BEFORE THE HON'BLE NATIONAL GREEN TRIBUNAL

At Principal Bench, New Delhi

Submission by Applicant

In

ORIGINAL APPLICATION NO. 418 OF 2025

IN THE MATTER OF

Priyank Bharati **------APPLICANT IN PERSON**
Versus
Union of India and others -----**RESPONDENTS**

INDEX

Date: 01.09.2025
Place : Meerut

Applicant In Person

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MOST RESPECTFULY SHOWETH;

I, Priyank Bharati aged about 36 years R/O Jagriti Vihar Meerut-250004, UP hereby solemnly affirm and declare as under :

1. That the Dharali assessment was carried out by Suhora Technologies utilizing Synthetic Aperture Radar (SAR) data, and a report titled *"Flash Flood Damage Assessment at Dharali, Uttarkashi: 05 August 2025"* was released on 07 August 2025. The concluding portion of the said report reads as follows :

> *This incident is a stark reminder of the* ***increasing vulnerability of Himalayan regions*** *to climate-induced natural hazards, emphasizing the need for proactive policy, planning, and community resilience strategies*

The said report, along with the accompanying photographs, is annexed herewith and marked as **ANNEXURE-1.**

2. That on 08 August 2025, *India Today* (online) published a news article titled ***"The Turn That Wasn't: How a Tampered Riverbed Turned Flood into Catastrophe."*** A copy of the said news report is annexed herewith and marked as **ANNEXURE-2.**

3. That on 12 August 2025, a news channel (PRASHANT News) published a report titled ***"Dharali Disaster: Experts Suggest CM to Implement Floodplain Zoning Act, 2012."*** A copy of the said news report is annexed herewith and marked as **ANNEXURE-3.**

4. That a peer-reviewed research paper entitled ***"Environmental and Economic Impact of Cloudburst-Triggered Debris Flows and Flash Floods in Uttarakhand Himalaya: A Case Study"*** (published in the year 2022) draws significant conclusions regarding the causes and consequences of such extreme hydrological events. The relevant and material portions of the conclusion are as follows :

> However, the severity of these natural calamities can be minimized. For example, the high impact of cloudburst-triggered debris flow on the four study villages was mainly due to their location along the streams and on the fragile slopes. This can be avoided by constructing the settlements in safer places generally away from the violent streams.

The complete paper is attached herewith and marked as ANNEXURE 4.

5. That the **Hon'ble Supreme Court**, in M/s Pristine Hotels and Resorts Pvt. Ltd. vs. State of Himachal Pradesh & Anr. [**SLP (C) No. 19426 of 2025**], at paragraph 16, has observed that forest fires, **encroachments**, overgrazing, and the expansion of agricultural and urban areas constitute major contributing factors.

> *11. It is not right to blame only nature for the disaster in Himachal Pradesh.* ***Humans, not nature, are responsible for phenomenon such as continuous land sliding of mountains and soil, land-slides on roads, collapsing of houses and buildings, subsidence of road etc.***
>
> *16. Climate change is having a visible and alarming impact on Himachal Pradesh. While Climate change defies categorisation, and has its impact on many of*

the problems listed, it is more than sufficient of a problem on its own to be documented separately and not as an additional factor to the other aspects. The State has been witnessing rising average temperatures, shifting snowfall patterns, and an increase in the frequency and intensity of extreme weather events. ***Glaciers, the primary source of many rivers in the region, are retreating at a concerning rate, raising the risk of Glacial Lake Outburst Floods****. The biggest Bara Shigri glacier in Lahaul Spiti has been reduced by almost 2-2.5kilometers.* ***Unseasonal rainfall and prolonged dry spells*** *affect agriculture and water availability. Erratic weather patterns also destabilize slopes and affect biodiversity. These changes threaten not only the environment but also the livelihoods of local communities dependent on farming, horticulture, and eco-tourism Deforestation and forest degradation are major concerns. Forest fires,* ***encroachments****, overgrazing, and the expansion of agricultural and urban areas are all contributing factors. All development-related projects often result in tree felling and habitat fragmentation. Loss of forest cover not only reduces biodiversity but also weakens the soil, increasing the risk of landslides and erosion. Forests in Himachal also play a vital role in regulating local climate, sequestering carbon, and maintaining the water cycle, making their protection essential for the region's ecological balance. This situation has been exacerbated by the removal of forest guard check posts earlier set up at various places within the State. Removal of such posts, even at the inter-district level, has compounded the problem of illegal felling of trees, which appears to be rampant,* ***as evident in the recent cloud bursts in District Kullu & Manali, and now there is no mechanism of control and checks on the exploitation of this precious resource.***

In many cases, hill slopes are cut steeply, unscientifically, without adequate stabilization measures, and natural watercourses are obstructed or diverted. *This not only alters the local hydrology but also makes the terrain more vulnerable to landslides and flash floods. The 2023 and 2025 monsoon season, for example, saw widespread devastation in the Kullu, Mandi, Shimla and Chamba districts, partly attributed to such unscientific construction. Despite having been an environmentally rich state, its own people are today responsible for*

such blind pursuit of development, to their own detriment. It is a classic example of not knowing your own surroundings.

19. ***The Himalayan region given its peculiarities*** *presents unique set of challenges which requires the optimum utilization of local expertise and understanding of the socio-cultural mileau in which the contemporary challenges of climate change etc. are arising and being further aggravated.* ***There is a need for all Himalayan states, pan India to collate resources and expertise so as to ensure that development plans are cognizant of these challenges***

24. We want to impress upon the State Government and Union of India respectively that earning revenue is not everything. Revenue cannot be earned at the cost of environment and ecology.

6. **That Hon'ble National Green Tribunal, in the matter of *M.C. Mehta vs. Union of India*, Original Application No. 200 of 2014,** has laid down important principles with respect to the preservation and protection of the floodplains of the river. The relevant and significant paragraphs of the said judgment, pertaining to the definition, scope, and legal sanctity of floodplains, are reproduced herein for consideration.

> ***The State of Uttarakhand enacted the Uttarakhand Flood Plain Zoning Act, 2012*** *to provide for zoning of the floodplains of the river in the State. Under Section 25, any person who prevents the Flood Plain Zoning Authority in discharging its functions or any act imposed on such authority under this Act, would be deemed to have committed an offence under Section 86 of Indian Penal Code, 1860. Despite lapse of three years,* ***no action had been taken in furtherance to the said Act.*** *The Central and the State Governments were fully cautious of the* ***ecosensitive area.*** ***<u>The Tribunal noticed that the Ganga Action Plan did not succeed primarily because of non implementation of the decisions and the directions issued by the authorities and courts</u>.***
>
> ***V. DIRECTIONS IN RELATION TO FLOOD PLAINS***
>
> ***A. The State of Uttarakhand shall prepare and submit to the MoEF&CC, Tourism-cum-Plain map, Flood Plain map and zoning of flood plain shall be in accordance with the Notification dated 18th December, 2012 issued by the Ministry and the***

Act of 2012 aforereferred positively within 3 months from the date of pronouncement of this judgement. Upon submission, MoEF&CC shall approve such plans with amendments or otherwise within 1 month thereafter and then it shall be notified and brought in the public domain.

B. Keeping in view the Notification of the MoEF&CC, intent of the Act of 2012, orders passed by the Tribunal in other matters, High Courts and the Hon'ble Supreme Court in various cases, we would order and direct that as an interim measure at least 100m from middle of the River would be treated and dealt with as 'Eco sensitive and prohibited zone'. No activity whether permanent or temporary in nature will be permitted to be carried on in this zone including camping. The only exception would be the points for picking up and dropping the guests who are doing rafting in River Ganga. The area beyond 100 meters and less than 300 meters would be treated as regulatory zone in the hilly terrain, for which the State will comply with the above directions.

The area upto 200 meters shall be the prohibited area in the plain terrain and more than 200 meters and less than 500 meters would be treated as regulatory zone.

Area/River bank/flood plain 2 kilometres. upstream to Rishikesh and till Border of the State of Uttarakhand towards Uttar Pradesh in River Gangaes would be treated as plain terrain while upstream the above hilly terrain.

The State Government while complying with its obligations under the Act of 2012 and this judgement in this regard would keep in mind 1 in 25 years flood to be the criteria for declaring flood plain and the regulated activities which would be permitted in that area. This is the guiding factor which has complete scientific and documented studies to impose such limitations.

C. Strict supervision in that regard shall be enforced by the State agencies responsible for that purpose, primarily by the Secretary of Irrigation Department, State of Uttarakhand and the Chief Conservator of Forests, Uttarakhand. The policy so framed, with the

restrictions as contemplated in the Notification of the MoEF&CC and the Act of 2012 formulated by Government of Uttarakhand shall be placed before the Tribunal after expiry of the above stated period.

D. Any activity or construction in the regulated area afore-referred where the gradient is beyond 35⁰ should be further checked and preferably no activity should be permitted, to prevent ecological damage and land sliding in that area. All precautionary steps should be taken in that behalf.

E. In this prohibited area, no public authority or State department, including the panchayat would grant permission for any activity whatsoever, including eco-tourism except to the extent of points for pick up and dropping for River rafting.

Being an integral part of the river, floodplain of the river requires protection. Floodplains play significant role in maintaining the bio-diversity and aquatic life of the river. ***It's significance cannot be overlooked, in terms of environment and ecology.*** *There are numerous dimensions involved while identifying the floodplains. It is required to categorize it into different zones, namely,* ***No Development Zone, Regulated Zone and a Free Zone for development. The principle of Sustainable Development itself justifies the classification of floodplains into such zones for protecting the river. This Tribunal in the case of Manoj Misra (supra) had the occasion to deal with the concept of floodplain, its zoning and management. The Tribunal held as under:***

79. Development and regulation of floodplain of Rivers falls within the purview of the State. Floodplain is an integral part of River system even though it is used only occasionally to pass down flood flows. ***When floodplain is not occupied by water it forms part of the land system providing possibilities of carrying on some restricted activity. It is not possible to provide uniformity in the extent of floodplains with respect to different Rivers as well as its various reaches.***

80. ***Floodplain zoning has been accepted as an important non structural strategy for flood management.*** *The basic concept of floodplain zoning*

is to regulate land use of floodplains to restrict damage caused due to floods.

The floodplain zoning, therefore, aims at determination of locations so that flood damages are reduced to minimum. A very restrictive activity can be allowed in that area. It is not only to protect the areas from damage resulting from floods and failure of water protective measures, but is also useful in reducing the damage caused due to drainage congestion, particularly in urban areas. The Commission claims to have prepared a model bill relating to floodplain zoning. This model bill provides for different categories based of priorities in floodplain.

