

Catastrophic Remobilization of Sediment During Extreme Rainfall Events

- M. Attal, E.L.S. Graf, H.D. Sinclair



THE UNIVERSITY of EDINBURGH

- E.L. Harvey



Durham
University

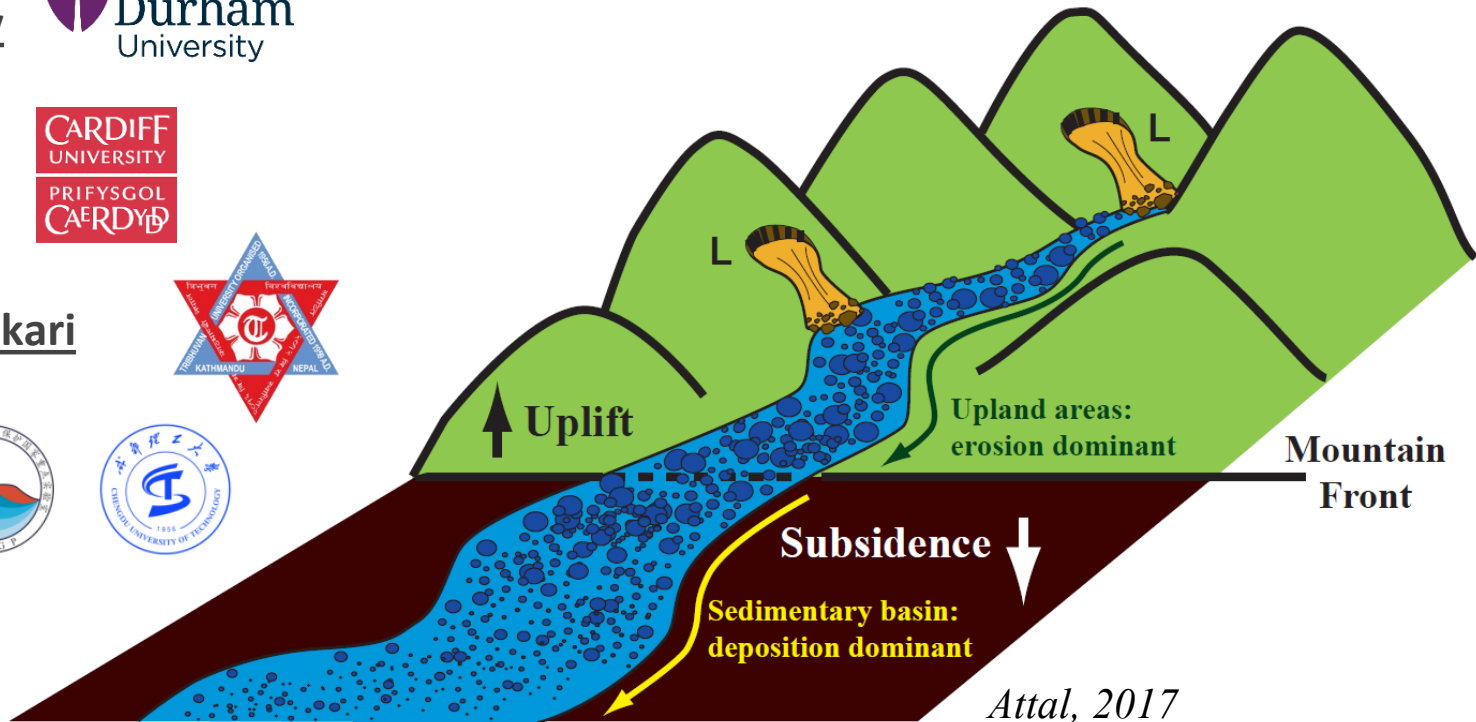
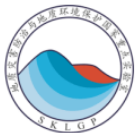
- T.C. Hales



