Where does all the gravel go? Tracking landslide sediment from the 2015 Gorkha earthquake along the Kosi River, Nepal

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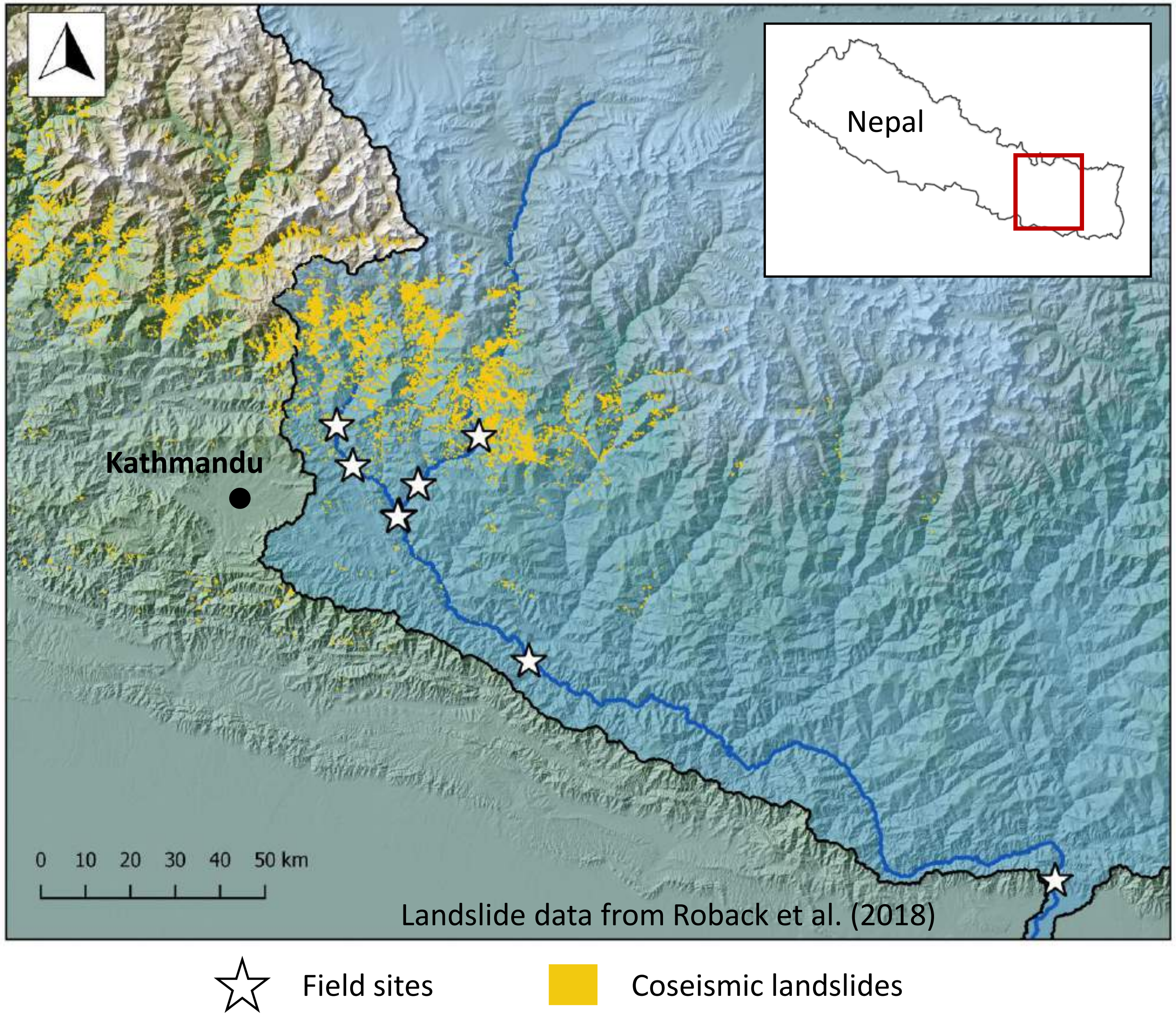
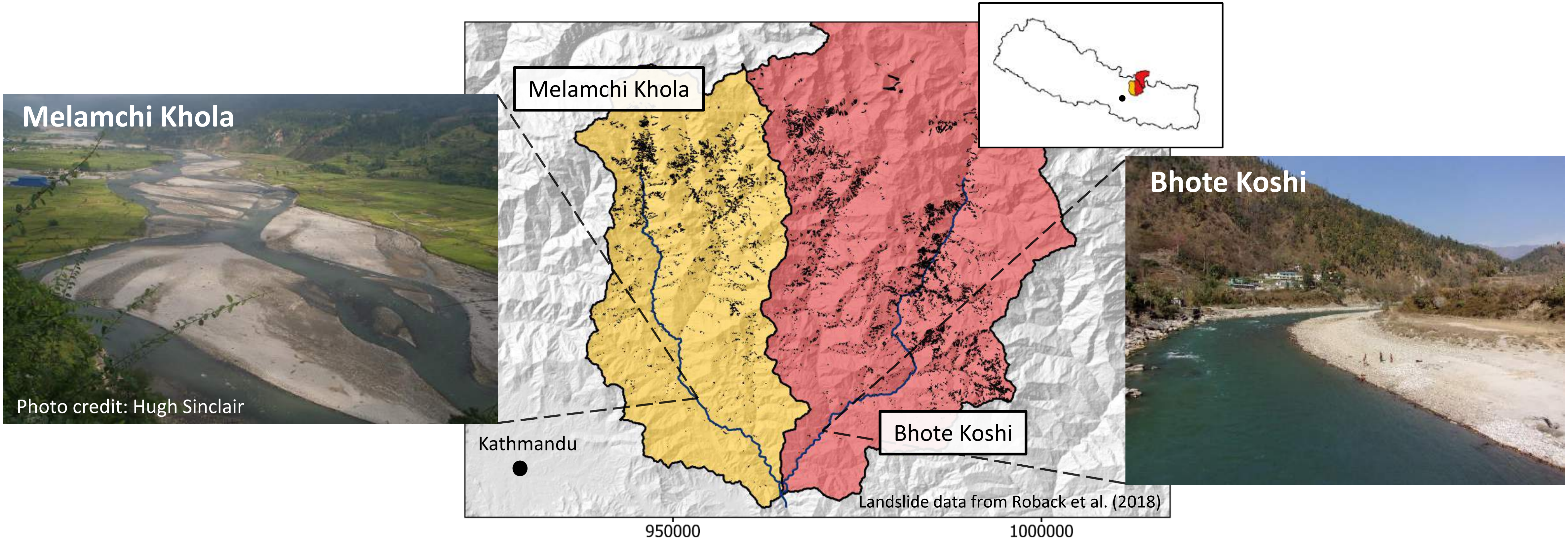
Why are we tracking landslide sediment?