16. The State Government, its instrumentalities, Departments and concerned public authorities shall ensure that there are no encroachments, unauthorized illegal constructions on the banks/flood plain of the major drains, river Ganga and its tributaries. Preferably, these areas should be utilized for creation of a Green Belt and biodiversity park, etc. (natural fringes of effluent and sewage).

7. *That Hon'ble Supreme Court in the matter of* ***C.R. JAYA SUKIN vs UNION OF INDIA & ORS. Writ Petition (Civil) No. 783/2025***

3. Upon the reading of the pleadings, we find that what has been presented through these petitions are only allegations with no material of probative worth. There appears to be no supporting material.

4. *Considering the sweep of the allegations made in the petitions inviting a counter from the private respondent or any other party will not serve much purpose. Ordinarily, a petition resting on such unsupported allegations does not deserve in law to be entertained rather warrant dismissal in limine. However, in the wake of the allegations that the statutory authorities or the Courts are either unwilling or incapable of discharging their mandate,* ***more particularly in the absence of verification of correctness of the factual situation, we consider it appropriate in the ends of justice to call for an independent factual appraisal which may establish the violation, as alleged, if any. Accordingly, we deem it appropriate to direct for***

constitution of a Special Investigation Team ('SIT') of respectable persons of impeccable integrity and high repute having long public service.

8. *That Hon'ble National Green Tribunal take suo-motu on the basis of the news item titled "**Experts blame decades of deodar tree felling for worsening Uttarkashi cloudburs**t" appearing in The New Indian Express dated 10.08.2025 and registered OA No 422 of 2025.*

For all the reasons stated above the Hon'ble Tribunal may kindly be pleased to take cognizance of all these facts and to pass appropriate orders to meets the ends of Justice and equity.

AND FOR THIS ACT OF KINDNESS THE APPLICANTS, AS IN DUTY BOUND, SHALL EVER PRAY.

Verification

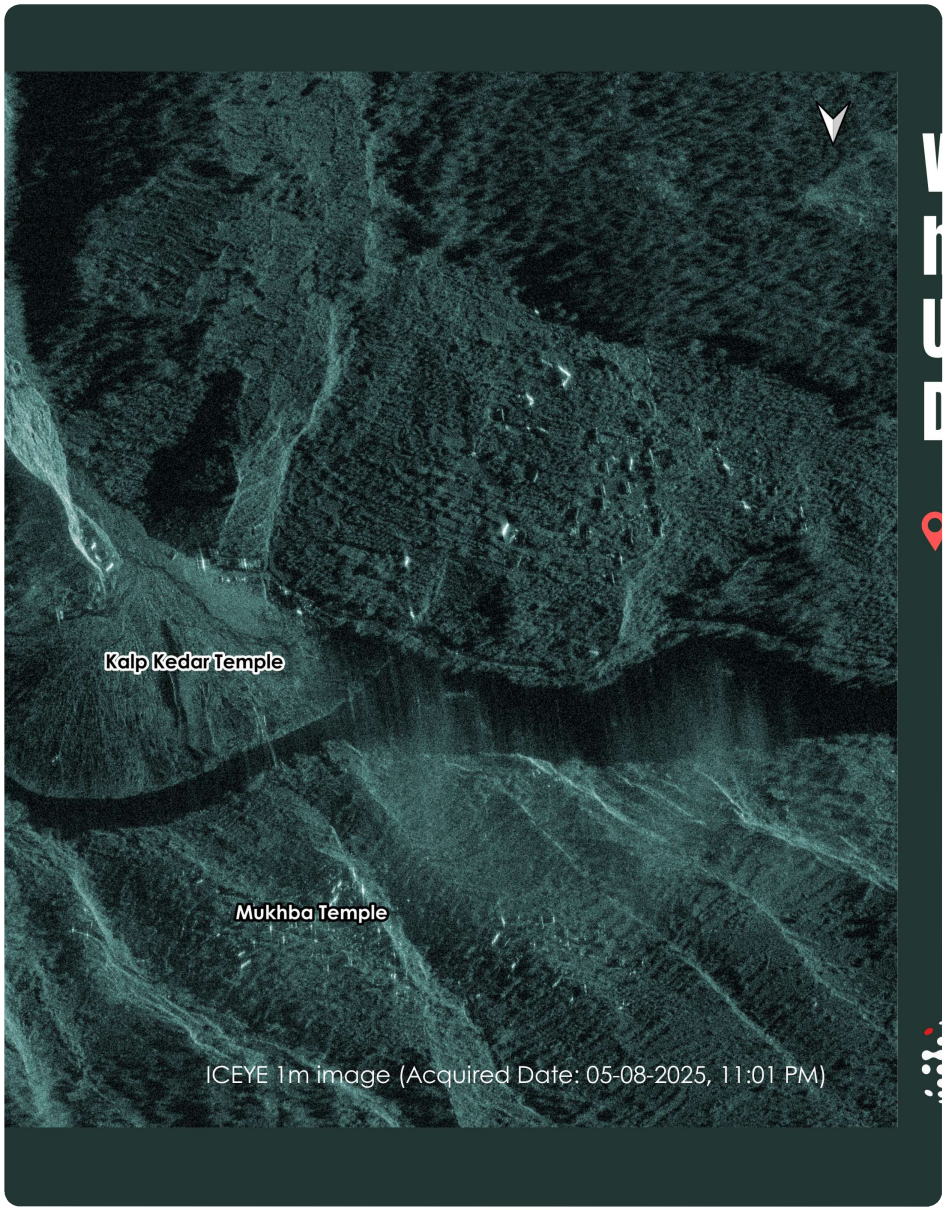
Verified on this 1st day of September 2025 that the contents of the present Application are true and correct to my knowledge and belief and nothing material is concealed therefrom.

Date : 01.09.2025
Place : Meerut

Priyank Bharati

Applicant in Person

ANNEXURE 1



Flood

Flash Flood Damage Assessment at Dharali, Uttarkashi: 05 August, 2025

By Suhora | 08-07-2025

On August 5, 2025, a cloudburst in the upper catchment of the Kheerganga River triggered a flash flood in Uttarkashi's Dharali village. The flood caused severe damage to infrastructure and resulted in casualties.

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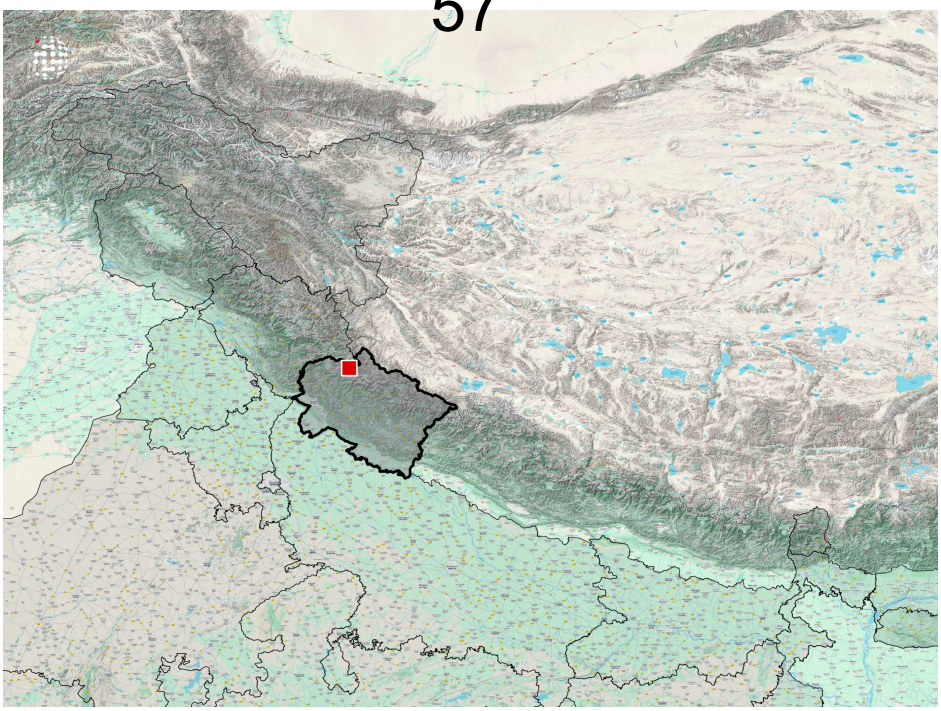
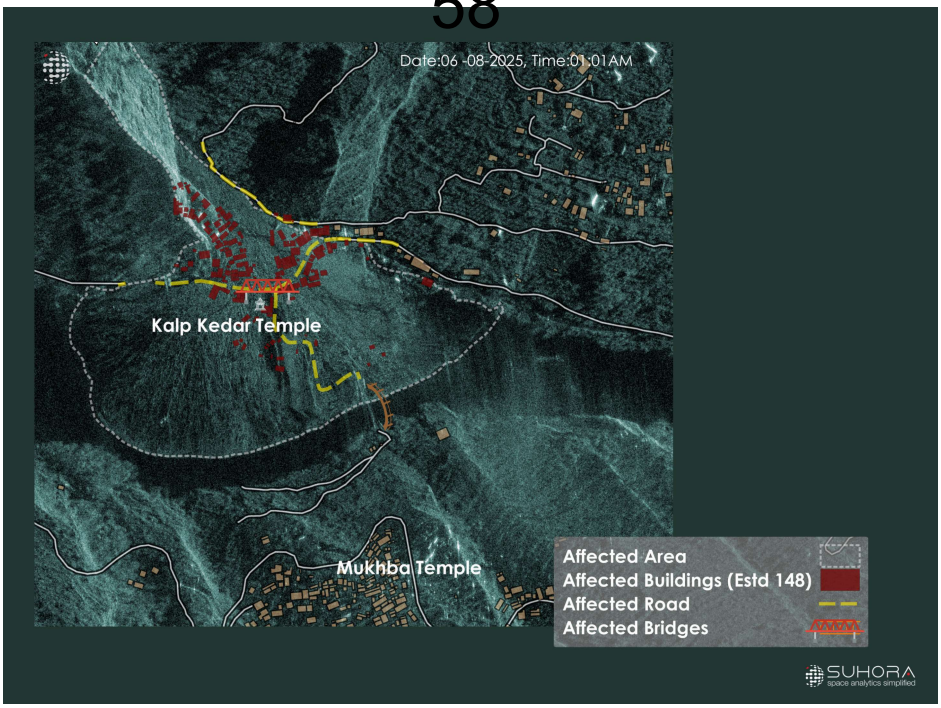


Map Showing
Disaster-Hit Zone - Dharali, Uttarkashi, Uttarakhand, India

In the immediate aftermath, many sources reported a glacial lake outburst being the source of the disaster. Given the terrain and the increasing frequency of glacial-related events in the Himalayas, this was a reasonable concern.