- B. Raj Adhikari

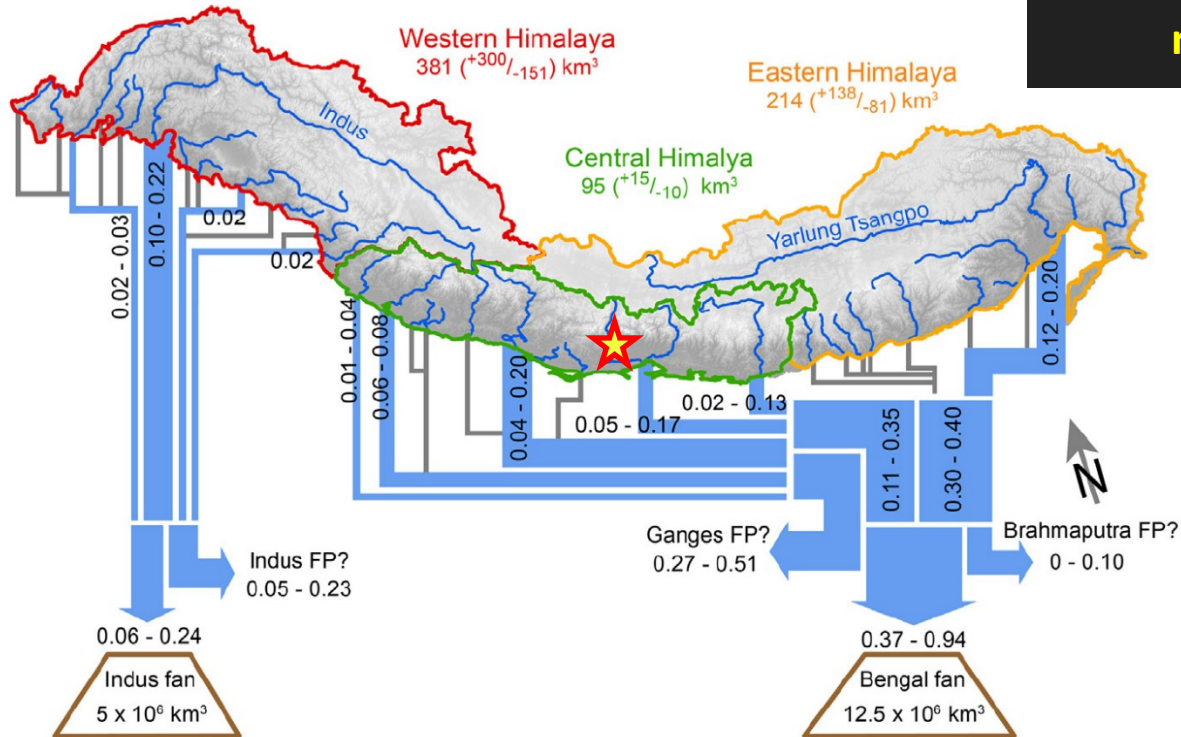


- X. Fan



Sediment production vs. sediment export

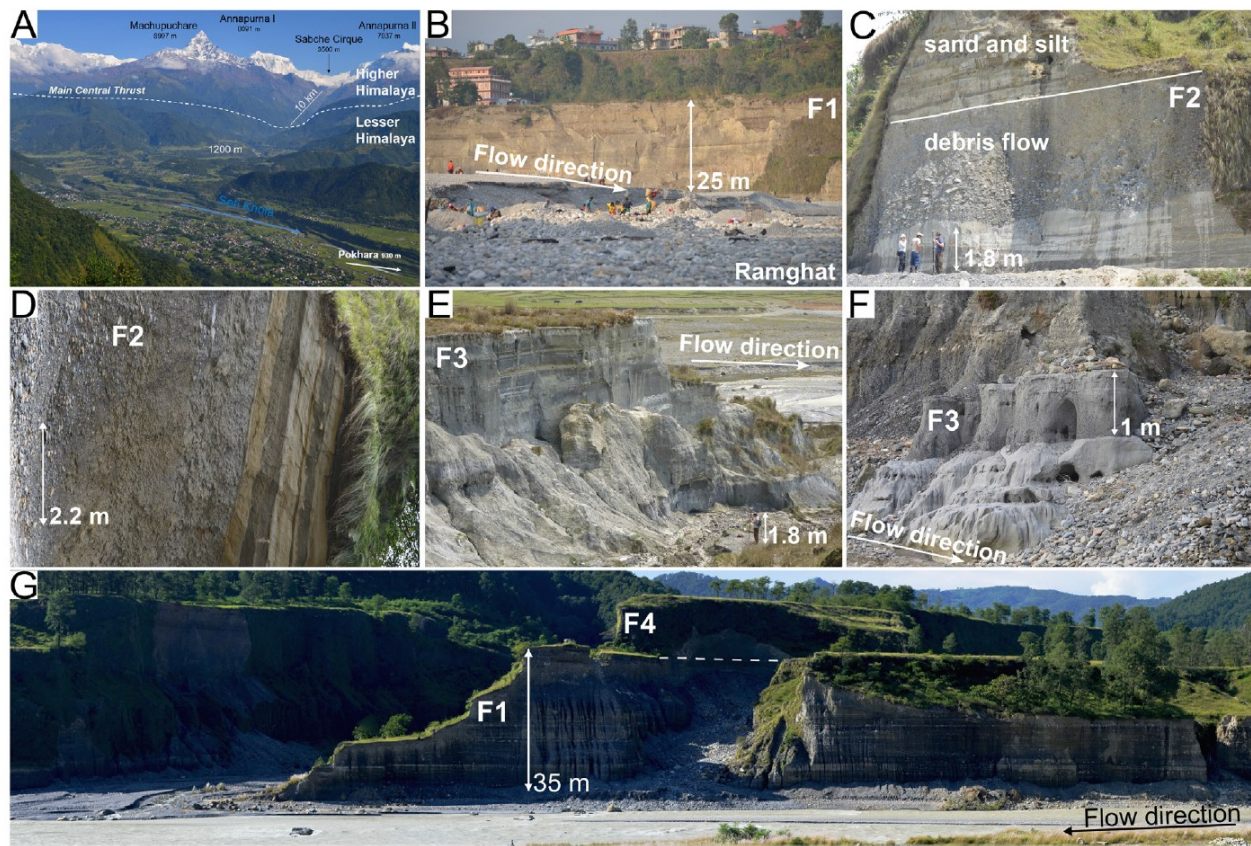
J.H. Blöthe, O. Korup / Earth and Planetary Science Letters 382 (2013) 38–46



There is excess sediment available for transport in modern mountainous landscapes

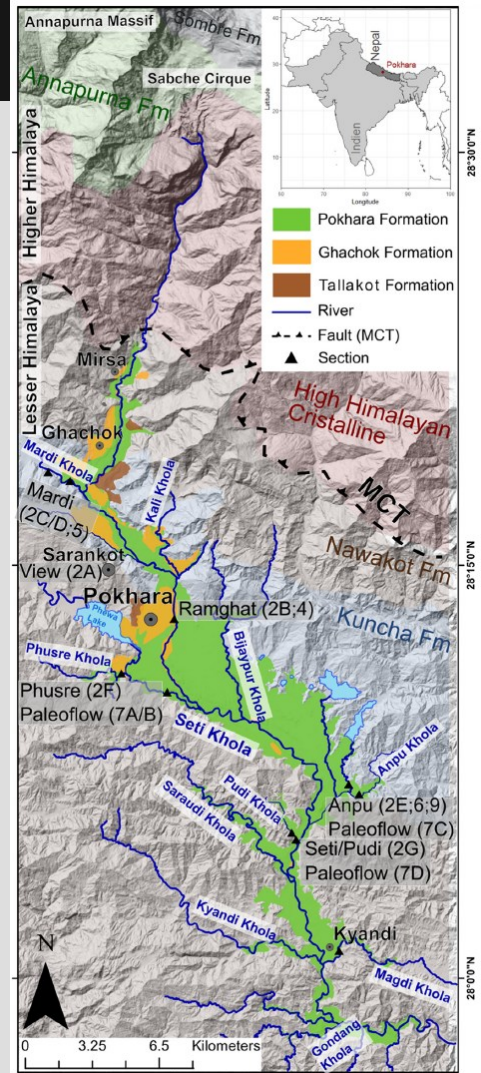
→ Sediment residence time within the mountain realm up to 100 ky

Sediment production vs. sediment export

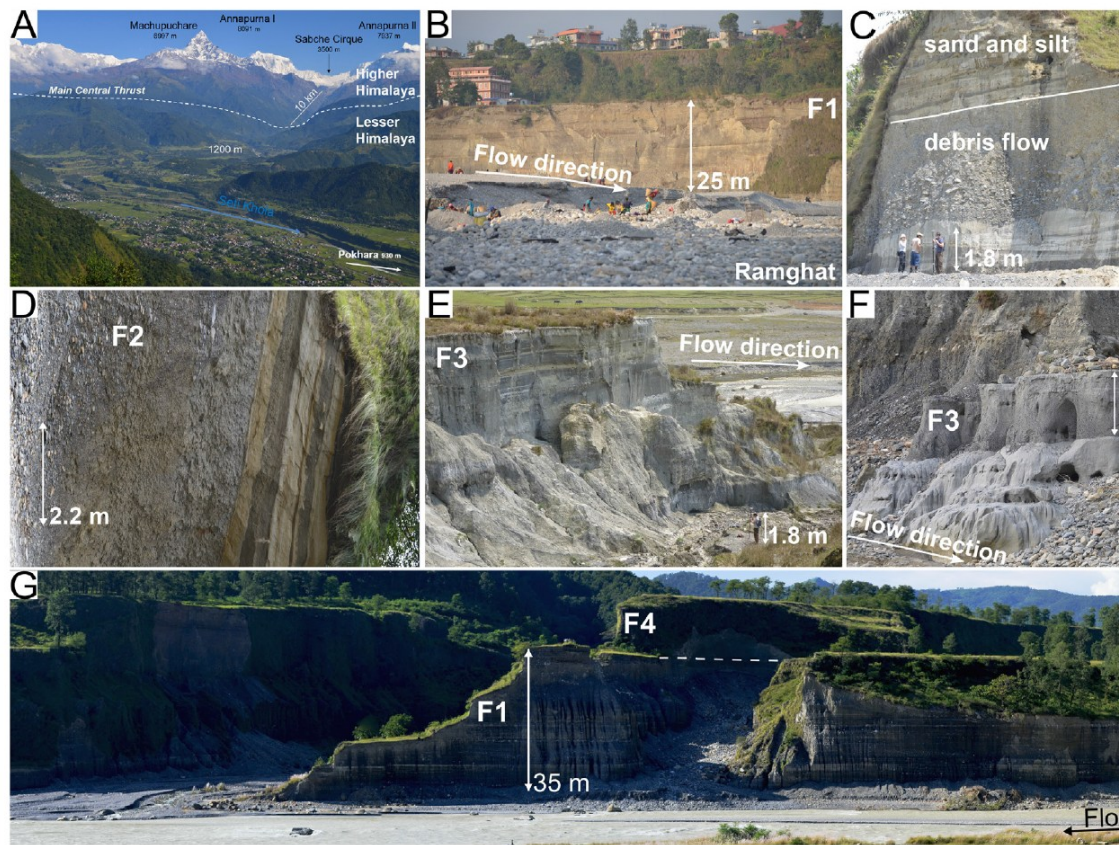


148-km² fan, 5 km³ of debris...

