Increasing cryospheric hazards and sediment supply threaten water quality and hydropower systems in high mountain areas

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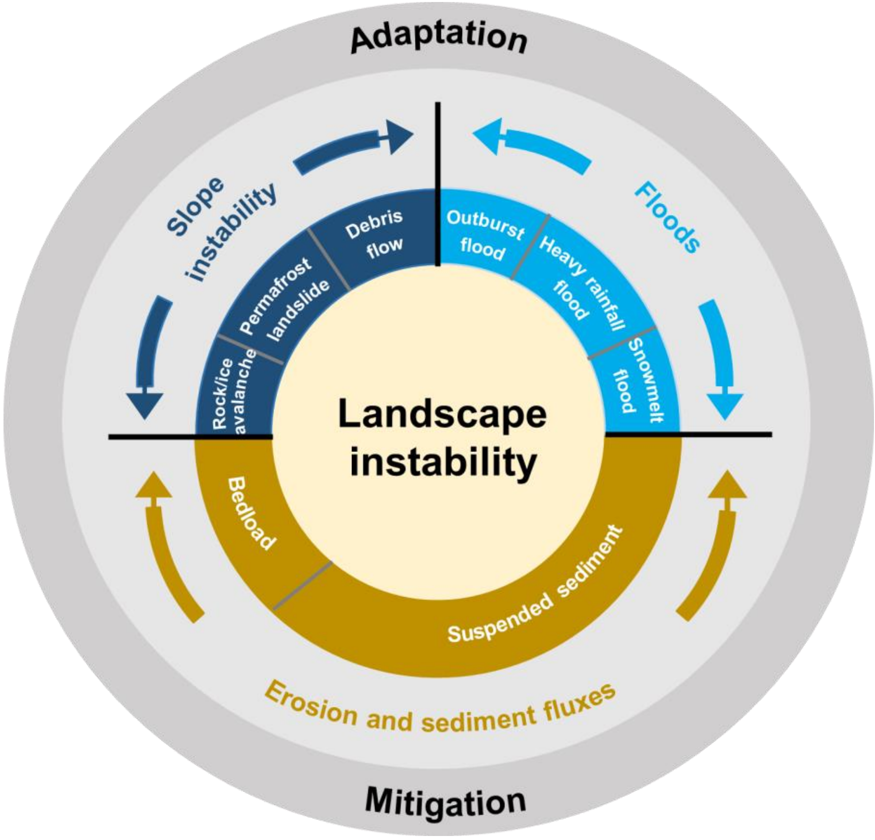

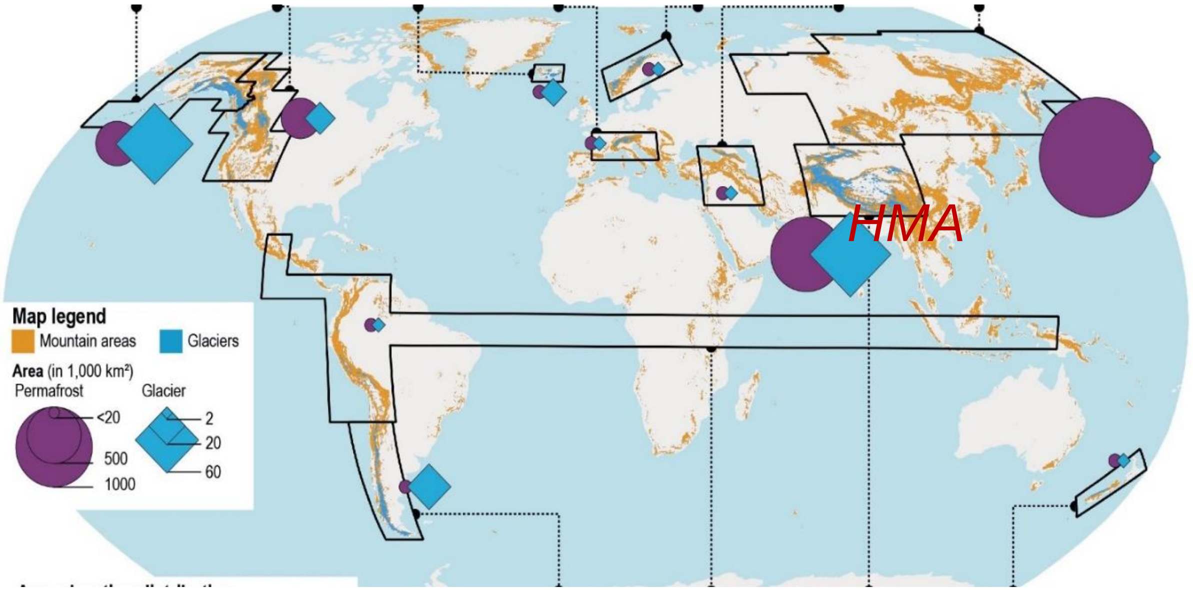

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ipcc INTERGOVERNMENTAL PANEL ON climate change

NUS National University of Singapore

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Motivation

Geomorphic and sedimentary effects of modern climate change

Earth's Future

COMMENTARY
10.1029/2022EF002983

Measuring and Attributing Sedimentary and Geomorphic Responses to Modern Climate Change: Challenges and Opportunities

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Key Points:

- Modern anthropogenic climate change affects a vast range of geomorphic settings
- We identify challenges of measuring physical landscape response to modern climate change and opportunities to improve studies
- Better understanding physical landscape impacts will prepare societies to manage hazards and economic effects of climate change

