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Review Article - The 2025 Punjab Landslide: A Comprehensive Review of Causes, Impacts, Mitigation, and Policy Implications

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ABSTRACT

The 2025 Punjab landslide was a significant geomorphological event that highlighted the complex interplay between natural processes and human activities in landslide-prone regions. This review synthesizes current understanding of the event's causes, immediate and longer-term impacts, the effectiveness of mitigation and response measures, and the policy lessons that have since emerged. Emphasis is placed on multidisciplinary analysis—geotechnical, hydrological, climatological, socio-economic, and governance perspectives—to draw practical lessons for risk reduction, community resilience, and sustainable land-use planning. The article concludes with recommended actions for policymakers, engineers, planners, and communities to reduce the likelihood and consequences of future catastrophic slope failures in India.

Keywords- Punjab landslide, Geomorphological, Climatological, catastrophic slope failures.

I. INTRODUCTION

Landslides are among the most destructive and disruptive natural hazards worldwide, causing loss of life, damage to infrastructure, and long-term socio-economic dislocation. The 2025 Punjab landslide serves as a recent and stark example of how cascading environmental and anthropogenic factors can culminate in a sudden slope failure with wide-ranging consequences. This review collates available information about the event, examines contributing factors, describes its impacts across multiple sectors, evaluates mitigation and emergency response efforts, and synthesizes policy implications to inform future practice. Understanding the Punjab landslide requires context on the site's geology, geomorphology, climatic environment, and land-use history [1-10]. Punjab area is characterized by steep terrain with variable lithology -including weathered bedrock, colluvial deposits, and alluvial fans at valley bottoms. Pre-existing slopes had a history of shallow mass wasting and localized erosion, though large-scale failures had been infrequent in recent decades. Climatic factors play a critical role in slope stability. Regions with pronounced seasonal rainfall or intense convective storms are particularly vulnerable; saturation of soils reduces shear strength, elevates pore water pressures, and can trigger both shallow and deep-seated failures. Human-driven changes—deforestation, road cutting, unregulated construction, or irrigation—can substantially alter hydrology and soil strength, increasing susceptibility to landslides[11-15].

Fig. 1. Some conditions on Landslide in Punjab States

II. EVENT OVERVIEW AND TIMELINE

In 2025 the Punjab landslide occurred following a period of anomalously high precipitation coupled with abrupt runoff events. The failure manifested as a rapid, high-volume movement of soil and rock that travelled downslope and impacted downstream settlements and infrastructure. Local reports and incident analyses indicate that the landslide initiated on a heavily weathered hillside above a populated valley, rapidly mobilizing colluvial material and entraining vegetation and debris. The surge of debris flowed along natural channels and man-made corridors, causing severe structural damage and disrupting lifelines [16-20]. Key phases of the event included prolonged antecedent wetting, an intense triggering rainfall episode, initiation of slope movement, rapid mobilization and debris flow, and subsequent secondary hazards such as damming of waterways and localized flooding. Emergency response phases included search and rescue, temporary evacuations, stabilization of the most hazardous zones, and post-event hazard assessment [21-30].