Stolle et al., 2017

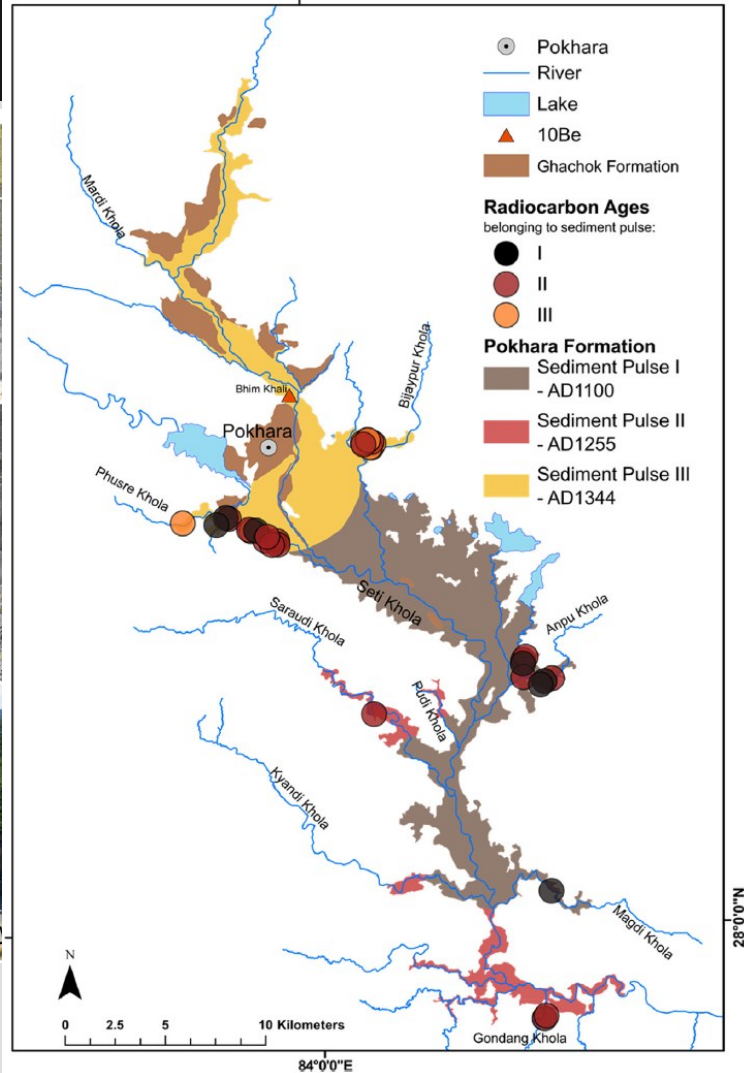


Sediment production vs. sediment export



... related to three great earthquakes

Stolle et al., 2017



Sediment production vs. sediment export



Hokkaido earthquake, 2018

The Guardian



Sediment production vs. sediment export



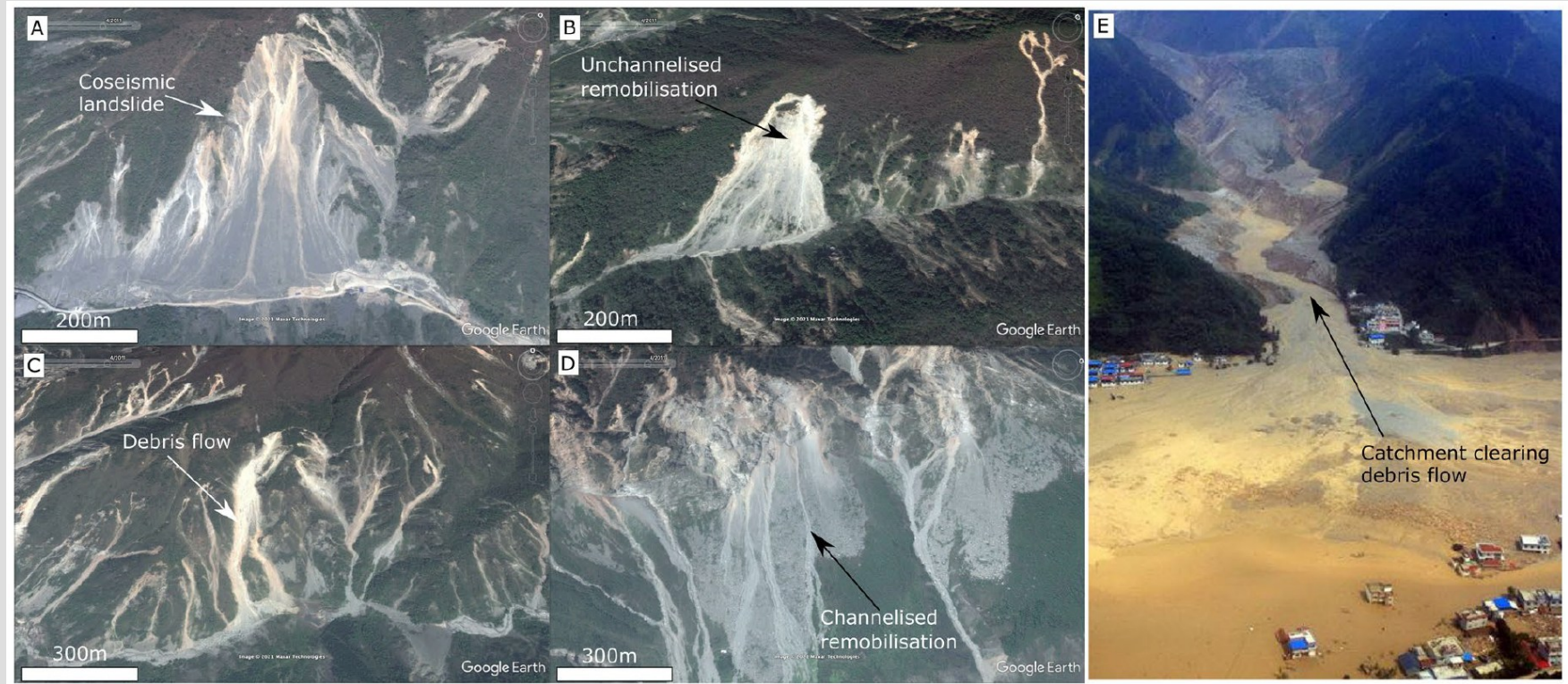
Wenchuan earthquake, 2008



www.chinasource.org/resource-library/chinasource-blog-posts/the-wenchuan-earthquake-10-years-later