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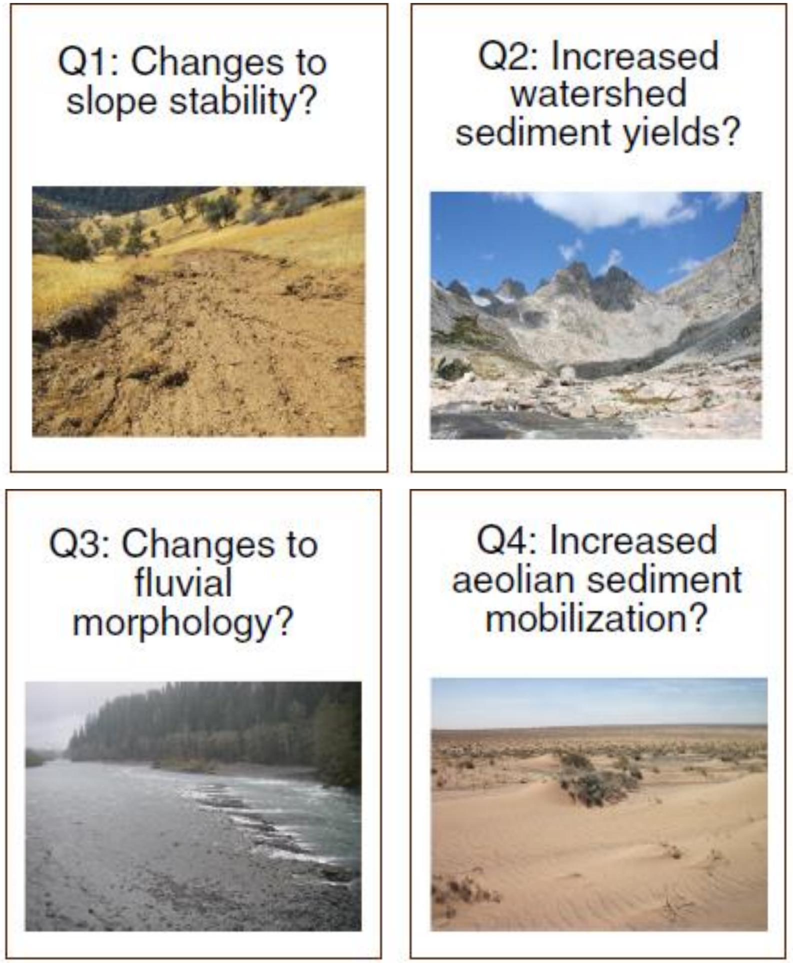
Author Contributions:
Conceptualization: Amy E. East
Investigation: Joel B. Sankey
Project Administration: Amy E. East
Writing – original draft: Amy E. East,

Abstract Today, climate change is affecting virtually all terrestrial and nearshore settings. This commentary discusses the challenges of measuring climate-driven physical landscape responses to modern global warming: short and incomplete data records, land use and seismicity masking climatic effects, biases in data availability and resolution, and signal attenuation in sedimentary systems. We identify opportunities to learn from historical and paleo data, select especially sensitive study sites, and report null results to better characterize the extent and nuances of climate-change effects. We then discuss efforts to improve attribution practices, which will lead to better predictive capabilities. We encourage the Earth-science community to prioritize scientific research on climate-driven physical landscape changes so that societies will be better prepared to manage the effects on health and safety, infrastructure, water–food–energy security, economics, and ecosystems that follow from climate-driven physical landscape change.

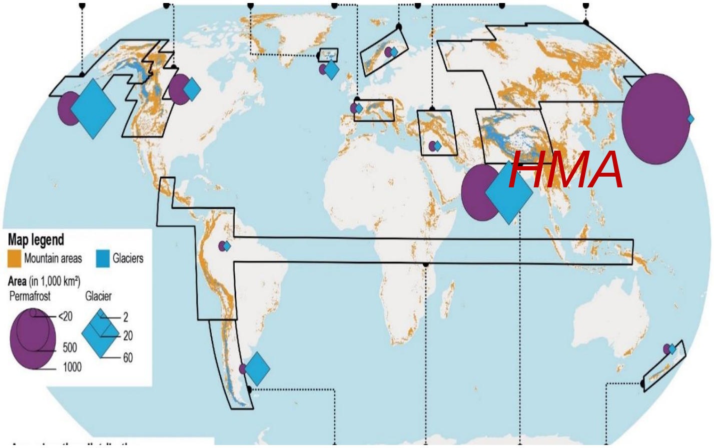
Plain Language Summary Modern global warming will ultimately affect physical landscape processes virtually everywhere on Earth, and some of those effects are evident already. This commentary describes the challenges to measuring climate-driven physical landscape responses to global warming: short and incomplete data records, land use and earthquakes masking climatic effects, biases in data availability and resolution, and climate signals becoming harder to read at the downstream end of a landscape. We discuss ways to collect more informative data in key locations to better understand climate-change impacts, while also diligently reporting where impacts are not evident. Forming a more complete picture in these ways will mean societies are better prepared to predict and manage impacts on human health and safety, infrastructure, water–food–energy security, economics, and ecosystems that are linked to climate-driven physical landscape change.



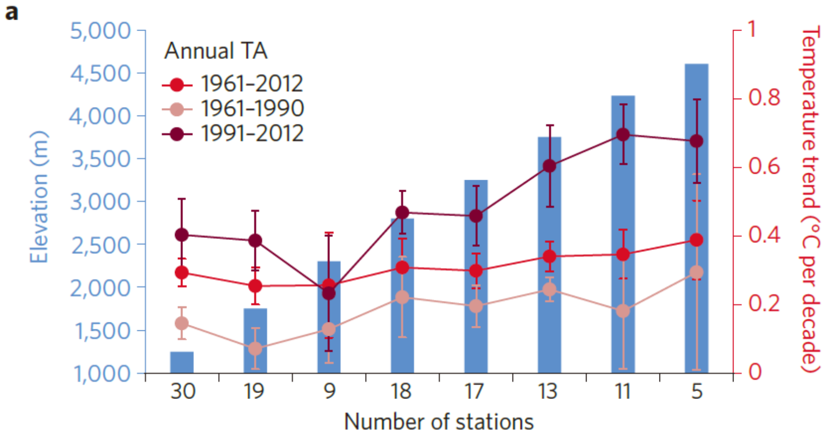
East and Sankey, 2020, Reviews of Geophysics