- Landslides triggered by the 2015 Gorkha (Nepal) earthquake supply **large amounts of sediment** to rivers. Given the significant amounts of channel aggradation observed in the aftermath of similar events (e.g. Chen and Petley, 2005; Huang and Fan, 2013), this may result in channel bed aggradation at the Himalayan mountain front, resulting in **higher flood risk** in future years (Dadson et al., 2004; Sims and Rutherfurd, 2017).
- To test this hypothesis, we track the **gravel fraction** of coseismic landslide sediment (covering gravel- to boulder-size sediment) by mapping from satellite imagery and measuring channel cross-sections at 8 field sites along the Kosi River.

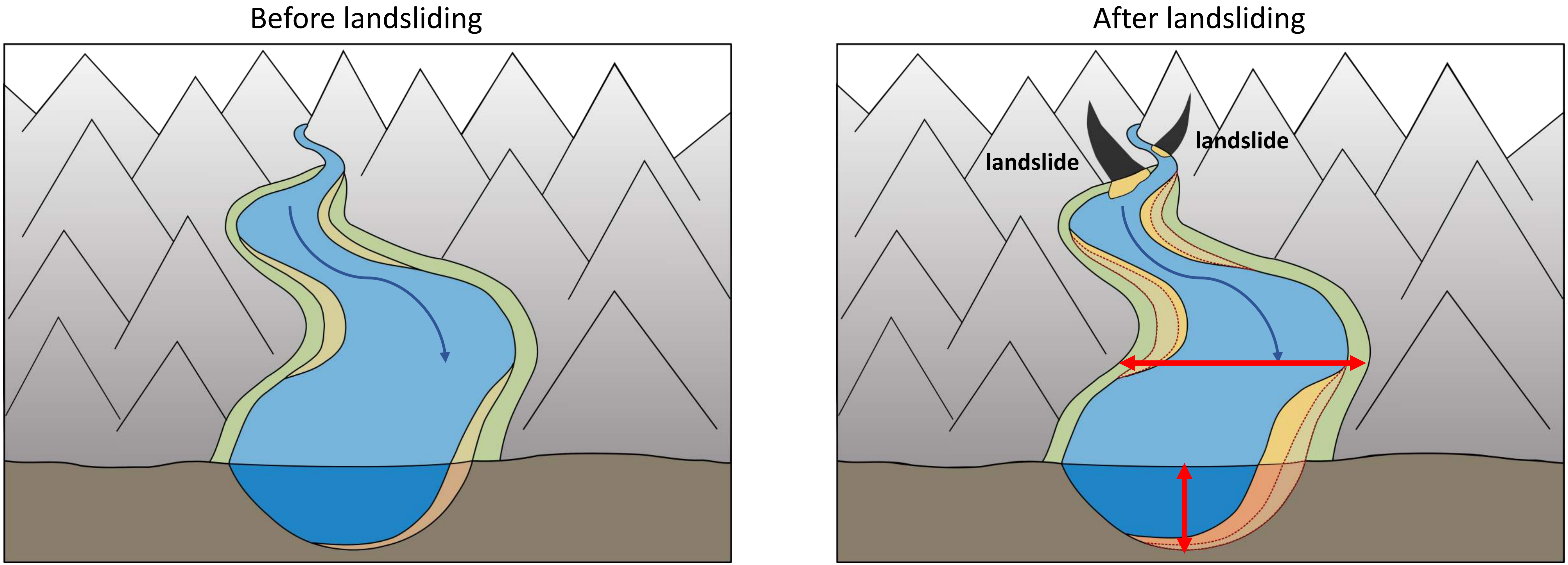


Zooming in on the landslide areas



- We focus on the upper parts of the Kosi catchment which are heavily affected by landsliding and are expected to show the first changes. Coseismic landslides are shown in black on the map.
- The two studied rivers have very different morphology (see photos) – we want to see how these different rivers respond to the input of landslide sediment.