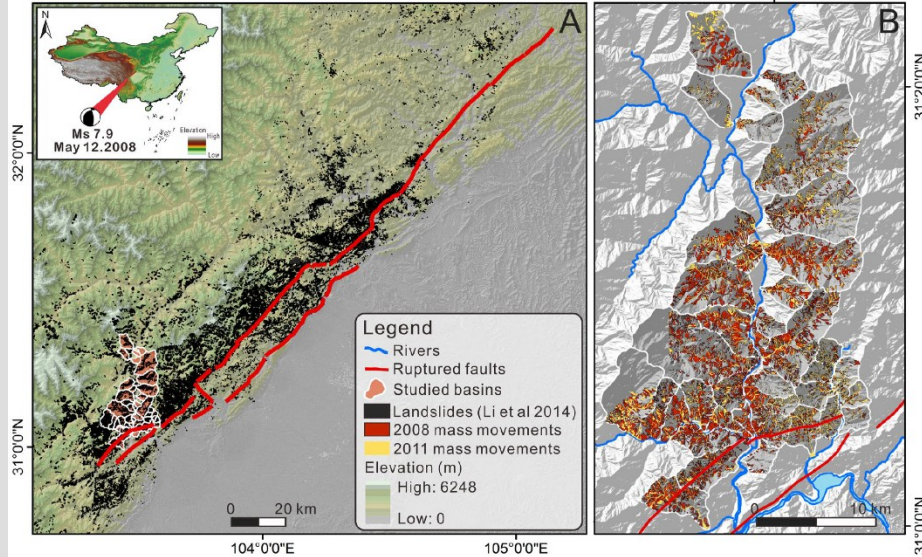
Sediment production vs. sediment export

Wenchuan earthquake, 2008



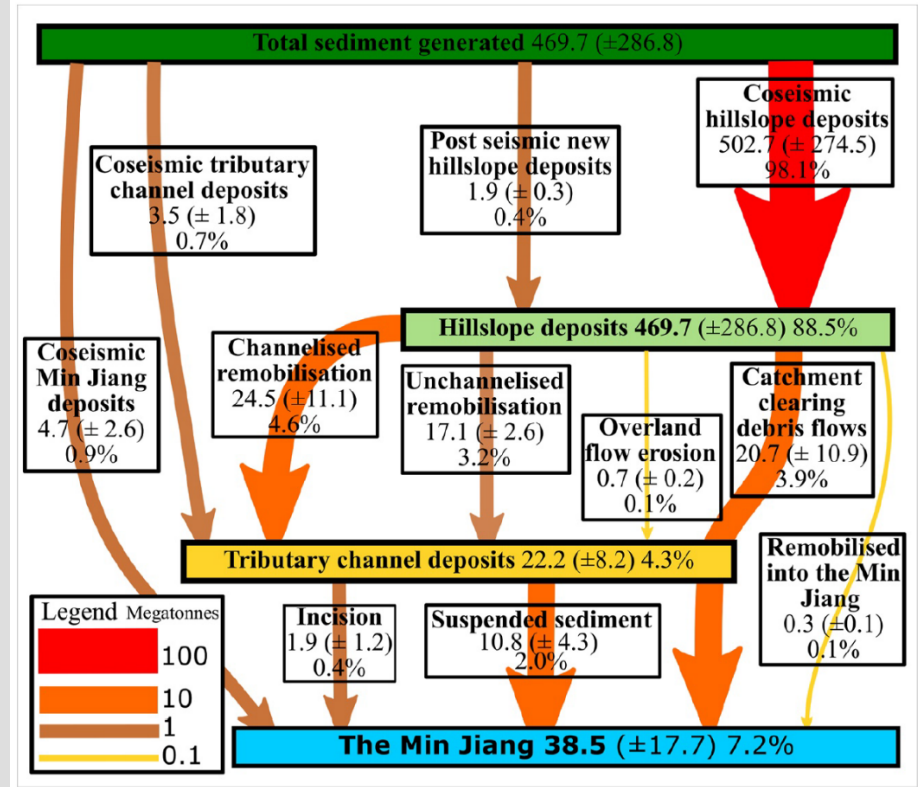
Sediment production vs. sediment export

2008-2018 sediment budget



→ There is excess sediment available for transport in modern mountainous landscapes

Wenchuan earthquake, 2008



Extreme rainfall events

Severe convective storms, atmospheric rivers, cloudbursts, Heavy-Precipitation Events are becoming more frequent. Events with precipitation >500 mm are recorded all over the world every year. When only water, it is problematic enough...

TOPICS EXPLORE PROJECTS

Dialogue Earth

NEWSLETTERS



In July 2021, Zhengzhou, a city of 13 million, saw almost as much rainfall in three days as it does in an average year (Image: Aly Song / Alamy)

Catastrophic Remobilization of Sediment During Extreme Rainfall Events

Severe convective storms, atmospheric rivers, cloudbursts, Heavy-Precipitation Events are becoming more frequent. Events with precipitation >500 mm are recorded all over the world every year. When only water, it is problematic enough...

Cloudburst in Dharali, India, August 2025

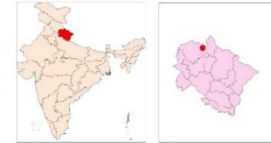
भारतीय अंतरिक्ष अनुसंधान संगठन, अंतरिक्ष विभाग
Indian Space Research Organisation, Department of Space

भारत सरकार / Government of India



Pre-Post Satellite Images -
Dharali Village, Uttarakshi District,
Uttarakhand, India.

Location Diagram



Interpretation

Satellite image acquired on 7th August, 2025 after the flood event. The impact is seen in Dharali village and surroundings depicting the disappearance of buildings, roads, plantations.

Data Source

Pre Event Image : Cartosat-3, 13th June 2024
Post Event : Cartosat, 07th August 2025

Frame Work

The best effort rapid mapping product is elaborated within a very short time frame, optimizing the available material, and has been quality checked as per NRSC/ISRO procedures. All geographic information has limitations due to scale, resolution, date and interpretation of the original source material. No liability concerning the content or the use thereof is assumed by the producer.
Note: When publishing this map as part of any report, source may be indicated as "NRSC (2025) - Flood inundated areas in Part of Uttarakhand State (as on 07.08.2025) - Map no : 2025/FL/UK/1/07082025, NRSC/ISRO, Hyderabad."