◻ Mountain landscape instability in a changing climate

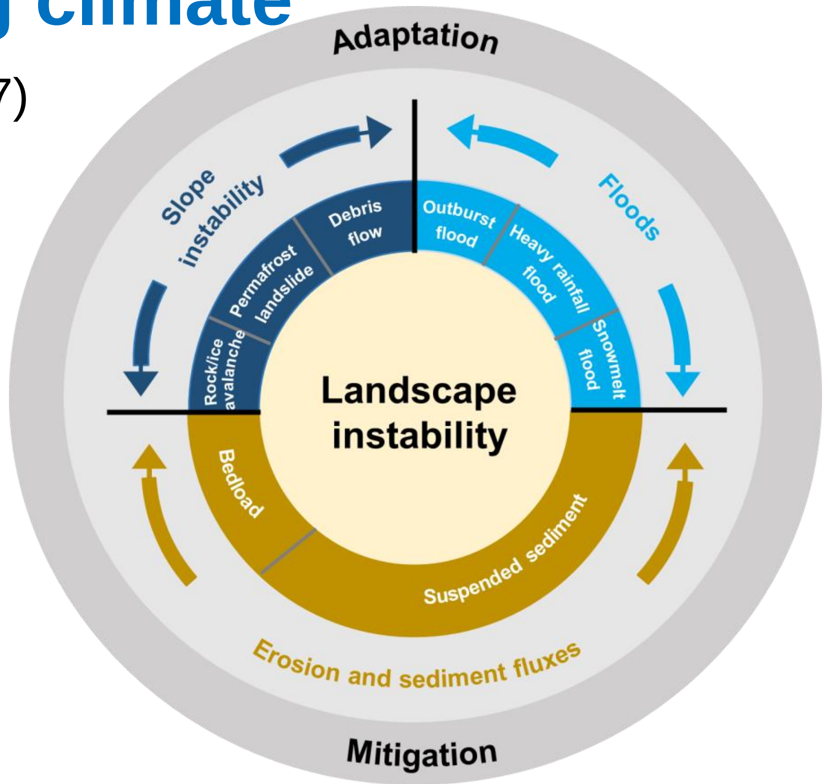
- **“Mountain Water Towers”** (Immerzeel et al., 2020; Viviroli et al., 2007)
- **Faster climate change than global average** (Pepin et al., 2015)
- **Mountain landscape instability**



(IPCC, 2019)

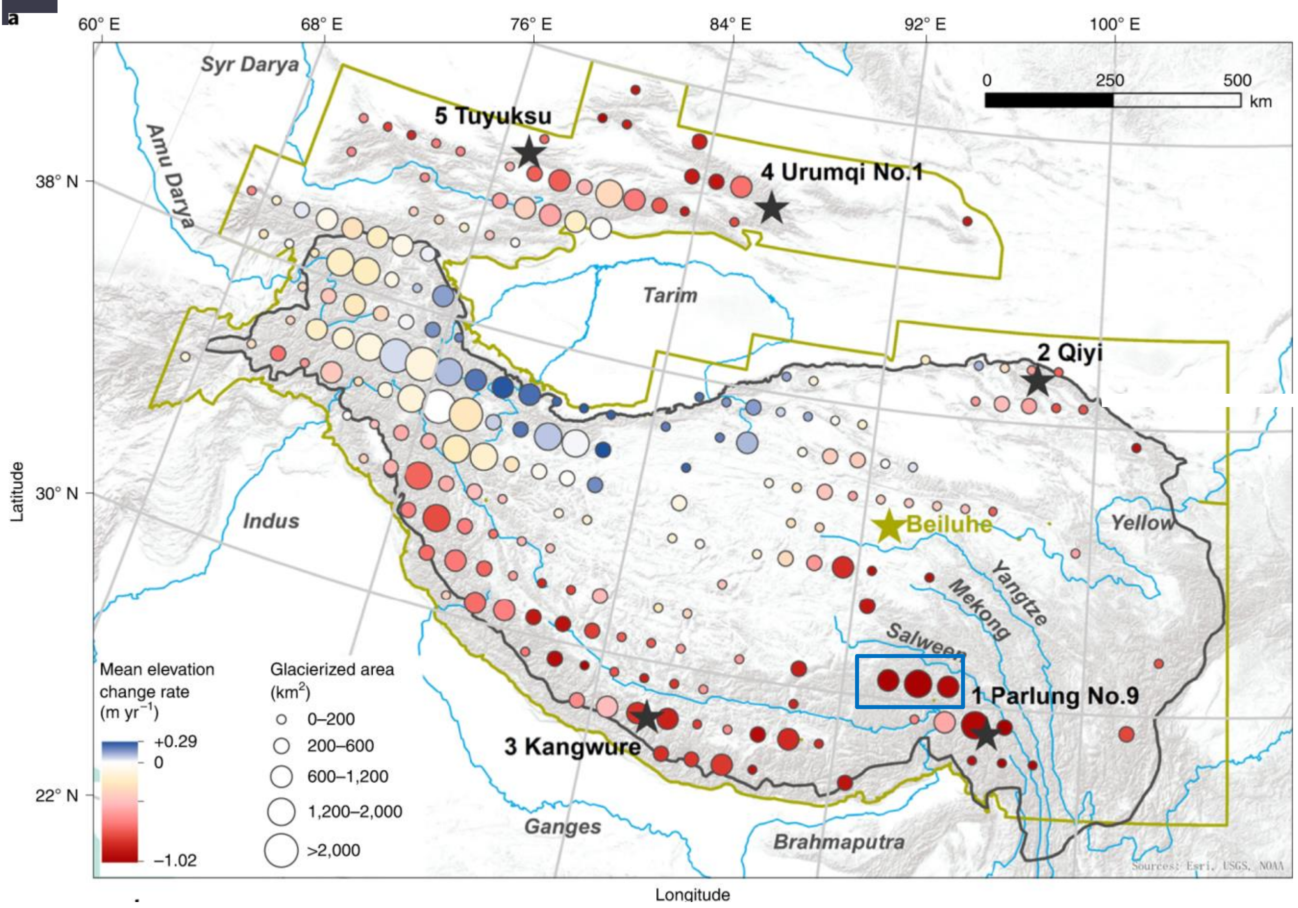


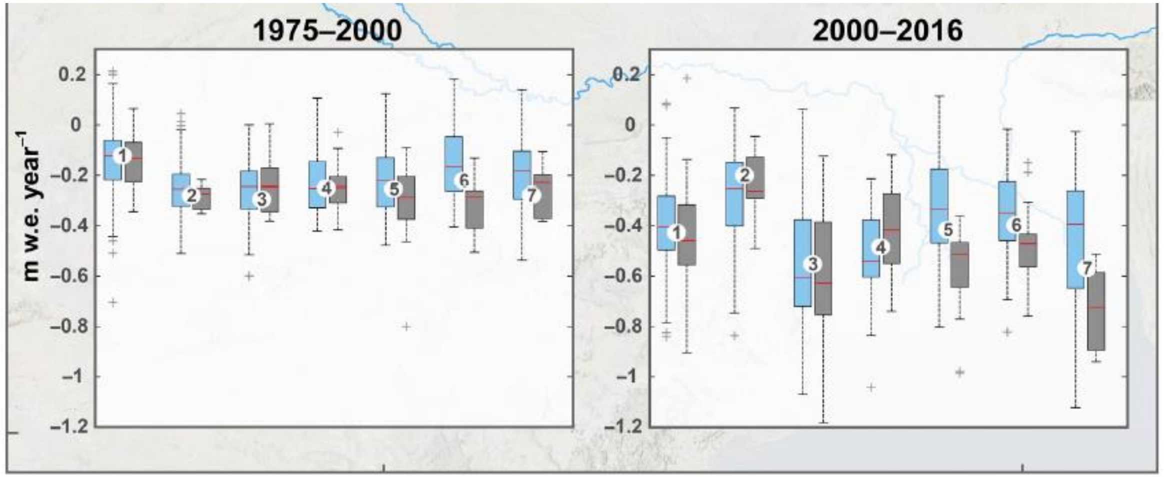
(Pepin et al., 2015, *NCC*)



