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Original Article

Flash flood formation, Mitigation and effect on Environment: A Geographical study of Darjeeling district, W. B.

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Abstract

Flash floods constitute one of the most destructive natural hazards in the Himalayan region, causing severe environmental degradation and socio-economic losses. The Darjeeling district of West Bengal, located in the Eastern Himalayas, is highly vulnerable to flash floods due to steep slopes, fragile geology, intense monsoonal rainfall, and increasing anthropogenic pressure. The present study examines the hydro-geomorphic and climatic causes of flash floods in the Darjeeling district. It also analyses the spatial characteristics of flash floods in both hilly and plain regions and assesses their social, economic, and environmental impacts. The study is based on Primary and secondary data. The findings reveal that flash flood risks in the region are intensified by unplanned development, deforestation, and climate-induced extreme rainfall events. The study emphasizes the need for integrated basin-level flood management, early warning systems, sustainable land-use planning, and community-based adaptation strategies to reduce future vulnerability.

Keywords*: Flash flood, Cloud Burst, land Side, Mitigation, Eastern Himalayas, hydro geomorphic processes, climate change, disaster management.*

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Introduction

Darjeeling, popularly known as the “Queen of Hills,” is one of the most charming and picturesque districts located in the Eastern Himalayas of northern West Bengal, situated at 27.04° N latitude and 88.26° E longitude. The district includes several important hill subdivisions, such as Darjeeling Sardar, Kurseong, Kalimpong, and Mirik, each with its unique geographical and climatic features. The area is known for its picturesque tea gardens, rich biodiversity, and tourism-based economy. The region lies at an altitude of above 2,000–3,000 meters above sea level and experiences heavy monsoon rainfall every year. The terrain of Darjeeling is mountainous and geologically complex. Due to continuous river incision and soil erosion, several flooded and thrust rock formations have been exposed, mainly belonging to the Siwalik and Gondwana groups, which are overlain by foliated Darjeeling gneiss. These formations create steep, northward-dipping slopes, making the region highly prone to landslides. The area receives intense monsoon rainfall, with an annual total often exceeding 2,000 to 3,000 mm, while the southern slopes record even higher amounts of 4,000 to 5,000 mm. Historical records even note extreme events, such as a 493 mm cloudburst in a single day in 1827. Situated in seismic Zone IV, the district also faces significant earthquake risk. The combination of steep relief, fragile geology, and heavy rainfall makes Darjeeling inherently prone to natural hazards.

While the natural landscape predisposes Darjeeling to slope instability, human activities have greatly intensified the risk. Over decades, extensive deforestation, hillside tea cultivation, and unregulated urban construction have removed stabilizing vegetation and disturbed soil cover. Studies confirm that most landslides occur in heavily deforested areas, where heavy and concentrated rainfall causes severe erosion and slope failure. Rapid road-building, increased vehicular traffic, and large-scale infrastructure projects—such as hydropower, railways, and tourism facilities—have further destabilized the terrain, exceeding the region’s limited carrying capacity. These combined natural and anthropogenic pressures make the district acutely susceptible to flash floods and landslides.

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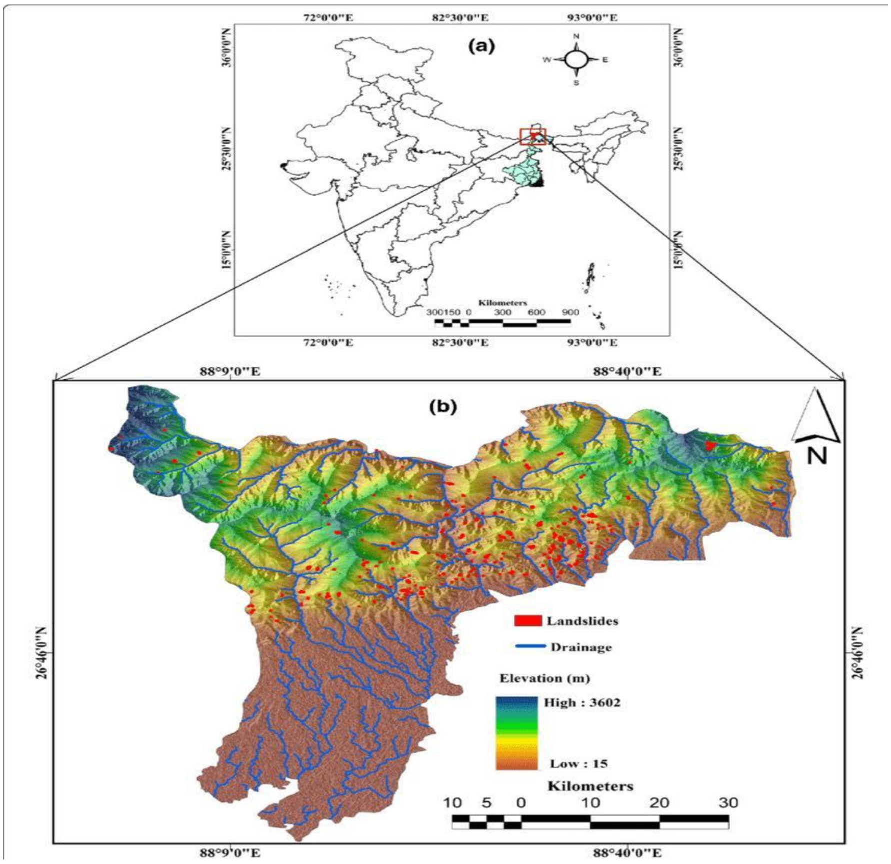
In the past few years, the Darjeeling, Mirik, and Kurseong subdivisions have experienced several damages due to landslides and heavy rainfall. As reported in local newspapers like The Telegraph and Times of India, in October 2025, exceptionally heavy rains struck the Darjeeling hills, triggering flash floods and landslides. In the Mirik subdivision, at least 11 people were killed, and floodwaters washed away the historic Dudhia Iron Bridge over the Balason River, severing the vital Siliguri–Mirik link. The event caused severe damage to homes, roads, and communication networks, stranding hundreds of residents and tourists. These losses reveal the ongoing severity of hydro meteorological hazards in the region and the high vulnerability of hill communities. In Kurseong, heavy rainfall caused road blockages along National Highway-55 and damaged several connecting roads in the rural hills. Local news reports also mention that the market in the hill regions faced a shortage of essential items due to the disruption of transport routes from the plains.