0 47.5 95 190 Meters



Disaster Management Support Group
National Remote Sensing Centre, ISRO
Dept. of Space, Govt. of India
Hyderabad-500 037
E-Mail: flood@nrsr.gov.in
www.nrsr.gov.in



Catastrophic Remobilization of Sediment During Extreme Rainfall Events

St-Martin-Vesubie, France, Oct. 2020

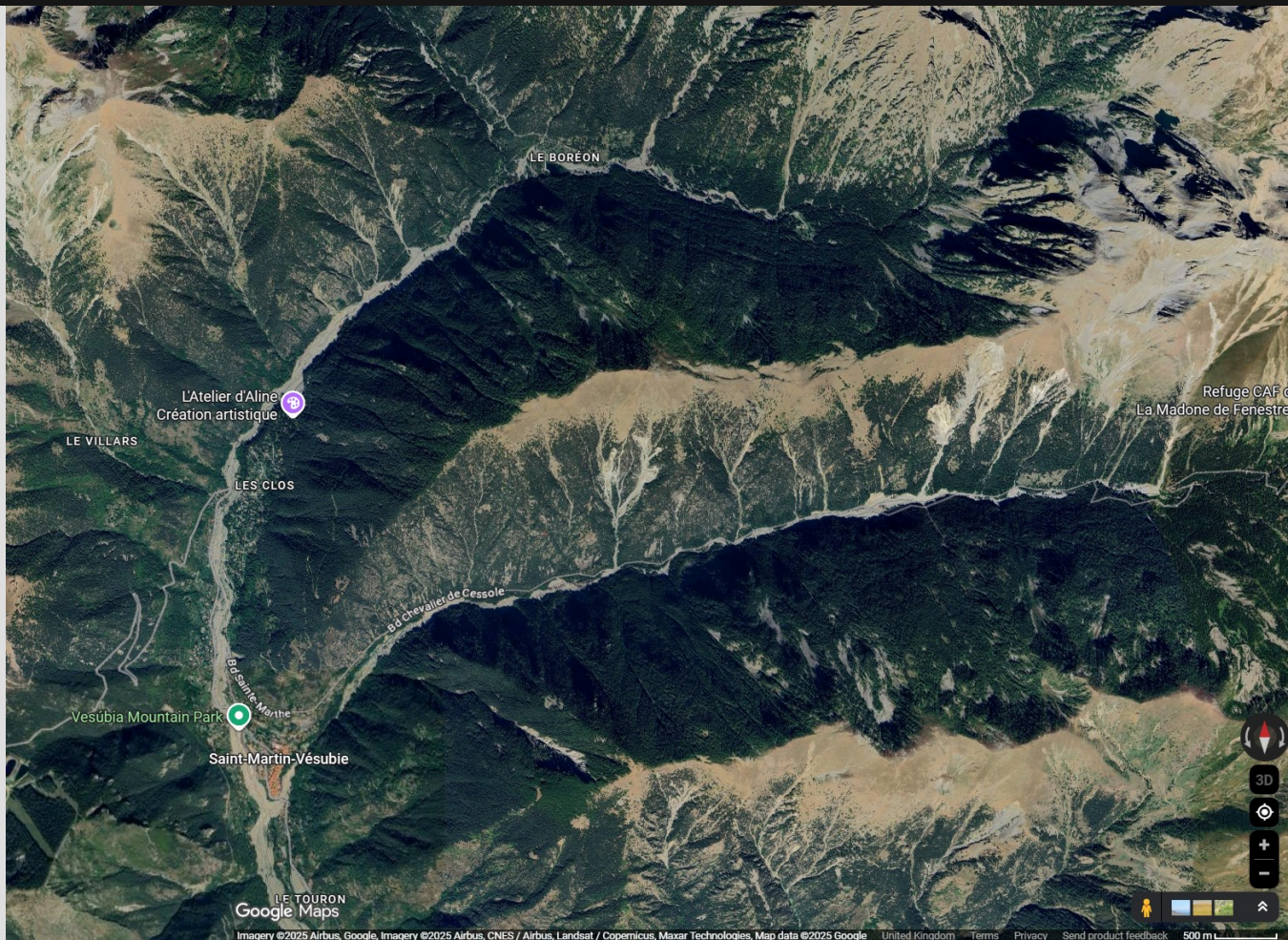


Precipitation > 500 mm / 24h

18 deaths,
€1bn losses,
4 Mm³ sediment mobilized
(Liebault et al., 2024)



Catastrophic Remobilization of Sediment During Extreme Rainfall Events



Catastrophic Remobilization of Sediment During Extreme Rainfall Events



St-Martin Vesubie, France, 2020

Precipitation > 500 mm / 24h



Catastrophic Remobilization of Sediment During Extreme Rainfall Events

St-Martin Vesubie, France, 2020

Precipitation > 500 mm / 24h



Catastrophic Remobilization of Sediment During Extreme Rainfall Events



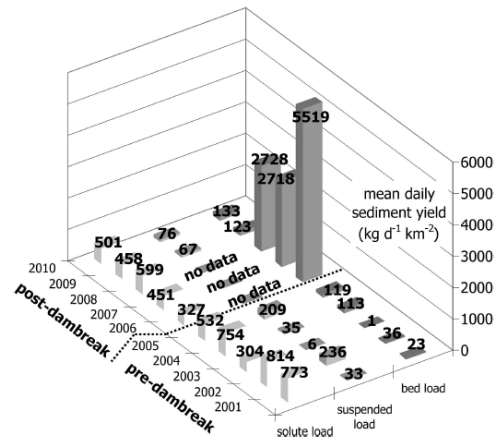
B



C

Morche and Schmidt, 2012
Partnach River (Reintal Valley,
Bavarian Alps)

PRE- AND POST-DAMBREAK SEDIMENT TRANSPORT IN THE PARTNACH RIVER



Catastrophic Remobilization of Sediment



Alpinemag



La Berarde,
Ecrins Massif

The 1892 church no longer exists, nor does this street, nor some of the houses visible in this 2022 photo. ©JC