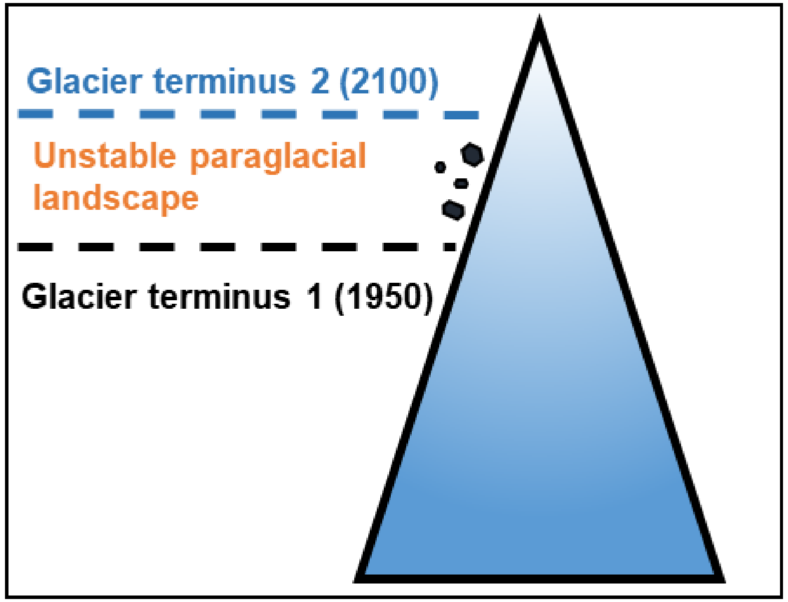
- **Slope instability**
- **Extreme floods**
- **Erosion and sediment flux**

02 Rapid deglaciation and paraglacial processes





(Maurer et al., 2019)

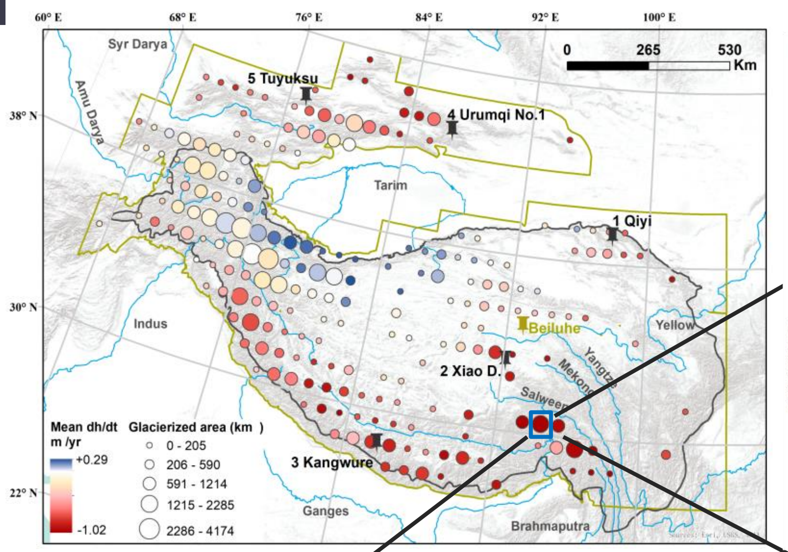


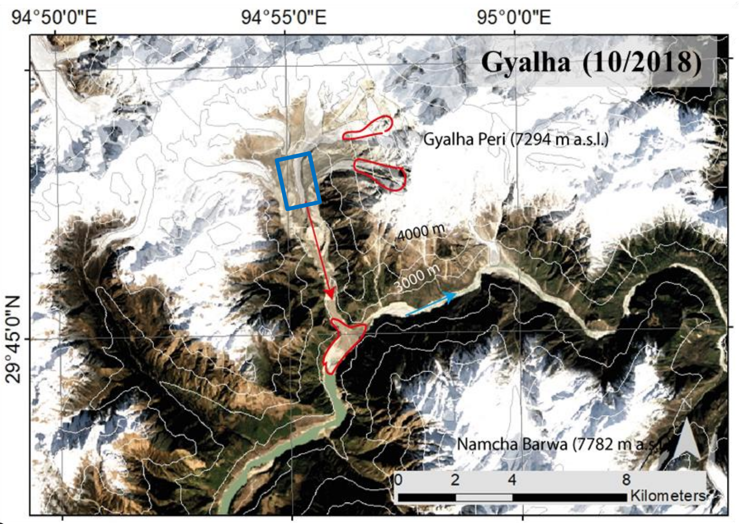
(Updated from Church and Ryder, 1972)

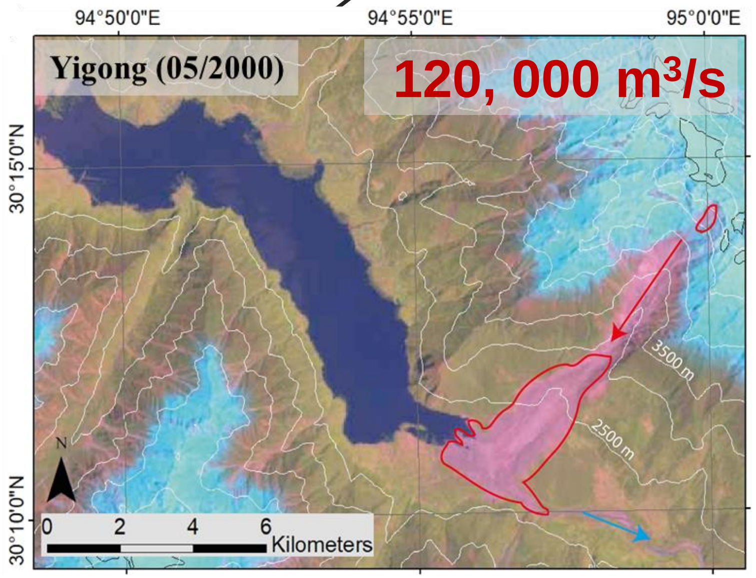
- **- 0.62 ± 0.23 m w.e./yr (Nyainqentanglha)** (Brun et al., 2017)
- **Unstable paraglacial landscapes** (Church and Ryder, 1972)