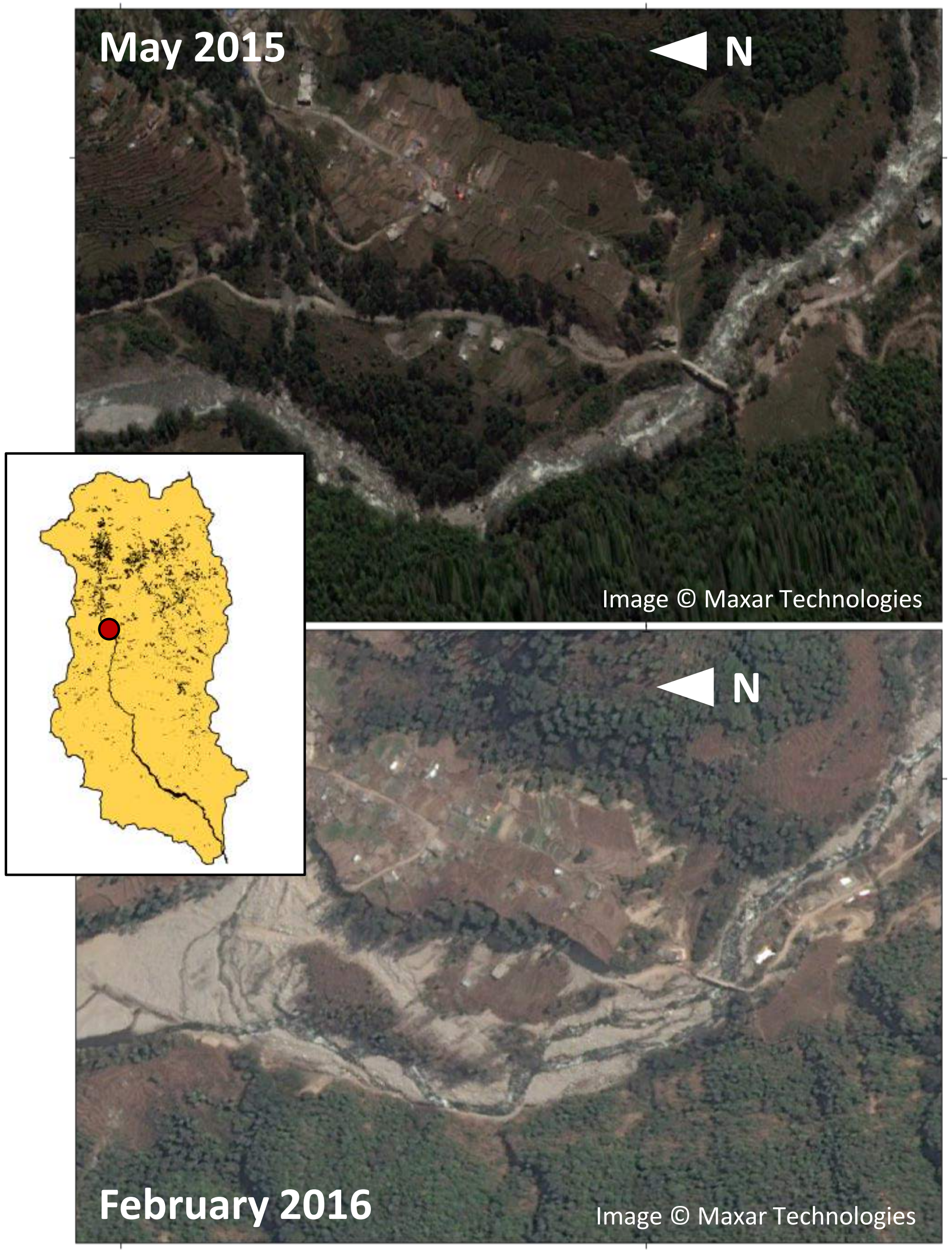
What changes do we expect to see?



- To detect response to landsliding, we are looking for changes in the **amount of gravel** present in the river channel.
- In plan view, we expect gravel bars to become **more extensive**, and in profile view, we expect more gravel to **accumulate on the channel bed**.
- Here, we focus on detecting changes in **plan view**.

Mapping channel change

- We first map any changes in the extent of gravel bars over time to identify potential sites of landslide sediment input.
- Gravel bars are mapped as polygons using Google Earth imagery for each year from 2012-2019, always documenting changes after each monsoon.
- We have mapped gravel bars along 60 km of both rivers.



Satellite imagery of Timbu in May 2015 (top; before major landsliding) and in February 2016 (bottom). There is a clear and dramatic increase in the amount of gravel present in the channel between these dates, mainly sourced from the tributary channel to the east (top of the image).