Location of the study area:



Objective:

To carry out a detailed geographical study of the origins, effects, and control strategies for flash floods and landslides within the Darjeeling district. Some objectives of the study are:

1. To identify and understand the impact of different physical / environmental factors in response to the flash flood and landslides in Darjeeling.
2. To Study on the understanding of human / anthropogenic causes which are responsible for the hazards in Darjeeling District.
3. To Study on the recent hazards like landslides and flash floods in the Darjeeling district.
4. Understand the effectiveness of these hazards and possible mitigation strategies.

Research Methodology:

The present study follows a descriptive research design, as it aims to describe, analyze, and interpret the nature, causes, and impacts of flash floods in the Darjeeling district. This design is appropriate for understanding existing geographical conditions, historical flood events, and their associated environmental and socio-economic effects.

The study is analytical in nature and is based primarily on the examination of secondary sources of data. It seeks to establish relationships between hydro-geomorphic conditions, meteorological factors, human activities, and the occurrence of flash floods in both hilly and plain regions of the study area.

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Result and Discussion:

1. **Historical context of Landslide Events in Darjeeling:**

The Darjeeling hills have a long history of landslide and flash floods due to their steep terrain, fragile rock structure and heavy monsoon rainfall. Records show that major landslide events occurred in 1899, 1934, 1950, 1968, 1975, 1980, 1991, 2011 and 2015. Among these, the 1968 disaster remains the most catastrophic, when continuous rainfall of nearly 1,000 mm in just 52 hours triggered massive landslides and floods killing more than a thousand people and causing severe damage to roads, bridges and tea estates.

In recent decades, landslide occurred in both 2015, and 2025 in the month of October, suggest a climatic shift as high intensity rainfall now occurred beyond the traditional monsoon period. The 2025 event caused flash floods and slope failures in Mirik, Kurseong, and Bijanbari, leading to significant loss of life and property.

Table no. 1: Historical record of Major Landslides and Flash flood Events in Darjeeling District

Year	Duration Of Rainfall	Approximate Rainfall (mm)	Locations Affected
1899		800 mm	Darjeeling town, tea gardens
1934	2-3 days	700 mm	Ghum, Sonada
1950	3 days	900 mm	Teesta valley
1968	4 days (52 hours continuous)	1,000 mm	Entire district
1975	2 days	650 mm	Kurseong
1980	3 days	700 mm	Ghum, Sukhiapokhri
1991	2 days	800 mm	Mirik, Teesta
2011	2-3 days	600 mm	Darjeeling-Kurseong Road
2015	3 days (October)	900 mm	Mirik, Kalimpong
2025	12 hours	300 mm	Mirik, Bijanbari, Kurseong

Formation of Landslide and Flash Flood:

The 2025 landslide and flash flood disaster in Darjeeling district was the result of a complex interaction of geomorphological, and hydrological and anthropogenic processes. The region's steep terrain, fragile rock structure and high rainfall intensity together created conditions highly conducive to slope instability and rapid surface runoff. The heavy rainfall recorded between 11-13 October 2025, brought by a deep low-pressure system over the Bay of Bengal, deposited more than 300 mm of rainfall within 24 hours an anomaly even for the already rain prone Darjeeling hills. The intense precipitation acted as the immediate triggering factor for multiple slope failures and flash flood occurrences.

Geological and Geomorphological Processes

Darjeeling lies in the Lesser Himalayan Belt, consisting mainly of Metamorphic rocks such as Schist, gneiss, and phyllite, which are highly fractured and weathered due to ongoing tectonic activities. The steep gradient of slopes ranging between 35° and 60° allows gravitational forces to act strongly on saturated soils. Prolonged rainfall infiltrates through the loose colluvial material, increasing pore water pressure and reducing the internal shear strength of the slope materials. When the equilibrium between driving and resisting forces is disturbed, it leads to slope failure or landslides. In 2025, this process was particularly visible in the regions of Kurseong, Mirik, and Pulbazar, where deep seated landslides and debris flows occurred along cut slopes and agricultural terraces.

Hydrological and Meteorological Factors:

Heavy rainfall in Darjeeling caused excessive runoff in streams like Rangbhang Khola, Little Rangeet and Balasun River. The saturated slopes led to flash floods in downstream areas, damaging roads, bridges and settlements. Poor drainage and silted riverbeds worsened the flooding. The Orographic effect of the Himalayas also caused heavy rainfall on windward slopes.

Anthropogenic Influence:

Unregulated urban expansion and road construction without proper slope engineering were key amplifying factors. Hill cutting for roads and buildings exposed bare slopes, while deforestation for tea plantations reduced root binding capacity. Poor drainage management around settlements such as Bijanbari and Sukhiapokhri causes water logging and accelerated slope saturation. These human induced stresses transformed a natural geomorphic process into a major disaster.

Impact of Landslide and Flash Flood

The 2025 landslides and Flash floods in Darjeeling caused widespread damage to life, Property and the Environment. The disaster was triggered by continuous heavy rainfall exceeding 300 mm within 12 hours, resulting in multiple slopes failures and river overflows. The event caused widespread damage across Mirik, Darjeeling and Kurseong subdivisions, revealing the complex interaction between natural processes and human activities in the region.