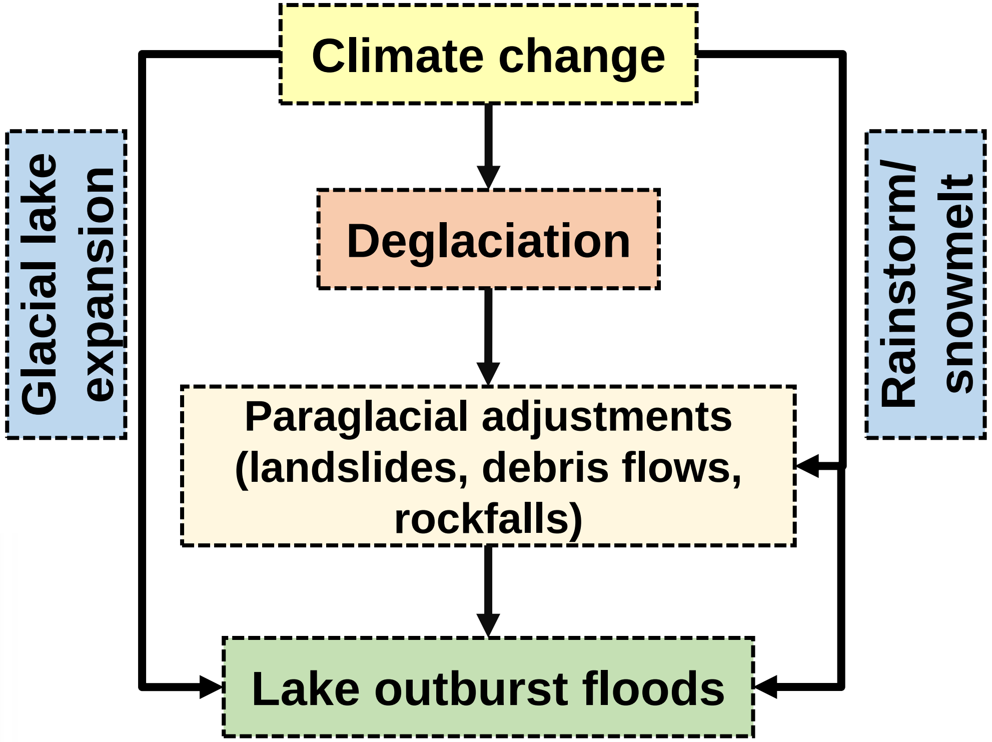
(from Li et al., 2022, Nature Geo. after Hugonnet, et al., 2021; Kraaijenbrink et al., 2017; Marzeion et al., 2020)