Helicopters Evacuate Flooded Village in the French Alps

June 21, 2024

Angela Benavides

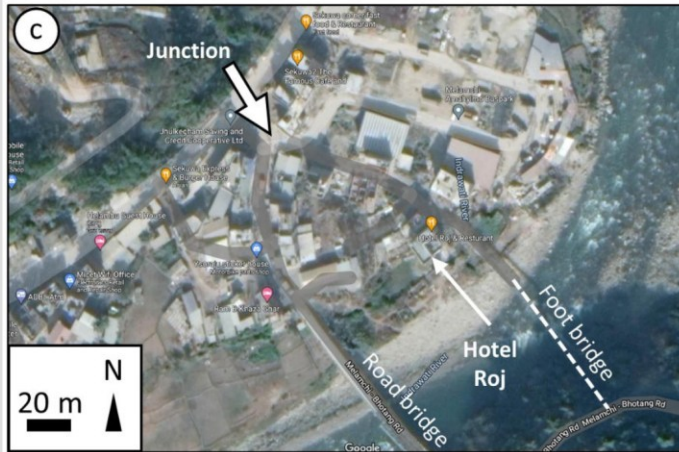
Alps



La Berarde today. Photo: Sécurité Civile

Catastrophic Remobilization of Sediment During Extreme Rainfall Events

Melamchi, Nepal, June 2021



Graf et al., 2024

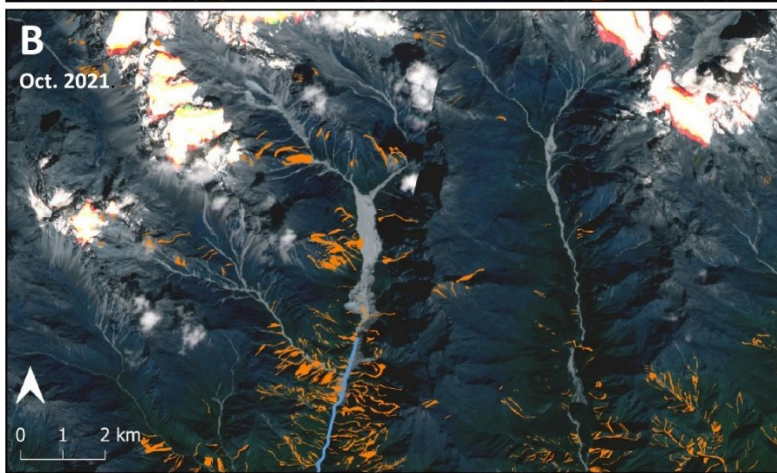
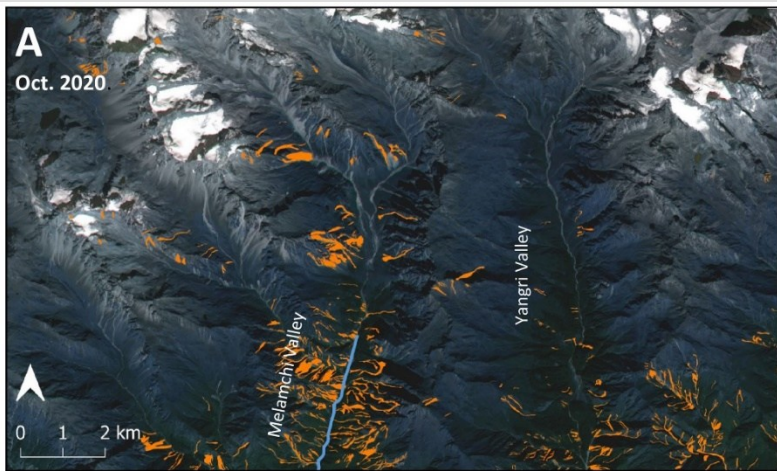
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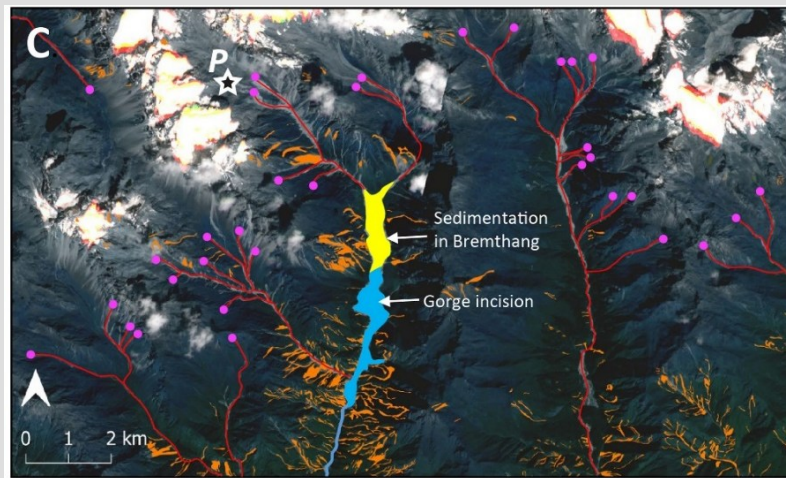


Catastrophic Remobilization of Sediment During Extreme Rainfall Events

Graf et al., 2024



Melamchi, Nepal, June 2021



No direct link to co-seismic landslides (Gorkha 2015): 64% of all the sediment came from Bremthang (Chen et al., 2025)

Catastrophic Remobilization of Sediment During Extreme Rainfall Events



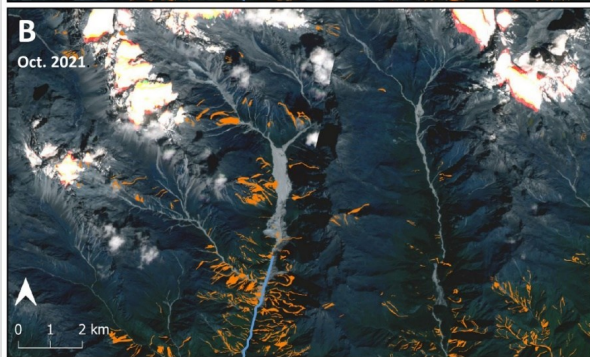
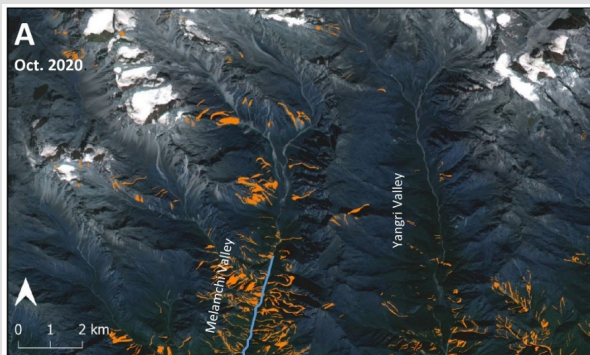
Melamchi, Nepal, 2021

Photos courtesy Basanta Raj Adhikari

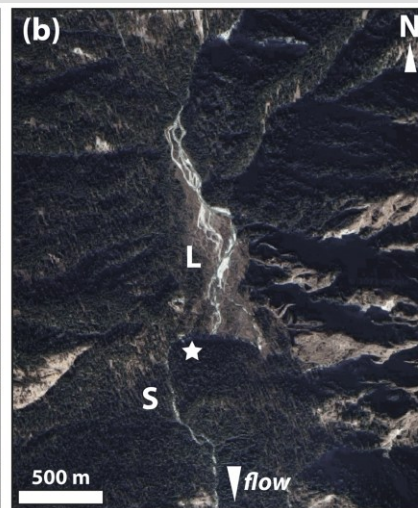
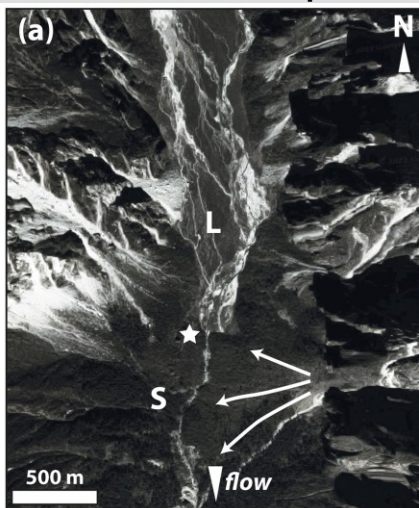


Beware:

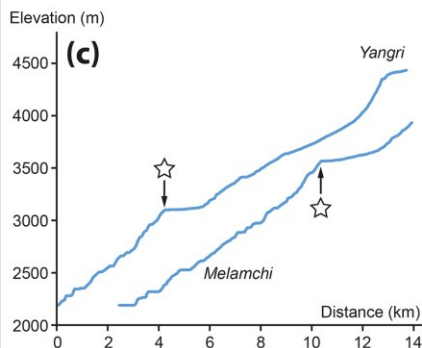
- Extreme precipitation
- “Sediment bombs”!