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Physical and Environmental Impacts: The High intensity rainfall saturated the already fragile slopes, leading to widespread soil erosion and slope failures. The geological structure composed mainly of weathered rock and unconsolidated soil failed to retain moisture, causing several major and minor landslides. The debris flow altered drainage patterns and blocked local streams, triggering flash floods in low lying valleys. Vegetation loss further intensified the risk of future landslides by exposing soil surfaces to erosion. The affected areas included Mirik, Ghoom, and Sarsaly, where hill slopes completely collapsed, altering the topography.

Human and Social Impacts: The disaster claimed around 24 Lives across the district, within 11 deaths reported in Mirik and 7 in Darjeeling Subdivision, while several others remained missing. Entire villages such as Dhar Gaon were declared uninhabitable after buried under the debris. Hundreds of families were displaced, seeking refuge in temporary shelters and relief camps organized by the district administration. Education and health services were severely disrupted. Schools and Health centers remained closed or inaccessible for weeks. The psychological trauma among the survivors especially among the children and elderly populations remains a long term social concerns.

Economic Impacts: The landslides and floods caused severe economic damage to agriculture and plantation sectors. Over 30-35 tea estates were affected, with an estimated loss of ₹50 crore. Productive tea bushes were uprooted, access roads to estates were washed away, and labor quarters were destroyed, the Darjeeling's tea exports economy, suffered a major setback. Local markets also faced food shortages and price hikes due to transport disruption. Tourism – another pillar of Darjeeling's economy was heavily impacted as roads to popular destinations like Tiger hill, Mirik lake, and Batasia Loop were closed for several days. Hotels reported mass cancellations, leading to substantial revenue loss.

Infrastructural Impacts: Critical infrastructure suffered extensive damage. Roads connecting Mirik, Kurseong, and Darjeeling were blocked by debris, while bridges such as Balasan River Bridge in Dudhia collapsed, cutting off access to remote areas. Power supply and telecommunications lines were disrupted, hampering rescue and communication efforts. Several villages remained inaccessible for more than 72 hours after the disaster.

Table no 2: Fatalities recorded during the 2025 Darjeeling Landslides and Flashfloods

AREA / SUBDIVISION	ESTIMATED NUMBER OF DEATHS
MIRIK SUBDIVISION	11
DARJEELING SUBDIVISION	7
KURSEONG SUBDIVISION	3
RURAL HILL AREAS (SARSALY, DHAR GAON, JASBIRGAON	3

Table No. 3

Date	Location	Event	Fatalities	Missing	Notes/Impacts	Sources
05-Oct-25	Mirik sub-division (Darjeeling hills)	Cloudburst-induced landslide (Soureni)	11	3	Village buried, homes flattened; 300+ displaced	Darjeeling Dist. officials
4-6 Oct 2025	Darjeeling hills (Mirik, Sukhiapokhri, Darjeeling Sadr, etc.)	Extreme monsoon landslides/floods	24	0	Bridges (Dhudia, Bijanbari) collapsed; NH/Roads cut; thousands stranded	PTI/NDTV
3-9 Oct 2025	North Bengal (Darj., Jalpaiguri, Kalimpong foothills)	Torrential rains – floods/landslides	39	–	Region-wide chaos; dozens of landslides; trekking routes closed	DDNews, DTI
04-Oct-23	Teesta Valley (Darj./Kalimpong)	Glacial outburst flash flood	–	–	Teesta River valley inundated; NH10 washed out (no big casualties reported in Darjeeling)	Darjeeling Chronicle
Various (monsoons)	Darjeeling district (hills and plains)	Recurrent landslides/floods	~10-20/yr	–	Annual monsoon-season slides (small to moderate); frequent Siliguri flooding	Darjeeling DDMA report

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Recent impact and Mitigation strategies:

Darjeeling district (red) occupies the northern Himalayan foothills of West Bengal, India, bordering Nepal, Bhutan and Sikkim. This steep terrain, combined with heavy monsoon rains, makes Darjeeling highly susceptible to landslides and flash floods. In October 2025 torrential rains triggered a cascade of landslides across Darjeeling district (especially Mirik subdivision) and adjoining hills. Reports indicate 20–32 fatalities (including children) and scores injured. In Mirik alone, 11 people were killed – the worst loss of life – with houses and tea-garden villages literally swept away by mudflows. Hundreds of people (many tourists) were stranded overnight. Officials described the disaster as "homes swept away, roads severed, and hundreds of tourists stranded". Nearly 35 slides were recorded, blocking villages and cutting off entire hamlets. (In context, Darjeeling has seen similar disasters before – e.g. ~40 dead in 2015 – underscoring its chronic vulnerability.)

Impacts on Population, Infrastructure and Economy

1. **Population and Settlements:** The 2025 deluge displaced thousands of residents. While casualty figures ranged between 23 and 32, many more were injured or missing. Entire communities – especially in Mirik, Sukhiapokhri and adjoining tea estates – lost homes and livelihoods. Temporary relief camps have been set up, but many villagers remain in peril. In addition, an expected surge in monsoon rains following the disaster has left tens of thousands on alert (with official warnings of more landslides due to saturated slopes).
2. **Infrastructure**: The storm wreaked havoc on roads, bridges and utilities.

   For example, the Dudhia iron bridge over the Balason River (linking Siliguri–Mirik) collapsed under the flood. Footage shows rubble and pillars sinking into raging waters. Many highways and local roads were similarly cut off or buried by debris. Communication lines and power were knocked out in remote villages.

   Across the hills, large boulders and mud have blocked mountain roads (as shown), isolating towns like Mirik and Kurseong for days. Officials reported two iron bridges collapsed and "huge tracts of land…inundated," underscoring the extensive damage. Hundreds of stranded tourists and local commuters only reached safety after emergency helicopter evacuations.