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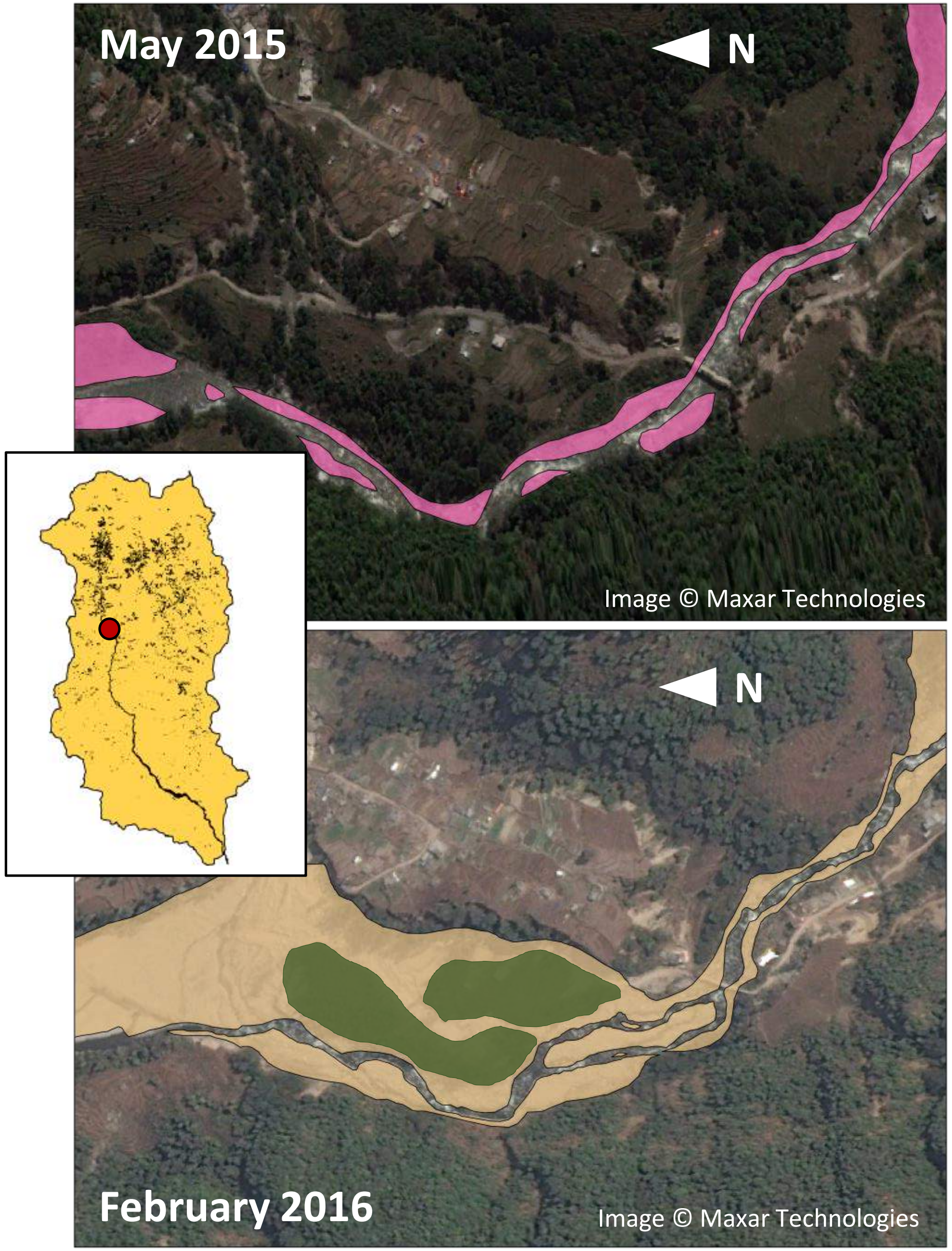
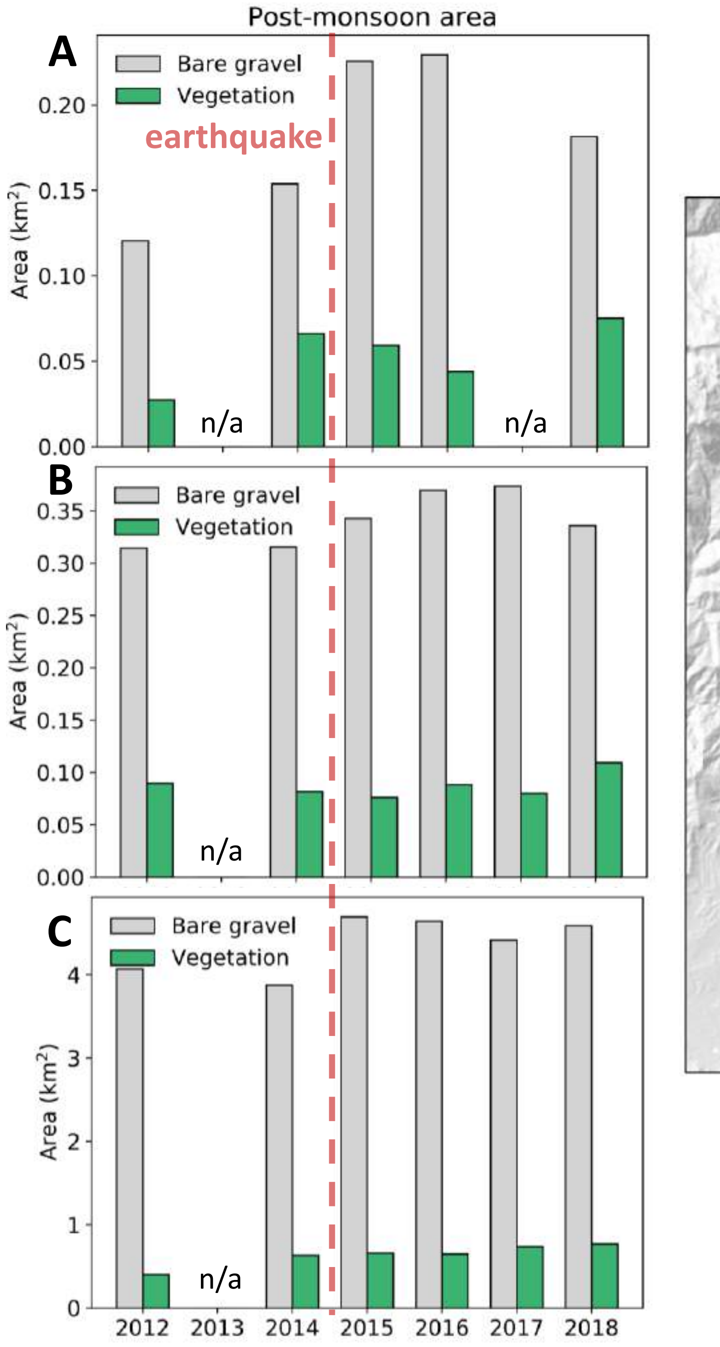


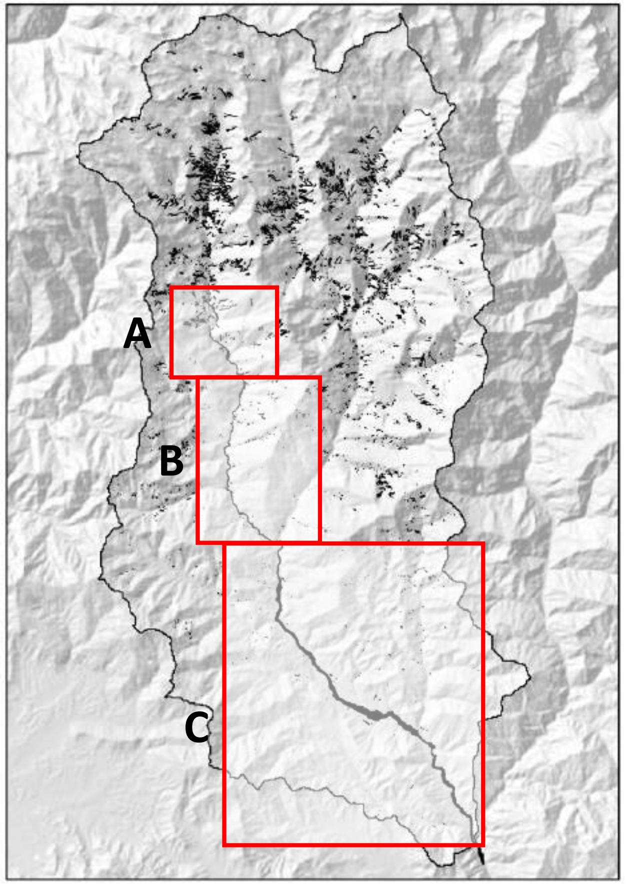
Gravel bar polygons around Timbu in May 2015 (pink; before major landsliding) and in February 2016 (yellow). There is a clear and dramatic increase in the amount of gravel present in the channel between these dates, mainly sourced from the tributary channel to the east (top of the image). Vegetation is mapped separately (green) and subtracted from the total bar area to obtain only bare gravel area.

