some of the most geologically fragile and landslide prone due to its rugged topography, deep river gorges, and elevations ranging from low valley floors to high mountain ridges (Singh et al., 2024). Geologically, the area is characterized by highly deformed lithology, weak sedimentary and metamorphic rock formations, active thrust systems including the Main Boundary Thrust (MBT) and Main Central Thrust (MCT, also known as Panjal Thrust (PT)) and several local faults/lineaments (Haq et al., 2019; Pandita et al., 2021; Singh et al., 2024; Mir et al., 2024). Due to these structures and as a part of Himalayan mountain building process, the rocks are having varying strength, widely spaced/closely spaced joints, varying foliation plane, rock

fabric, fault gouge zones, and huge debris thickness. Slopes are commonly steep to precipitous, structural discontinuities often dip parallel to slope faces, and frequent freeze–thaw weathering processes creating favorable conditions for slope failures. Climatically, the region experiences strong monsoonal influence with high-intensity rainfall events, while snowmelt and glacier-fed tributaries contribute to seasonal hydrological variability.

Human activities such as road construction, uncontrolled road widening along NH-44, hydropower construction, slope cutting, blasting, deforestation, unscientific excavation, episodic climatic events, agricultural irrigation, and urban expansion have significantly altered natural slope and drainage conditions resulting in recurrent mass wasting and slope failures (Fig.1). The Ramban and Doda districts have witnessed repeated catastrophic landslide disasters including the Pernote landslide of 2024, Ramban flash flood of 2025, Thattri landslide of 2023, Chashoti flash flood of 2025 and multiple recurrent landslide and slope failures along the Highway (Singh et al., 2024, 2025, 2026; Mir et al., 2025) (Fig.1). Geological investigations and susceptibility studies have consistently identified Ramban and adjoining Chenab Valley districts among the highest landslide hazard zones in the Indian Himalaya, where both natural geomorphic evolution and rapidly increasing developmental pressures are jointly accelerating landscape instability and environmental degradation (Dwivedi et al., 2023).

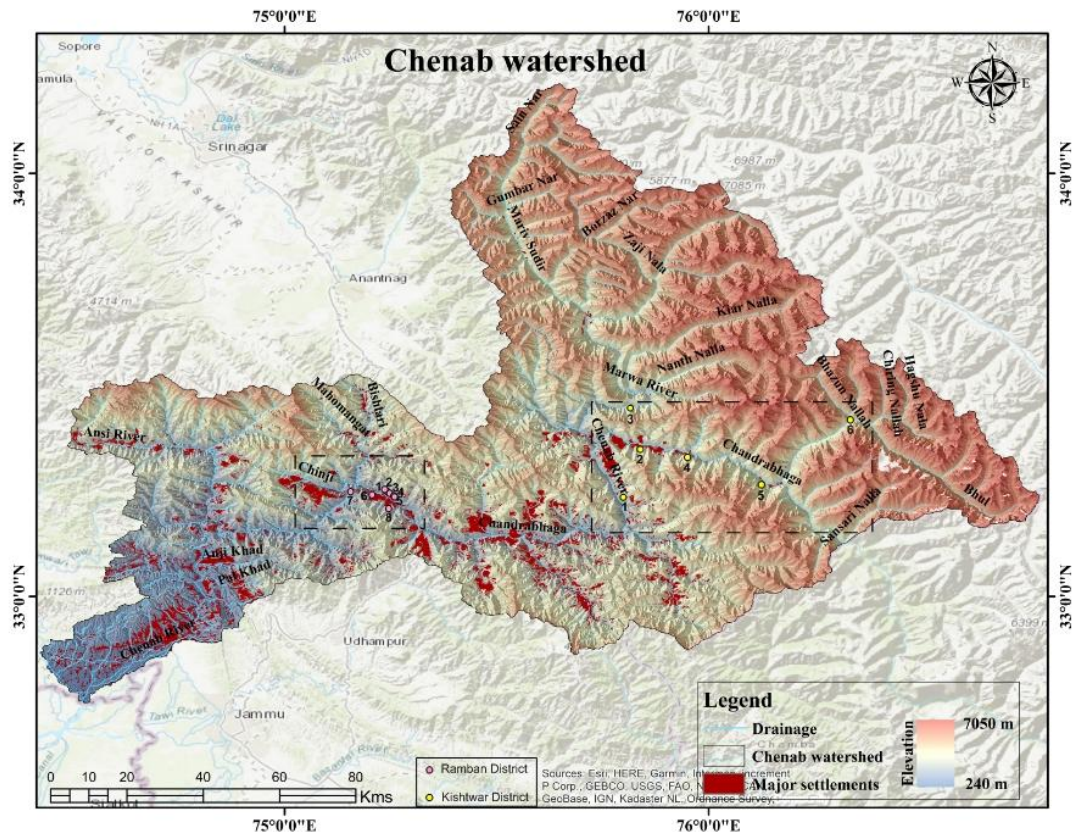


Fig.1. Map showing two hotspots prioritized for detailed study where the landslides and flash floods are prominent and regularly occurring. The studied sites falling in Kishtwar district are represented by yellow colored circles where number corresponds to: 1= Drabshalla, 2 Noos Slide; 3 Pathar Nakki slide; 4=Kajai nahalla flashflood; 5= Chashoti flash flood/cloud burst site; 6= Dangdoru slide and for Ramban district the sites are represented by pink circle, 1=Sunari

nahalla; 2= Bowli bazar nahalla; 3=Bus stand; 4=Hospital nahalla; 5= Cafeteria morh; 6= Pernote; 7= Tanger; 8= Dalwas.

3. Methodology

A multidisciplinary team conducted systematic and comprehensive field investigations at identified landslide hotspot zones over a five-day period from 24 to 28 April 2026, with the objective of evaluating prevailing hazard, vulnerability, and risk conditions. The methodological framework was predominantly field-based, integrating geological, geomorphological, hydrological, and anthropogenic assessments to achieve a holistic understanding of slope instability and mass movement processes (Fig.2). At each investigated site, structured and in-depth discussions among expert team members were carried out to collectively interpret field evidence and to characterize site-specific hazard type, vulnerability level, and associated risks. This collaborative, expert-driven evaluation strengthened the reliability of the field interpretations and ensured consistency in hazard, vulnerability, and risk classification across sites. Subsequently, laboratory based analyses were undertaken, wherein remote sensing imagery and ancillary datasets were evaluated and integrated with field observations to support detailed analysis, validation, and refinement of the field-based assessments (Fig.2). This approach enabled a robust understanding of landslide processes, their controlling factors, and the associated risks at the investigated hotspot zones.

Field Investigation and Site Characterisation:

Detailed field surveys were undertaken at critical landslide hotspot zones, focusing on the identification and documentation of geomorphological and ground-surface features indicative of slope instability. The investigation covered a wide range of landslide environments, including active and relict/fossil landslide zones, debris-flow channels and depositional areas, and flood-prone zones. Each site was systematically examined to understand slope geometry, material characteristics, and evidence of past and ongoing mass movement activity.

Geological and Structural Assessment

Geological investigations involved detailed observations of lithology and rock mass characteristics, with particular attention to structural controls on slope stability. Structural parameters were qualitatively recorded to assess the vulnerability of different slides. These observations were used to infer potential failure mechanisms and to identify structurally controlled zones of weakness contributing to landslide initiation and propagation.

Hydrological Evaluation

Hydrological conditions were assessed through qualitative field indicators, including surface runoff patterns, spring discharge points, seepage zones, groundwater emergence, and overall drainage efficiency. Particular emphasis was placed on identifying areas of water concentration and poor drainage, as these factors significantly influence pore-water pressure build-up and slope destabilization, especially during intense rainfall events.

Assessment of Anthropogenic Influence

Anthropogenic modifications to the natural slope system were systematically documented. These included road cutting and widening activities, slope encroachments, excavation at the toe of

slopes, improper disposal of excavated material, and blockage or diversion of natural drainage channels. Such interventions were recognized as major contributors to slope instability and hazard amplification, often acting as critical triggers or exacerbating natural instability processes.

Hazard Classification

Based on integrated field observations, each investigated site was classified according to its dominant hazard type, including rockfall, debris flow, debris slide, rotational slide, and subsidence following standard methodology by Varnes, 1974. The classification was guided by observable failure characteristics, material type, slope morphology, and evidence of movement history.

Vulnerability and Risk Assessment

Vulnerability levels were qualitatively categorized as high, moderate, or low, depending on both the susceptibility of the terrain and the exposure of elements at risk. These elements included human settlements, transportation corridors (roads), educational institutions, and utility infrastructure. Risk evaluation was carried out by integrating hazard type and intensity, field-based indicators of activity and frequency, and the vulnerability of exposed elements. Special emphasis was placed on identifying short-term triggering factors, particularly those likely to become active during the forthcoming monsoon season, to support preparedness and mitigation planning.

