Feature

A growing threat of multi-hazard cascades highlighted by the Birch Glacier collapse and Blatten landslide in the Swiss Alps

Nazimul Islam[1], Jonathan L. Carrivick[2], Tom Coulthard[3], Matthew Westoby[4], Stuart Dunning[5], Saskia Gindraux[6]

[1]Birmingham Institute for Sustainability & Climate Action (BISCA) and School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham, UK
[2]School of Geography and water@leeds, University of Leeds, Leeds, UK
[3]Department of Natural Sciences, Manchester Metropolitan University, Manchester, UK
[4]School of Geography, Earth and Environmental Sciences, University of Plymouth, Plymouth, UK
[5]School of Geography, Politics and Sociology, Newcastle University, Newcastle upon Tyne, UK
[6]Centre for Research on the Alpine Environment (CREALP), Sion, Switzerland
n.islam.1@bham.ac.uk

Rapid atmospheric warming, especially at high altitude, leads to alpine mountain landscapes becoming more vulnerable to mass movements and consequently unstable. For example, decay of mountain permafrost contributes to rockfalls, landslides and debris flows; glaciers are retreating and losing mass at alarming rates, exposing unstable slopes that are more likely to fail; and meltwater, which collects in a growing number of glacial lakes, can pose an outburst flood hazard, putting communities and infrastructure downstream at risk of damage. Occurring now with increasing frequency, these natural phenomena often combine to create complex multi-hazard cascades that are more powerful and have a greater reach down-valley than a singular isolated event. Combined with increasing population and infrastructure and economic activity in high mountains, there is therefore increased vulnerability of society to natural hazards in high alpine mountains, as has been experienced in the Swiss Alps in 2025, with the collapse of the Birch Glacier and the destruction of the alpine village of Blatten. Here, we review the physical processes of this recent event, their impact on environment, people and economy, and consider what can be learned from them.

In the last few decades the frequency and magnitude of natural hazards have increased, with a 13 percent increase in global natural disasters in 2021 compared to the average of the past three decades between 1990 and 2020. According to the Emergency Events Database (EM-DAT; www.emdat.be), the majority of these disasters occurred in Asia; 41 percent of all disasters globally, including 58 percent of landslides globally.

The EM-DAT database maintained by the Centre for Research on the Epidemiology of Disasters (CRED) in Brussels has recorded over 4000 major disaster events in High Mountain Asia between 1980 and 2015. These landslide events have killed tens of thousands of people and affected millions of others; the total number of fatalities is estimated as over 100 000 by landslides, including earthquake-induced landslides, 49 000 by floods, 400 by glacial lake outburst floods (GLOFs) and 150 by forest fires. In addition to the staggering loss of life, the economic impacts of these events are significant. The 2025 UNDRR Global Assessment Report on Disaster Risk Reduction estimates the global average annual cost of disasters has increased from 80 billion US dollars between 1970 and 2000 to 200 billion US dollars for the period 2001–2020.

A recent study by C. Taylor and colleagues, 'Glacial lake outburst floods threaten millions globally' published in *Nature Communications* (v.14, p. 487, 2023), reported that over 15 million people globally are exposed to the impacts from potential glacial lake outburst floods, of which 9.3 million reside in High Mountain Asia. India alone has experienced at least three extreme floods of high mountain origin in the last 12 years, including the October 2023 glacial lake outburst from South Lhonak Lake in Sikkim which caused more than 80 fatalities; the so-called 'Chamoli Disaster', which caused over 200 fatalities in February 2021, and an outburst from Chorabari glacial lake in June 2013, which killed more than 5000 people in the Kedarnath Valley and stranded 100 000 pilgrims and tourists. All these three events destroyed critical transport and energy infrastructure. Each of these events is an example of a multi-hazard cascade; the 2023 Sikkim flood was triggered by a landslide into a glacial lake, which caused it to overtop; the 2021 Chamoli disaster originated as a rock-ice avalanche which transitioned into a fast-moving debris flow; and the Kedarnath disaster was triggered by heavy rainfall and snowmelt which caused the overtopping and breaching of Chorabari Lake.