Mapping channel change within reaches

- All reaches show a clear increase in sediment area following the earthquake.
- There is some indication of a gradual decrease following the initial post-earthquake pulse



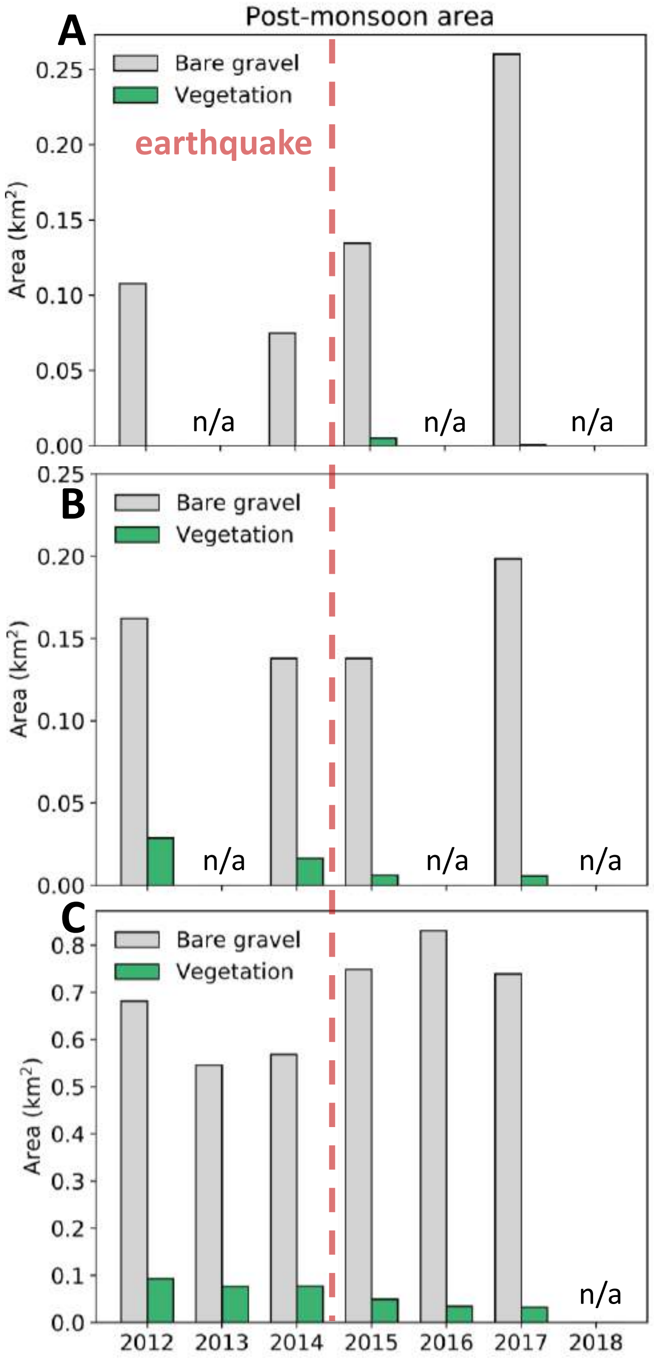
Melamchi Khola

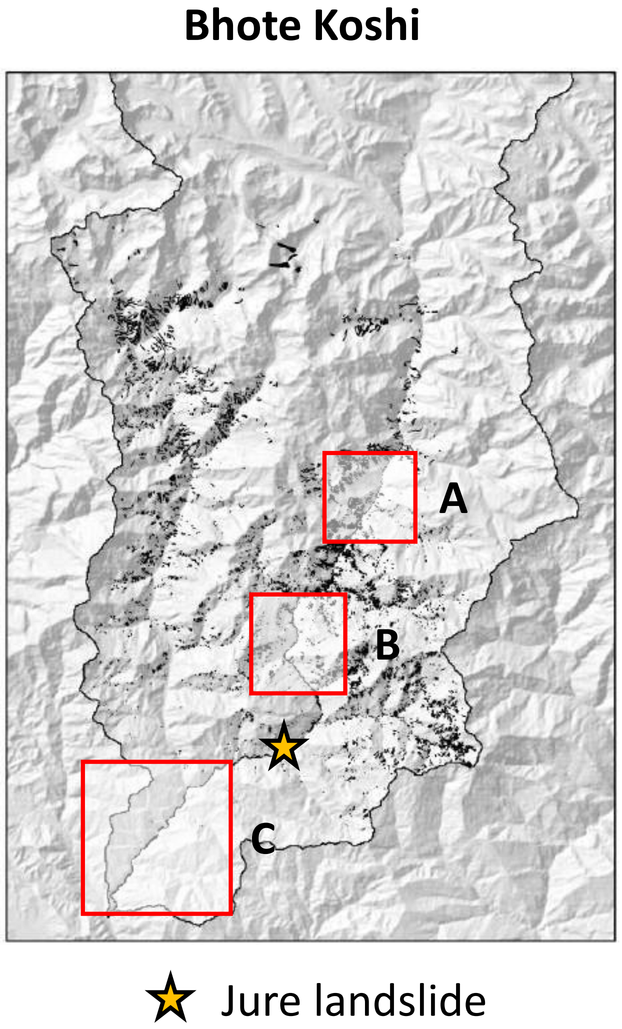


Gravel area over time calculated for three reaches of the Melamchi Khola. Years with insufficient coverage are marked n/a. Dashed red line shows approximate occurrence of Gorkha earthquake. Coseismic landslides are shown in black on map.

Mapping channel change within reaches

- The signal is more mixed in the Bhote Koshi, although all reaches show an overall increase in sediment area in the post-earthquake years compared to the pre-earthquake years
- The signal in reach C is likely partly due to the 2014 Jure landslide, which dammed the river completely.