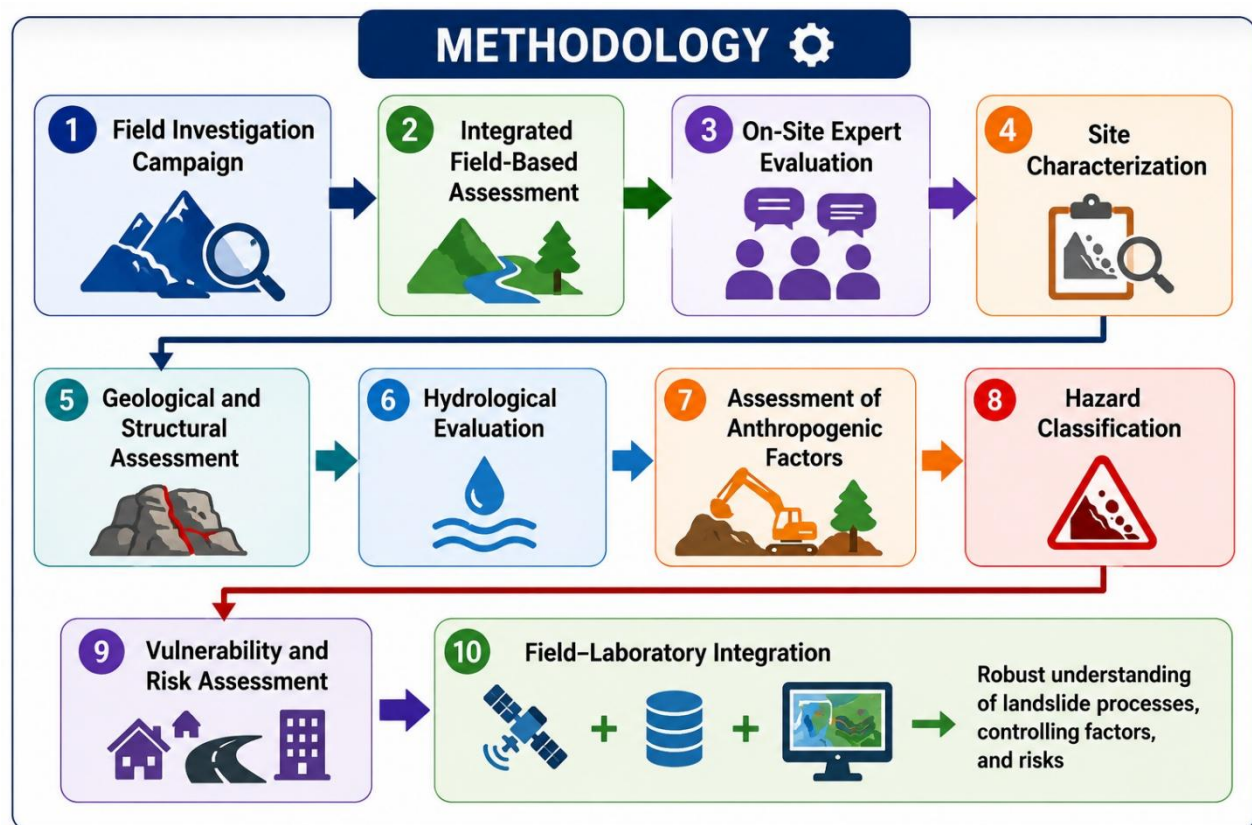


Fig.2. Workflow showing the methodological adopted for landslide hazard, vulnerability, and risk assessment, illustrating the integrated field-based investigations, expert-driven site

evaluation, geological-geomorphological-hydrological and anthropogenic assessments, hazard classification, vulnerability and risk analysis.

4. Results

Field investigations and site observations indicate that steep slopes, fragile geological formations, complex tectonic and structural settings, unplanned construction practices, and inadequate drainage systems significantly enhance landslide hazard susceptibility and vulnerability. These inherent risks are further exacerbated by climate-induced extreme rainfall events, particularly during the monsoon season. Interactions with local residents and government officials revealed noticeable gaps in disaster awareness, preparedness, and emergency response mechanisms, especially at the local level. As critical infrastructure and residential areas are repeatedly exposed to damage and disruption, the assessment underscores the urgent need for targeted interventions, including slope stabilization measures, improved drainage management, and the enforcement of stricter land-use regulations and urban planning norms. Several landslide and flash-flood-prone sites in the Ramban and Kishtwardistricts were examined, and appropriate short-term mitigation measures have been recommended accordingly.

4.1. Landslide Site investigation in Ramban District

The Ramban district headquarter has been observed to be highly vulnerable to debris flows and flash floods as the lower order streams are laden with huge scree and slope material. Encroachment and blockage of natural drainage channels have significantly reduced flow capacity, leading to channel aggradation and localized flooding. Weak lithology, structural discontinuities, and inadequate drainage, slow slope deformation driven by spring discharge and irrigation-induced saturation also caused slope instability at various sites. Several landslide locations have been visited to collect the ground data, identify the cause and suggest the mitigation measures. These include, Sunari nallah, Hospital Nallah, Bowli Bazar Nallah, Cafeteria Morh Slide, Pernote Slide, Tanger slide and Dalwas slide (Fig.3-6).

(a) Sunari Nallah

This nallah (streamlet) is narrow with steep channel walls, filled with a chaotic mix of boulders, cobbles, and finer sediments, which are typical deposits of debris flows (Fig.3b,d,e). The poorly sorted material, ranging from large angular rocks to gravel and mud, indicates rapid downslope movement where water and sediment moved together as a dense slurry. The steep gradient and confined channel would have accelerated the flow allowing it to transport large clasts that are now stranded in the channel bed. Vegetation is present on the upper slopes, but the exposed roots and bare earth indicate recent or repeated erosion triggered during rainfall. The study area exhibits a high-energy geomorphic regime characterized by episodic debris flows. These events facilitate rapid sediment redistribution and significant channel morphology alterations, posing a high risk to infrastructure within the transport path. Notably, the drainage terminus below the Old NH44 lacks a defined conveyance channel, resulting in the massive aggradation of sediments and debris directly onto the road (Fig.3a-c).

(b) Hospital Nallah

The nallah originate from the upper slopes of the town and follow relatively short path before reaching lower elevations. It mainly carries coarse sediments, such as cobbles and pebbles, indicating high-energy flow conditions and an active supply of material from the surrounding slopes. In several locations, the channels are encroached upon and hydraulically narrowed, which reduces their flow capacity and promotes sediment buildup in downstream sections where blockages occur. Ongoing rockfall activity in the upslope areas further adds coarse debris to the channel, increasing the likelihood of debris flows and channel instability (Fig.3a).

(c) Ramban Nallah/ Bowli Bazar Nallah

The nallah exhibits relatively wide channel morphology infilled with a heterogeneous assemblage of boulders, cobbles, and finer-grained sediments, indicative of typical debris flow deposit and high-energy transport processes. The presence of at least three distinct terrace levels along the channel margins suggests multiple phases of aggradation and incision associated with episodic debris flow events. These geomorphic features reflect a dynamic system characterized by repeated sediment mobilization and channel reworking. Importantly, active toe erosion along the channel banks poses a significant hazard to nearby residential structures, as progressive undercutting may compromise slope stability and increase the risk of structural damage during future debris flow occurrences (Fig.3b).