   Economy (Tea and Tourism): Darjeeling's economy took a severe blow. Nearly 30–35 tea gardens in Mirik, Pokhriabong and western Darjeeling reported landslide damage. Planters estimate ~₹50 crore in losses – about half of Darjeeling's annual autumn tea output – due to washed-away tea bushes and slides removing topsoil. Hundreds of acres of plantation were rendered unusable. In the short term, autumn tea yields and rural incomes will plunge.
3. **Tourism:** many hotels saw last-minute cancellations after the slides (fueled by social-media panic) even though some routes remained open. Overall, officials warn of a tourism slump during the crucial Puja season, compounding economic distress.

Mitigation Strategies:

Given Darjeeling's recurring disasters, a multi-pronged strategy is needed. Key measures fall into four categories:

1. **Government-Level Planning and Engineering:** Hazard Zonation & Land-Use Regulation: Strictly enforce landslide hazard maps and building codes. The National Disaster Management Authority (NDMA) mandates landslide risk mapping (LHZ maps) at multiple scales. Darjeeling must update such maps and bar construction on steep (>30°) or slide-prone slopes. For example, villages identified as "very high susceptibility" should be considered for relocation or fortified land-use restrictions. Urban expansion (including tourism infrastructure) should be directed to safer zones, and unregulated cutting of hill slopes must be banned.
2. **Slope Stabilization:** Engineer critical slopes with retaining walls, buttresses, soil nails or shot Crete where feasible. Key examples include reinforcing highway cuts and protecting settlements. Government programs (e.g. the ₹1,000 crore National Landslide Risk Mitigation Project covering West Bengal) should fund slope treatments. Techniques like bioengineered vegetation support (vetiver grass walls, brush layering) can complement concrete works. Regular maintenance of existing stabilizing structures is essential (many fail after long monsoons).
3. **Improved Drainage**: Water is the prime landslide trigger. Invest in robust drainage systems on all hillside roads and villages. Cross-drains and slope drains should channel rainwater away from vulnerable cuts. Culverts must be kept clear each monsoon. At the community level, the government can supply rainwater-harvesting tanks to reduce surface runoff. Where streams emerge on slopes, redirect or pipe them safely downhill. NDMA guidelines even advise diverting ephemeral streams from slide-prone zones. Early Warning Systems (EWS): Build on current pilot efforts. The Geological Survey of India (GSI) – under the LANDSLIP project – has developed a prototype Landslide Early Warning System using terrain-specific rainfall thresholds, piloted in Darjeeling district. GSI already issues daily monsoon landslide bulletins to local authorities. This should be expanded to a real-time warning service for villagers (e.g. SMS alerts or village sirens when thresholds are crossed). The system's success in pilot districts (Darjeeling, Kalimpong) shows feasibility. Likewise, state IMD rain gauges must be networked with district control rooms. All weather alerts should trigger local action plans. Indeed, West Bengal recently announced a "Bhooskhalan" app and Bhushanket portal for geo-targeted warnings; these must be leveraged for Darjeeling with vernacular messages.

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4. **Emergency Funds and Relief Plans:** Ensure contingency funds and pre-positioned relief materials (food, medicines, engineering gear) in North Bengal. West Bengal's disaster response should prioritize landslide-prone regions. The government can supplement existing NDMA schemes (e.g. Landslide Risk Mitigation sub-components) with rapid compensation payouts and housing grants. Rebuilding should follow "build back better" standards, relocating irreparably damaged houses away from slide zones. Infrastructure Resilience: Reconstruct key roads and bridges with climate resilience in mind. For example, the NH-10 (connecting Darjeeling to plains) should be upgraded with higher embankments and multiple drainage paths. Future bridges (like one collapsed above) should be built to withstand unprecedented flood flows. The government may also reroute strategic links (if possible) off the most vulnerable hillsides. The restoration of the Darjeeling Himalayan Railway (motorized lorries) was swift; this multi-modal transport network ought to be part of resilience planning.
5. **Community-Based Preparedness and Response:** Local Volunteer Corps: Train and equip local volunteers as first responders. India's Aapda Mitra program – training 100,000 community disaster volunteers nationwide – can be implemented in Darjeeling's blocks. Volunteers (preferably youth and experienced villagers) should learn basic search-and-rescue, first aid, and radio communication. Village-level "task forces" – as envisioned under NDMA's landslide project – should be formed in high-risk villages. These groups can conduct drills, manage relief kits, and coordinate evacuations on warnings. A "Yuva Aapda Mitra" initiative is also rolling out for NCC/NSS youth, which can further bolster manpower.
6. **Awareness and Education:** Conduct intensive awareness campaigns every year before monsoon. Teach communities to recognize early landslide signals (e.g. new cracks on slopes, bulging ground, leaning trees) and to monitor local rainfall gauges. Schools and tea garden communities should run mock drills for evacuation during heavy rain. Widely circulate hazard information in local languages (Nepali/Gorkha, Bengali). Simple tools – like the "Landslide Tracker" or local apps – can enable citizens to report minor slides or ground cracks.
7. **Local Early Warnings:** Even without high-tech systems, villages can use improvised alarms. For example, river gauges (flood marks) along the Balason or Teesta can trigger bells when cresting. Community radio or WhatsApp groups can broadcast caution after any significant rain. Darjeeling's government agencies should coordinate with gram panchayats so that as soon as regional bulletins warn of heavy rainfall, hamlets go on alert (keeping vulnerable people awake and ready to flee).
8. **Self-Sufficiency Measures**: Encourage households to prepare emergency kits (food, water, medicines, torch) and identify safe assembly points (field edges, community halls). Since roads can be blocked unexpectedly, villages should stockpile non-perishables each monsoon. Locals can also plant vetiver grass or bamboo on vulnerable slopes around their homes to help bind soil and slow runoff (a low-cost biotechnical fix).
9. **Environmental and Land-Use Strategies:** Reforestation and Ecosystem Conservation: Protect and expand forest cover on Darjeeling's steep slopes. Native deep-rooted species (bamboo, banyan, local shrubs) stabilize soil. Reforestation in critical watersheds (e.g. Rohini, Rangeet) will reduce rapid runoff. The government should partner with NGOs (like Save The Hills) for massive tree-planting drives. Importantly, forest clearance for agriculture or tourism must be strictly regulated. Past landslide studies highlight that deforestation and unplanned development are major landslide drivers, so reversing these trends is key.