02 Slope instability and outburst floods following deglaciation





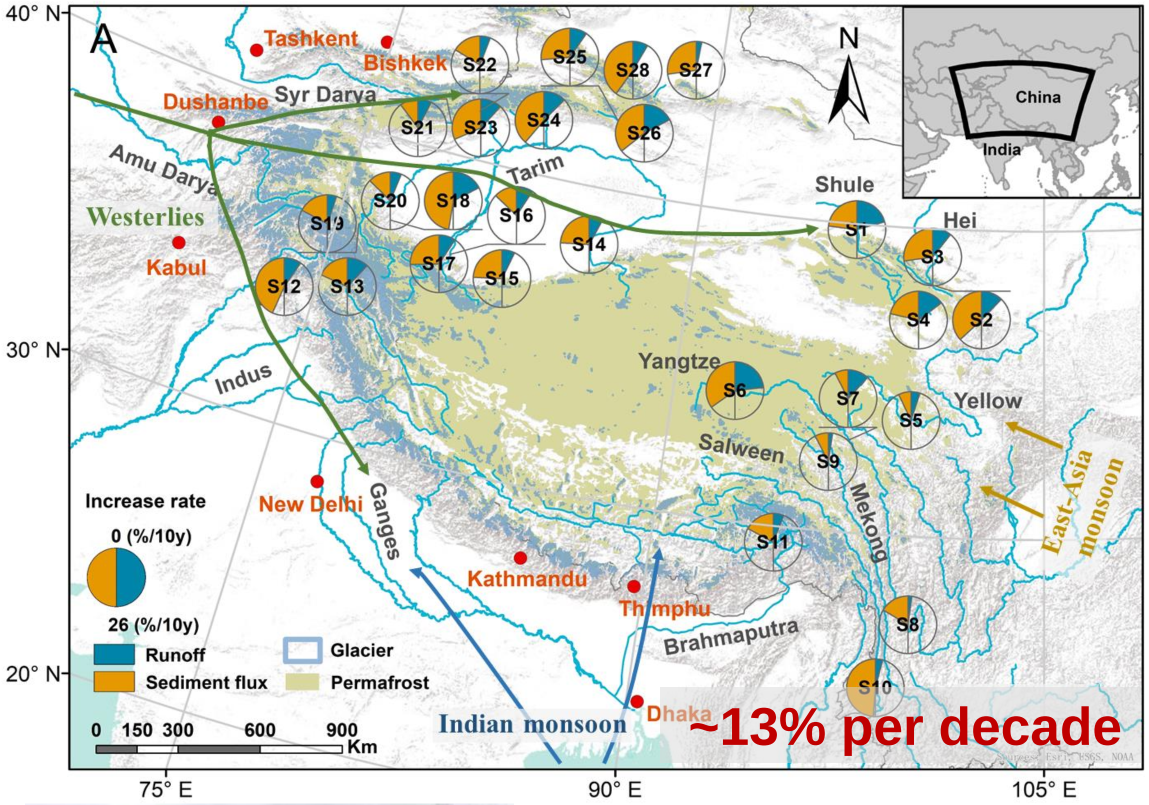


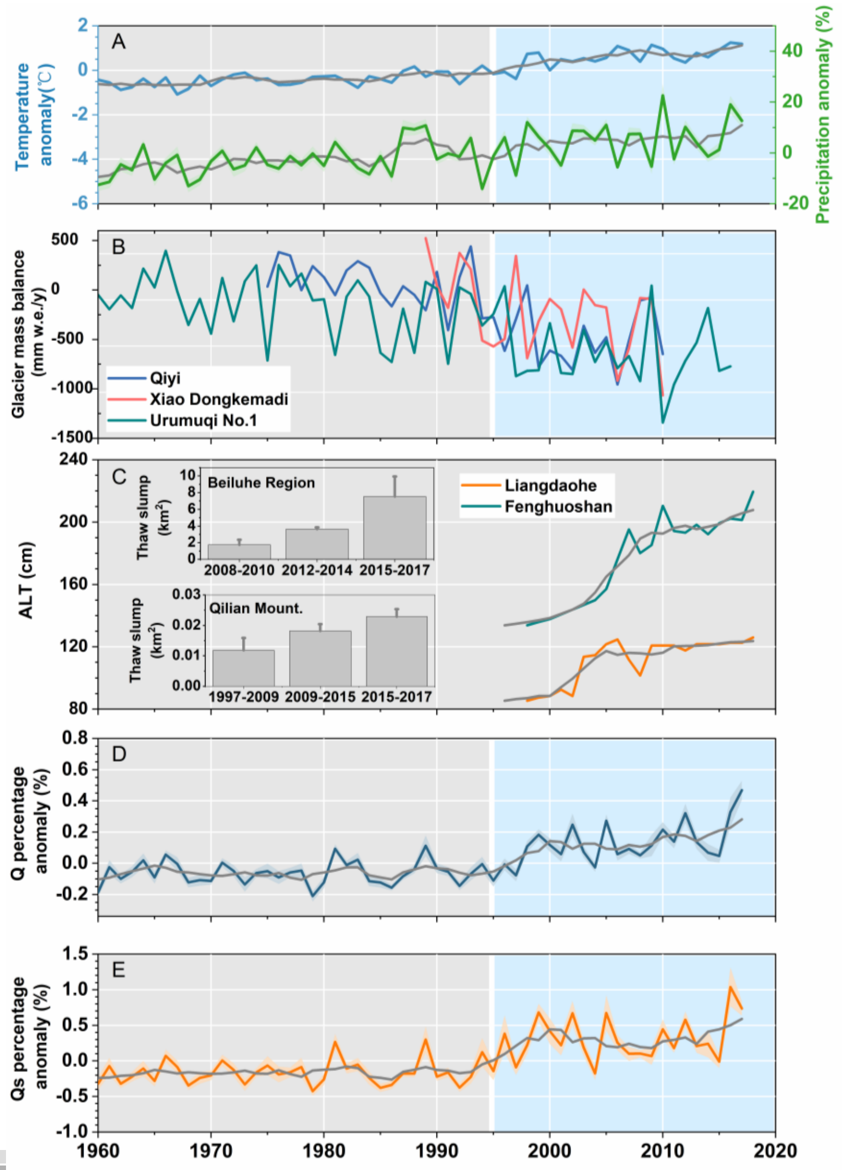


- **Landslide-lake outburst floods (LLOFs)**
- **Glacial lake outburst floods (GLOFs)**

*(from **Li** et al., 2022, Nature Geo. after Kääb & Myleyne et al., 2021, Hugonnet et al., 2021; Zheng et al., 2021)*

03 Increasing fluvial sediment loads in a warmer and wetter HMA





Li, D., Lu X., Overeem, I., Walling, D., Syvitski J., Kettner, A. J., Bookhagen B., Zhou, Y., & Zhang, T. (2021). Exceptional increases in fluvial sediment fluxes in a warmer and wetter High Mountain Asia. *Science*, 374(6567), 599-603.

03 Increasing fluvial sediment loads - a global perspective

nature reviews earth & environment

https://doi.org/10.1038/s43017-022-00362-0

Review article

Check for updates

Warming-driven erosion and sediment transport in cold regions

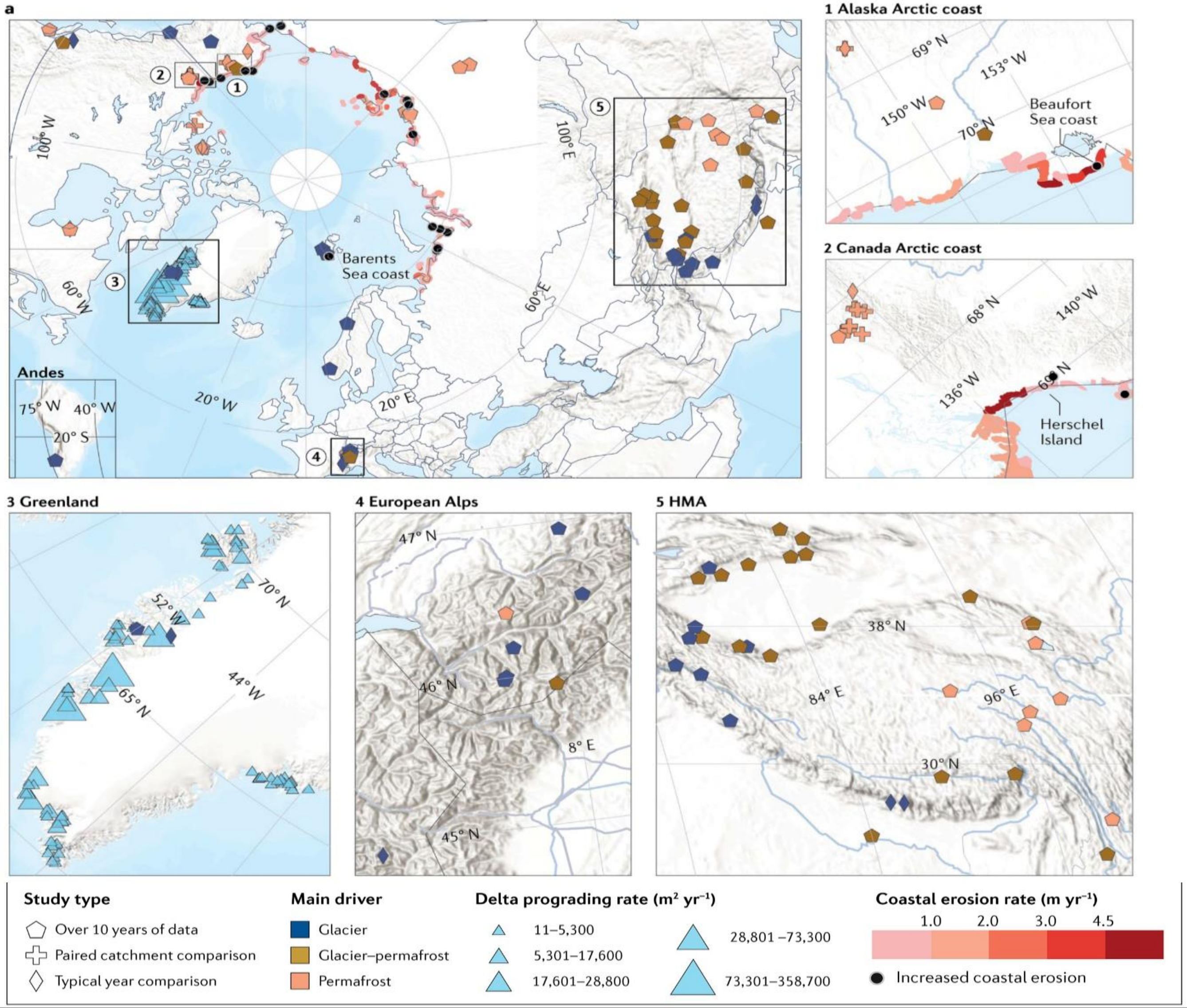
Ting Zhang[1], Dongfeng Li[1], Amy E. East[2], Desmond E. Walling[3], Stuart Lane[4], Irina Overeem[5], Achim A. Beylich[6], Michèle Koppes[7] & Xixi Lu[1]