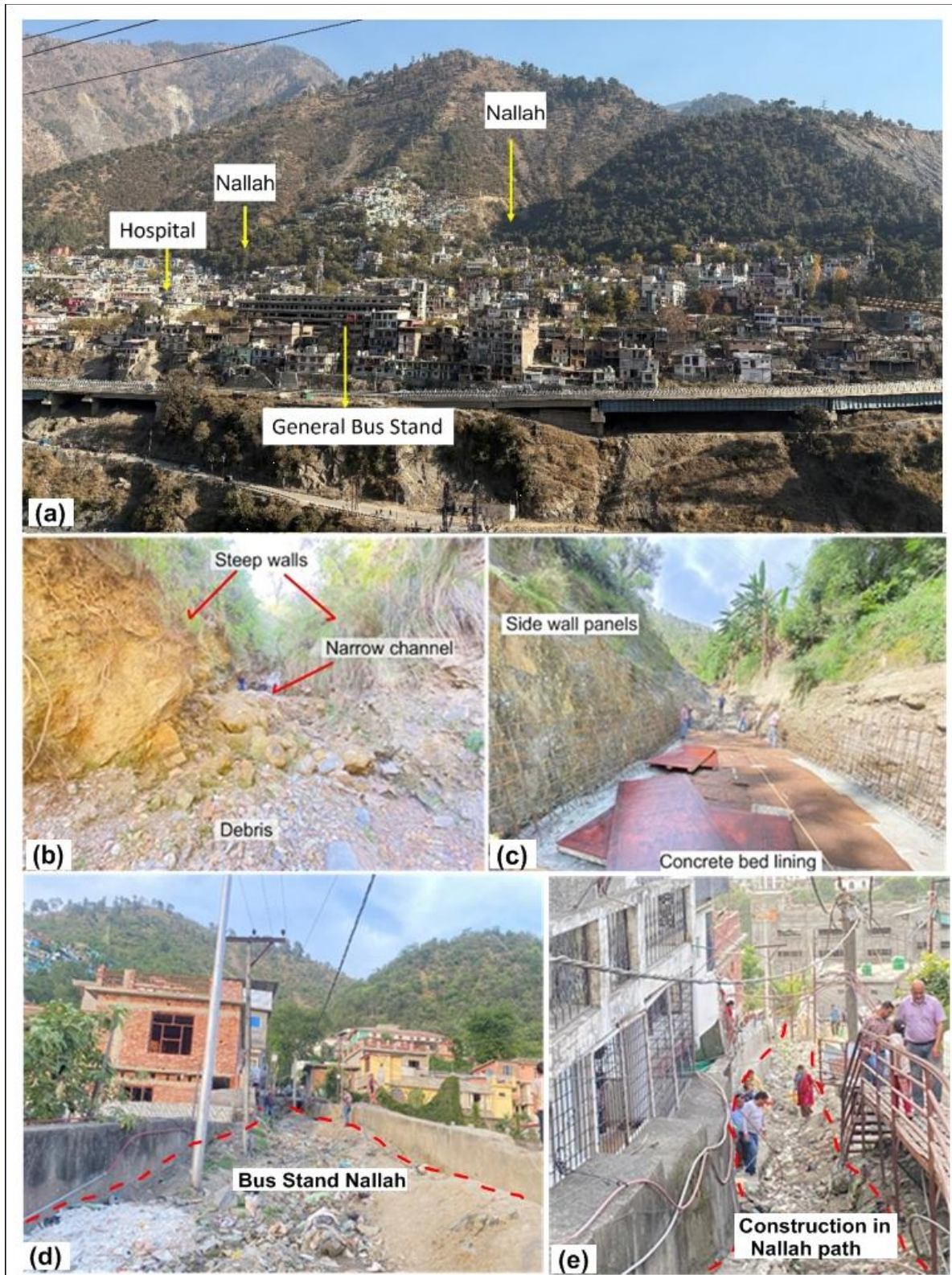


Fig. 3. Field photographs showing (a) steep mountain slope in the backdrop of Ramban town building and road infrastructure, and geomorphic features (ridges, slopes and nahallas) (b) Bowli nallah having debris flow (c) concrete bed lining constructed within Sunari nallah thereby

reducing its cross-sectional area (d) Bus Stand nallah with constructed channel sidewalls, and construction within the nallah path (e) highly vulnerable construction on the nallah path exposing the population to major flash flood risk.

(d) Cafeteria Morh Slide

This is a cut-and-cover structure (artificial tunnel) built to maintain an important strategic stretch of the road and to ensure the safety of commuters. The design was adopted after repeated failures of open-cut road widening, which made tunneling necessary. The site lies on an old and complex landslide made up of rock and debris, in a highly fragile and water-sensitive geological setting. The slope is unstable due to heavily weathered and fractured rocks and probably has not been properly evaluated during the initial road widening works. The landslide zone is located along a major geological discontinuity called Murree Thrust (MT). Field observations show that the cut-and-cover tunnel does not have a proper drainage system. As a result, rainwater flows directly down the slope towards the Chenab side, causing severe erosion at the base and may wash away the supporting material (Fig.4). This uncontrolled water flow is weakening the foundation of the structure. If proper drainage and channelization are not provided, there is a high risk of serious foundation failure in the near future.



Fig.4. Photograph showing the Cafeteria Morh landslide and the associated engineering structure along a vital road connectivity corridor.

(e) Pernote Slide

The Pernote slide occurred in Pernote village located on a north facing slope where sunlight exposure remains limited, resulting in moist slope materials. The Pernote landslide occurred on 25 April 2024 due to a complex interaction between the slope's hydrogeological conditions and the geomechanical properties of the soil (Mir et al., 2025b; Singh et al., 2026). The event caused damage to property, disrupted road connectivity, and affected the local geo-environment (Fig. 5a). During the present site visit, no significant movement was observed at the toe of the landslide. However, the landslide mass remains highly vulnerable to reactivation during periods of intense rainfall or increased subsurface water infiltration. Groundwater seepage was observed along the road, indicating active moisture conditions within the slope. The landslide lies within a

fossil landslide zone, characterized by alternating bands of siltstone, mudstone, and sandstone (Murree Formation). It is located along the Murree Thrust (MT) zone and drains towards the Chenab River, further increasing its instability and hazard potential.

(f) Tanger Slide

The subsidence and mass movement in the Tanger village is primarily attributed to the hydrogeological saturation of the clay-rich overburden. Persistent groundwater discharge from three natural springs one exhibiting a discharge of approximately 15 litre/sec. and the others around 2 litre/sec., combined with antecedent rainfall, has led to elevated pore water pressure within the subsurface. The fine-grained, low-permeability clay matrix inhibits efficient drainage, resulting in prolonged saturation and a consequent reduction in shear strength. This has led to ground instability, as evidenced by cracks, wall distress, and the formation of wetlands at various locations. Additionally, anthropogenic factors, such as paddy cultivation and inadequate surface and subsurface drainage systems, enhance infiltration and water retention. These conditions promote progressive ground deformation (Fig.5b). The landslide lies within a fossil landslide zone, characterized by alternating bands of siltstone, mudstone, and sandstone (Murree Formation). It is located along the Murree Thrust (MT) zone and drains towards the Chenab River, further increasing its instability and hazard potential (Fig.5c).

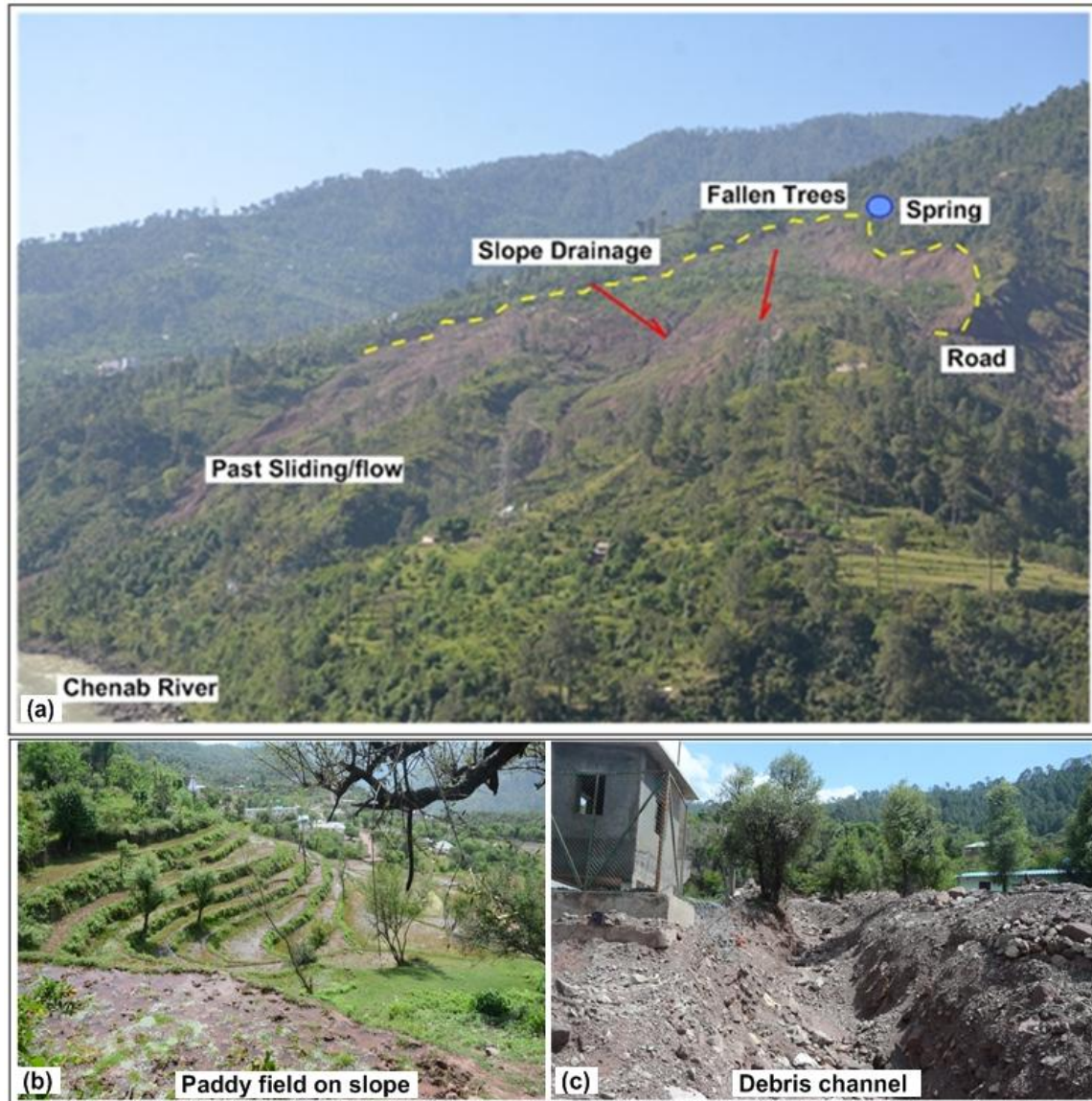


Fig. 5. Photograph showing (a) Pernote landslide and its current geomorphic features (b) terrace farming of Paddy fields in Tanger village retaining water and causing saturation of the slope mass, (c) debris-flow activity along the nallah adjacent to the NHPC Office complex.