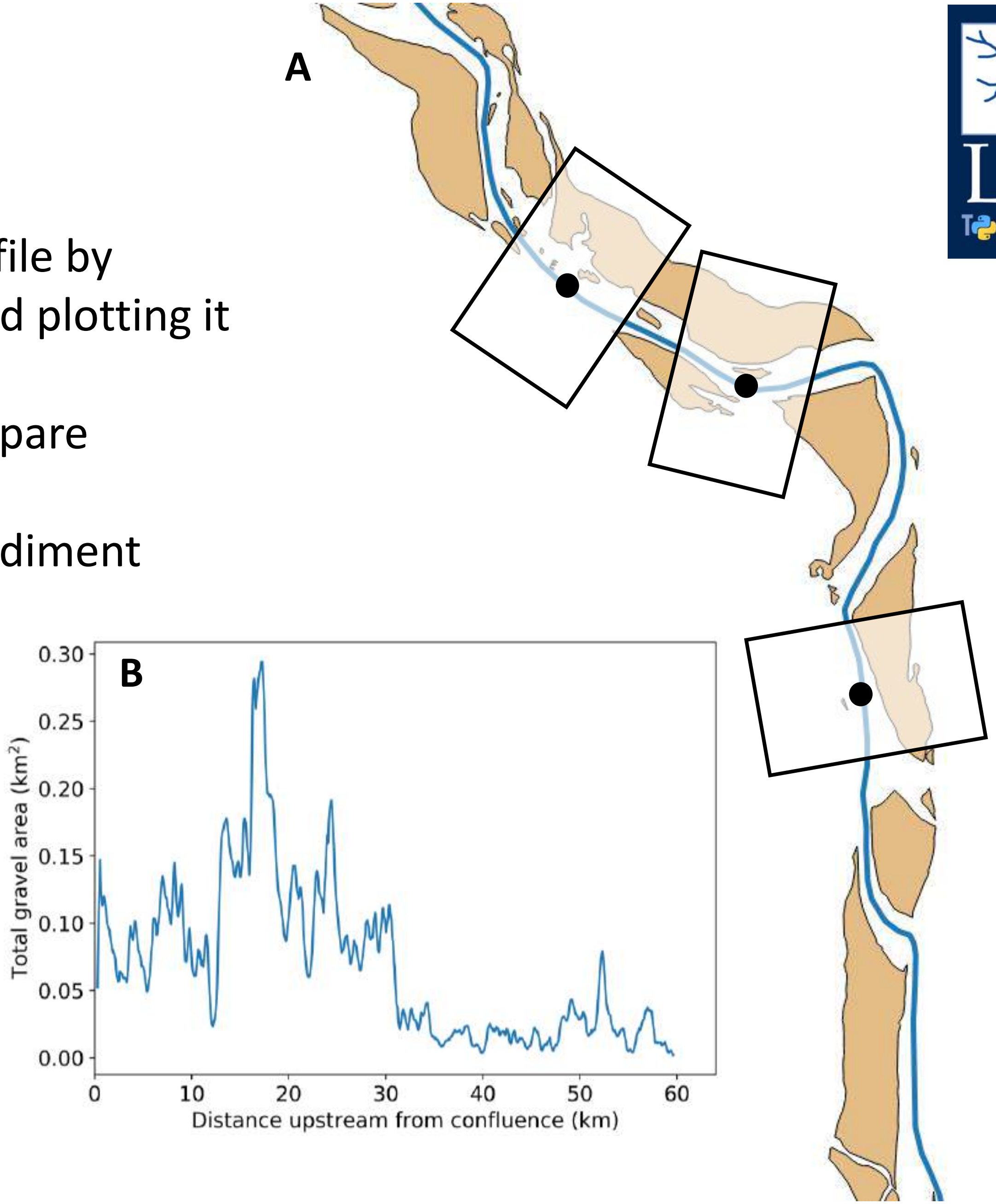


Gravel area over time calculated for three reaches of the Bhote Koshi. Years with insufficient coverage are marked n/a. Dashed line shows approximate occurrence of Gorkha earthquake. Yellow star on map indicates 2014 Jure landslide. Coseismic landslides are shown in black.

Mapping channel change along the profile

- We also explore gravel area along the longitudinal profile by calculating the gravel area within a moving window and plotting it as a function of distance along the river channel.
- We do this for each year between 2012-2019 and compare between the years.
- This will provide a clearer picture of where zones of sediment input are located and whether they move over time.

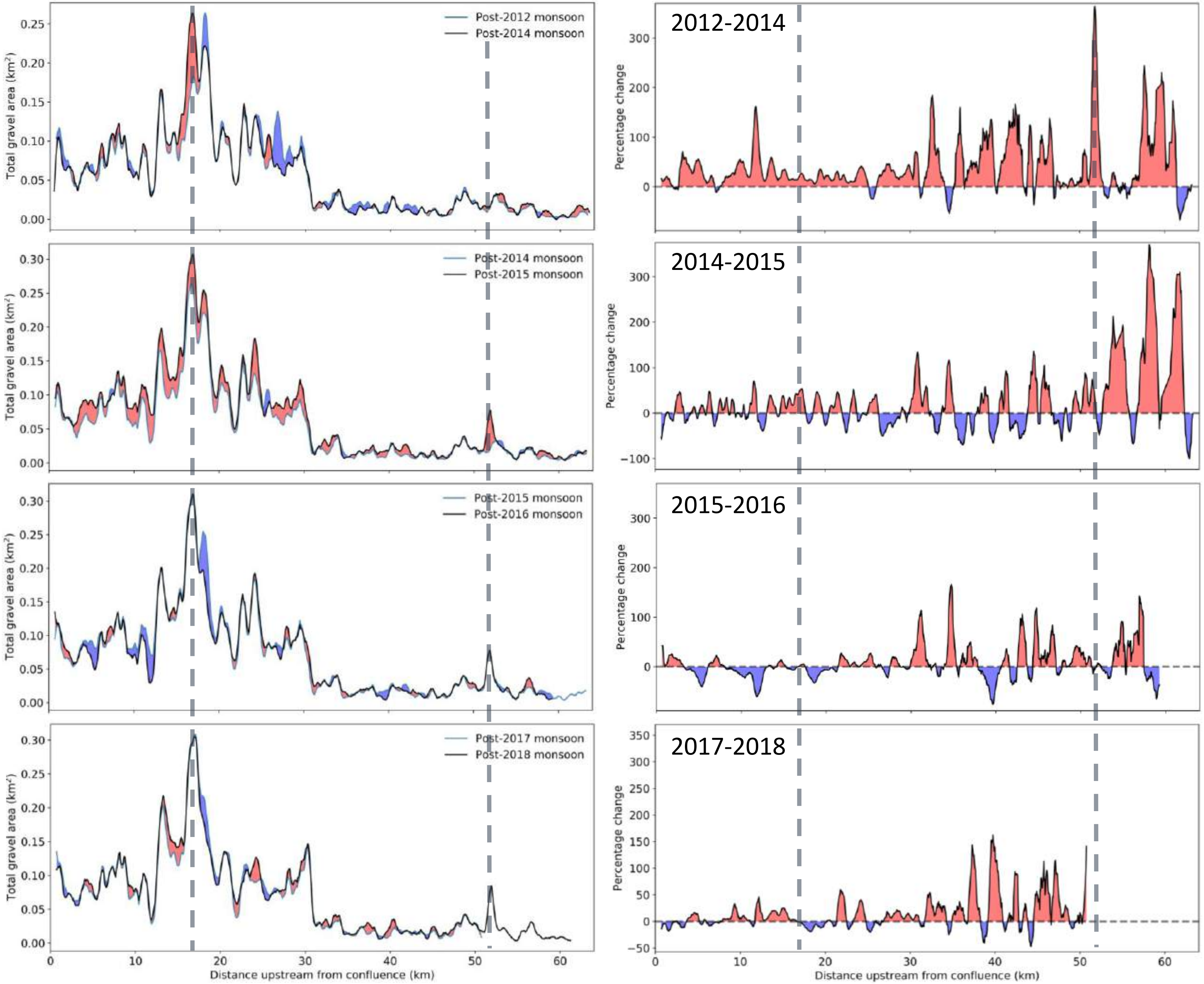
Using the LSDTopoTools-lsdtopytools framework, the total gravel area is calculated within a moving window every 500 m along the channel (A shows example moving windows). We then plot this as a function of distance along the channel (B).