Abstract

Rapid atmospheric warming since the mid-twentieth century has increased temperature-dependent erosion and sediment-transport processes in cold environments, affecting food, energy and water security. In this Review, we summarize landscape changes in cold environments and provide a global inventory of increases in erosion and sediment yield driven by cryosphere degradation. Anthropogenic climate change, deglaciation, and thermokarst disturbances are causing increased sediment mobilization and transport processes in glacierized and periglacierized basins. With continuous cryosphere degradation, sediment transport will continue to increase until reaching a maximum (peak sediment). Thereafter, transport is likely to shift from a temperature-dependent regime toward a rainfall-dependent regime roughly between 2100–2200. The timing of the regime shift would be regulated by changes in meltwater, erosive rainfall and landscape erodibility, and complicated by geomorphic feedbacks and connectivity. Further progress in integrating multisource sediment observations, developing physics-based sediment-transport models, and enhancing interdisciplinary and international scientific collaboration is needed to predict sediment dynamics in a warming world.

Sections

76 rivers and 18 permafrost coasts!



04 Impacts on water quality

- Water quality: fine sediment bonded with phosphorus and most heavy metals (e.g., mercury, chromium, arsenic, and lead, etc.)


TIBETAN PLATEAU

COMMENT

Check for updates

Securing water quality of the Asian Water Tower

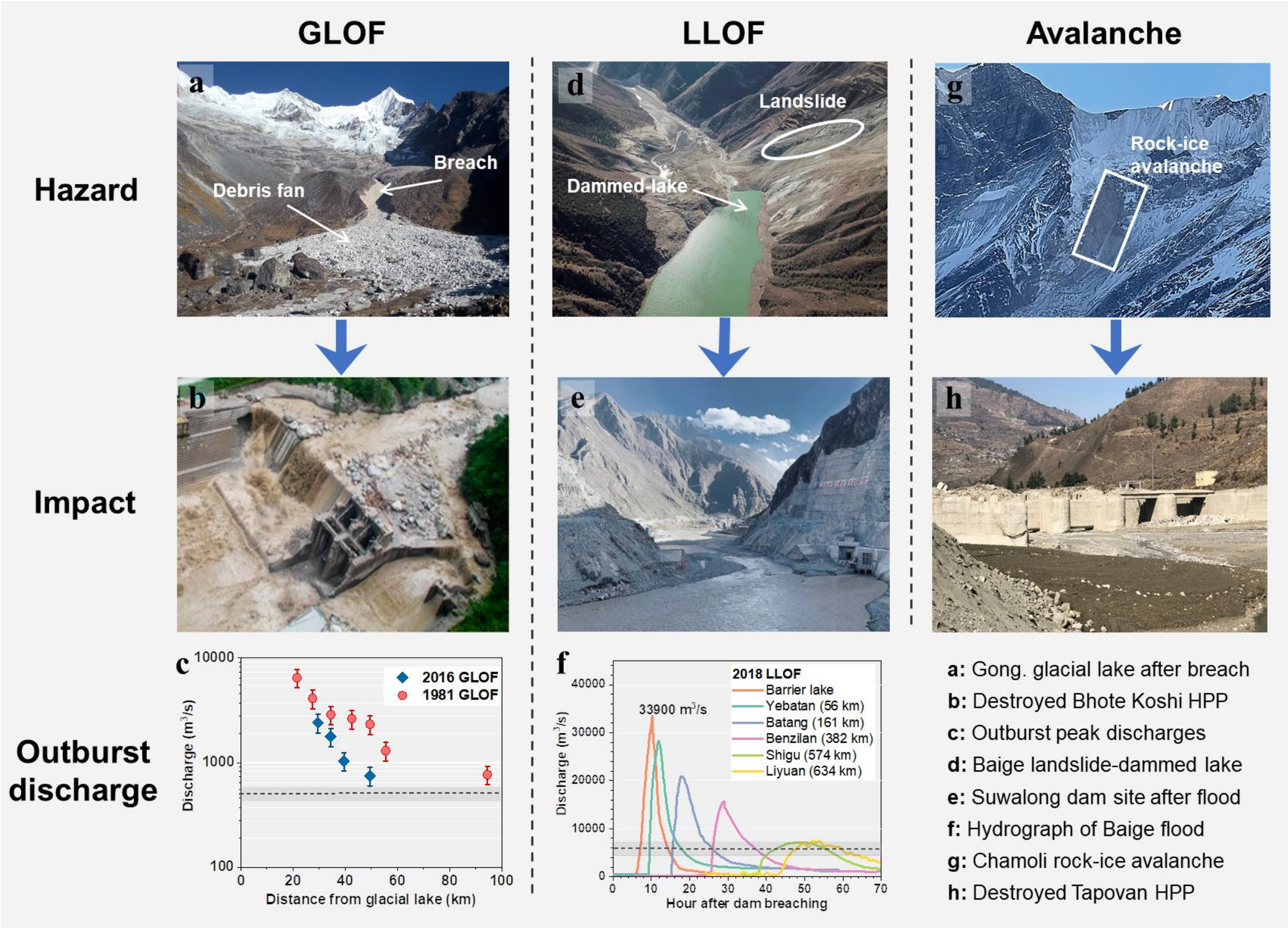
Fan Zhang[1,2], Chen Zeng[1], Qianggong Zhang[1,2] and Tandong Yao[1,2]