(g) Dalwas Slide

The slope is predominantly composed of clay-rich material, which exhibits low permeability and reduced shear strength under saturated conditions (Fig.6a-c). The presence of shallow aquifers has led to persistent subsurface saturation, further exacerbated by unscientific slope modifications that have disturbed the natural stability of the slope (Fig.6c). A concrete retaining wall constructed to stabilize the slope has become ineffective, as its weep holes are clogged with fine sediments, preventing adequate drainage (Fig.6a). This blockage has resulted in the buildup of pore-water pressure behind the structure, ultimately leading to its structural failure. The consequent instability has caused damage to the Dalwas-Karma road and has significantly increased the risk to residential buildings and adjoining cultivated land situated along the crown zone, placing them under imminent threat of further slope failure (Fig.6).



Fig. 6. Photographs showing (a) landslide along Jammu-Srinagar national highway at Dalwas, (b) linear cracks along the Dalwas-Karma Road, (c) temporary restoration works carried out on the Dalwas-Karma Road.

4.2. Landslide Site investigations in Kishtwar District

(a) Drabshallah

The landslide is located near Drabshallah village and is marked by the continuous movement of large volumes of earth material, which frequently disrupts road connectivity. During the site

inspection, a large amount of loose debris and detached rock blocks were observed resting on steep slopes. These unstable rock blocks pose a serious rockfall hazard, especially when the slopes become saturated during prolonged or intense rainfall. In addition, the Chenab region is seismically active and experiences frequent seismic events. Even a moderate earthquake could trigger further slope failure or a major earthquake-induced landslide in this area (Fig.7a).

(b) Noos Slide

The landslide is located on the left bank of Noos nallah, where a large volume of material has moved downslope. The site is composed of fragile lithology, including phyllitic rocks, fault gouge material, shear zones and slope cracks (N325). This, combined with active water seepage (dripping conditions), has contributed to slope failures during the rainy season (Fig.7b). Notably, residential structures are located in very close proximity to the hazard zone, with a distance of only about 3.5 meters from the landslide crown. Due to these inherent geological weaknesses and ongoing water infiltration, the slope remains highly vulnerable to further failure, particularly during periods of prolonged rainfall.

(c) Pathar Nakki

The Pathar Nakki Slide, located close to the Kiru hydropower dam site, represents a significant geological hazard with active movement of material on both slopes of Payass nallah. Field observations show that the slope remains unstable due to very steep slope (Slope 65°/030) and the presence of detached rock blocks. The instability is further controlled by structural weaknesses, including a fault zone crossing the nallah, along with continuous water infiltration and cracks (N30°W to N45°W and having 2-5cm opening towards east) on the right bank of Payass nallah. The structural fabric of the granitic gneissic rocks, along with the slope gradient and orientation, is directed towards the road cut slope, creating favorable conditions for planar and rockfall failures towards the roadway (Fig.7c). Although mitigation measures such as rock bolting and rock nailing are currently being implemented, these interventions appear to require greater technical precision and improvement. Given its proximity of about 100 meters to the upcoming hydropower project area, the slide is highly vulnerable to extreme rainfall events as well as moderate seismic activity typical of the Kishtwar region. Therefore, additional short-term mitigation measures are required to strengthen the ongoing efforts by local agencies.

(d) Dangdoru

Dangdoru is located on the left bank of the Maru Sudhar River, close to the Dangdoru Hydropower project site. Field assessments indicate that there is no evidence of large-scale regional subsidence; however, minor localized subsidence has been observed in individual structures. These small cracks are mainly confined to the slope-facing sides of buildings and are primarily linked to inadequate household drainage system. At the base of the slope near the dam camp site, several structures show wider cracks associated with localized slope subsidence. This instability is largely driven by the continuous accumulation of water along the road and moisture infiltration from multiple sources. Blasting activities of high intensity, if being carried out in the vicinity, may also contribute to these minor impacts on the infrastructure by inducing vibrations that can weaken already fragile slope materials and exacerbate existing cracks and localized subsidence (Fig. d-f). Although some protective measures were implemented after earlier slope failures, significant drainage deficiencies still remain. These issues are further reflected in a

noticeable bulge in the toe-strengthening wall at the village base, along with poorly functioning drainage infrastructure along the adjacent roadway.



Fig. 7. Photograph showing (a) active landslide (rockfall) site at Drabshallah (b) landslide near Noos nallah, depicting downslope movement of material (c) rockfall at Pathar Nakki, where structurally controlled granitic gneiss slopes dip towards the road-cut, promoting planar failures and rock detachment (d) Dangdoru village along the Maru Sudhar River near the hydropower project site, (e-f) depicting localized minor structural subsidence, and deformation in the toe-strengthening wall.

(e) Kajai Nahalla

Kajai nallah is located approximately 2 km from Karthai village towards the Paddar Sub-division, near Kajai village. The village itself is situated on a relatively stable and gentle slope; however, the nallah represents a high-risk flood and debris-flow zone. The channel is heavily choked with a large volume of unsorted glacial and colluvial material, including erratic boulders exceeding 3 m in diameter. Evidence of high-energy hydraulic activity is clearly visible in the form of extensive lateral bank erosion. Historical flood levels (HFL) are indicated by vertical scour marks ranging from 4 m to 5.5 m, reflecting past extreme flow events (Fig.8a). The high sediment load within the catchment indicates active headward erosion, increasing the likelihood of debris flows during intense rainfall events. The most critical vulnerability is the presence of Upper Primary School at Kajai, located on the left bank in close proximity to the active channel. Any flash flood or sudden upstream mass movement could result in bank failure, posing a direct threat to the school infrastructure and its occupants.

(f) Chashoti

On 14 August 2025, Chashoti village, located along the Paddar-Machil road, was affected by a catastrophic event that caused significant loss of life, missing persons, and extensive damage to property and the local geo-environment. A technical field assessment indicates that the geomorphology of the area played a key role in amplifying the disaster. The Chashoti nallah shows strong topographical asymmetry. The right bank is characterized by a steep, east-facing slope composed of widely spaced, jointed rock units, while the left bank consists of a gentler, south-facing slope covered with thick overburden and dense vegetation. The primary hazard drivers include a steep channel gradient and a narrow, V-shaped gorge located a few hundred meters upstream of the village. This confined valley geometry severely limited the ability of the nallah to dissipate hydraulic energy (Fig.8b). During a cloudburst event in the upper catchment, sudden and intense runoff overwhelmed the drainage system, triggering a high-velocity flash flood along with associated mass-wasting processes. These were rapidly funneled downstream and deposited in the low-lying accumulation zone at Chashoti village, resulting in severe destruction. As a mitigation measure, construction of a protective wall at the slope break and along the right bank of the nallah is recommended to divert debris-laden floodwaters away from Chashoti village and reduce the impact of future flash flood and debris-flow events.