Regulating Development: Ban new construction (homes, hotels, roads) on ridge lines or steep cuts. Enforce setbacks above waterways. Review and halt projects in high-risk zones (e.g. some tea- garden housing clusters may need relocation). Impose stricter environmental impact assessments for hillside projects. For surviving landslide scars, allow natural regrowth or carefully managed afforestation rather than leveling the site.

Green Engineering Solutions: Adopt bio-engineering (terracing with vegetation, coir logs, geotextiles) in addition to concrete works. For example, retaining walls can be built with stone-filled gabions overlaid with grasses. In Himachal and Uttarakhand, experts advocate a "nature-based" landslide resilience framework that integrates land-use planning, forest management and bioengineering rather than relying on hard infrastructure alone. Darjeeling can emulate this by coupling engineering works with slope greening to yield longer-term stability.

Water Management: Given the "flash flood" character of events, rationalize rainwater use. Encourage check-dams in upper catchments (to slow runoff) and community rainwater harvesting. Restore ponds in high villages (that may otherwise trigger overland flow). Maintain the jungle cover along rivers to absorb peak flows. Overall, an environmental strategy means treating the hills not as mere backdrops, but as living watersheds whose health mitigates disasters.

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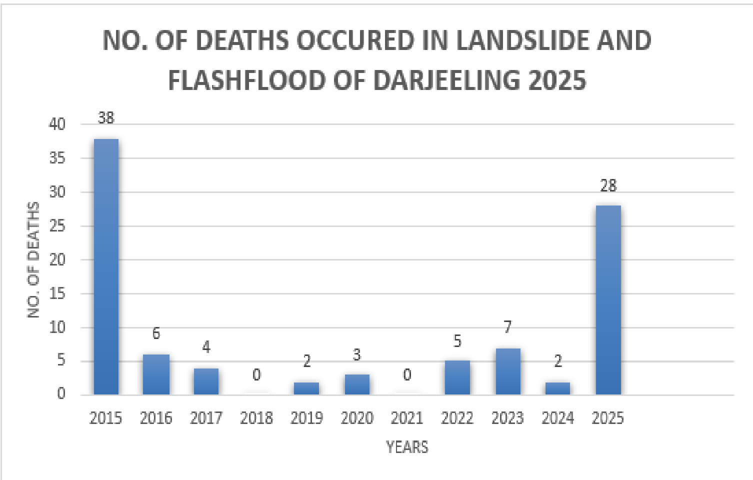
Fig. Effects on Flash flood

Table 4 – Landslide and Flash Flood Events in Darjeeling District (2015–2025)

Year	Major Event	Affected Areas	Deaths / Injuries	Remarks
2015	Monsoon landslides	Mirik, Kalimpong, Rimbick	38 deaths	One of the worst monsoon disasters in recent years
2016	Flash flood	Bijanbari, Rangit Valley	6 deaths	Caused by heavy overnight rain
2017	Localized slope failure	Ghoom–Sonada, Kurseong	4 deaths	Continuous rainfall triggered small slides
2019	Heavy rain & road blockage	Peshok–Lamahatta, Goke	2 deaths	Disrupted NH-55 route
2020	Monsoon rain + soil erosion	Mirik, Relling	3 deaths	Moderate landslide activity
2022	Pre-monsoon landslides	Kurseong, Tindharia	5 deaths	Triggered by unseasonal rainfall
2023	Flash flood event	Teesta, Bijanbari	7 deaths	Overflow of river & slope saturation
2025	Major flash flood & landslides	Mirik, Bijanbari, Sukhiapokhri	28 deaths	October 2025—most destructive recent event

Table 5: Human And Property Loss (2025 Disaster)

Area	Deaths (%)	Injured (%)	Houses Damaged (%)
Mirik	5.23	6.66	88
Sukhiapokhri	4.44	6.66	88.88
Bijanbari	5.61	6.74	87.64
Kurseong	4.76	6.34	88.88
Rangbull-ghoom	6.25	4.16	89.58



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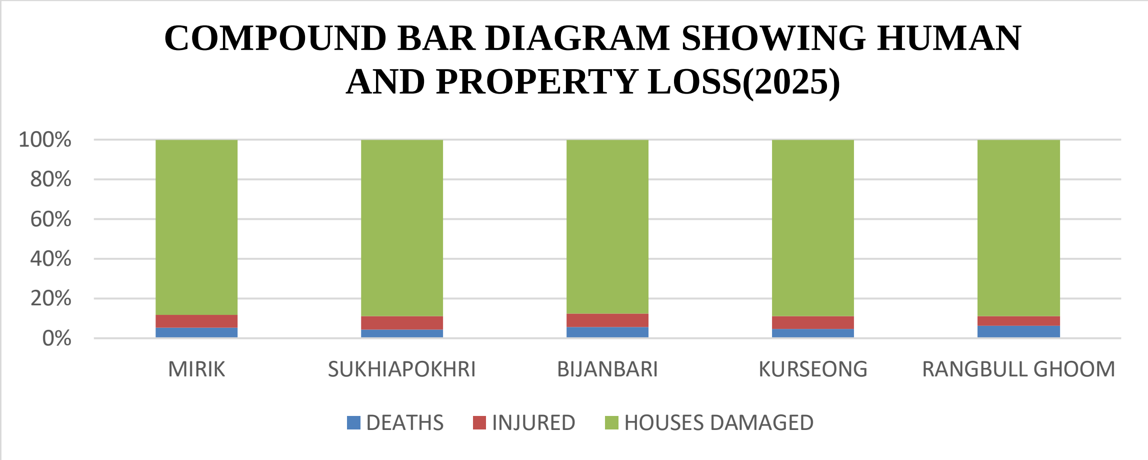