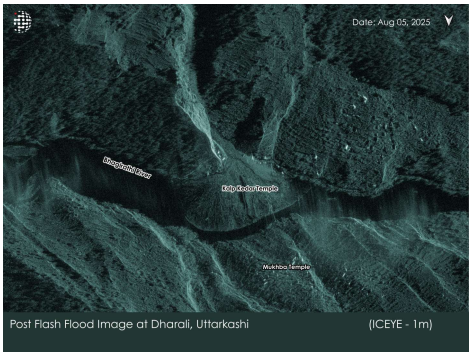
Following the incident, Suhora's team of experts carried out a thorough analysis utilizing Satellite intelligence and confirmed that the source of the flash flood was not a glacial burst. To verify this, we examined data from the National Remote Sensing Centre (NRSC) and also utilized our own comprehensive **Inventory of around 33,000 glacial & non-glacial lakes and approx 3000 supraglacial lakes**, along with cross-checking through high-resolution optical imagery.

To conduct this assessment, we utilized **Synthetic Aperture Radar (SAR)** because of its ability to penetrate cloud cover and capture surface-level changes even during adverse weather conditions and **high-resolution optical imagery.**



Key Highlights from Damage Assessment:

S. No.	Items	Affected Area in Approx
1.	Affected Area	16 ha.
2.	Affected Buildings	148
3.	Affected Bridge	1
4.	Affected Road	0.95 km



According to the analysis, approximately **16 hectares of area have been affected**, impacting nearly 148 buildings and resulting in widespread disruption to housing, schools, and public infrastructure. In addition, **1 bridge has been damaged**, and **about 0.95 km of road has been affected**, leading to significant road closures and interruptions in connectivity.

Highlights and Emerging Concerns from the Uttarkashi Flash Flood

· Several homes and farmlands were inundated.

· Portions of the NH-34 route to Gangotri were temporarily blocked due to debris.

· Power and communication lines were disrupted in surrounding areas.

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- Missing report of 100+ lives was reported, though multiple families were displaced, and livestock loss was significant.

This incident is a stark reminder of the increasing vulnerability of Himalayan regions to climate-induced natural hazards, emphasizing the need for proactive policy, planning, and community resilience strategies

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Industries

Defence & Intelligence

Disaster & Insurance

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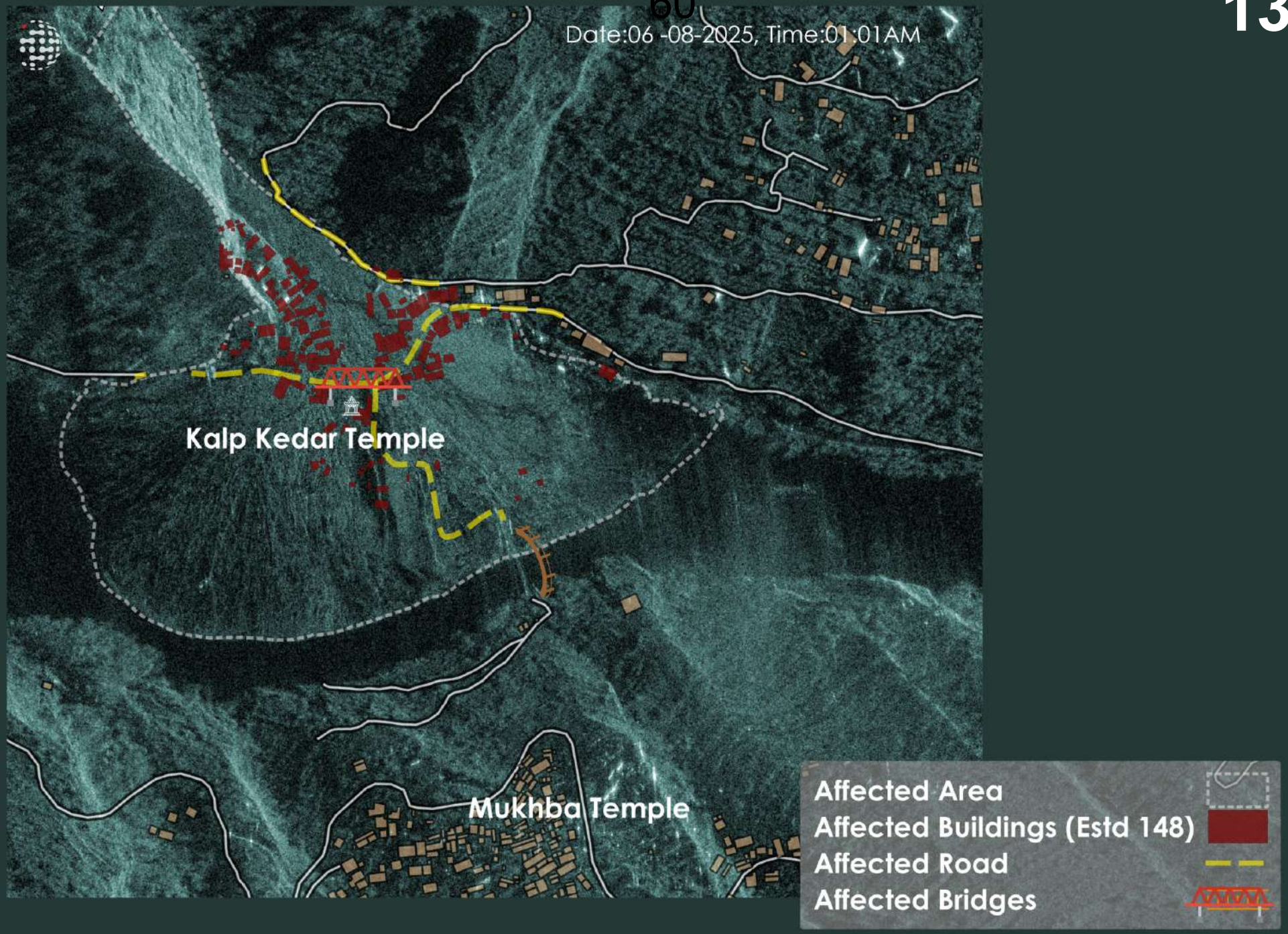

SUHORA
space analytics simplified

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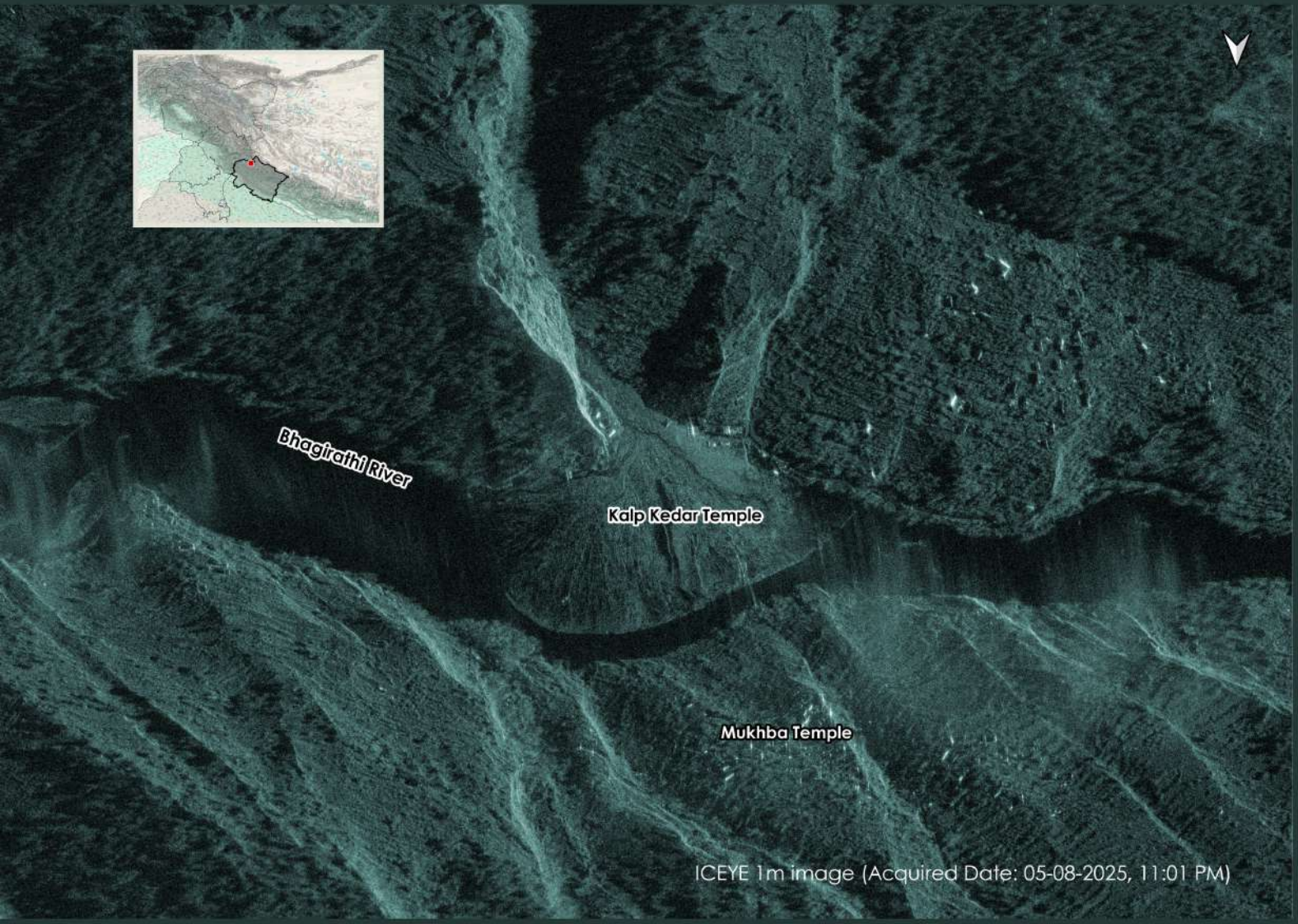
What happened at Uttarkashi's Dharali Village ?



31°02'15.15" N, 78°46'36.92" E

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Image before the devastating flash flood at Dharali (PlanetScope - 3m)

Post Flash Flood Image at Dharali, Uttarkashi (ICEYE - 1m)

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The turn that wasn't: How a tampered riverbed turned flood into catastrophe

The scale of destruction seen in Dharali village was amplified due to human intervention in the river's natural course.