Elsewhere, one of the worst multi-hazard cascade disasters globally started as a rock/ice fall on the Huascaran Mountain in the Cordillera Blanca, Peru, on 31 May 1970. The ensuing debris flood killed over 6000 people. On 28 April 2025 a Glacial Lake Outburst Flood (GLOF) in the Peruvian Andes was triggered by rock slope failure on the Vallunaraju mountain. Rockfall entering the lake triggered a wave of water and subsequent debris flow along the Casca River, killing three people and destroying more than 100 houses. In Canada, a landslide (~50 million tonnes of mass) on 28 November 2020 entered a mountain lake and displaced water so suddenly and intensely to form a tsunami wave ~100 m high before transforming into an outburst flood affecting Elliot Creek, thankfully with no reported fatalities.

Multi-hazard cascades are also prevalent in the European Alps, and arguably increasingly so. Sadly, 11 people died when part of the Marmolada glacier collapsed in Italy in 2022. This article has been written as the issues surrounding multi-hazard cascades have been brought to the fore yet again with a very well documented and publicized event in the Swiss Alps.

Birch glacier collapse: Impacts on environment, people and economy

On 28 May 2025, a large portion of *Birchgletscher* (Birch Glacier) collapsed and transitioned into a fast moving landslide in the Swiss Canton of Valais. The event mobilized millions of tonnes of rock and ice and took approximately 40 seconds to reach Blatten village on the valley floor, which was largely buried.

Following snow and ice avalanches that impacted local infrastructure in 1993 and 1999, Birch Glacier has been continuously monitored by Canton authorities, and knowledge gained from this monitoring was instrumental in surveillance and evacuation prior to the May 2025 glacier collapse. Monitoring revealed that the front and lower part of the glacier advanced by ~50 m since 2019 (and 0.5 m per day immediately before its collapse—see Fig. 1) and thickened by 20 m over roughly the same period. The ice thickness increased by ~30 m between 2011 and 2023 at the glacier snout. This was likely driven by the weight of rock debris that accumulated on the glacier surface. Most of this debris is believed to have originated from the adjacent Kleines Nesthorn, a formerly 3335 m.a.s.l. mountain peak prone to rock avalanching, and which sits at an altitude and exposition where