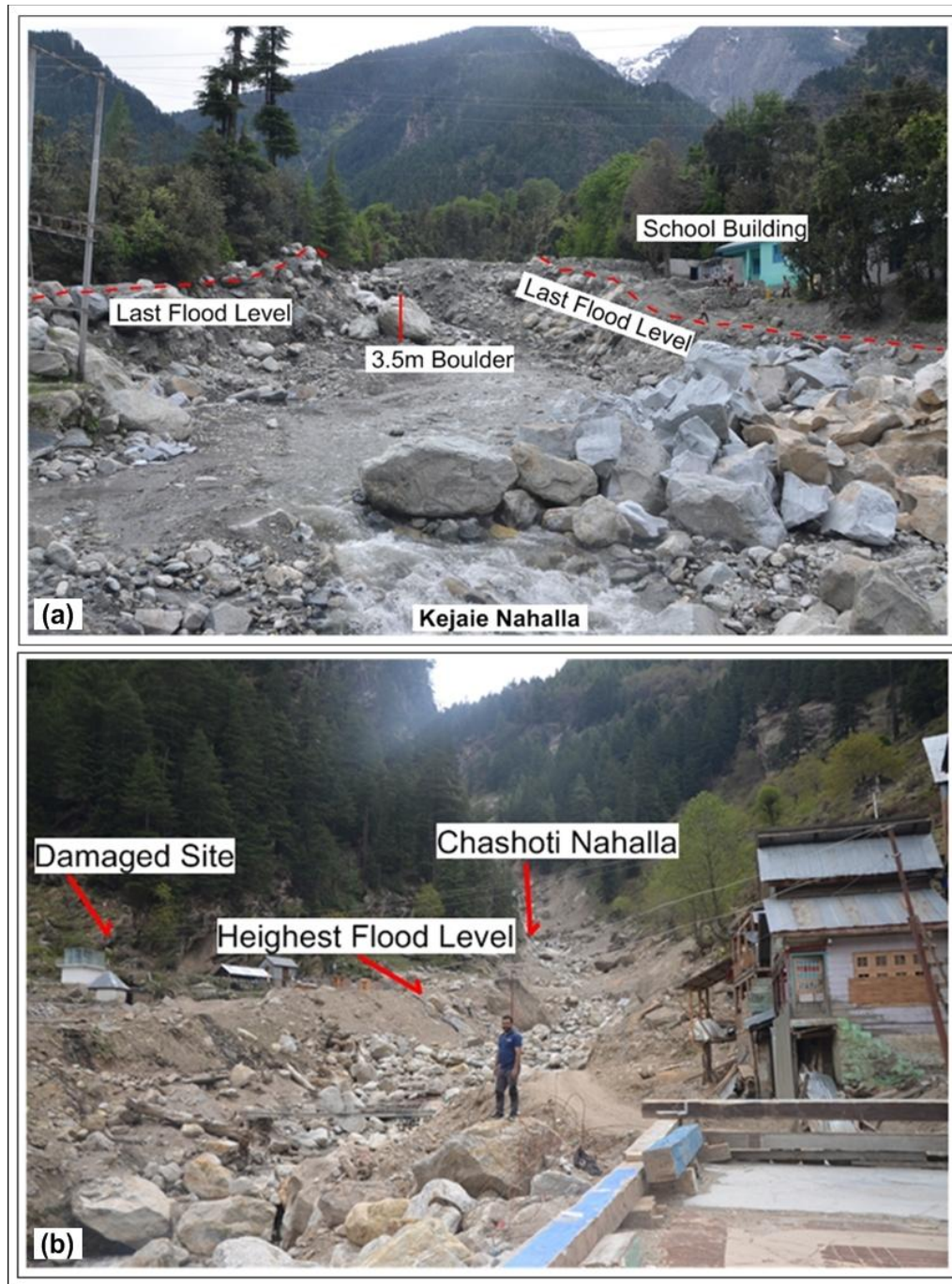


Fig.8. Photograph showing (a) flood hazard site at Kajai nallah, depicting a debris-choked channel with large boulders, evidence of high-energy flow, and proximity to the school building (b) Chashoti flash flood site, depicting the narrow V-shaped gorge, high-energy channel flow, and the devastated accumulation zone affected by debris-laden floodwaters.

4.3 Description of Mass Movement Types

Field-based investigations across the landslide and flood-prone sites of Ramban and Kishtwar districts reveal the dominance of rainfall and water-controlled mass movement processes operating under fragile geological and geomorphological conditions. Channelized debris flows

and debris floods represent the most widespread hazard, particularly along steep, confined nallahs where poorly sorted mixtures of boulders, cobbles, gravel, and fine sediments are rapidly mobilized during intense rainfall and cloudburst events. These processes are frequently exacerbated by channel encroachment, sediment aggradation, and inadequate drainage infrastructure. Earth slides, including reactivated palaeo- and fossil landslides, are common on clay-rich and fine-grained lithologies, where persistent groundwater seepage, spring discharge, and anthropogenic irrigation elevate pore-water pressure and progressively reduce shear strength, leading to slow to moderately rapid slope deformation and localized subsidence. Structurally controlled rockfalls and rockslides occur on steep slopes characterized by fractured rock masses, adverse joint and fault orientations, and road-cut excavations, with instability often triggered or intensified by heavy rainfall and regional seismicity. Several sites exhibit complex landslide behavior, where sliding, flowing, and subsidence processes operate simultaneously, reflecting the combined influence of lithological weakness, tectonic discontinuities, poor drainage conditions, and human modifications. The observed mass movements underscore a dynamic and highly sensitive slope system, where hydro-meteorological extremes and unplanned land use significantly amplify hazard intensity and recurrence. The detailed description of the investigated landslides is given in Table 1.

Table 1. Classification of mass movement types based on field observations

Distri ct	Site / Location	Hazard Type	Dominant Mass Movement Type	Material Involved	Movement Style	Primary Triggering Factors
Ramb an Distri ct	Sunari Nallah	Flash Flood	Debris flow	Boulders, cobbles, gravel, mud	Rapid, channelize d flow	Intense rainfall, steep gradient, confined channel
	Hospital Nallah	Flash Flood	Debris flow with rockfall input	Cobbles, pebbles, rock blocks	Episodic flow + free fall	Rainfall, upslope rockfall, channel encroachment
	Bowli Bazar / Ramban Nallah	Flash Flood	Recurrent debris flow	Heterogene ous debris	Episodic, multi-phase	High sediment supply, channel aggradation, rainfall
	Cafeteria Morh Slide	Landslide	Complex landslide (rock slide + debris slide)	Weathered rock and debris	Sliding with flow component	Poor drainage management, weak rocks, geological discontinuity
	Pernote Slide	Landslide	Earth slide (reactivated)	Siltstone, mudstone,	Slow to moderate	Groundwater seepage, rainfall

			paleo-slide)	sandstone	sliding	
	Tanger Slide	Landslide	Earth slide with subsidence	Clay-rich overburden	Slow-moving, progressive deformation	Spring discharge, pore-water pressure, irrigation
	Dalwas Slide	Landslide	Earth slide (rotational/translational)	Clayey soil	Sliding with minor rotation	Drainage blockage, saturation, slope modification
Kishtwar District	Drabshallah	Landslide	Rockfall (dominant) with debris slide	Rock blocks, debris	Free fall and rolling	Rainfall, seismic shaking
	Noos Slide	Landslide	Debris slide / rock slide	Phyllite, fault gouge	Translational sliding	Seepage, shear zones, prolonged rainfall
	Pathar nakki	Landslide	Rockslide (planar) with rockfall	Granitic gneiss	Sliding and falling	Structural control, steep slope, rainfall/seismicity
	Dangdoru	Landslide	Localized subsidence and soil creep	Fine soil, weathered material	Very slow deformation	Poor drainage, moisture accumulation, vibrations
	Kajai Nallah	Flash Flood	Debris flow / debris flood	Glacial and colluvial debris	High-energy channelized flow	Cloudburst, high sediment load
	Chashoti	Flash Flood	Debris flow with flash flood	Mixed debris and water	Rapid, catastrophic flow	Cloudburst, confined gorge geometry

4.4 Potential controlling factor of landslide susceptibility and slope instability

Landslide susceptibility in the investigated areas of Ramban and Kishtwar districts is primarily governed by a combination of unfavourable geological, geomorphological, and structural conditions. The assessment demonstrates that slope failures are rarely driven by a single factor. Instead, instability results from the combined effects of fragile geology,

unfavorable structural orientations, intense rainfall, and human-induced disturbance (Table.2). Among these, poor drainage and water mismanagement emerge as the most critical short-term trigger. The widespread presence of weak and highly weathered lithologies, including clay-rich overburden, phyllites, fault gouge, and interbedded siltstone-mudstone-sandstone sequences, significantly reduce slope strength. These materials are further compromised by intense tectonic deformation associated with major thrusts and shear zones, which introduce closely spaced discontinuities, fractured rock masses, and adverse joint orientations that promote planar sliding, rockfall, and translational failures. Steep slope gradients, deeply incised valleys, and confined channel geometries enhance gravitational driving forces and concentrate mass movement along preferred pathways. The occurrence of palaeo and fossil landslide zones further indicates long-term slope instability, with inherited weakness planes repeatedly reactivating under changing hydrological conditions.

Hydrological and anthropogenic factors play a critical role in triggering and accelerating slope instability across the study area. Intense monsoonal rainfall, cloudburst events, and prolonged antecedent precipitation lead to rapid infiltration and elevated pore-water pressure, particularly in low-permeability clay-rich soils and poorly drained slopes. Groundwater seepage, natural springs, irrigation practices, and leakage from unscientific drainage systems contribute to persistent subsurface saturation, reducing effective stress and shear resistance. Channel blockage, encroachment, and aggradation within nallahs amplify debris-flow and flash-flood hazards by limiting flow conveyance and increasing sediment availability. Human interventions such as road widening, slope cutting, blasting, and unplanned construction further disturb natural slope equilibrium by removing toe support, altering drainage paths, and inducing vibrations in already fragile terrain. Collectively, these interacting geological, hydrological, and anthropogenic controls create a highly sensitive slope system, where even moderate rainfall or seismic events can trigger significant landslide activity and infrastructure damage.

Scientific evidence from the field indicates that immediate improvements in surface and subsurface drainage can substantially reduce landslide risk. Measures such as desilting nallahs, diverting spring water, channelize household drainage and protecting slope toes are particularly effective in the Himalayan context, where saturation-driven failures dominate. Projected increase in rainfall intensity and variability are likely to exacerbate existing hazards. Therefore, short-term mitigation measures must be integrated into a broader climate-resilient planning framework to ensure long-term sustainability.