ANNEXURE 2

Live TV

Share

Damage reported in Dharali market area due to flash floods. (Photo: PTI)

Sibu Tripathi

New Delhi, UPDATED: Aug 8, 2025 13:47 IST

Two days after a massive mudflow inundated the Dharali village in Uttarkashi, experts are still looking for an answer to pinpoint the exact reason behind the tragedy that has led to at least five deaths and over 60 missing.

While the verdict is out on the cause of the tragedy, experts are cautioning on why it led to such an extensive damage, with hundreds of buildings struck, buried under the debris of mud and boulders.

The loss of life and property could have been exacerbated by encroachment in the riverbed of the Bhagirathi River, according to Prof. K Seshagiri Rao, a renowned geology expert and Emeritus Professor at the Indian Institute of Technology Delhi.

Prof. Rao, who was travelling through Rudraprayag, explained that the region experienced heavy rainfall continuously for three to four days, which likely triggered a massive mudflow that struck Dharali.

Before and after pictures of Dharali village show how the riverbed was enchroached that led to massive destruction. (Photo: Isro)

RIVERBED ALTERED

While mountainous regions often face natural hazards such as cloudbursts, glacier lake outburst floods (GLOFs), and monsoonal mudflows, he emphasised that the scale of destruction seen in Dharali was amplified due to human intervention in the river's natural course.

The encroachments and constructions within the riverbed altered the flow dynamics, and when the powerful mudflow struck the built-up areas, it collided with buildings with immense thrust and force, causing catastrophic loss of life and property.

The width needed for the mudflow to pass was missing due to construction in and around it, which worsened the disaster.

The professor posed critical questions about why constructions in such vulnerable riverbed zones were allowed, highlighting the consequences of unchecked urbanisation driven largely by tourism development in the region. This unplanned expansion into ecologically sensitive and disaster-prone zones has increased the risk exposure of local communities.

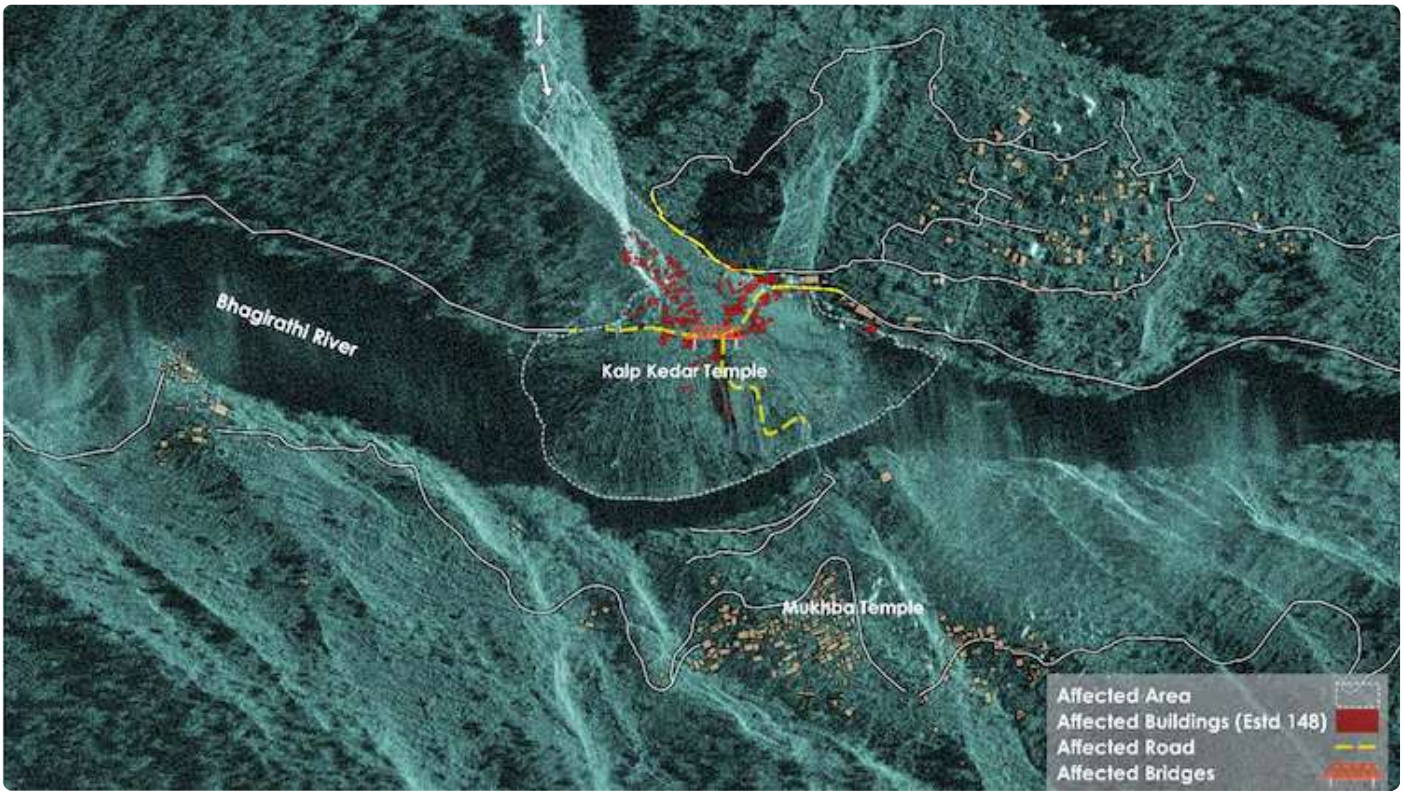
SATELLITE DATA REVEALS EXTENT OF DAMAGE

Supporting these observations, recent satellite analyses performed by Suhora Technologies, using Synthetic Aperture Radar (SAR) and high-resolution optical imagery, revealed the extensive impact of the Uttarkashi disaster.

The data, captured at 11:01 PM on August 5, showed approximately 148 buildings damaged and an area of about 16 hectares affected. The imaging also highlighted damage to critical infrastructure, including one bridge and nearly 0.95 km of roadway, leading to significant disruptions in connectivity and emergency response.

The Uttarkashi tragedy highlights the urgent need to regulate and enforce land-use policies to prevent encroachment on riverbeds and other high-risk zones.

It also calls for sustainable urbanisation practices that respect the natural dynamics of mountainous ecosystems to mitigate loss and enhance community resilience against future disasters.



Flash flood damage assessment map. (Photo: Suhora Technologies)

As rescue operations in flood-ravaged Uttarkashi entered the third day on Thursday, the Indian Army confirmed that 70 people have been rescued so far, while more than 50 remain missing.

Efforts are being intensified to airlift advanced equipment to Dharali village—one of the worst-affected areas—to aid in locating those still trapped under debris, officials said.

The Army, working in close coordination with local authorities, has scaled up Humanitarian Assistance and Disaster Relief (HADR) efforts in Dharali and the nearby

region of Harsil. Both areas remain largely cut off due to extensive landslides and multiple road breaches caused by the flash floods.

- Ends

Published By: Sibu Kumar Tripathi

Published On: Aug 7, 2025

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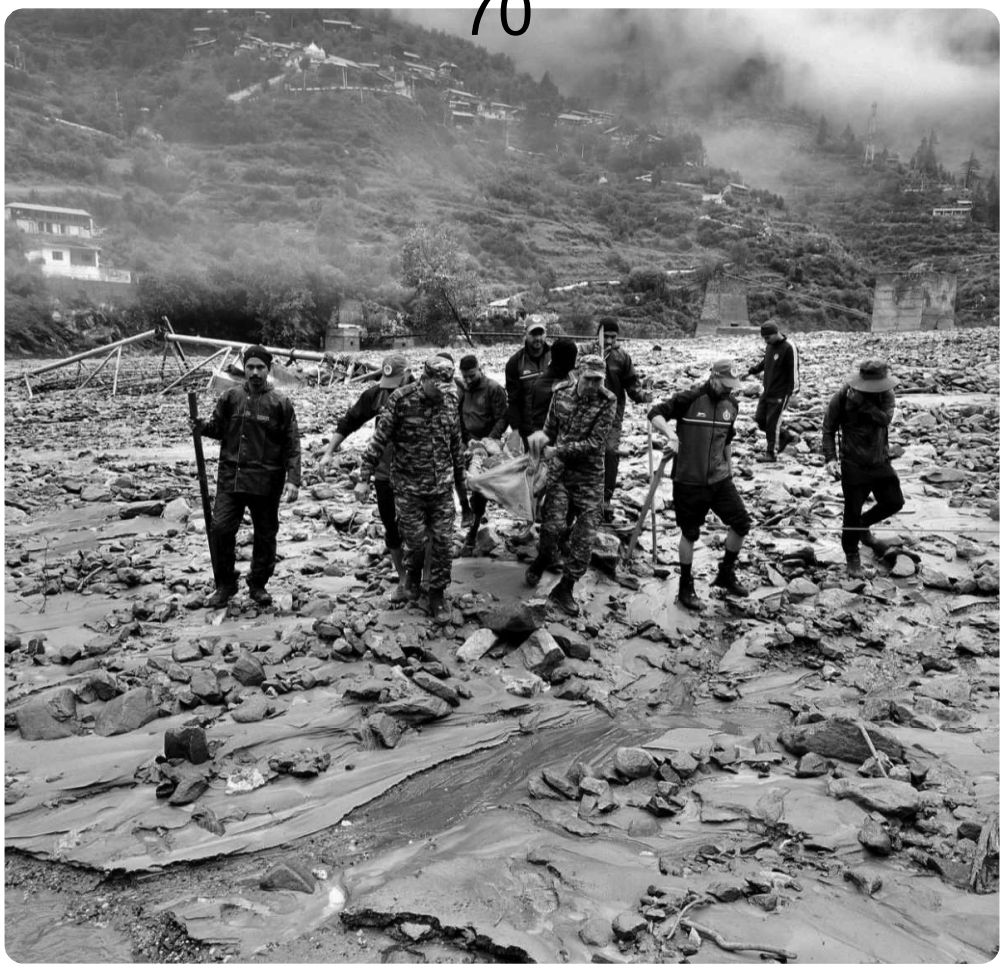
PRASHANT NEWS

ANNEXURE 3

disaster Uttarakhand

Dharali disaster: Experts suggest CM to implement Floodplain Zoning Act 2012

By Shishir Prashant Aug 12, 2025 No Comments



Post Views: 413

PrashantNews

A day after Chief Minister Pushkar Singh Dhami decided to ban new constructions and settlements at all vulnerable areas close to rivers and streams, experts on Tuesday asked him to implement the Uttarakhand Floodplain Zoning Act, 2012 in toto.