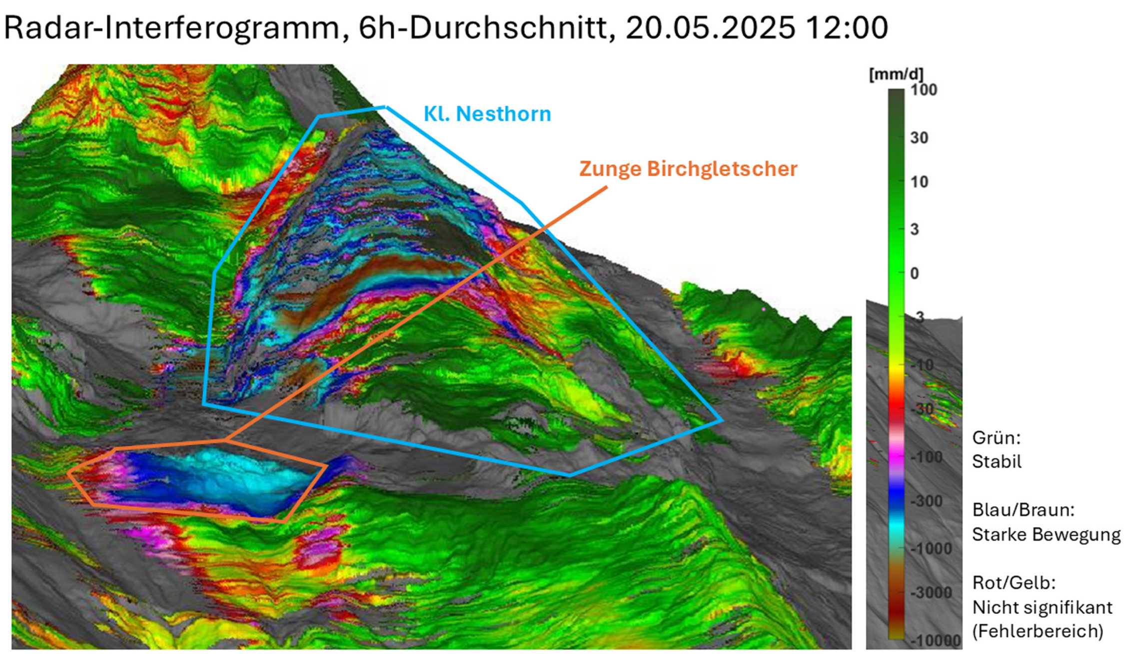

Fig. 1. Radar interferogram shows the displacement of the Birch glacier snout prior to the collapse. Figure derived from online news portal Walliser Zeitung (https://walliser-zeitung.ch/blatten-felssturz-zeitraffer/).

permafrost is expected. In places on the glacier surface, the thickness of the accumulated rock debris cover exceeded 80 m — the equivalent mass of several hundreds of metres of ice. Since 13 May 2025, rapid acceleration of the glacier ice flow (~10 m per day), along with minor rainfall, was observed. A potential hazard cascade was predicted days before the glacier collapsed. Therefore, on 19 May 2025, local authorities issued an immediate evacuation order to leave the village of Blatten within 2 h. Such early warning supported the evacuation of around 300 people with their livestock and relocation to nearby villages in the Lotschental valley. One person was reported missing in this event.

The landslide deposited a 100 m-thick debris drape which covered the valley floor and impacted the opposing valley side, and covered a 2.5-km long section of the Lonza River. Approximately 90 percent of Blatten village was buried under debris and a temporary lake formed as the river was dammed (Figs 1, 2). Two days later, on 30 May, a drone survey captured the immediate imprint of the landslide, and it was also mapped using satellite imagery and aerial photography acquired by the Swiss Federal Office of Topography (Swisstopo). These data enabled a rapid assessment of the damage and destruction; most houses in the village have been completely or partially destroyed by the landslide debris and subsequent flooding, as shown in Fig. 3. From 31 May, the water level in the lake formed in front of the debris cone in Blatten village slowly started lowering and the Lonza River started flowing across the landslide deposit, ultimately reconnecting with the Ferden reservoir downstream.

Alongside the environmental impacts, the Blatten landslide also caused a significant economic impact; initial estimated losses total 320 million CHF (US$ 395 million), of which 260 million CHF (US$ 31 million) are attributed to building damages. The Federal Government of Switzerland provided immediate emergency aid of 5 million CHF (US$ 6 million), including 15 000 CHF (US$ 18 000) per local resident, intended to cover uninsured costs. Moreover, the government pledged emergency funds to help the evacuated families relocating until returning to Blatten. At the time of writing, there are plans to rebuild the village quickly.