Melamchi, Nepal, June 2021



- Points of failure?
- Engineering solutions?
- Early warning systems?



Beware:

- Extreme precipitation
- “Sediment bombs”!
- Engineering can make things worse...

RESEARCH ARTICLE

ESPL WILEY

The impact of sediment flux and calibre on flood risk in the Kathmandu Valley, Nepal

Saraswati Thapa^{1,2} | Hugh D. Sinclair¹ | Maggie J. Creed³ | Simon M. Mudd¹ | Mikael Attal⁴ | Alistair G. L. Borthwick^{4,5} | Bhola N. Ghimire² | C. Scott Watson⁶

Water Resources Research

RESEARCH ARTICLE

10.1029/2024WR037742

Key Points:

- Inclusion of sediment processes is very important in predicting the effect of embankments on river flood risk
- For the embanked Nakkhu, predicted

Sediment Transport and Flood Risk: Impact of Newly Constructed Embankments on River Morphology and Flood Dynamics in Kathmandu, Nepal

Saraswati Thapa^{1,2}, Hugh D. Sinclair¹, Maggie J. Creed³, Alistair G. L. Borthwick^{4,5}, C. Scott Watson⁶, and Manoranjan Muthusamy⁷



Kathmandu, Nepal, Sep. 2024
Precipitation up to 320 mm / 24h



Figure 1 | Flooding of the Nakkhu River in Lalitpur, Nepal. Record rainfall in late September caused extreme flooding of the Nakkhu River, a small river in the Kathmandu Valley. The water flowed over the embankments that are designed to mitigate the risk of flooding, seen here in the middle of the river.

Environmental science

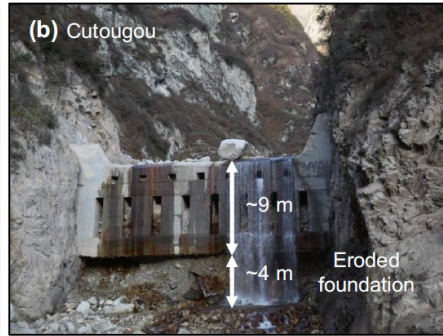
Shifting sands threaten flood-mitigation measures

Kristen L. Cook

land available for urbanization, municipalities often turn to river engineering, building embankments that are designed to diminish this risk. But flooding is a multifaceted problem, and seemingly small factors can have dire consequences. Writing in *Water Resources Research*, Thapa et al.² modelled the effects of embankments on flooding of the Nakkhu River, a small river in the Kathmandu Valley, and found that sediment movement has a profound impact on the effectiveness of these

Cook, 2024

Identification and mitigation of risks



Landslides (2022)19:913–928
DOI 10.1007/s10346-021-01809-z
Received: 6 April 2021
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Technical Note

Jian He · Limin Zhang · Ruilin Fan · Shengyang Zhou · Hongyu Luo · Dalei Peng

Evaluating effectiveness of mitigation measures for large debris flows in Wenchuan, China

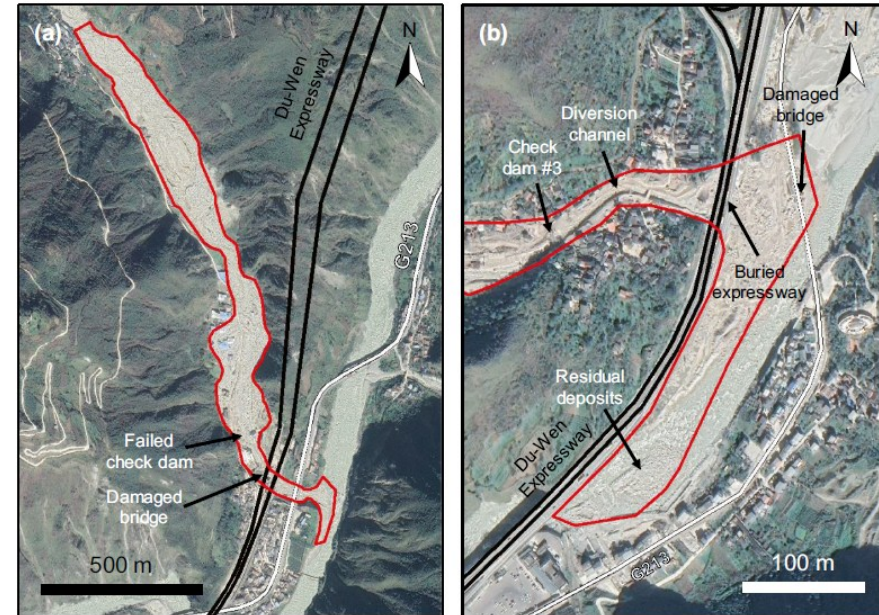


Fig. 2 Observed distribution of deposits in a Banzigou and b Cutougou (satellite image: Google Earth shot by CNES/Airbus in October 2019)

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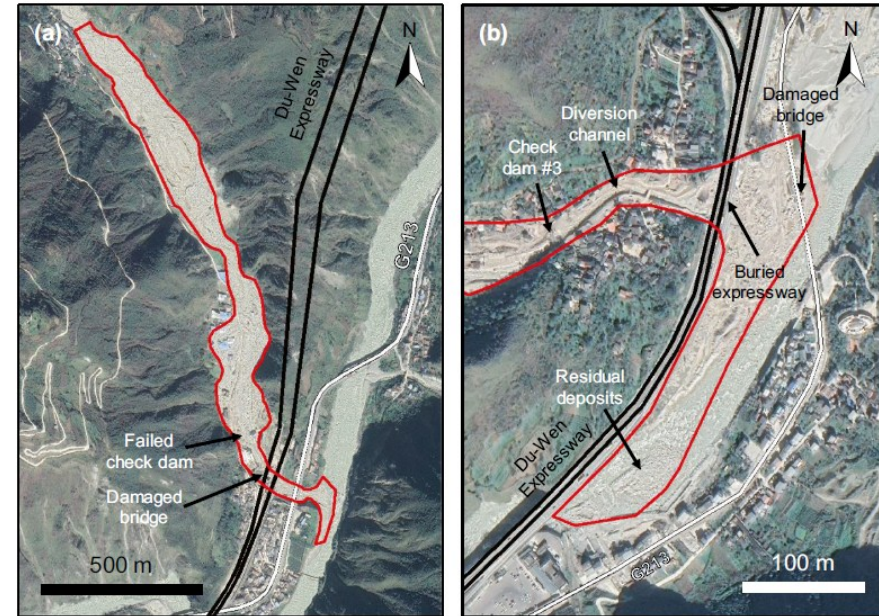
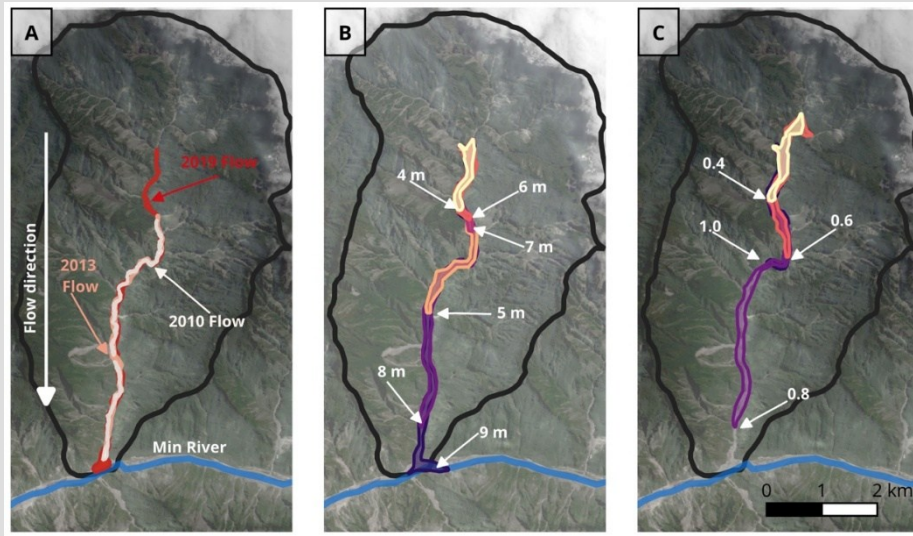