Table 2. Factors Controlling Landslides and Flash Floods hazards in the Ramban and Kishtwar districts

Categor y	Parameter	Influence on Landslides	Influence on Flash Floods	Interrelationship
Geology	Lithology (weak shale, mudstone, weathered rock, slope material)	Very High (Cafeteria morh slide, Pernote slide, Dalwas slide)	Moderate (Sunari nahalla, Bowli bazar nahalla, Bus stand nahalla, Kajaie nahalla Chashoti nahalla)	Weak rocks generate debris that can obstruct channels and enhance flooding
	Degree of Weathering	Moderate (Noos slide,	High (Sunari nahalla,	Highly weathered material is easily

		Cafeteria morh slide, Pernote slide, Dalwas slide)	Bowli bazar nahalla, Bus stand nahalla, Kajaie nahalla Chashoti nahalla)	mobilized by runoff.
	Structural Discontinuities (faults, joints, fractures, bedding planes)	Very High (Cafeteria morh slide, Pathar nakki slide)	Absent/None	Promote slope instability and water infiltration.
Topography	Slope Gradient	Very High (Cafeteria morh slide, Pathar nakki slide)	High (Chashoti nahalla)	Steep slopes accelerate both mass movement and runoff.
	Slope Aspect	Moderate (Cafeteria morh, Pernote slide, Noos Slide, Pathar nakki slide)	Moderate (Sunari nahalla, Chashoti nahalla)	Controls moisture retention and weathering. South facing slopes are dry and undergo physical weathering whileas north facing slopes are moist and undergo trigger due to pores water
	Relative Relief	High (Pathar nakki, Cafeteria morh, Drabshallah)	High (Sunari nahalla, Chashoti nahalla)	Influences energy available for erosion and debris transport.
	Valley Confinement	Moderate	Very High (Sunari nahalla, Chashoti nahalla, Bowli bazar nahalla; Bus stand nahalla)	Narrow valleys amplified flash-flood intensity and debris flows in Bowli bazar nahalla, Sunari nahalla, Bus stand nahalla and Chashoti nahalla
Hydrology	Intense Rainfall/Cloudburst	Very High (Tanger Slide)	Very High (Sunari nahalla, Chashoti nahalla, Bowli bazar nahalla; Bus stand nahalla)	Primary trigger for both hazards in the study area.
	Antecedent Soil Moisture	High (Pernote slide,	Moderate (Tanger slide)	Saturated slopes fail more easily and

		Noos Slide, Tanger)		generate greater runoff.
	Groundwater Seepage/Spring Activity	High (Pernote slide, Tanger slide, Noos slide)	Low/Absent	Reduces slope stability and contributes to failures and mass movement. Pernote slide is an old slide caused by the seepage from groundwater and springs.
Geomor phology	Toe Erosion by Rivers/Streams	Moderate (Noos slide)	Low/Absent	Decreases slope support and increases sediment load in the downstream.
	Loose Colluvium and Debris Cover	High (Pernote slide, Tanger slide)	High (Kajaie nahalla, Chashoti nahalla, Sunari nahalla; Bowli bazar nahalla; Bus stand nahalla)	Easily mobilized into landslides and debris floods.
	Gully Erosion	Low	High (Sunari nahalla; Bowli bazar nahalla; Bus stand nahalla)	Enhances sediment transport and channel instability.
Land Use/Lan d Cover	Deforestation and Vegetation Loss	Moderate (Cafeteria slide; Noos slide)	High (Sunari nahalla; Bowli bazar nahalla; Bus stand nahalla)	Reduces root reinforcement and interception of rainfall.
	Agricultural Terracing	Moderate (Dangdoru slide)	Low/Absent	Alters drainage and slope stability due to which the water may get percolate and the cracks to cause slides.
	Urbanization/Im pervious Surfaces	Low/Absent	Very High (Bowli bazar nahalla; Bus stand nahalla)	Increases peak runoff and flood magnitude due to decrease in the overall infiltration of rain water

Infrastr ucture Develop ment	Road Cutting and Hill Excavation	Very High (Dalwas slide, Cafeteria morh slide, Drabshalla slide)	High (Bowli bazar nahalla; Bus stand nahalla)	Road construction creates unstable slopes due to road and hills cutting and building structures disrupts natural drainage and may cause flash floods.
	Over-steepening of Slopes	Moderate (Pathar nakki slide, Cafeteria morh slide)	Moderate (Chashoti nahalla)	Increases likelihood of slope failure and velocity of flashflood /debris flow.
	Vertical Cuts without Retaining Structures	Moderate (Drabshalla slide)	Low	The vertical cut without retaining wall has caused slope instability in Drabshallah stretch.
	Disturbance of Natural Drainage	Low/Absent	Very High (Bowli bazar nahalla; Bus stand nahalla)	Leads to water accumulation and concentrated runoff.
Climate Change Factors	Increase in Extreme Rainfall Events	High (Tanger Slide)	Very High (Bowli bazar nahalla; Bus stand nahalla)	Enhances frequency and magnitude of both landslides and flash floods.
	Freeze-Thaw Weathering	Low	Moderate (Chashoti)	Weakens rock masses and physical weathering due to freeze-thaw promotes failures.
Additio nal Domina nt Factors	Sediment Availability	Moderate (Cafeteria morh slide, Noos slide)	Very High (Chashoti slide, Kajaie slide, Bowli bazar nahalla; Bus stand nahalla)	Controls rock fall, debris-flow and flash-flood severity.
	River Channel Encroachment	Low (Noos slide)	High (Kajaie nahalla)	Reduces channel capacity and increases flood risk.
	Landslide Dammed Lakes	Low	Low	Sudden breaching can generate catastrophic flash floods.

4.5 Short-Term Mitigation Measures

Based on the field observations and identified failure mechanisms, a comprehensive and integrated approach is required to address slope instability and landslide hazards across the study area. Emphasis should be placed on restoring and maintaining natural drainage systems to ensure unobstructed flow and prevent water accumulation within slopes and channels. Effective surface and subsurface drainage measures are essential to control infiltration and reduce pore-water pressure, which is a primary trigger for slope failures in the region. Structural interventions, including protective and energy-dissipating measures, are necessary to stabilize vulnerable slopes, control erosion, and protect infrastructure located downslope. In addition, proactive management of steep cut slopes and road corridors is required to minimize rockfall hazards through appropriate protective measures. Regulation of land use and construction practices on unstable terrain is equally important to prevent further degradation of slope stability. These engineering measures should be supported by eco-friendly bio-engineering and surface protection techniques that enhance soil binding, reduce erosion, and contribute to long-term slope resilience. A detailed description highlighting the site specific mitigation measures is given below for both the districts.

4.5.1 Ramban District

Across the Ramban sector, short-term mitigation should prioritise integrated drainage control, slope stabilization, and debris-management to reduce erosion, debris-flow activity, and rainfall-induced instability. Restoration of natural drainage through regular desilting, construction of check dams, interceptor drains, and properly channelized flow paths is essential to regulate runoff and dissipate hydraulic energy. Structural measures such as retaining walls, gabions, toe protection, and debris-deflection structures should be provided at critical locations to protect roads, settlements, and infrastructure. Effective surface and subsurface drainage, including lined drains and pressure-relief provisions, is necessary to minimize slope saturation and pore-water pressure. Bio-engineering interventions, such as afforestation, turfing, and plantation of deep-rooted native species, should be implemented on vulnerable slopes to control surface erosion and enhance long-term stability. Crack sealing, restriction of construction and water-intensive activities in highly unstable zones, and temporary protective measures during the monsoon should be strictly enforced. These interventions must be supported by continuous monitoring and timely maintenance, particularly during and after intense rainfall events, to ensure early detection of instability and sustained slope safety. The detailed, site-specific mitigation measures recommended are presented in Table3.

Table 3. Site-specific short-term mitigation measures for Ramban district

Site / Landslide Zone	Key Problems Identified	Recommended Short-Term Mitigation Measures
Sunari Nallah	Erosion, debris flow, flooding, high runoff energy	Rock barriers and gabion walls at failure zones; afforestation and bio-engineering on vulnerable slopes; retaining walls and check dams; pre-monsoon desilting; discharge transition structures downstream; controlled debris channels; conversion of flat channels into stepped/cascade systems
Hospital Nallah	High flow velocity,	Check dams to reduce flow velocity; rock piles and gabion walls on upper slopes; plantation of trees, shrubs, and grasses; regular

	sediment transport, slope instability	desilting and cleaning
Ramban / Bowli Bazar Nallah	Channel blockage, debris flow, slope saturation, risk to habitation	Immediate desilting and check dams; concrete retaining walls along inhabited banks; proper channelization and regulated greywater disposal; restriction on construction in unstable terraces (Terrace-1); debris-deflection walls upstream
Cafeteria Morh Slide	Poor drainage, foundation scouring, slope erosion	Lined catchwater drains; filling of scour holes with masonry/concrete; geotextiles, protective matting, and plantation; subsurface drainage (weep holes/perforated pipes); toe protection using pitching or gabions; temporary covers (tarpaulin/shotcrete) with monitoring
Pernote Slide	Surface runoff, spring discharge, slope movement	Interceptor drains; sealing of cracks and fissures; retaining structures for lateral support; horizontal/subsurface drains; coir matting, turfing, and plantation of deep-rooted species, Dedicated concrete channels for draining out household and spring discharge
Tanger Slide	Spring seepage, ground cracking, toe erosion	Collection and diversion of spring water through sealed pipelines; deep drainage trenches; sealing of cracks with soil-cement/concrete; lined runoff channels; toe protection with pitching/gabions; continuous monitoring and restriction on heavy loading
Dalwas Slide	Poor drainage, hydrostatic pressure, clayey slope saturation	Clearing of clogged weep holes; top-slope drainage trench; sealing of cracks; restriction of wet agricultural practices; temporary tarpaulin cover on exposed clay; temporary toe support; regular inspection during rainfall

4.5.2 Kishtwar District

Across the Kishtwar district, short-term mitigation should focus on reducing rockfall, debris-flow, and flood-related hazards through integrated slope stabilization, drainage management, and protective works. Immediate removal of unstable rock masses, combined with installation of rockfall protection systems such as nets, draped wire mesh, and roadside barriers, is essential to safeguard traffic and infrastructure. Effective surface and subsurface drainage, including catch drains, concreted channels, and seepage-control measures, should be prioritized to limit water infiltration, reduce pore-water pressure, and stabilize shear zones. Structural support in the form of gabion walls, toe protection works, and check dams is required to control debris movement, dissipate flow energy, and prevent lateral and forward erosion along nallahs. Land-use regulation measures, including restriction of construction in flood- and debris-prone zones, protection of vulnerable institutions, and proper management of household wastewater and runoff, are critical to reducing exposure. These engineering interventions should be supported by regular monitoring of slopes, drainage performance, and upstream catchments, along with public awareness initiatives and resilient bridge and road design, to enhance overall disaster preparedness and long-term slope safety. The detailed, site-specific mitigation measures recommended are presented in Table.4.