Table 6: Average Monthly Rainfall for Darjeeling District (1971-2000)

MONTH	RAINFALL (mm)
January	16
February	35
March	55
April	218
May	362
June	435
July	525
August	387
September	290
October	121
November	16
December	17

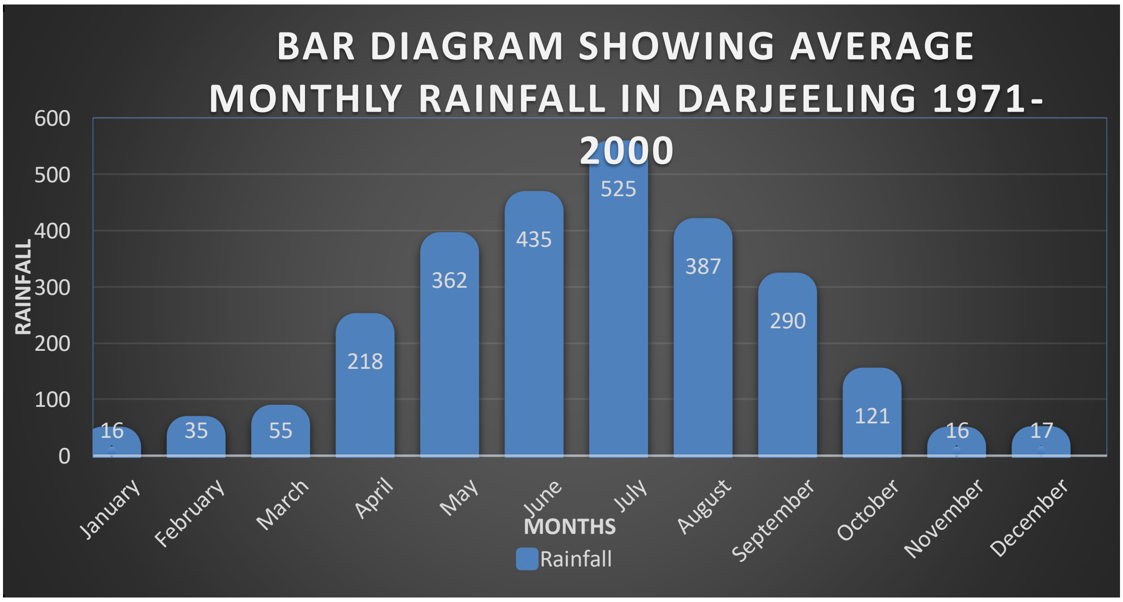

Table 7: Average Monthly Rainfall for Darjeeling District (1991-2020)

MONTH	MEAN RAINFALL (mm)
January	27.5
February	30.7
March	35.5
April	38.9
May	39.3

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June	37.5
July	141.1
August	108.1
September	71.1
October	7.6
November	1.4
December	0.1

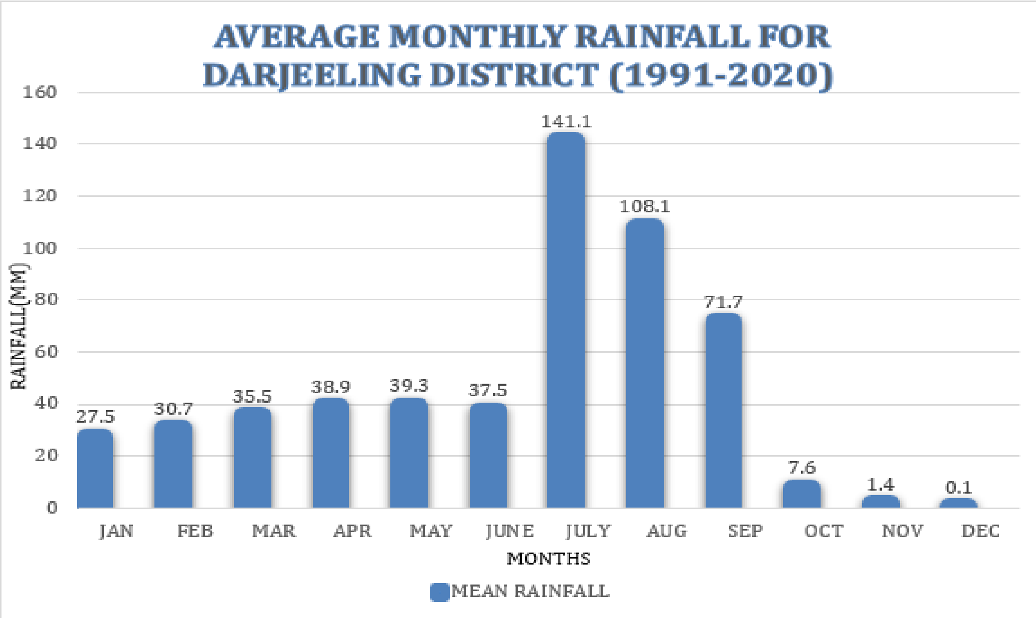

Table 8 – High-Risk And Repeatedly Affected Areas in Darjeeling District

Area	Type of Hazard	Frequency (Last 10 Years)	Severity Level	Remarks
Mirik	Landslide & flood	8	Very High	Bridge and road collapses
Sukhiapokhri	Landslide	7	High	Tourist route, heavy slope cutting
Bijanbari	Flash flood	6	High	River valley location
Kurseong	Landslide	5	Moderate–High	Urban slope failure
Rimbick–Lodhoma	Landslide	4	Moderate	Forest area with fragile slope
Ghoom–Sonada	Landslide	3	Moderate	Frequent blockage of NH-110
Peshok–Lamahatta	Landslide	3	Moderate	High rainfall zone