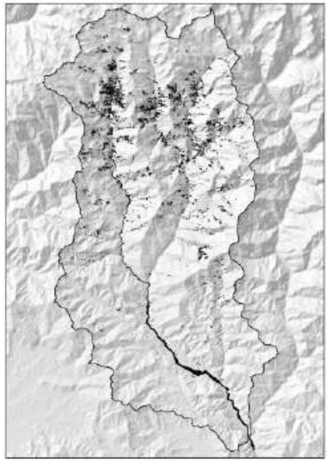
Melamchi Khola

- Clear increase in sediment present in channel following the 2015 monsoon – most likely linked to input from coseismic landslide sediment.
- No clear evidence for large-scale downstream transport of sediment.

Comparison of sediment exposed in the Melamchi Khola channel between different years: Absolute change (left); percentage change (right). Red shading indicates an increase; blue shading a decrease. Dashed lines highlight position of peaks over time.



Increase
Decrease

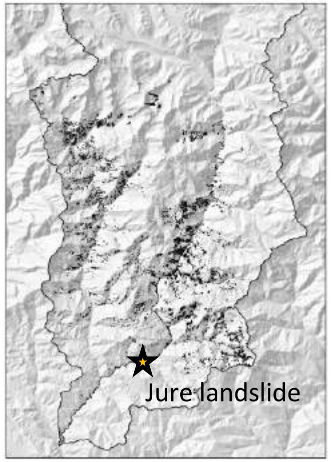


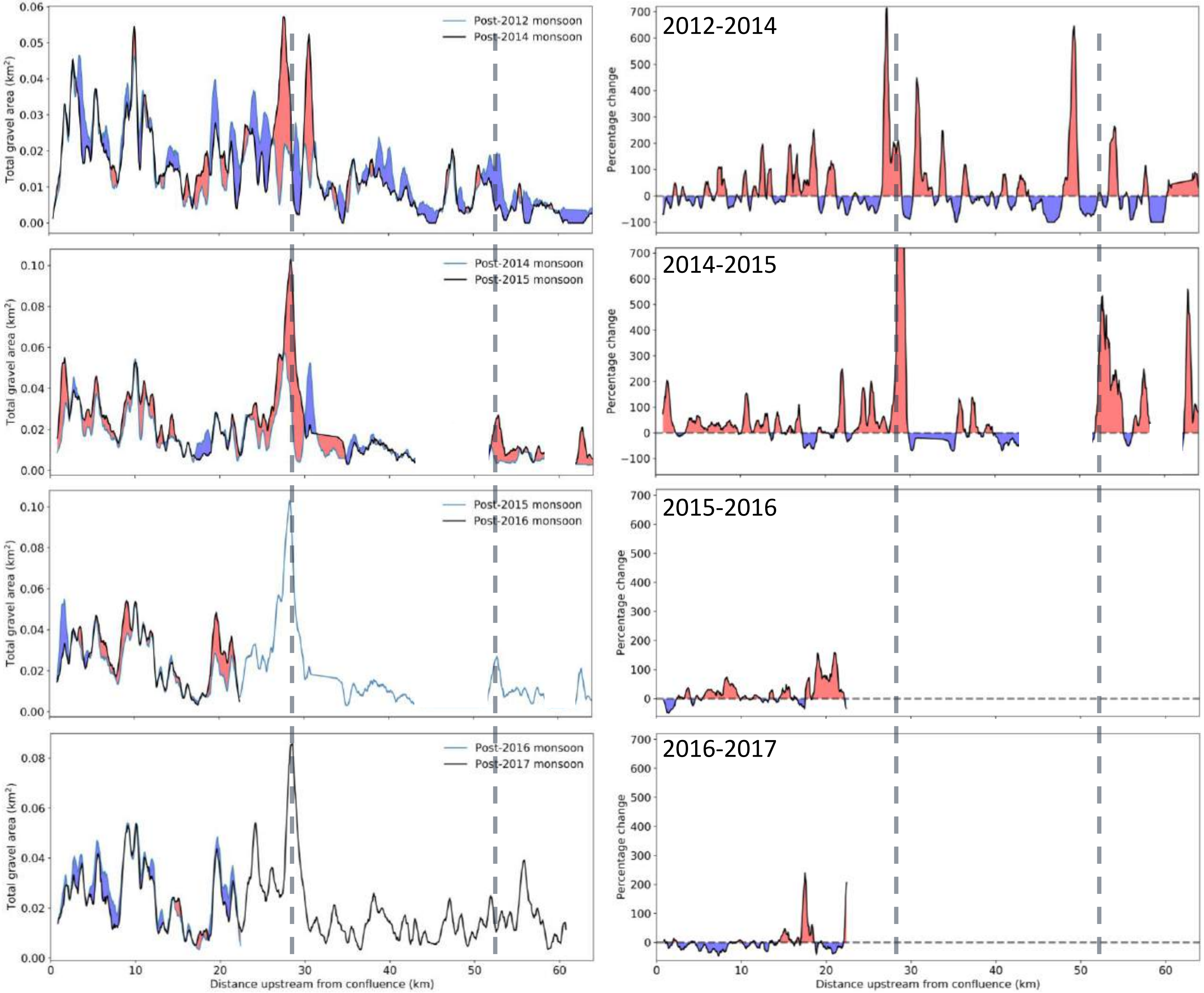
Bhote Koshi

- Clear peak associated with Jure landslide following the 2014 monsoon.
- Potential increase in sediment in the higher reaches following the Gorkha earthquake
- No clear evidence for large-scale downstream transport of sediment

Comparison of sediment exposed in the Bhote Koshichannel between different years: Absolute change (left); percentage change (right). Red shading indicates an increase; blue shading a decrease. Dashed lines highlight position of peaks over time: line at 30 km indicates Jure landslide; line at 55 km indicates peak potentially linked to coseismic landslide sediment.