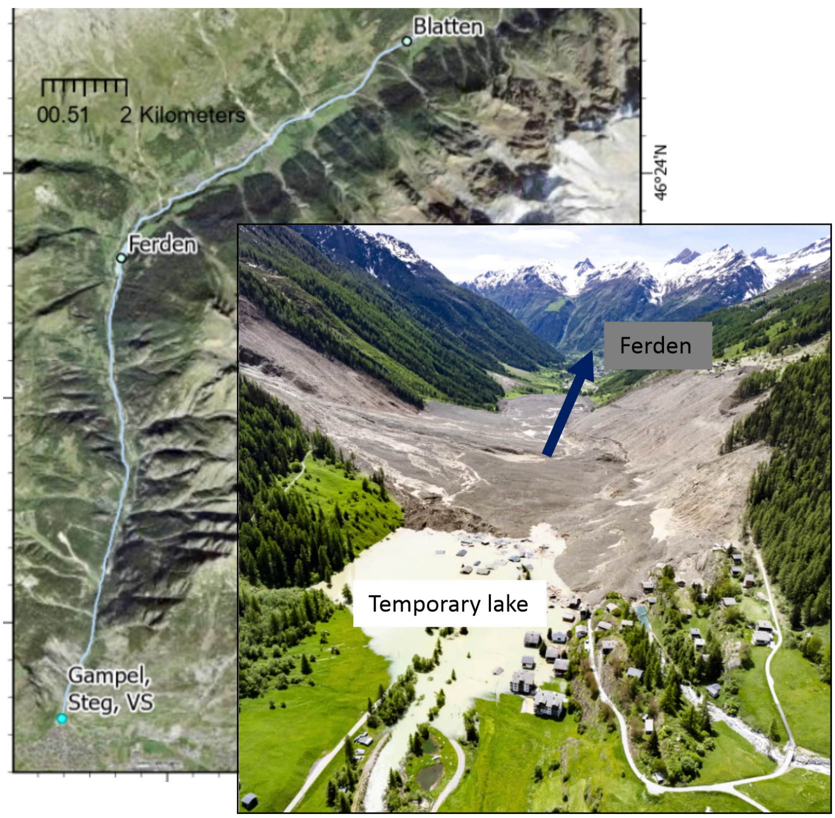

Fig. 2. Lotschental valley with the flow path of the Lonza river and the formation of debris cone and temporary lake. Inset image credited to J.-C. Bott/AP.

Lessons learned and future research directions

Whereas many of the multi-hazard cascades summarized at the start of this article had severe consequences, the Birch Glacier and Blatten landslide was dominated by environmental and economic impacts, with humanitarian effects largely restricted to the displacement of local residents as well as loss of property and belongings. Rigorous and comprehensive field monitoring, data collection and analysis pre-, during and post-event enabled predictions, adaptive planning, efficient warning and coordinated responses.

General scientific consensus is that this multi-hazard cascade was driven by terrain displacement caused by the partial collapse of Kleines Nesthorn, and the accumulation of a vast mass of rock debris on the glacier snout, which in turn led to increased pressure at the glacier bed and the enhanced production of meltwater, causing glacier flow to accelerate dramatically. Other factors, including water contributed by antecedent rainfall, may have played a role. Ultimately, a large section of the glacier collapsed, transitioning into an ice avalanche which then incorporated sediment from the valley floor and sides as it barrelled down-valley.

Can this event be attributed to climate change? Climate is of course a long-term average and individual events often coincide with unusual weather events. However, the average annual temperature in the Swiss Alps has risen by 1.35°C during the twentieth century, almost twice the global average, reaching 2.9°C in 2024. This atmospheric warming trend, which affects the European Alps broadly, has impacted precipitation patterns and snow cover and is associated with substantial glacier retreat, particularly over the last two decades.

Accurately attributing natural hazards to climate change is challenging, but the frequency of complex, cascading events in mountain landscapes, such as