Under the Act, the notification for which was issued on Jan 28, 2013, the floodplains have been defined as water channels, flood channels and low areas which are susceptible to floods by inundation. The floodplain zoning means restricting any human activity in the floodplains of a river where the plains are created by overflow of water from the channels of rivers and streams.

"This Act should be implemented in its true spirit to mitigate the sufferings in any Dharali-like future calamities," said Alok Jain

the former chief secretary of Uttarakhand. This is on top of the Environment Ministry's declaration of Bhagirathi river being an eco-sensitive zone from Gaumukh to Uttarkashi in 2012, Jain said.

According to a rough estimate, hundreds of new constructions and structures mushroomed after the Floodplain zoning Act was passed in 2012.

The Floodplain Zoning Act stipulates that a survey be made of a river for the purpose of determining the limits within which the provisions of this Act are to be applied and that proper charts and registers be prepared specifying all boundaries and landmarks and any other matter necessary for the purpose of ascertaining such limits.

The State Government may on the basis of a report from the Flood Zoning Authority or otherwise, by notification in the Official Gazette, declare its intention to demarcate the flood plain areas and either prohibit or restrict the use of land therein.

Supporting the Act, H P Uniyal, former Director state planning commission also said the government must take all steps to stop encroachments along rivers especially in the floodplains.

ANNEXURE 4

RESEARCH Open Access

Environmental and economic impact of cloudburst-triggered debris flows and flash floods in Uttarakhand Himalaya: a case study

Vishwambhar Prasad Sati* and Saurav Kumar

Abstract

This paper examines the environmental and economic impact of cloudburst-triggered debris flow and flash flood in four villages of Uttarkashi district, Uttarakhand Himalaya. On 18th July 2021 at 8:30 p.m., a cloudburst took place on the top of the Hari Maharaj Parvat, which triggered a huge debris flows and flash floods, affecting 143 households of four villages of downstream areas. Immediately after the cloudburst occurred, the authors visited four affected villages—Nirakot, Mando, Kankrari, and Siror. A structured questionnaire was constructed and questions were framed and asked from 143 heads of affected households on the impact of debris flows and flash floods on people's life, settlements, cowsheds, bridges, trees, forests, and arable land in and around the villages. The volume of debris, boulders, pebbles, gravels, and mud was assessed. It was noticed that all four villages got lots of destructions in terms of loss of life—people and animals, and property damage—land, crops, and infrastructural facilities. This study shows that the location of the settlements along with the proximity of the streams, which are very violent during the monsoon season, has led to the high impact of debris flow on the affected villages. We suggest that the old inhabited areas, which are located in the risk zones, can be relocated and the new settlements can be constructed in safe places using suitability analyses.

Keywords: Cloudburst, Debris flow, Flash flood, Calamity, Impact, Himalaya

Introduction

Cloudburst, a geo-hydrological hazard, refers to a sudden and heavy rainfall that takes place within a short span of time and a particular space (Sati 2013). The intensity of rainfall is often more than 100 mm/h (Das et al. 2006). The disruptive events, cloudbursts occur during the monsoon season in the Himalaya and trigger debris flows, flash floods, landslides, and mass movements (Fig. 1). Fragile landscape, rough and rugged terrain, and precipitous slope accentuate the magnitude of geo-hydrological hazards. Cloudburst-triggered debris flows, flash floods, landslides, and mass movements have become more intensive and frequent worldwide, mainly in the mountainous regions, causing large-scale destruction of people, land, and property (Houghton et al. 1996; Wang et al. 2014; Mayowa et al. 2015; Malla et al. 2020; Sim et al. 2022). Similarly, the Himalayan region is prone to the occurrences of cloudburst-triggered hazards, causing huge loss of life and property and degradation of forest and arable lands (Bohra et al. 2006; Allen et al. 2013; Balakrishnan 2015; Ruiz-Villanueva et al. 2017).

The Uttarakhand Himalaya, one of the integrated parts of the Himalaya, is the most fragile landscape and prone to geo-hydrological hazards—cloudbursts, avalanches, and glacier bursts (Sati 2019). It receives many hazards mainly cloudburst-triggered debris flows, flash floods, landslides, and mass movements during the monsoon season every year. The intensity, frequency, and severity of these hazards have been observed to increase during the recent past. Devi (2015) stated that the changing

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Department of Geography and Resource Management, Mizoram University (A Central University), Aizawl 796004, India

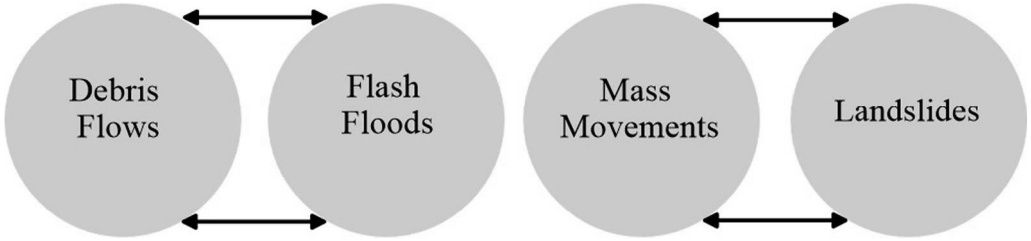

Fig. 1 Cloudburst-triggered hazards in the Uttarakhand Himalaya

monsoon patterns and increasing precipitation in the Himalaya are associated with catastrophic natural hazards. However, these hazards are the least understood because of the remoteness of the areas and lacking meteorological stations (Thayyen et al. 2013).

The Uttarakhand Himalaya has many eco-sensitive zones, vulnerable to natural hazards mainly for geo-hydrological hazards. Every year, many cloudburst events occur here, cause to roadblocks, land degradation, forest and cropland loss, and losses of life and infrastructural facilities. One of the most devastating cloudburst-triggered debris flow events of this century occurred on the night of 16th and 17th June 2013 in the famous Hindu pilgrimage 'Kedarnath', which killed more than 10,000 people and devastated the entire Mandakini and Alaknanda river valleys (Upadhyay 2014; Sati 2013). The entire region had received 16 major geo-hydrological and terrestrial hazards within the last 50 years (Bhambri et al. 2016). Some of the devastating cloudburst-triggered debris flows and flash floods that occurred in the Uttarakhand Himalaya are Rudraprayag on 14th September 2012, Munsiyari on 18th August 2010, Kapkot on 19th August 2010, Nachni on 7th August 2009, Malpa and Ukhimath on 17th August 1998, Badrinath on 24th July 2004, and the Alaknanda River valley on 1970. About 20,000 people died and a huge loss of property took place due to these calamities (Das 2015). It has been noticed that these catastrophic events occurred mainly during the three months of the monsoon season—July, August, and September.

Debris flows and flash floods caused by glacier-bursts incidences were although not much frequent and intensive yet, during the recent past, their number has increased owing to changes in the climatic conditions. The increasing number of infrastructural facilities on the valley bottom has accelerated damages owing to exposed elements in risk-prone areas (Sati 2014; ICIMOD 2007a, b; Chalise and Khanal 2001; Bhandari 1994; Uttarakhand 2017). Many drivers exist, which affect the severity of cloudburst-triggered hazards in the Uttarakhand Himalaya. Growing population and the construction of settlements and infrastructural facilities on the fragile slopes and along the river valleys have also caused severe hazards. The Uttarakhand region is home to world-famous pilgrimages and natural tourism. Mass tourism during the rainy season enhances the intensity of disasters.

Several studies have been carried out on glacier-bursts and cloudburst-triggered debris flows and flash floods in the Himalaya (Shugar et al. 2021; Byers et al. 2018; Cook et al. 2018; Asthana and Sah 2007; Bhatt 1998; Joshi and Maikhuri 1997; NIDM 2015; IMD 2013; Khanduri et al. 2018; Sati 2006, 2007, 2009, 2011, 2018a, b, 2020; Naithani et al. 2011). These studies were conducted from broader perspectives, mostly covering the entire Himalaya. However, the present paper looks into the case study of four villages of the Uttarakhand Himalaya, which were severely affected and damaged by cloudburst-triggered debris flows and flash floods, which occurred on July 18th, 2021. It analyses the environmental impact of cloudbursts in terms of forest and fruit trees dislocation, land degradation, and soil erosion—arable, forests, and barren land of the four affected villages. It also evaluates the human and economic losses like the killing of people, loss of existing crops, and damage of houses and cowsheds, respectively. The study suggests policy measures to risk reduction and rehabilitation of settlements from danger zones to safer areas after suitability analysis.

Study area

The Uttarakhand Himalaya is located in the north of India and south of the Himalaya. It is also called the Indian Central Himalayan Region. Out of the total 93% mountainous area, 16% is snow-capped, called the Greater Himalaya. The terrain is undulating and precipitous and the landscape is fragile, vulnerable to natural hazards. This catastrophic event occurred in the four villages of Uttarkashi district. The Uttarkashi town lies about 10 km downstream of the affected villages. A National Highway number 108, connecting Haridwar and Gangotri, is passing through Uttarkashi town. The four affected villages—Nirakot, Mando, Kankrari, and Siror

are located in the upper Bhagirathi catchment, which is prone to geo-hydrological hazards. The slope gradient of these villages varies from 15° to 70°. Indravati is a perennial stream, a tributary of the Bhagirathi River that meets Bhagirathi from its left bank. All three Gadheras (streams)—Mando, Diya, and Siror are seasonal but violent during the monsoon season. Nirakot (1530 m) village is located in the middle altitude of the Hari Maharaj Parvat (2350 m) in a steep slope, Mando village (1180 m) is located on the left bank of the Bhagirathi River along the Mando Gadhera with gentle to a steep slope, Kankrari (1620 m) village is located on the moderate to the gentle slope on the bank of the Diya Gadhera, and Siror village (1280 m) is situated on the left bank of both Bhagirathi and Siror Gadhera with gentle to the steep slope (Fig. 2). One of the prominent eco-sensitive zones of the Uttarakhand Himalaya, the 'Bhagirathi Eco-Sensitive Zone' is 120 km long, spanning from Uttarkashi to Gaumukh, along the Bhagirathi River valley (Sati 2018a, b). The rural people depend on the output of the traditional farming systems, often face intensive natural hazards. The settlements are located either on the fragile and steep slopes or on the banks of streams, which are very violent during the monsoon season when a heavy downpour occurs. Therefore, heavy losses of life and property in these areas are common, taking place every year.