Table 4. Site-specific short-term mitigation measures for Kistwar district

Site / Landslide Zone	Key Problems Identified	Recommended Short-Term Mitigation Measures
Drabshallah	Rockfall hazard, debris movement	Scaling and removal of unstable rock masses; surface catch drains above crown; toe protection; temporary concrete barriers/gabions; rockfall netting or draped wire mesh
Noos Slide	Toe erosion, seepage, fault gouge exposure	Flexible gabion walls at toe; geotextile covering on shear zones; surface and subsurface drainage; strong toe protection along Noos nallah; diversion of household wastewater and roof runoff
Pathar Nakki	Tension cracks, seepage, rockfall risk	Improved surface drainage; sealing of crown cracks; identification and treatment of seepage zones; integration of rock nailing with weep holes; rockfall nets; traffic restriction during heavy rainfall
Dangdoru	Wastewater infiltration, seepage-induced instability	Proper wastewater drainage network; concreting of irrigation channels; surface and subsurface drainage; sealing of cracks in houses; regular monitoring during rainfall
Kajai Nallah	Flash floods, debris flow, threat to school and bridge	Immediate relocation of Upper Primary School; temporary RC flood protection wall; upstream gabion check dams; seasonal desilting; strengthening of bridge abutments; designated debris storage zones
Chashoti	Flooding, debris accumulation, encroachment	Enforcement of 100 m no-construction buffer; prohibition of encroachments; monitoring of upstream gorge; upstream gabion check dams; public awareness programmes; bridge design above maximum flood level with adequate debris clearance

4.6 Recommendations for similar mass movement processes in the Northwestern Himalayan region

Based on the failure mechanisms documented in the study area and their close resemblance to slope instability patterns widely observed across the Northwestern Himalaya, it is recommended that mitigation strategies prioritise hydrology-driven slope stabilization as the first line of defense. In much of the Northwestern Himalayan terrain, landslides, debris flows, and slope deformations are predominantly triggered by intense monsoonal rainfall, cloudburst events,

and sustained antecedent precipitation acting on weak, highly weathered, and tectonically disturbed lithologies. Therefore, immediate and systematic improvement of surface and subsurface drainage-through restoration of natural nallahs, desilting of channels, diversion of spring discharge, and installation of interceptor drains-should be treated as a critical regional intervention. Experience from the field clearly indicates that effective drainage management alone can substantially reduce pore-water pressure, delay failure initiation, and limit the magnitude of mass movement even under extreme rainfall conditions.

Structural mitigation measures across the Northwestern Himalaya should be failure-mechanism specific and terrain-responsive, rather than uniform or adhoc. For debris-flow- and flash-flood-dominated catchments, priority should be given to energy-dissipating systems such as gabion check dams, stepped or cascade-type channels, debris barriers, and controlled flow pathways to safely guide sediment-laden flows. In translational and rotational landslides developed within clay-rich overburden, fault gouge, and paleo/fossil-landslide zones, short-term stabilization should focus on toe protection, lightweight retaining structures, sealing of tension cracks, and, where feasible, reduction of slope angles through benching. In rockfall- and structurally controlled slope failures, especially along road corridors, controlled scaling, rockfall netting, draped mesh, and temporary barriers are essential to minimize risk to life and infrastructure. Importantly, all structural measures must be integrated with proper drainage provisions, as drainage failure is a recurrent cause of structural ineffectiveness in Himalayan conditions.

Equally critical is the regulation of anthropogenic activities in landslide-prone Himalayan terrain. Unplanned construction, indiscriminate slope cutting, blasting, encroachment into drainage channels, and water-intensive agricultural practices significantly amplify natural instability in an already fragile geological setting. It is strongly recommended that land-use zoning be enforced in identified active, paleo-, and fossil landslide zones, with strict restrictions on new construction and infrastructure expansion. Short-term mitigation should be supported by bio-engineering and surface protection measures-such as coir matting, turfing, native vegetation plantation, and geotextiles-to reduce erosion and enhance slope resilience in an eco-compatible manner. Given projected increases in rainfall intensity and climate variability in the Western Himalaya, these measures must be embedded within a climate-resilient slope management framework, supported by continuous monitoring, early-warning awareness at the community level, and periodic reassessment of hazard conditions to ensure long-term risk reduction. The details of the recommendations are shown in Figure.9.

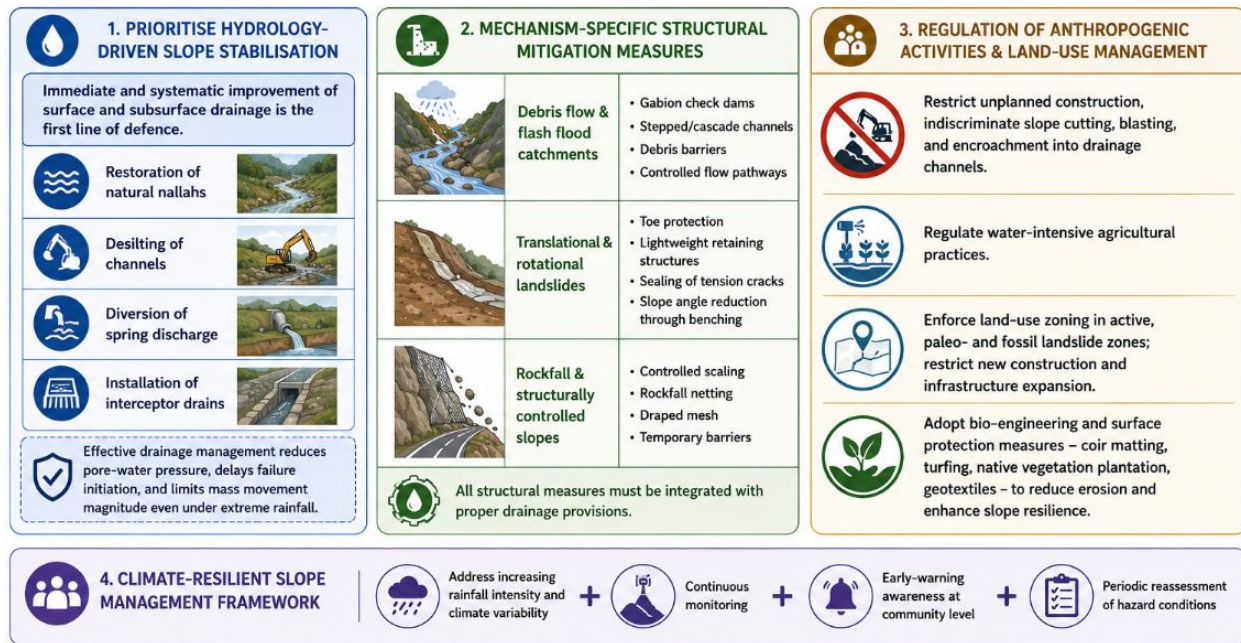


Fig.9. Conceptual recommendation framework for landslide risk reduction in the Western Himalaya, highlighting hydrology-driven slope stabilization as the primary mitigation measure, complemented by failure-mechanism-specific structural interventions, regulation of anthropogenic activities and land-use practices, and adoption of a climate-resilient slope management approach integrating monitoring, early warning, and periodic hazard reassessment.

7. Conclusions

This study presents a comprehensive field-based Hazard, Vulnerability, and Risk Assessment (HVRA) of the Ramban and Kishtwar districts, identifying the dominant drivers of landslides, debris flows, and flash floods in the Northwestern Himalaya, Jammu and Kashmir. The findings demonstrate that drainage mismanagement, slope saturation, and increasing anthropogenic disturbance, when combined with complex geology, steep terrain, and intense rainfall, are the primary short-term risk factors. Hydrologically driven processes, particularly uncontrolled surface runoff, spring discharge, and subsurface seepage emerge as the most critical triggers of slope instability and flash floods. The study underscores that timely implementation of scientifically grounded, site-specific mitigation measures can substantially reduce disaster risk, offering a robust evidence base for engineers, disaster managers, planners, and researchers engaged in Himalayan slope stability and climate-resilient infrastructure development.

Furthermore, the assessment highlights significant gaps in existing planning and policy frameworks, as landslide hazards are often inadequately addressed in current acts, plans, and regulatory mechanisms. While sustainable slope-cutting practices, controlled excavation, and engineered stabilization measures may involve higher initial costs, they are essential long-term investments for safety, sustainability, and infrastructure longevity. An integrated mitigation approach, combining structural measures (retaining walls, gabions, check dams, toe protection, and rockfall control) with bio-engineering, effective drainage management, land-use regulation, and regular monitoring is therefore crucial. Strengthening institutional coordination, improving maintenance and monitoring, and enhancing community awareness, particularly during extreme rainfall and cloudburst events, are key in reducing short-term vulnerability while supporting

long-term slope stability in the Northwestern Himalayan terrain. Collectively, the proposed interventions provide a practical and scalable framework for reducing short-term hazard and vulnerability while contributing to long-term slope stability and infrastructure safety in the Western Himalayan region.