Table 9– Recent Actual Rainfall and Anomalies (2025)

Indicator	Value	Period / Note
Actual cumulative rainfall	348.9 mm	Oct 1 – Nov 12, 2025
Normal rainfall	171.3 mm	Same period
Rainfall anomaly	+104% above normal	IMD record
Localized peak rainfall	270–300 mm in 12 hrs	Oct 4–5, 2025
Impact	28 deaths, massive slope failures	Mirik–Bijanbari corridor

Table 10: High-Risk Sub-Areas and Key Indicators

Sub-Area	Major Events	Remarks
Mirik	Oct 2025: 11 deaths	Bridge collapse, high rainfall
Sukhiapokhri	Oct 2025: 6 deaths	Road blockage, steep slopes
Bijanbari	2025 flash flood	Valley bottom, debris deposition

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Kurseong	2011, 2015, 2025 events	Urban sprawl on slopes
St. Mary's Hill	Recurrent slides	Deforestation and construction
Relling–Peshok	2020, 2023 slides	Weak drainage, agricultural slope cutting

Table 11: Mitigation Strategies and Implementation Data

No.	Mitigation Strategy	Measure	Area	Quantitative Data
1	Early Warning System	Mobile app + rainfall alerts	Kurseong	5 pilot villages
2	Community Warning System	Rain gauges & WhatsApp alerts	Mirik, Giddapahar	3 gauges, 200 trained
3	Hazard Zonation Map	LSZ mapping	Entire district	17% high-risk area
4	Land-use Regulation	Construction restrictions	Urban slopes	12 zones proposed
5	Slope Stabilization	Retaining walls & drains	Mirik, Bijanbari	26 walls, 12 km drainage
6	Bio-Engineering	Vetiver & bamboo planting	NH-110	3,000 saplings
7	Relief & Rehabilitation	Camps & aid	Mirik region	18 camps, 850 people
8	Relocation	Moving vulnerable villages	Dhar Gaon, Seyok	34 families relocated
9	Awareness & Education	School disaster drills	47 schools	3,000 students trained
10	Multi-Hazard Warning	Integrated sensors	Darjeeling hills	Proposal under NDMA

Analysis of Landslide and Flash flood events in Darjeeling district:

The provided data reveals clear patterns of increasing disaster frequency, high human cost, and chronic vulnerability in specific areas of the Darjeeling District, culminating in an extreme rainfall anomaly in 2025. High-Risk and Repeatedly Affected Areas: The analysis of disaster events and high -risk mapping identifies certain areas as highly vulnerable, indicating a consistent geographical risk factor. Mirik is the most frequently affected area, recording 8 events in the last 10 years, with a very high severity level. It was severely affected in 2015(38 deaths) and 2025 (major flash flood and landslides, 28 deaths). Bijanbari is highly prone to flash floods (6 months) due to its river valley location. It experienced significant events in 2016 and 2023, and was a major location in the 2025 disaster. Sukhiapokhri and Kurseong are also frequently hit, primarily by landslides (7and 5 events, respectively). Kurseong is noted for urban slope failure. The Ghoom- sonada corridor is a major concern as landslides there frequently cause the blackage of NH-110.

Trends of Landslides and flash flood (2015-2025): The region shows high vulnerability to climate-induced hazards. Rainfall intensity, especially short-duration cloudbursts, is the major triggering factor. Increasing slope instability is linked to urbanization, soil erosion, and road cutting.

In table (4) we observe some key facts like –Disaster events are increasing in both frequency and severity in the Darjeeling districts. Major spikes in loss of life occurred in 2015(38 deaths) and 2025(28 deaths).

Repeatedly affected areas include: Mirik, Bijanbari, Kurseong, Rimbick, and Ghoom-Sonada.

Most events are monsoon- related, triggered by continuous heavy rainfall or overnight extreme rain.

In table (5) we observe human and property loss matrices-

The 2025 disaster resulted in high impact metrics across affected areas.

Highest mortality rate: Rangbull -Ghoom recorded the highest percentage of deaths in the 2025disaster at 6.25%.

Highest injury rate: Bijanbari reported the highest percentage of injured persons at 6.74%.

Widespread house damage: House damage was consistently devastating, with all five affected areas reporting damage percentage of 88% or higher. Rangbull-Ghoom recorded the highest property loss at 89.58% of houses damaged.

In table (6), table (7) and table (9) we observe that the rainfall anomaly as a key trigger (2025 disaster)-

The 2025 disaster was directly linked to an extreme deviation from normal rainfall patterns.

Significant Anomaly: The actual cumulative rainfall between Oct 1 and Nov 12,2025, was 348.9mm, which is+104% above the normal rainfall of 171.3mm for the same period.

High intensity: The impact was driven by a concentrated downpour, with a Localized peak rainfall of 270-300mm in just 12 hours (oct 4-5,2025).

Shifting Rainfall patterns: The long-term average rainfall data (1971-2000) vs, (1991-2020) suggests a possible shift, with the mean rainfall (mm) for the key month of October dropping significantly from 121mm (1971-2000) to 7.6mm (1991-2020). This makes the 348.9mm figure in October-November 2025 even more anomalous and catastrophic, confirming a trend of erratic, high- intensity, post- monsoon rainfall events.

In table no 8we observe some key facts like:

Mirik is the highest-risk area, with 8 major incidents in 10 years and very high severity, causing frequent road and bridge collapses.