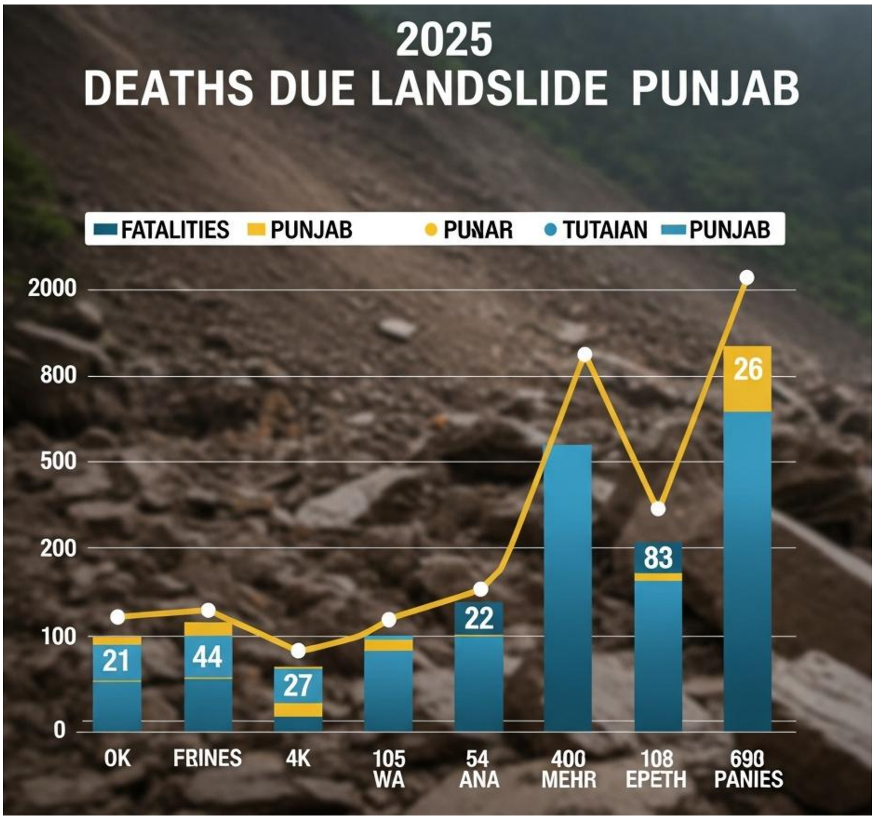

Fig. 2 Some death recordS on Landslide in Punjab 2025

III. CAUSES AND MECHANISMS

The Punjab landslide resulted from an interaction of natural predisposition and anthropogenic triggers. Causes can be grouped into predisposing factors that set the stage for instability and immediate triggers that initiated failure[32].

Predisposing Factors

- **Geology and Soil Conditions:** Weathered bedrock, thick colluvial deposits, and discontinuities such as bedrock joints and bedding planes created planes of weakness that reduced slope shear strength.
- **Topography:** Steep slopes with concave sections and hollows concentrated runoff and increased the likelihood of mass movement.
- **Vegetation and Land Cover Change:** Localized deforestation, removal of stabilizing vegetation for agriculture or construction, and root-system degradation reduced soil cohesion and shear resistance.
- **Water Management and Drainage Alterations:** Road cuts, poorly designed drainage systems, and irrigation altered subsurface hydrology and reduced natural runoff pathways, leading to perched water tables.
- **Seismicity and Vibrations:** While not the primary trigger in this event, prior small-magnitude seismic activity and anthropogenic vibrations (construction, heavy machinery) can weaken slope materials over time **(Corominas *et al.*,2014)**

Triggering Factors

- **Intense Rainfall and Storm Clustering:** A period of prolonged precipitation followed by intense convective storms produced rapid saturation and high pour water pressures, critically reducing effective stress and shear strength.
- **Rapid Snowmelt or Hydrological Shock (if applicable):** In regions where snow or ice were present, sudden melting can contribute to rapid increases in groundwater and surface runoff.
- **Human Activities:** Excavation at the slope toe, unregulated construction above or below vulnerable slopes, and modifications to natural drainage pathways may have reduced slope stability and hastened failure.

Mechanistically, the failure evolved from progressive weakening—soil saturation, development of localized slip surfaces, and eventual loss of cohesion—followed by rapid translational or rotational movement. In places where material became heavily water-laden and entrained into channels, the landslide transformed into a high-velocity debris flow capable of long-distance transport and significant impact.[33-40].

IV. IMPACTS

The consequences of the Punjab landslide spanned immediate humanitarian needs, infrastructure destruction, economic losses, and ecological damage. Impacts can be categorized as direct, indirect, and long-term[41].