Increase
Decrease

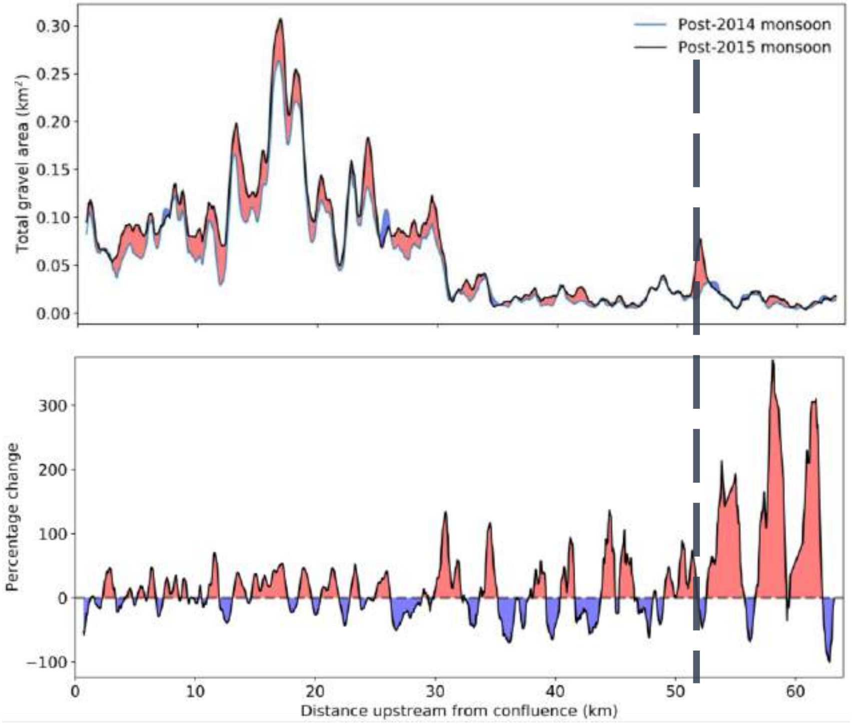




Where does the gravel come from?

- In the Melamchi Khola, we see an increase in gravel all along the river → sediment must come from upstream.

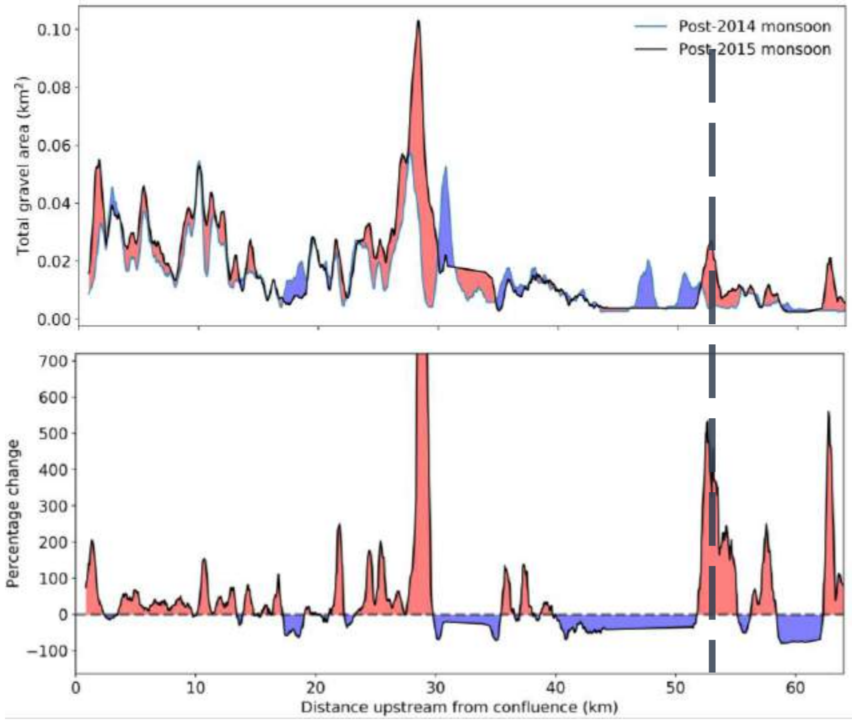
Satellite imagery shows example sediment input site along the Melamchi Khola at Timbu, corresponding to peak at ca. 51 km (marked by dashed vertical line).



Where does the gravel come from?

- In the Bhote Koshi, we see a clear increase in gravel linked to the 2014 Jure landslide
- Following the 2015 monsoon, there is an increase in gravel in the upper reaches as well.

Satellite imagery shows example sediment input site along the Bhote Koshi, corresponding to peak at ca. 53 km (marked by dashed vertical line).



Where does the gravel go?

- Increase in coarse sediment following the 2015 monsoon, but less than expected giving the extent of landsliding
  - Landslides not well connected to the fluvial network?
  - Did the landslides revegetate rapidly, thereby not providing additional sediment after 2015 monsoon?
- Little evidence of large-scale downstream migration of a coarse sediment pulse
  - Sediment too coarse to be entrained during normal monsoon flow?
  - Sediment quickly abraded and transported as suspended load?

Work in progress

- Mapping channel width and total channel area (gravel + active channel) to account for seasonal water level variations
- Error calculations using repeat mapping
- Identifying sediment sources

Additional information

All the analysis is made within the LSDTopoTools framework, a fully open-source framework for topographic analysis accessible via command-line, c++ or python:

https://lsdtopotools.github.io/

https://github.com/LSDtopotools/LSDTopoTools2

https://github.com/LSDtopotools/lsdtopytools

References

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