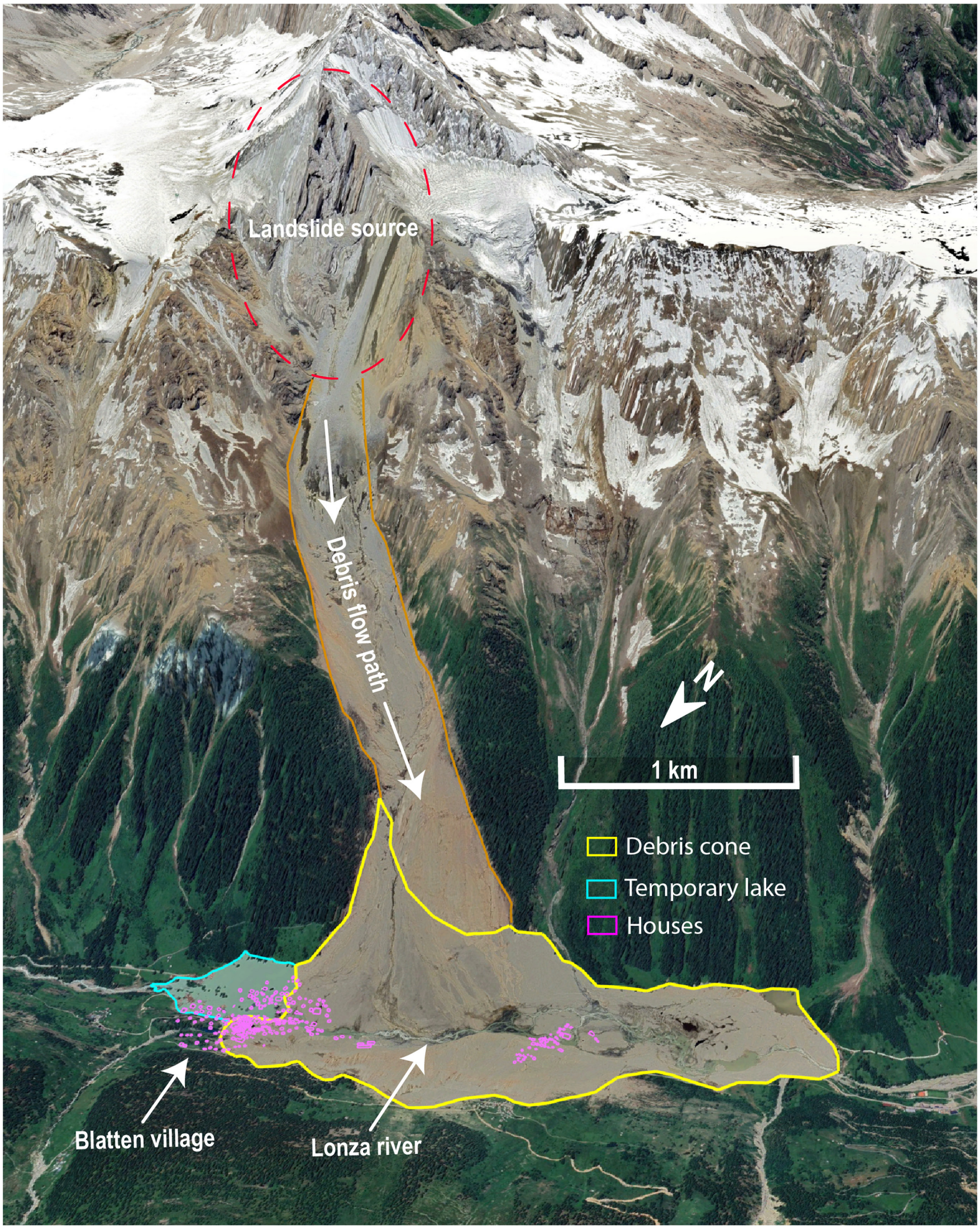

Fig. 3. Houses buried under the debris and flood in the Blatten village aftermath of the Birch glacier collapse. *Data source*: Building footprints from OpenStreetMap, Google Earth image.

the collapse of Birch Glacier, is expected to increase because of climate change. Such events also appear to be featuring more prominently in public discourse: around the time of writing, news outlets are reporting on a devastating debris flow that has caused loss of life in and around the village of Dharali in the Uttarakhand Himalaya, possibly driven by cloudburst rainfall and slope instability, although the precise causes remain unclear. The convergence of scientific understanding and media attention underscores a growing urgency to better anticipate and manage such hazards.

To anticipate and manage multi-hazard cascades, key challenges remain. We need a better understanding of how multi-hazard cascades develop through the interaction of different environmental domains and processes, human action and the role of climate change in accelerating hazard development. Moreover, one of the lessons that can be gained from the Birch glacier