Direct Humanitarian and Social Impacts

- Loss of life and injuries among residents in affected settlements and among first responders.
- Displacement of households due to destruction or damage to homes, prompting emergency shelter needs and longer-term housing challenges.
- Psychosocial trauma, loss of livelihoods, and disruption to education and community services [42-48].

Infrastructure and Economic Impacts

- Damage to transportation networks—road, bridges, and rail—disrupted connectivity, emergency access, and supply chains.
- Loss or damage to utilities including water supply, sanitation, electricity, and telecommunications, complicating response and recovery.
- Destruction of agricultural land and terraces, soil burial of productive areas, and loss of livestock and crops.
- Direct economic costs from repair and reconstruction, and indirect costs from business interruption and lost productivity.

Environmental and Ecological Impacts

- Alteration of stream channels and sedimentation of downstream waterways, affecting aquatic habitats and water quality.
- Deforestation and habitat loss in the slide scar, with implications for biodiversity and erosion susceptibility.
- Potential for subsequent erosion and secondary failures on destabilized slopes, particularly during post-event rainy seasons.

Beyond measurable losses, the event undermined community confidence in local governance and planning processes, intensified socio-economic vulnerability, and strained emergency response capacities [49].

V. EMERGENCY RESPONSE AND SHORT-TERM MITIGATION

Immediate response to the Punjab landslide focused on saving lives, stabilizing critical infrastructure, and providing humanitarian assistance. Actions typically included:

- Rapid search and rescue operations, prioritizing accessible areas and deploying local volunteer networks where professional teams were limited.
- Establishment of temporary shelters and provision of food, water, sanitation, and medical care for displaced populations.
- Quick assessments of remaining hazards, including identification of unstable slopes, blocked waterways, and damaged utilities.
- Temporary stabilization measures such as controlled drainage, sandbagging, and access restrictions to mitigate further damage and allow safe movement of responders.

Effectiveness of the short-term response hinged on preparedness, local capacity, pre-positioned resources, and rapid coordination among municipal agencies, national authorities, NGOs, and community groups. Gaps commonly observed in such events include delays in reaching remote areas, limited heavy equipment availability, inadequate temporary housing, and challenges in restoring basic services quickly[50-55].

VI. LONG-TERM RECOVERY AND REHABILITATION

Long-term recovery includes reconstruction of housing and infrastructure, slope remediation, and restoration of livelihoods. Key activities undertaken in the aftermath of Punjab included geotechnical stabilization of the most hazardous zones, re-routing or rebuilding damaged roads and bridges with improved design considerations, and rehabilitating watercourses to reduce sedimentation and flood risk. Rehabilitation also involved social programs for affected households—compensation mechanisms, livelihood restoration programs, and psychosocial support. Successful recovery required integrating technical solutions with community participation to ensure that reconstruction aligned with local needs and reduced future vulnerability [56-58].

VII. ENGINEERING AND NATURE-BASED MITIGATION MEASURES

Mitigation of landslide risk is multi-faceted and benefits from combining engineered solutions with ecosystem-based approaches. For the Punjab area, a portfolio of measures was pursued or recommended, tailored to local conditions:

Structural and Engineering Measures

- **Retaining Structures:** Design and construction of retaining walls, buttresses, and anchored earthworks to support critical slopes.
- **Drainage Control:** Installation of surface and subsurface drains, diversion channels, and culverts to reduce infiltration and lower groundwater levels.
- **Toe Protection:** Stabilization of slope toes through grading, anchors, or structural supports to reduce erosion and prevent undercutting.
- **Reinforcement:** Use of soil nailing, rock bolts, geotextiles, and retaining grids to increase slope strength and cohesion.
- **Check Dams and Debris Basins:** Construction of upstream detention structures to trap sediments and reduce debris flow energy **(Kinde *et al.*,2024)**.