Landslides are the dominant hazard across most regions, affecting 6 out of the 7 listed areas.
Sukhiapokhri and Bijanbari show high vulnerability, with 7 and 6 incidents respectively, linked to slope cutting and river-valley conditions.
Transport routes like NH-110 face repeated disruption, especially in Ghoom–Sonada due to moderate but frequent landslides.
In table no 10 we observe some key facts like:
Rainfall was extremely above normal, with actual rainfall (348.9 mm) being 104% higher than the normal value for the same period.
A localized cloudburst-like event occurred on Oct 4–5, delivering 270–300 mm of rain within just 12 hours.
This excessive rainfall created severe hydrological stress, triggering widespread slope failures in multiple vulnerable zones.
The Mirik–Bijanbari corridor suffered the worst impact, with 28 reported deaths and major landslide damage.
In table no 11we observe some key facts like:
Mirik and Sukhiapokhri suffered the most recent fatalities, with 11 and 6 deaths in October 2025 due to intense rainfall, bridge collapse, and road blockages.
Bijanbari remains highly vulnerable to flash floods, as its valley-bottom location causes heavy debris deposition during extreme rainfall events.
Kurseong and St. Mary's Hill show long-term instability, with repeated landslide events linked to urban expansion, deforestation, and construction on fragile slopes.
Relling–Peshok faces recurring landslides due to weak drainage systems and agricultural slope cutting, indicating human-induced aggravation of natural hazards.
In table no.8 we observe some key facts like:
Early warning and community alert systems are expanding, with mobile-based alerts in 5 Kurseong villages and 3 rain gauges plus 200 trained residents in Mirik–Giddapahar.
Structural mitigation is significant, including 26 retaining walls and 12 km of drainage in Mirik and Bijanbari, along with 3,000 bio-engineering saplings planted along NH-110.
Risk-sensitive planning is improving, as hazard zonation identifies 17% of the district as high-risk, and 12 urban slope zones are proposed for construction restrictions.
Human-centered disaster response is active, with 18 relief camps supporting 850 people, 34 families relocated, and 3,000 students trained through school disaster drills.

Mitigation Strategies and Implementation Data:

The district has adopted a range of structural and non-structural mitigation measures with specific implementation figures-

High-Risk Area Mapping: The Hazard Zonation Map (LSZ mapping) has classified 17% of the entire district as a high-risk area.
Physical Stabilization: Structural measures in Mirik and Bijanbari include the construction of 26 retaining walls and 12 \text{km} of drainage.
Community-Based Warning: The Community Warning System in Mirik/Giddapahar is active with 3 rain gauges installed and 200 people trained.
Relocation Status: As a permanent solution, 34 families have been relocated from the vulnerable villages of Dhar Gaon and Seyok.
Planning and Proposal: Land-use Regulation proposes construction restrictions in 12 urban slope zones, and the district is pursuing a proposal under NDMA for an Integrated sensor Multi-Hazard Warning system for the Darjeeling hills.

Findings:

The study on flash floods and landslides in the Darjeeling District revealed that both natural and human factors are responsible for the increasing frequency and severity of these hazards. Heavy and continuous rainfall during the 2025 monsoon season triggered several flash floods and landslides, especially in Mirik, Soureni, and nearby areas. The steep slopes, fragile soil structure, and weak geological formations of the region make it naturally prone to slope failure. Excessive rainfall caused the soil to become oversaturated, leading to the collapse of hill slopes and blockage of streams. Deforestation and the loss of vegetation further reduced slope stability, increasing soil erosion and runoff intensity.
Recent events (early October 2025) show that intense, short-duration rainfall (reported >300 mm in 12 hours in some areas) was the immediate trigger for widespread landslides and flash-flooding across Darjeeling. Key transportation routes, including national highways and bridges / (like Balason/Balasun iron bridge linking Siliguri to Mirilk). Are frequently severed, isolating communities and stranding tourists.
Human activities have significantly worsened the problem. Unplanned construction, road cutting, and deforestation have destabilized slopes and weakened natural drainage systems. Poor waste management and blocked drains diverted

water flow, causing local flooding. Encroachment along riverbanks and the expansion of settlements in hazard-prone zones have heightened the vulnerability of people and property.

Overall, the study concludes that the flash floods and landslides in Darjeeling result from a combination of natural vulnerability and human interference. Effective disaster mitigation demands integrated efforts — including sustainable land-use planning afforestation, structural safety, early warning systems, and community awareness. Strengthening coordination among local authorities, residents, and disaster management teams will help build long-term resilience and reduce the destructive impact of such hazards in the future

Conclusion:

The present study shows that the Darjeeling district, owing to its unique geographical location, steep terrain, fragile geological formations, and extremely high monsoon rainfall, is inherently prone to flash floods and landslides. However, the analysis of both historical and recent disaster events strongly indicates that human-induced activities—such as deforestation, unplanned urban expansion, slope cutting for roads, unregulated construction, and tourism-related pressure—have significantly intensified the natural vulnerability of the region. The major incidents recorded between 2015 and 2025, particularly the devastating October 2025 event, highlight the increasing frequency and severity of hydro meteorological hazards, resulting in loss of life, widespread property damage, road failures, and the disruption of essential services.

The data from rainfall anomalies, hazard-prone zones, and repeated disaster-affected areas clearly reflect that climatic variability and extreme rainfall patterns are becoming more common. This underscores the need for proactive and scientifically grounded mitigation measures. The district has begun implementing several strategies such as early warning systems, community alert networks, bio-engineering, land-use regulation, and hazard zonation mapping. However, the success of these measures depends on strict enforcement, community participation, and continuous monitoring.

Overall, the study concludes that reducing the risk of flash floods and landslides in Darjeeling requires an integrated approach—one that combines scientific assessment, sustainable land management, improved infrastructure planning, and community awareness. With coordinated efforts from the government, local bodies, and residents, it is possible to minimize disaster impacts and build long-term resilience in the hill communities of Darjeeling.

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