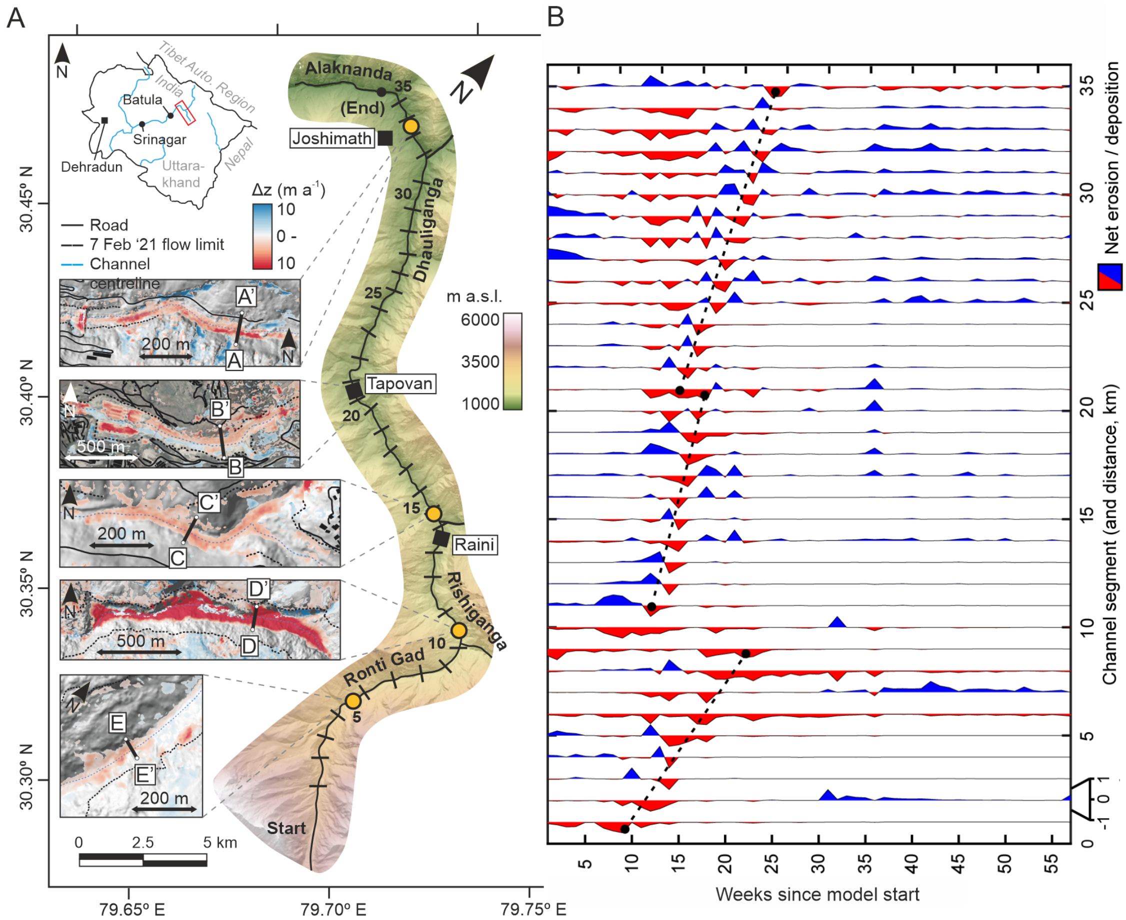

Fig. 4. Geomorphological adjustment following the 7 February 2021 Chamoli multi-hazard cascade. Panel A map shows the study domain; black transects are channel cross-sections, and left panels show spatially distributed vertical change from satellite digital elevation model differencing at 5 km distance increments. Panel B shows positive (blue) and negative (red) elevation changes along the study domain simulated by a landscape evolution model. Black dashes highlight the passage of fast-moving sediment waves in the 12 months following the event (Westoby *et al.*, 2023).

collapse and Blatten landslide is that an advanced early warning system is effective to communicate potential risks of developing cascades for evacuating hazard-prone areas well in advance and eventually save lives. However, such technological advancement and infrastructures for continuous monitoring of developing cascades are not available in the majority of the mountain regions across the globe. Thus, people in most mountain regions globally live with very high exposure and vulnerability to multi-hazard cascades.

Therefore, a focus needs to be on technological innovation such as establishing early warning systems, advance monitoring and assessment of glaciers and other associated phenomena in the mountains. Additionally, we need to innovate to develop and better integrate numerical modelling and remote sensing approaches (Fig. 4) to understand the evolution, flow paths and impacts of multi-hazard cascades. These impacts can manifest for years or decades after an initial event: Fig. 4 shows that the immediate aftermath (c. 12 months) of extreme, sudden-onset floods can be characterized by a sediment wave or 'superslug' with the potential to alter river channel morphology, conveyance and flood risk, as well as impacting water quality with issues for hydropower and freshwater ecology, for example. Scientific work must be carried out in collaboration with hazard practitioners and communities to develop robust and adaptive risk reduction and resilience frameworks for mitigating any potential risks (both environmental and economic risks) and fatalities, which need to be adequately funded.

Suggestions for further reading

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