Methodology

This study was empirically tested and a qualitative approach was employed to describe data. A structured questionnaire was constructed. The main questions framed and asked from the heads of households were—human and animal death, damage to self property—houses and cowsheds, and existing crops—cereals, fruits, and vegetables. Loss to public properties such as bridges, public institutions, and forest land was assessed. Based on the questions framed, we surveyed 143 heads of households of four villages, which were partially or fully affected due to cloudburst-triggered debris flow. These villages are Nirakot, Mando, Kankrari, and Siror. To assess the debris and the damaging areas, the authors travelled from the source areas to the depositional zones and measured the volume of debris—boulders, pebbles, sands, and soils using a formula; circumference = $2\pi R$ and area = $\pi * R^2$. The slope gradient, accessibility, economic conditions, and climate of the villages were

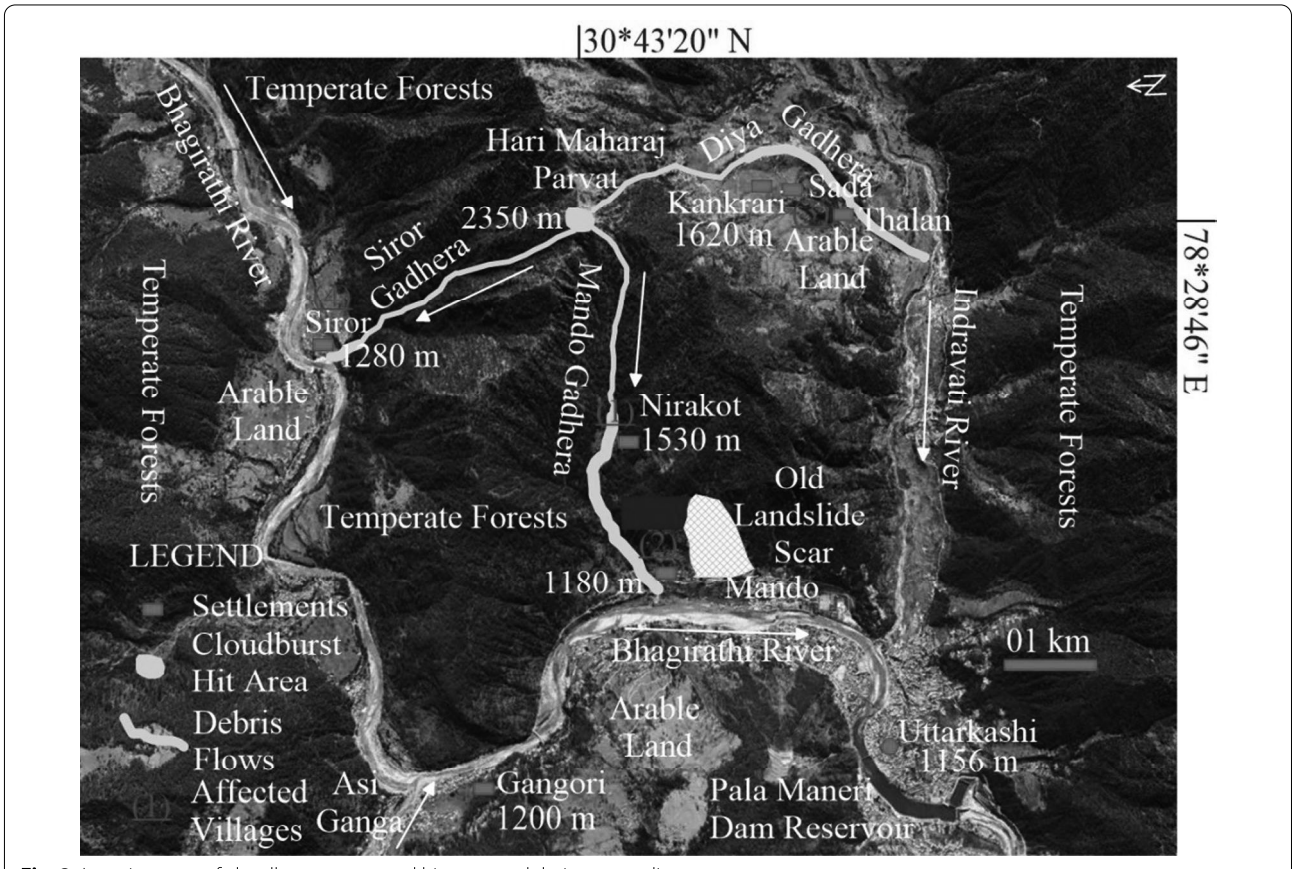

Fig. 2 Location map of cloudburst source and hit areas and their surroundings

assessed and based on which, the susceptibility analysis of the villages was carried out. The villages were divided into very high susceptibility, high susceptibility, and moderate susceptibility levels. Both environmental degradation and economic losses in four villages were assessed. We used Geographical Positioning System (GPS) to obtain the data of altitude, longitude, and latitude. Two maps—case study villages and the major cloudburst incidences—2020 and 2021 were prepared and data were also presented using graphs. Photographs of four villages were used to present the destruction of villages due to the cloudburst event.

Results and analysis

Major cloudburst incidences in the Uttarakhand Himalaya

Past incidences depict that the Uttarakhand Himalaya suffered tremendously due to cloudburst-triggered calamities. We gathered data on the major cloudburst incidences in Uttarakhand in the monsoon seasons of 2020 and 2021 from the state disaster relief force (SDRF), Dehradun. From May to September 2020, 13 major cloudburst incidences were noticed in Uttarakhand (Table 1). These incidences resulted in the death of 22 people and 77 animals, and 19 houses were fully damaged. Similarly, from May to September 2021, 17 major cloudburst incidences were occurred in the Uttarakhand Himalaya, resulting in the death of 34 people and 144 animals, and 106 houses were buried. Besides, it caused a huge loss to public property and landscape degradation.

The economic losses in 2021 were much higher than the losses in 2020 (Fig. 3). In 2021, the frequency and intensity of cloudburst-triggered calamities were also higher. The loss of animals was quite high both the years. Houses that collapsed due to calamity were six times higher in 2021 than in 2020. The loss of human life was substantial in both years. Several bridges were washed away.

District-wise major cloudburst events of 2020–2021 are shown in the map of the Uttarakhand Himalaya (Fig. 4). A total of 30 major cloudburst incidences were recorded, out of which, 17 occurred in 2021. The Uttarkashi district received the highest incidences (07), followed by the Chamoli district (05). Dehradun and Pithoragarh districts have recorded 04 incidences each. Rudraprayag 03 and Tehri, Almora, Bageshwar have recorded 01 each. It has been observed that cloudburst-triggered incidences mainly occurred in remote places along the fragile river valleys and middle slopes.

Case study of affected villages

On July 18, 2021, a cloudburst hits the Hari Maharaj Parvat (hilltop) at an altitude of 2350 m at 8:30 p.m., which triggered huge debris flows and flash floods. The four villages—Nirakot, Mando, Kankrari, and Siror of Uttarkashi district, located down slopes of the hilltop and close to the Uttarkashi town, were severely affected due to debris flow (Table 2). At the cloudburst hit area, it formed three gullies, which later on merged into three streams, along which these villages are located. Debris, from the source i.e. hilltop of Hari Maharaj Parvat, equally flew in three directions. Since the cloudburst event occurred at 8:30 p.m., the people did not have time to move with their movable property and therefore, the magnitude of damage was enormous.

The villages are located from the altitudes of 1180 m (lowest) to 1620 m (highest). Mando village is located at 1180 m, Kankrari village at 1620 m, Nirakot at 1530 m, and Siror has 1280 m altitude. The two villages—Nirakot and Mando have west-facing slopes, Kankrari has a south-facing slope, and Siror has a north-facing slope. These villages are located along the tributaries of the Bhagirathi River, with 2 to 5 km distance from the road. The intensity and volume of debris were different in different villages, therefore, the casualties and losses were also varied. The villages are surrounded by agricultural and forestlands. The farmers mainly grow subsistence cereal crops—paddy, wheat, pulses, oilseeds, fruits, and vegetables. Forest types comprise pine (sub-tropical) and oak and coniferous forests (temperate), used for fodder, firewood, and wild fruits.

Located at the high-risk zones, these villages face several disaster incidences every year. Out of the total 143 heads of households surveyed, more than 80% of heads were in favour of rehabilitating them in the safer areas. They wanted to relocate their houses and cowshed within the village territory with financial assistance from the state government. The streams, along which the settlements are constructed, are fragile and highly vulnerable to landslide hazards. Further, the cloudburst incidences are increasing due to climate change, the heads of households perceived.

Figure 5 shows four villages—Nirakot, Mando, Kankrari, and Siror, which were severely affected by cloudburst-triggered debris flow and flash flood. The volume of debris and boulders can be seen in all the villages. These villages are surrounded by dense sub-tropical and temperate forests that vary from pine to mixed-oak and deodar. Kharif crops were growing in the arable land whereas a large cropland has been washed away.

Impact of cloudburst-triggered debris flow and flash flood

Environmental impact

The environmental impact of cloudburst-triggered debris flow and flash flood in four villages of Uttarkashi district was analyzed (Table 3). The major variables were the number of forest trees dislocated, total land degradation,

Table 1 Major cloudbursts occurred in Uttarakhand in 2020 and 2021. *Source:* SDRF (2021)