Despite providing a comprehensive site-specific and sector wide assessment, the study has certain limitations. The recommendations are primarily based on short-duration field investigations and visual assessments, which may not fully capture temporal variations in slope behaviour but also groundwater dynamics, and rainfall thresholds. Detailed geotechnical testing, long-term instrumentation (such as piezometers, inclinometers, and extensometers), and high-resolution monitoring data were not available for all sites, limiting the ability to quantify factor of safety values or predict failure timing. The effectiveness of proposed measures may also be influenced by future changes in rainfall intensity, land-use patterns, and maintenance practices. Additionally, implementation feasibility may be constrained by logistical challenges, financial resources, and institutional coordination. Therefore, the proposed mitigation measures should be viewed as adaptive and indicative, requiring periodic review, detailed design studies, and integration with long-term monitoring and regional land-use planning frameworks.

Nevertheless, a dedicated policy document outlining short-term mitigation measures has been developed as part of this collaborative effort and is presented in Annexure I.

Declarations:

Ethics approval and consent to participate,

This study does not involve human interview or sample. All field investigations and data collection were conducted in accordance with standard scientific and ethical practices all published work has been duly cited.

Consent for publication,

Not Applicable

Availability of data and materials,

The datasets generated and analyzed during the current study, involve field measurements, supporting geological site specific observations and policy framework. The dataset is openly accessible and can be used to support the results and conclusions presented in this article.

Competing interests,

The present research work does not involve any competing interest

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Authors' contributions,

Dr. Yudhbir Singh has conceptualized the manuscript as well as field work

Dr. Riyaz Ahmad Mir has done field work and compiled the policy document

Dr. Ahsan Ul Haq has conceptualized the manuscript as well as involved in the field work

Prof. S. K Pandita has supervised the research team in manuscript writing and interpretation work.

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Annexure I

Policy Document: Short-Term Mitigation Measures for Landslide and Flood Hazards

1. Purpose of the Policy

This policy document provides an **elaborated and operational framework for short-term disaster risk mitigation** in Ramban and Kishtwar districts, based on field-based Hazard, Vulnerability, and Risk Assessment (HVRA) conducted during April 24–28, 2026. The primary purpose of the policy is to translate scientific observations and site-specific recommendations into administratively actionable, technically feasible, and time-bound measures that can be implemented before and during the monsoon season. The policy focuses on life safety, protection

of critical infrastructure, maintenance of connectivity, and reduction of recurring losses due to landslides, debris flows, rockfalls, flash floods, and slope subsidence. It emphasizes immediate interventions that do not require long gestation periods, complex land acquisition, or high-end engineering, while laying the foundation for medium- and long-term risk reduction.

2. Policy Scope and Applicability

2.1 Geographic Scope

- Ramban District (urban areas, nallah corridors, NH-44 influence zone, hill villages)
- Kishtwar District (NH-244 corridor, river valleys, hydropower influence zones, remote settlements)

2.2 Hazard Coverage

- Rainfall- and snowmelt-triggered landslides
- Debris flows and flash floods in steep nallahs
- Rockfalls along road corridors
- Slowmoving subsidence and ground settlement
- River toe erosion and slope undercutting

2.3 Temporal Scope

- **Immediate actions:** 0-3 months (pre-monsoon)
- **Short-term actions:** 3-12 months (monsoon and post-monsoon)

3. Policy Rationale and Risk Context

The Himalayan terrain of Ramban and Kishtwar is characterized by:

- Fragile lithology and active tectonic structures (thrusts, shear zones)
- Steep slopes exceeding natural stability thresholds
- Clay-rich and colluvial materials prone to saturation
- High-intensity rainfall and increasing climate variability
- Unregulated construction and encroachment on natural drainage

Field evidence shows that poor drainage management and anthropogenic interference are the most dominant short-term triggers of slope failures. Therefore, this policy prioritizes water control, slope protection, and land-use regulation as the most effective immediate risk-reduction strategies.

4. Policy Objectives

1. Reduce loss of life and injury from landslides and floods during monsoon seasons.
2. Protect critical infrastructure such as roads, schools, hospitals, and utilities.
3. Maintain all-weather connectivity on strategic road corridors.
4. Prevent reactivation of known landslides through drainage and slope management.
5. Enhance preparedness and risk awareness at district and community levels.

5. Strategic Pillars of Short-Term Mitigation

Pillar I: Drainage and Water Control (Core Strategy)

Uncontrolled surface and subsurface water is identified as the single most important driver of slope instability. Immediate drainage correction yields the highest risk reduction per unit cost.

Policy Directives:

- Mandatory desilting of all nallahs, roadside drains, culverts, and cross-drainage structures before monsoon onset.
- Construction of lined catchwater drains above landslide crowns and road cut slopes.
- Provision of weep holes, perforated pipes, and horizontal drains in retaining walls and saturated slopes.
- Piping and diversion of spring discharge away from unstable slopes and habitations.
- Strict prohibition of wastewater discharge onto slopes and road embankments.

Pillar II: Slope Stabilization and Structural Safety

Policy Directives:

- Construction of gabion walls, breast walls, and retaining structures at active toes of landslides.
- Temporary toe strengthening using boulders, sandbags, or rip-rap where permanent works are delayed.
- Installation of rockfall nets, draped wire mesh, and catch fences along vulnerable road sections.
- Controlled scaling and trimming of loose and overhanging rock blocks.
- Benching and terracing of soil slopes to reduce effective slope angles.

Pillar III: Debris-Flow and Nallah Management

Policy Directives:

- Construction of series of small gabion check dams upstream of settlements.
- Restoration and protection of natural flow paths of nallahs through urban areas.
- Removal of all encroachments obstructing drainage channels.
- Creation of designated debris storage and expansion zones near bridges and culverts.

Pillar IV: Land-Use Regulation and Administrative Controls

Policy Directives:

- Declaration of no-construction and no-excavation zones in identified high-risk areas.
- Temporary suspension of new construction and slope cutting during monsoon months.
- Regulation or prohibition of wet farming and irrigation on unstable slopes.
- Enforcement of building safety advisories in landslide-prone villages.

Pillar V: Bio-Engineering and Surface Protection

Policy Directives:

- Immediate plantation of native grasses, shrubs, and bushes on exposed slopes.
- Use of coir matting, jute netting, and geotextiles to control erosion.
- Temporary covering of clay-rich slopes with tarpaulins during heavy rainfall periods.

Pillar VI: Protection of Critical Infrastructure

Policy Directives:

- Priority protection of schools, hospitals, roads, bridges, and hydropower assets.
- Temporary relocation of highly exposed facilities where risk is imminent.
- Construction of flood and debris protection walls around vulnerable infrastructure.

Pillar VII: Monitoring, Early Warning, and Preparedness

Policy Directives:

- Regular inspection of cracks, seepage, retaining walls, and drainage systems.
- Community-based monitoring of early warning indicators (muddy water, sudden discharge rise, cracking sounds).
- Installation of warning signage, barricades, and temporary closures during high-risk periods.
- Preparation of site-specific evacuation and response plans by district authorities.

Pillar VIII: Capacity Building and Public Awareness

Policy Directives:

- Awareness campaigns in landslide- and flood-prone villages.
- Training of engineers, contractors, and field staff on slope-safe practices.
- Community participation in drain cleaning, monitoring, and reporting.

6. District-Specific Priority Actions

Ramban District

- Immediate restoration of Sunari, Bowli Bazar, Hospital, and Bus Stand nallahs.
- Drainage correction and toe protection at Cafeteria Morh and Pernote landslide zones.
- Spring-water management and irrigation regulation in Tanger and Dalwas villages.

Kishtwar District

- Rockfall scaling, drainage management, and toe protection along NH-244 hotspots.
- Emergency flood protection and relocation at KajaiNallah.
- Strict land-use enforcement and debris monitoring at Chashoti.
- Drainage correction and subsidence monitoring at Dangdoru.

7. Implementation Framework

- **Nodal Agency:** Department of Disaster Management, Relief, Rehabilitation & Reconstruction (DMRRR)
- **Executing Agencies:** District Administrations, PWD, R&B, Rural Development, Forest Department, Urban Local Bodies
- **Technical Support:** GSI, NIH, academic and research institutions

Funding:

- District Disaster Response Fund (DDRF)
- State Disaster Response Fund (SDRF)
- Convergence with MGNREGA, PMGSY, and other ongoing schemes

8. Monitoring, Review, and Compliance

- Monthly progress review during monsoon season.
- Post-monsoon performance evaluation of mitigation measures.
- Integration of successful short-term measures into DPRs for long-term mitigation.

9. Expected Outcomes

- Reduced loss of life and infrastructure damage during monsoon seasons.
- Improved slope stability and drainage performance.
- Enhanced preparedness and institutional coordination.
- Stronger foundation for long-term disaster risk reduction planning.