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Landslides in India: Monsoon-Induced Slope Failures, Risk Management and Disaster Resilience

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Recent Developments:

- **Torrential monsoon rainfall** triggered widespread **landslides** across **Maharashtra**, resulting in the temporary closure of the **Mumbai–Pune Expressway** and the **Mumbai–Goa Highway**, disrupting transport and emergency services.
- Intense rainfall saturated hill slopes, causing **boulder falls**, **debris flows** and repeated slope failures along several vulnerable transport corridors.
- The incident has renewed focus on the need for **scientific slope management**, **early warning systems** and **land-use regulation** in India's landslide-prone regions.

Landslides:

Definition:

- A **landslide** is the rapid downward and outward movement of **rock, soil, debris, weathered material or artificial fill** under the influence of **gravity**.
- Landslides occur when the **shear stress** acting on a slope exceeds the **shear strength** of soil or rock, causing slope failure.
- Landslides are a form of **mass wasting** and may occur as **rock falls, debris flows, mudflows, rotational slides, translational slides or complex slope failures**.

Landslide Scenario in India:

Key Facts:

- Nearly **15%** of India's geographical area, approximately **0.42 million sq km**, is susceptible to landslides.
- Major landslide-prone regions include the **Himalayas, Northeast India, Western Ghats** and **Eastern Ghats** due to fragile geology, steep slopes and intense rainfall.
- A large proportion of vulnerable areas also lie within **Seismic Zones IV and V**, where earthquakes further destabilize mountain slopes.
- The **Geological Survey of India** is the nodal agency for landslide studies and operates the **National Landslide Forecasting Centre** through the **BhuSanket** platform for forecasting and impact assessment.
- The **Landslide Atlas of India**, prepared by **Indian Space Research Organisation**, contains an inventory of nearly **80,000** mapped landslides covering **17 States** and **2 Union Territories** using satellite-based geospatial data.

Major Causes of Landslides in India:

Natural Factors:

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- **Intense and prolonged rainfall** increases groundwater pore-water pressure, reduces soil cohesion and substantially increases the weight of unstable slopes.
- **Earthquakes** generate ground shaking that destabilizes already fractured rock masses, particularly in tectonically active mountain belts.
- **Young fold mountains**, weathered rocks, geological faults and highly fractured strata create natural planes of weakness that promote slope failure.
- **River erosion**, glacial activity and natural weathering continuously undercut hill slopes, increasing instability.
- **Climate change** is increasing the frequency of extreme rainfall events, thereby elevating landslide risks in mountainous regions.

Anthropogenic Factors:

- **Unscientific hill cutting** for highways, railways and urban expansion disturbs natural slope equilibrium and weakens hill stability.
- **Deforestation** removes root systems that bind soil, accelerating erosion and slope instability.
- **Mining, quarrying and blasting** create artificial fractures and weaken rock formations.
- **Unplanned urbanisation**, encroachment on steep slopes and poor drainage systems increase landslide vulnerability.
- **Improper disposal of construction debris** and overloading of hill slopes further aggravate slope failures.

Impacts of Landslides:

Socio-Economic and Environmental Impacts:

- Landslides cause **loss of human lives**, livestock and widespread destruction of houses and public infrastructure.
- Roads, railways, tunnels, bridges, transmission lines and communication networks often remain disrupted for extended periods.
- Landslides block rivers, creating temporary lakes that may subsequently trigger catastrophic flooding.
- Productive agricultural land is buried under debris, reducing agricultural productivity and affecting livelihoods.
- Mountain ecosystems experience severe habitat degradation, biodiversity loss and accelerated soil erosion.
- Tourism, local economies and supply chains suffer significant disruptions in hill regions.

Challenges in Landslide Risk Management:

Major Constraints:

- Remote mountainous terrain delays rescue, evacuation and relief operations.
- Continuous rainfall, cloud cover and recurring slope failures hamper both aerial and ground-based disaster response.
- Weak enforcement of **land-use zoning regulations** permits construction in highly vulnerable locations.
- Many regions lack **meso-scale**, real-time monitoring networks capable of detecting initial ground movement before failure.
- Hazard maps are often inadequately integrated into infrastructure planning and local development decisions.
- Coordination among multiple agencies involved in forecasting, planning and emergency response remains uneven.

National Disaster Management Authority Guidelines:

Recommended Measures:

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- **Geological Survey of India** should continuously update comprehensive national landslide inventories and hazard databases.
- **Landslide Hazard Zonation** mapping should be prepared at **1:50,000** and **1:10,000** scales to guide infrastructure planning and land-use decisions.
- Engineering measures such as **retaining walls, rock bolting, wire mesh netting, soil nailing, anchoring systems** and **slope reinforcement** should be adopted in vulnerable locations.
- Efficient **surface** and **sub-surface drainage systems** should be developed to reduce pore-water pressure and improve slope stability.
- Community awareness, capacity building, preparedness planning and multi-agency coordination should be strengthened at all administrative levels.
- The **National Disaster Management Authority** also recommends institutional coordination, hazard mapping, capacity building and scientific land-use planning under its **Landslide Risk Management Strategy, 2018** and **Guidelines on Management of Landslides and Snow Avalanches**.

Institutional Framework:

Major Institutions:

- **Geological Survey of India** serves as the national nodal agency for landslide investigation, hazard mapping, forecasting and technical support.
- **National Disaster Management Authority** formulates national policies, guidelines and disaster risk reduction strategies.
- **National Disaster Response Force** undertakes specialised search, rescue and emergency response during landslide disasters.
- **India Meteorological Department** provides rainfall forecasts and weather advisories supporting landslide preparedness.
- **Indian Space Research Organisation** supports landslide mapping through satellite observations, remote sensing and geospatial databases.
- **State Disaster Management Authorities** and **District Disaster Management Authorities** coordinate preparedness, evacuation and rehabilitation at State and district levels.

Way Forward:

Priority Measures:

- Deploy **Artificial Intelligence-enabled** early warning systems integrating rainfall data, ground sensors, extensometers and automated monitoring stations.
- Install **rockfall barriers, steel catch fences, protective galleries** and engineered shelters along vulnerable highways and railway corridors.
- Use **Light Detection and Ranging**, drones and high-resolution satellite imagery for periodic monitoring of unstable slopes before every monsoon.
- Make **scientific geotechnical investigation** mandatory before approving hill infrastructure, mining or large construction projects.
- Strictly prohibit unscientific hill cutting and adopt **terraced benching, bio-engineering techniques, geotextiles** and proper drainage systems.
- Strengthen community-based disaster preparedness through trained local volunteers, mock drills, first-aid training and emergency communication systems.
- Integrate landslide risk assessment into **Environmental Impact Assessment**, district disaster management plans and climate adaptation strategies.
- Align national landslide risk reduction initiatives with the **Sendai Framework for Disaster Risk Reduction 2015–2030** and **Sustainable Development Goal 11** to enhance resilience and sustainable mountain development.

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Conclusion:

Building Resilient Mountain Ecosystems:

- Recurring landslide disasters demonstrate that disaster resilience requires scientific planning, strict land-use regulation, resilient infrastructure and continuous monitoring rather than post-disaster response alone.
- A combination of **risk-informed development, advanced forecasting, community participation** and **ecosystem-based slope management** will be essential for protecting lives, infrastructure and fragile mountain environments