Date of occurrence	Cloudburst hit area	Casualties
April–August 2020		
April 23, 2020	Kotdwar (Pauri district)	Low-lying areas were flooded and arable land was washed away
April 27, 2020	Naugaon and Mori (Uttarkashi district)	Five houses were partially damaged and agricultural land flown
July 14, 2020	Dharchula (Pithoragarh)	Landslide on the road connecting India–Tibet boarder
July 19, 2020	Madkot and Tanga (Pithoragarh)	Three people were killed and six injured
July 20, 2020	Bata, Sirtaul, and Munsiyari	Eight houses were buried, three people killed, 10 cattle died, and bridges and farmlands washed away
July 28, 2020	Banagapani (Uttarkashi)	47 cattle died
July 28, 2020	Ghat (Chamoli district)	Three houses flown, cowsheds collapsed, and three people died
August 9, 2020	Gangi village (Tehri)	20 cattle were buried
August 10, 2020	Sirwadi (Rudraprayag)	Seven houses were fully damaged
August 10, 2020	Bageshwar	A house was collapsed and a bridge flown
August 18, 2020	Mori village (Uttarkashi)	12 people died
August 19, 2020	Near Lakhwar Dam (Uttarkashi)	A bridge was collapsed
August 24, 2020	Tali-Ansari (Chamoli)	One person died and one injured
May–July 2021		
May 3, 2021	Kumrada, Baldogi, and Kamad (Uttarkashi)	Three people died
May 3, 2021	Narkota (Rudraprayag)	On Three houses damaged and 1-acre arable land was washed away
May 3, 2021	Khankra, Fatehpur Kotli, Gairsari Narkota	One person died
May 11, 2021	Devprayag town	Sixteen buildings were collapsed
May 20, 2021	Bijnad, Chakrata	Three people and 24 animals died
May 30, 2021	Bangwari village (Pauri)	Two cows died and 0.5-acre agricultural land washed away, exiting crops damaged and fruit trees dislocated
July 18, 2021*	Nirakot	One person died, 0.7-acre arable land washed away and three buildings and 5 bridges collapsed
July 18, 2021*	Mando	Three people and two animals died, 1.2-acre arable land washed away, and five buildings and two bridges collapsed
July 18, 2021*	Kankrari	One person died, 20.6-acre arable land was washed away, 11 buildings were damaged, and 6 bridges collapsed
July 18, 2021*	Siror	0.6-acre arable land flown and one bridge collapsed
August 07, 2021	Khirsu	50 cattle died, six cowsheds collapsed
August 08, 2021	The Valley of Flowers	20-m pathways and a footbridge was washed away
August 13, 2021	Marchula (Almora)	Houses, cowsheds, water pipes, and a road was washed away
August 27, 2021	Bihar (Vikas Nagar)	Vyasi hydropower project was impacted
August 30, 2021	Jumma village (Dharchula)	Seven people died
September 7, 2021	Syunsad village (Pauri)	Farmlands and crops were damaged
September 20, 2021	Panti village (Chamoli)	Houses, shops, and cowsheds were washed away. Karnprayag-Gwaldom road was blocked for several days

*Present case study villages

land degradation under existing crops, number of fruit trees dislocated, land degradation under arable land, number of buildings were damaged, number of bridges damaged, and boulders' volume. Forest trees, which dislocated were pine in the middle altitude and mixed-oak and deodar in the higher altitude. A total of 770 forest trees were dislocated from all four villages, out of which, 500 were from the Kankrari village (highest). The lowest trees dislocated were from Siror village (70). The total land degradation from the cloudburst hit areas to the affected areas was huge, however, we have measured the land which was within and surrounding each village. The total land degradation was 52.5 acres with the highest in Kankrari (45 acres) and the lowest in Siror (0.5 acres). The land degradation under existing crops was 22.6 acres in all four villages, varying from 0.1 acres in Siror to 20.6 acres in Kankrari. The total number of fruit trees dislocated was 486. Land degradation under arable land was 22.6 acres. It includes the area under existing crops both agriculture and horticulture. A total of 19 buildings were

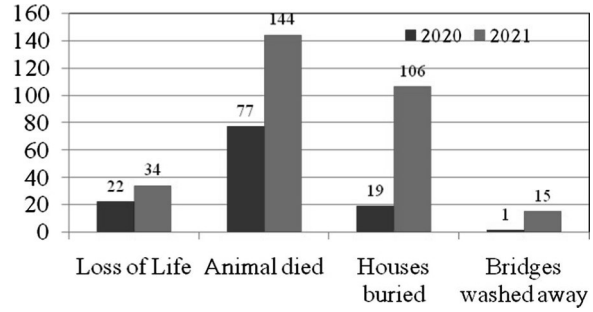

Fig. 3 Loss of human lives, livestock, houses and bridges due to cloudburst in Uttarakhand during the 2020 and 2021

damaged whereas a total of 14 bridges, connecting the affected villages were washed away.

Economic impact

The economic impact due to cloudburst calamity was tremendous in the forms of a household affected, loss of human and animal life, building loss, forest loss, loss of existing crops including fruits, loss of arable land, and loss of bridges (Table 4). The value of all these assets was calculated in Indian Rupees (INR) at the current price. The total number of households affected was 143, of which, 100 households belonged to the Kankrari village (highest) and three households (lowest) were from Siror village. Four people died due to the calamity—three women from Mando village and 1 man from Kankrari village. Two cows from Mando village died. The total loss from the collapse of the building was 1.7 million INR, with the highest (1.1 million INR) from Kankrari village. A total of 0.77 million INR was lost due to forest loss, and the loss from existing crops was 3.35 million INR. Loss from dislocation of fruit trees was noted high, which was about 0.5 million INR. A large portion of arable land was flown which value was 11.3 million INR. About 14 million INR was lost due to the collapse of bridges. As a whole, about 31.62 million INR was lost due to cloudburst calamity. Per household loss by the cloudburst calamity was noted 0.22 million INR.

Average circumference, area, and volume of boulders

We calculated the average circumference, area, and volume of boulders in the case study villages using a formula: circumference $= 2\pi R$; Area $= \pi * R^2$; volume = length × width × depth (Table 5). We noticed that

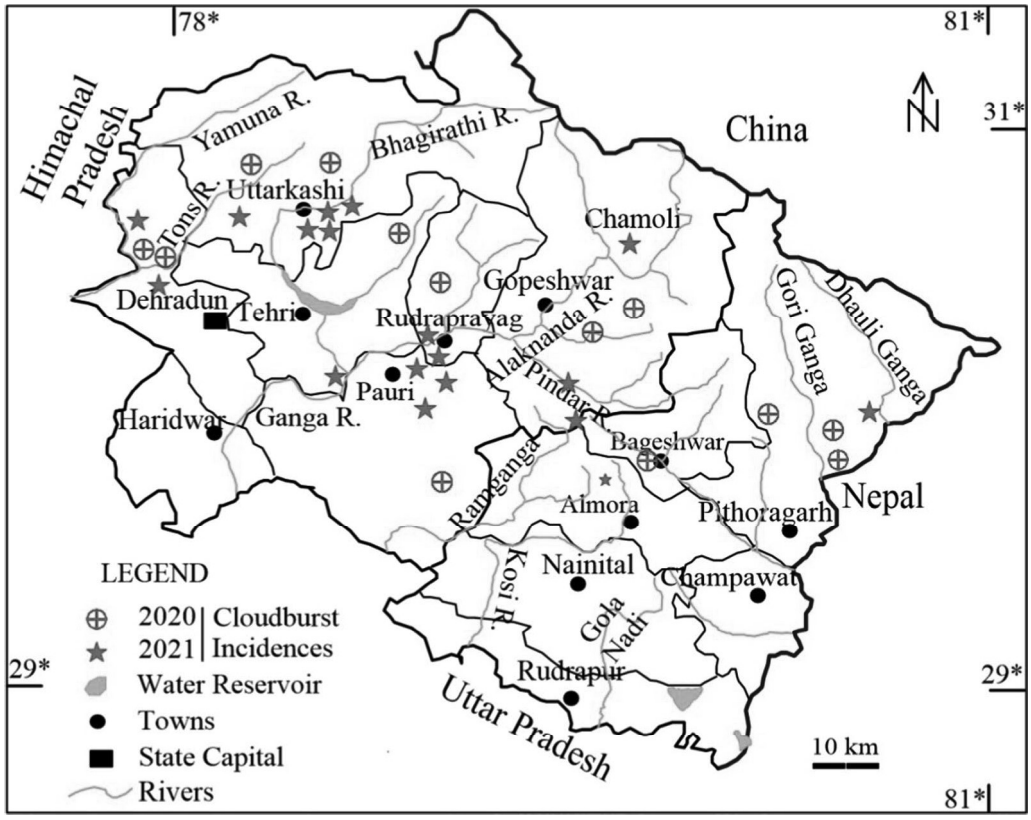

Fig. 4 Location map of cloudbursts hit areas in 2020 and 2021

Table 2 Salient geographical feature of cloudburst hit areas. *Source:* By authors

Variables	Nirakot	Mando	Kankrari	Siror
Date of cloudburst	18-07-21 (time: 8:30 p.m.)	18-07-21 (time: 8:30 p.m.)	18-07-21 (time: 8:30 p.m.)	18-07-21 (time: 8:30 p.m.)
District	Uttarkashi	Uttarkashi	Uttarkashi	Uttarkashi
Altitude (m)	1530	1180	1620	1280
Latitude	30° 45′ 23″ N	30° 44′ 09″ N	30° 38′ 56″ N	30° 44′ 27″ N
Longitude	78° 25′ 56″ E	78° 27′ 16″ E	78° 27′ 56″ E	78° 29′ 15″ E
Slope aspect	West-facing	West-facing	South-facing	North-facing
Cloudburst hit area	Hari Maharaj Parvat (2350 m)	Hari Maharaj Parvat (2350 m)	Hari Maharaj Parvat (2350 m)	Hari Maharaj Parvat (2350 m)
Distance travel by debris	2 km	4 km	5 km	3.5 km
Name of stream	Mando Gadhera (Tributary of Bhagirathi)	Mando Gadhera (Tributary of Bhagirathi)	Diya Gadhera (Tributary of Indravati River)	Siror Gadhera (Tributary of Bhagirathi)
Debris composition and size	Large boulders, pebbles, gravels, and mud; boulders' volume ranging from 65 cubic m to 2300 cubic m (boulder-mud ratio: 55:45)	Large boulders, pebbles, gravels, and mud; boulders' volume ranging from 70 cubic m to 2400 cubic m (boulder-mud ratio: 60:40)	Large boulders, pebbles, gravels, and mud; boulders' volume ranging from 40 cubic m to 2200 cubic m (boulder-mud ratio: 30:70)	Large boulders, pebbles, gravels, and mud; boulders' volume ranging from 30 cubic m to 2200 cubic m (boulder-water ratio: 70:40)