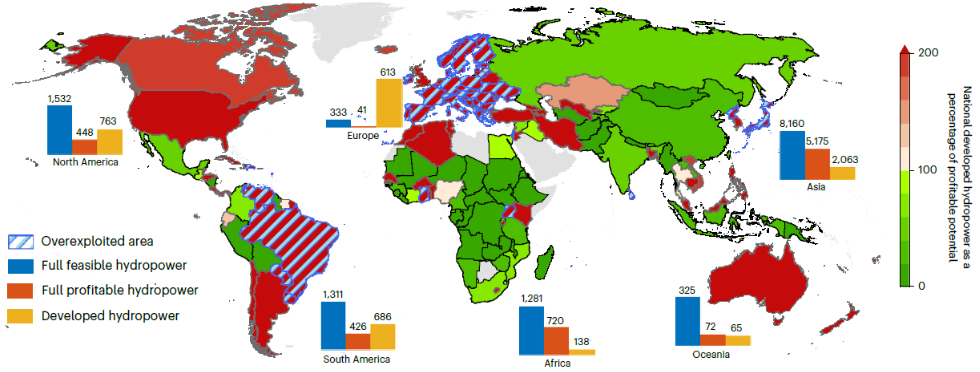
Water quality of the Asian Water Tower is far less studied than water quantity, but expected increases in upstream riverine chemical fluxes and lowland pollutant release could exacerbate water quality deterioration downstream. Data sharing, integrated modelling, and joint actions are needed to mitigate this problem.

Li, D., Lu X., Overeem, I., Walling, D., Syvitski J., Kettner, A. J., Bookhagen B., Zhou, Y., & Zhang, T. (2021). Exceptional increases in fluvial sediment fluxes in a warmer and wetter High Mountain Asia. *Science*, 374(6567), 599-603.

04 Impacts on hydropower

◻ Hydropower systems





Xu et al., 2023, Nature Water

nature geoscience

PERSPECTIVE

https://doi.org/10.1038/s41561-022-00953-y

Check for updates

High Mountain Asia hydropower systems threatened by climate-driven landscape instability

Dongfeng Li[1], Xixi Lu[1], Desmond E. Walling[2], Ting Zhang[1], Jakob F. Steiner[3], Robert J. Wasson[4,5], Stephan Harrison[6], Santosh Nepal[3,7], Yong Nie[8], Walter W. Immerzeel[9], Dan H. Shugar[10], Michèle Koppes[11], Stuart Lane[12], Zhenzhong Zeng[13], Xiaofei Sun[14,1], Alexandr Yegorov[15,16] and Tobias Bolch[17]

Global warming-induced melting and thawing of the cryosphere are severely altering the volume and timing of water supplied from High Mountain Asia, adversely affecting downstream food and energy systems that are relied on by billions of people. The construction of more reservoirs designed to regulate streamflow and produce hydropower is a critical part of strategies for adapting to these changes. However, these projects are vulnerable to a complex set of interacting processes that are destabilizing landscapes throughout the region. Ranging in severity and the pace of change, these processes include glacial retreat and detachments, permafrost thaw and associated landslides, rock-ice avalanches, debris flows and outburst floods from glacial lakes and landslide-dammed lakes. The result is large amounts of sediment being mobilized that can fill up reservoirs, cause dam failure and degrade power turbines. Here we recommend forward-looking design and maintenance measures and sustainable sediment management solutions that can help transition towards climate change-resilient dams and reservoirs in High Mountain Asia, in large part based on improved monitoring and prediction of compound and cascading hazards.

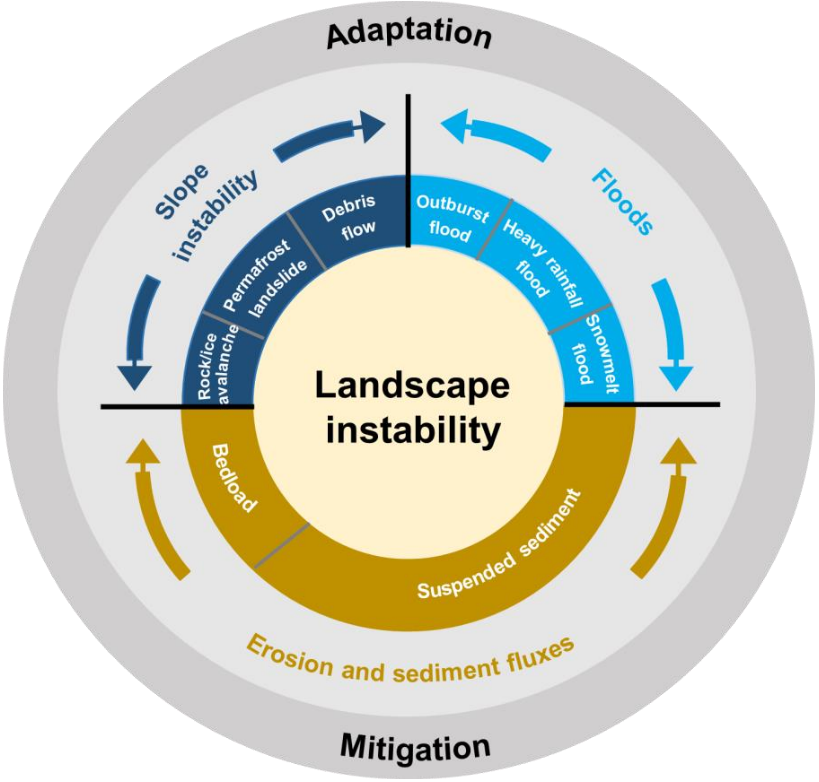
Li, D., Lu, X., Walling, D.E. *et al.* High Mountain Asia hydropower systems threatened by climate-driven landscape instability. *Nat. Geosci.* 15, 520–530 (2022).

05 Several thoughts

- **Climate change and cryosphere degradation are destabilizing high mountain landscapes**

- **Future needs**

  - **Landscape studies:** paraglacial adjustments, glacial/permafrost erosion and related sediment yields
  - **Cascading processes**: cascading links between climate change, glacier retreat, slope instability, outburst floods
  - **Securing water quality**: better monitoring of sediment and related contaminant fluxes
  - **Climate-resilient infrastructure**: forward-looking planning, adaptation capacity expansion, and rapid recovery
  - **Transboundary collaboration**: transboundary coordination and data-sharing and joint-operation strategies



Thanks and we are hiring phd, postdoc, and RAs!!!

- **Cryosphere And Rivers (CAR Lab), Peking University**
  - Large-scale river water/sediment/carbon fluxes and river channel change in a warming climate
  - Cryosphere hazards and related societal impacts (infrastructure, water quality, etc)

水沙科学与地貌学

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