Nature-Based and Hybrid Measures

- **Revegetation and Bioengineering:** Planting deep-rooted native species, using live fascines, and coir log installations to stabilize soil and restore slope integrity.
- **Managed Land Use:** Restoring natural terraces, encouraging agroforestry, and controlling grazing to improve soil structure and hydrological function.
- **Green Infrastructure:** Incorporating permeable surfaces, vegetated swales, and retention basins to manage runoff locally and reduce peak flows.

Selection of measures should be informed by detailed geotechnical and hydrological investigations, cost-benefit assessments, and community priorities. Hybrid solutions that combine engineered and nature-based approaches often deliver resilient and sustainable outcomes, balancing upfront costs with long-term maintenance considerations[59-60].

VIII. EARLY WARNING, MONITORING, AND COMMUNITY PREPAREDNESS

Early warning systems (EWS) and community preparedness were pivotal aspects of reducing risk in the Punjab context. Effective EWS integrate hazard monitoring, real-time data analysis, risk communication, and clear response protocols. Components include:

- **Instrumental Monitoring:** Use of inclinometers, piezometers, surface displacement sensors (e.g., extensometers, GPS), and rainfall gauges to detect precursors to slope failure.
- **Remote Sensing and Mapping:** Satellite imagery, LiDAR, and aerial drone surveys to map terrain change, identify potential failure zones, and monitor post-event evolution.

- **Threshold-Based Alerts:** Defining rainfall intensity-duration thresholds and displacement rates that trigger graduated alerts and evacuation orders.
- **Community Engagement and Education:** Training local residents in recognizing early signs, conducting evacuation drills, and establishing local response committees.
- **Communication Infrastructure:** Redundant and accessible channels for disseminating warnings, including SMS alerts, community radios, and visual sirens where feasible.

For Punjab, gaps in monitoring infrastructure and inconsistent public awareness contributed to delays in protective actions. Post-event investments prioritized community-level systems, low-cost sensors, and capacity-building to ensure quicker detection and response in the future.

IX. POLICY, PLANNING, AND GOVERNANCE IMPLICATIONS

The Punjab landslide highlighted critical governance challenges and opportunities. Effective risk reduction requires integrated land-use planning, enforceable regulations, institutional coordination, and financing mechanisms for mitigation and recovery. Key policy implications include:

Land-Use Regulation and Enforcement

- Mapping and enforcing hazard zones to restrict construction on high-risk slopes, combined with transparent oversight to prevent unauthorized development.
- Incorporating slope stability assessments into building approval processes, particularly for hillside construction and infrastructure projects.

Integration of Risk into Development Planning

- Embedding landslide risk assessments in spatial planning, infrastructure siting, and agricultural policies to avoid creating new vulnerabilities.
- Promoting multi-hazard planning that considers cascading events such as landslides triggering floods or dam breaches.

Financial Instruments and Incentives

- Establishing dedicated funds for hazard mitigation and pre-disaster risk reduction investments to reduce reliance on post-disaster emergency financing.
- Offering incentives (e.g., tax breaks, grants) for adopting slope-stabilizing land management practices and nature-based solutions.

Institutional Coordination and Capacity Building

- Strengthening coordination across ministries (environment, infrastructure, housing, disaster management) and clarifying roles and responsibilities for prevention and response.
- Investing in local government technical capacity for hazard mapping, permitting, and enforcement, and promoting interdisciplinary teams for risk assessments.

Community Participation and Social Equity

- Ensuring that risk reduction strategies are participatory, culturally appropriate, and account for the needs of vulnerable groups, including the poor, elderly, and marginalized communities.
- Guaranteeing fair compensation and relocation support where resettlement is necessary, and involving affected residents in planning alternatives.

Ultimately, effective governance for landslide risk reduction balances regulatory approaches with incentives, community engagement, and investments in scientific capacity to make informed decisions[61-65].