Fig. 2 Observed distribution of deposits in **a** Banzigou and **b** Cutougou (satellite image: Google Earth shot by CNES/Airbus in October 2019)

Identification and mitigation of risks

Harvey et al., 2025, in press



(A) debris flows in the Luoquanwan catchment.
(B-C) simulations with changing depth of erodible sediment and degree of saturation, respectively

→ Availability of sediment is the main control on whether a debris flow becomes “catastrophic” or not.
Are check dams “fuelling” these debris flows?

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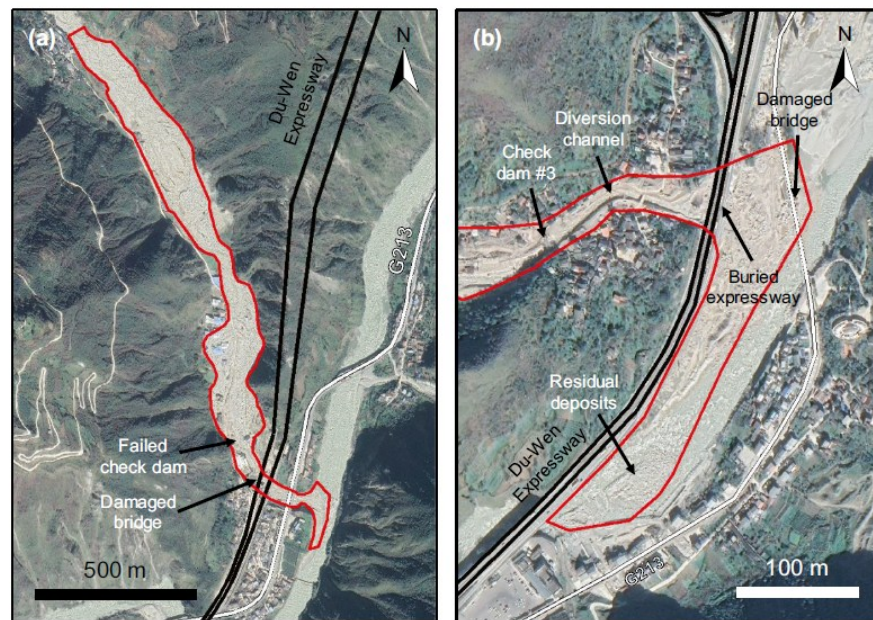


Fig. 2 Observed distribution of deposits in a Banzigou and b Cutougou (satellite image: Google Earth shot by CNES/Airbus in October 2019)

SUMMARY

- A very small fraction of the sediment produced by earthquake and storms is exported in the following decade. Glacial retreat also makes glacial sediment stores available for erosion and transport → **Sediment is widely available in modern mountainous landscapes.**
- Extreme rainfall events are becoming more frequent.
- They can cause catastrophic flooding, but also mobilize huge amounts of sediment, **including sediment stores that have been stable historically.**

Helicopters Evacuate Flooded Village in the French Alps

June 21, 2024

Angela Benavides

Alps

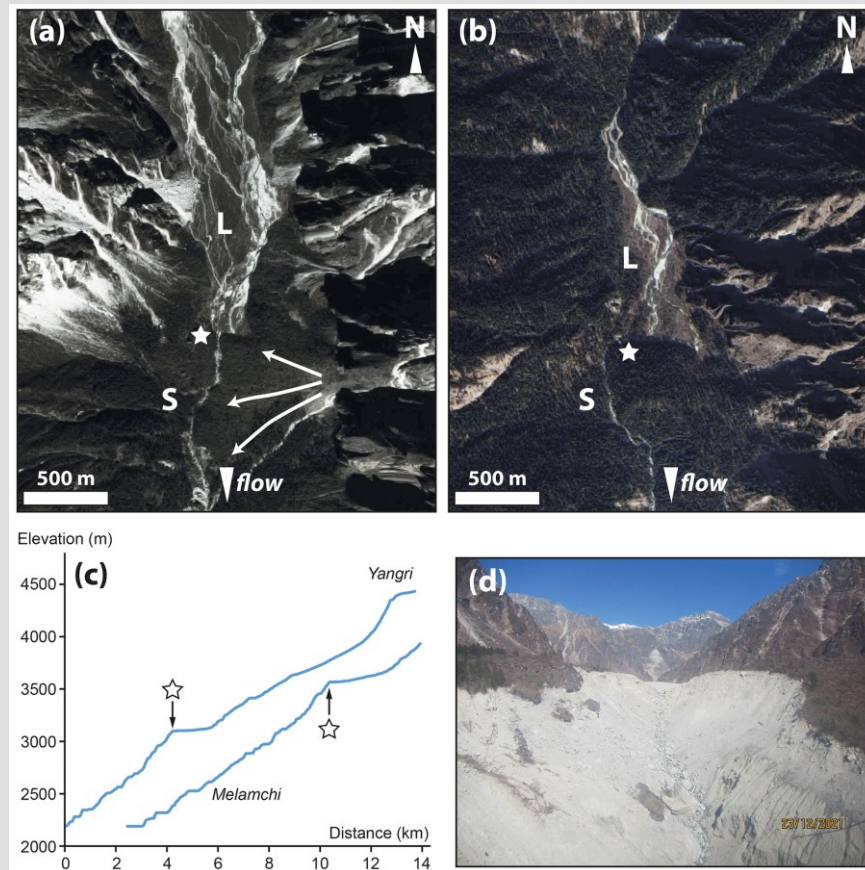


La Berarde today. Photo: Sécurité Civile

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- Extreme rainfall events are becoming more frequent.
- They can cause catastrophic flooding, but also mobilize huge amounts of sediment, **including sediment stores that have been stable historically.**
- Mitigation relies on predicting extreme rainfall events, identifying “sediment bombs” and ensuring engineering measures are effective on the long-term.

谢谢



Graf et al., 2024