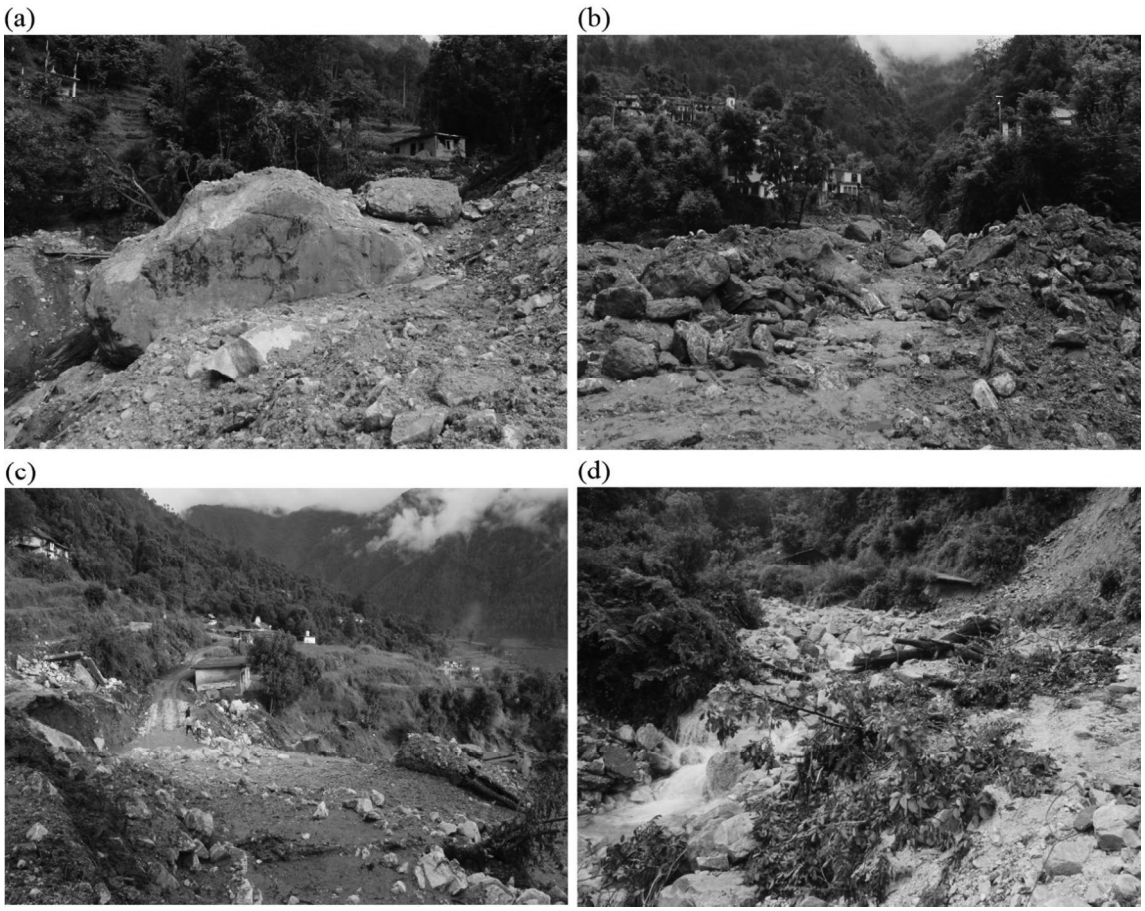

Fig. 5 Cloudburst affected villages **a** Nirakot, **b** Mando, **c** Kankrari, **d** Siror; Photo: by authors

Table 3 Environmental impact of cloudburst-triggered debris flow and flash flood. *Source*: by authors

Variables	Nirakot	Mando	Kankrari village	Siror	Total
Number of forest trees dislocated	100	100	500	70	770
Total land degradation (acre)	2	4	45	0.5	51.5
Land degradation under existing crops (acre)	0.7	1.2	20.6	0.1	22.6
Number of fruit trees dislocated	162	20	300	4	486
Land degradation under arable land (acre)	0.7	1.2	20.6	0.1	22.6
Number of buildings damaged	3	5	11	Nil	19
Number of bridges damaged	5	2	6	1	14

the highest average area of boulders was in Mando village, which is 28.3 m^2 followed by Kankrari 19.6 m^2, Nirakot 12.57 m^2, and Siror 7.1 m^2. In terms of the total volume of debris, it was the highest in Kankrari village, followed by Mando, Nirakot, and Siror villages.

Figure 6 shows the average diameter of boulders in the cloudburst-affected villages. We drew the figure with a scale of 1 cm is equal to 1 m. The average biggest diameter of boulders was found in Mando village (6 m), followed by Kankrari (5 m) and Nirakot (4 m) villages. The average smallest diameter of boulders was found in Siror village (3 m).

Susceptibility analysis

Based on the above description, susceptibility analysis of the case study villages was carried out (Table 6).

Table 4 Economic impact of cloudburst-triggered debris flow and flash flood. *Source*: By authors

Variables	Nirakot	Mando	Kankrari	Siror	Total
Number of affected HHs	22	18	100	03	143
Loss of human life	Nil	3	1	Nil	04
Loss of animals (cows)	Nil	2	Nil	Nil	02
Building loss (million INR)	0.25	0.45	1.1	Nil	1.7
Forest loss (million INR)	0.1	0.1	0.5	0.07	0.77
Crops loss (million INR)	0.4	0.8	1.4	0.75	3.35
Loss of fruits (million INR)	0.162	0.02	0.3	0.004	0.5
Loss of arable land (million INR)	0.35	0.6	10.3	0.05	11.3
Loss of Bridges (million INR)	5	2	6	1	14
Total (INR)	6.26	3.97	19.6	1.87	31.62

Table 5 Average circumference, area, and volume of boulders. *Source*: By author

Variables	Nirakot	Mando	Kankrari	Siror
Radius (m)	2	3	2.5	1.5
Diameter (m)	4	6	5	3
Circumference (m)	12.57	18.8	15.7	9.4
Area (m^2)	12.57	28.3	19.6	7.1
Total volume of debris (cubic m)	36,000	48,000	62,000	24,000

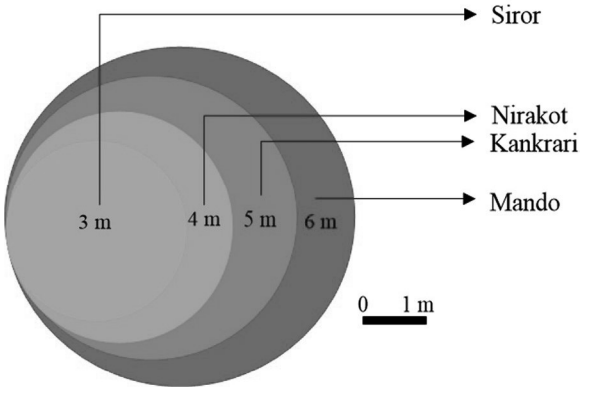

Fig. 6 Village-wise average diameter of boulders

The main variables of susceptibility were slope gradient, accessibility of villages, economic conditions of households, and climatic conditions. We noticed that Nirakot village has very high susceptibility, Kankrari has high, and Siror and Mando have moderate susceptibility.

Discussion

The Uttarakhand Himalaya is highly vulnerable to geo-hydrological disasters because of its geological formation (Vaidya 2019). It is an ecologically fragile, geologically sensitive, and tectonically and seismically very active mountain range (Sati 2019). The geo-hydrological events—cloudbursts and glacier bursts-triggered catastrophes are very common and devastating. The monsoon season poses severe threats to natural hazards because of heavy downpours. About 93% of the Uttarakhand Himalaya is mountainous mainland, of which 16% is snow-capped. The undulating and precipitous terrain and remoteness are the most vulnerable for disaster risks.

This study reveals that most of the cloudbursts incidences in 2020–21 occurred mainly in the remote mountainous districts of the Uttarakhand Himalaya. The villages in the Uttarakhand Himalaya are located on the sloppy land and along the river valleys, which are fragile and very vulnerable to disasters. The rivers flow above danger marks during the monsoon season cause threats to rural settlements. The roads of Uttarakhand are constructed along the river banks and on fragile lands. These roads lead to the highland and river valley pilgrimages where the number of tourists and pilgrims visit every year mainly during the monsoon season. There are many locations along the river valleys where the houses are constructed on the debris, deposited by rivers during debris flow events. Therefore, the environmental and economic losses due to debris flows and flash floods are high. The construction of hydropower projects along the river valleys without using sufficient technology further accentuates the vulnerability of debris flows and flash floods. One of the recent examples is the Rishi Ganga tragedy in Chamoli district where more than 200 people died with a huge loss to property (Sati 2021). We observed that the cloudburst triggered calamity in 2021 was higher than in 2020. The trend of occurring natural hazards has been increasing. Similarly, the intensity and frequency of natural hazards were observed high.

The present study shows that the environmental and economic loss in the four villages of the Bhagirathi River valley was huge due to cloudburst-triggered debris flows and flash floods. Almost every household of the villages were affected by cloudburst calamity. There were large forest and arable land degradation, forest and fruit trees were dislocated, loss of life—human and animal, and the houses and bridges were collapsed. The calamity also poses threat to the future, in terms of, the large deposition of debris including boulders, pebbles, and gravels in the villages along the streams and gullies. The rural people are poor and their livelihood is dependent on practicing subsistence agriculture. Many of them are living below the poverty line

Table 6 Susceptibility analysis of case study villages. *Source*: By authors

Variables	Nirakot	Mando	Kankrari (including Sada and Thalan)	Siror
Slope gradient	30°–55°	30°–55°	30°–45°	20°–30°
Accessibility	Highly inaccessible	Accessible	Inaccessible	Accessible
Economic condition	Not favourable	Average	Not favourable	Average
Climate	Cold in winter	Conducive	Cold in winter	Conducive
Susceptibility	Very high	Moderate	High	Moderate

in these villages. Because the existing crops have been lost, they are facing food insecurity. Further, the psychological problems are immense. The fear of another calamity is always there in the mind of people as all villages are situated in very high to moderate susceptible areas. The national highway is passing through the right bank of the Bhagirathi River and the affected villages are situated on the left bank. The connectivity problem is immense all the time in these villages. The entire rural areas of the Uttarakhand Himalaya are facing similar problems.

Conclusion

Cloudburst-triggered debris flows and flash floods are natural calamities in the Himalayan regions. They occur naturally and cannot be stopped. The losses—environmental and economic are also huge. However, the severity of these natural calamities can be minimized. For example, the high impact of cloudburst-triggered debris flow on the four study villages was mainly due to their location along the streams and on the fragile slopes. This can be avoided by constructing the settlements in safer places generally away from the violent streams. In the disaster risk zones, scenario analysis can be carried out under which, identifying driving forces of disaster risks is the first step. Then, the critical uncertainties are to be identified, and finally, a possible scenario can be developed. Nature-based eco-disaster risk reduction can be adopted to prevent further disaster risks. A large-scale plantation drive in the degraded land will restore the fragile landscape. Both pre and post-disaster risk reduction measures can be adopted to reduce the economic and environmental impact of debris flows. There must be policies implementation programmes for providing immediate relief packages for the affected people in terms of food and shelters. In a long run, susceptibility analyses should be carried out to understand the risk to the settlements so that the settlements can be replaced on the safer side if needed. A special budget can be allocated to hazard-prone villages during adverse situations.

Authors' contributions

The first author analyzed data, prepared maps, and diagrams, and wrote the manuscript. The second author conducted a field survey and collected data. All authors read and approved the final manuscript.

Declarations

Ethics approval

This article does not contain any studies with human participants performed by any of the authors.

Competing interests

There is no competing interests in the manuscript.

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