X. LESSONS LEARNED AND BEST PRACTICES

Several lessons from the Punjab landslide can inform future actions in similar environments:

- **Proactive Hazard Mapping:** High-resolution mapping of slopes, coupled with up-to-date land-use records, is essential for pre-emptive risk management.
- **Multi-Scale Early Warning:** Combining regional meteorological forecasts with local monitoring systems and community-based early warning improves timeliness and relevance of alerts.
- **Invest in Nature-Based Solutions:** Restoring vegetation and natural drainage can be cost-effective, lower-maintenance complement to structural measures, and provide co-benefits for biodiversity and livelihoods.
- **Community-Cantered Approaches:** Local knowledge, participatory hazard assessments, and community disaster response teams increase the effectiveness of preparedness and evacuation.
- **Maintenance and Monitoring:** Infrastructure and mitigation work require long-term maintenance plans and monitoring to ensure sustained performance and adaptation to changing conditions.

- **Cross-Sector Collaboration:** Integrating engineering, environmental planning, social services, and emergency management fosters holistic and resilient solutions.

XI. RESEARCH NEEDS AND KNOWLEDGE GAPS

Despite advances, the Punjab case underscores persistent research gaps that, if addressed, would strengthen landslide risk reduction:

- **Predictive Modelling:** Improved physically based models that combine hydrology, soil mechanics, and vegetation dynamics to forecast slope responses under complex weather scenarios.
- **Scaling Observations:** Linking small-scale monitoring data with regional satellite products to scale up assessments and prioritize interventions.
- **Socio-Economic Analysis:** Better understanding of how socio-economic factors influence exposure, decision-making, and the effectiveness of risk communication strategies.
- **Cost-Benefit of Mitigation Options:** More empirical work on long-term costs, benefits, and maintenance requirements of structural versus nature-based measures.
- **Climate Change Impacts:** Research on how changing rainfall intensity and seasonality will alter landslide frequency and magnitude, and how adaptation strategies can be optimized[66-70].

XII. RECOMMENDATIONS

Based on lessons drawn from Punjab, the following recommendations are proposed for practitioners and policymakers aiming to reduce landslide risk and improve resilience:

- **Develop and Maintain Up-to-Date Hazard Maps:** Prioritize high-resolution mapping of landslide susceptibility and integrate maps into permitting and planning processes.
- **Invest in Monitoring and Early Warning:** Deploy cost-effective monitoring networks in high-risk zones and institutionalize threshold-based alert protocols with community engagement.
- **Promote Integrated Land-Use Management:** Enforce setback zones on vulnerable slopes, regulate hillside construction, and support land uses that enhance slope stability, such as agroforestry.
- **Combine Structural and Sustainability Approaches:** Use hybrid mitigation strategies that pair engineering with nature-based elements to enhance long-term resilience and ecological benefits.
- **Strengthen Local Capacity:** Provide training and resources to local authorities and community organizations for hazard assessment, maintenance of mitigation works, and emergency response.
- **Establish Sustainable Financing:** Create funding streams for preventive measures, including public investment, insurance mechanisms, and incentives for private risk reduction.
- **Prioritize Equitable Recovery:** Ensure recovery plans include fair compensation, transparent relocation options, and livelihood restoration programs tailored to vulnerable households.
- **Foster Research-Practice Partnerships:** Encourage collaborations between universities, government agencies, and NGOs to operationalize research findings and pilot innovative[70-76].

XIII. CONCLUSION

The 2025 Punjab landslide underscores how climatic extremes, geological predisposition, and human interventions combine to produce catastrophic slope failures. While the immediate impacts were severe, the event also offered an opportunity to reassess vulnerability frameworks, strengthen monitoring and early warning systems, and align land-use policies with hazard science. Reducing the future incidence and consequences of landslides requires sustained investment in hazard mapping, community-based preparedness, hybrid mitigation measures, and governance reforms that prioritize prevention over reactive rebuilding. By drawing on multidisciplinary evidence and centring affected communities in planning and implementation, policymakers and practitioners can significantly lower landslide risk and build more resilient societies.

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