Where does all the gravel go? Abrasion-set limits on Himalayan gravel flux

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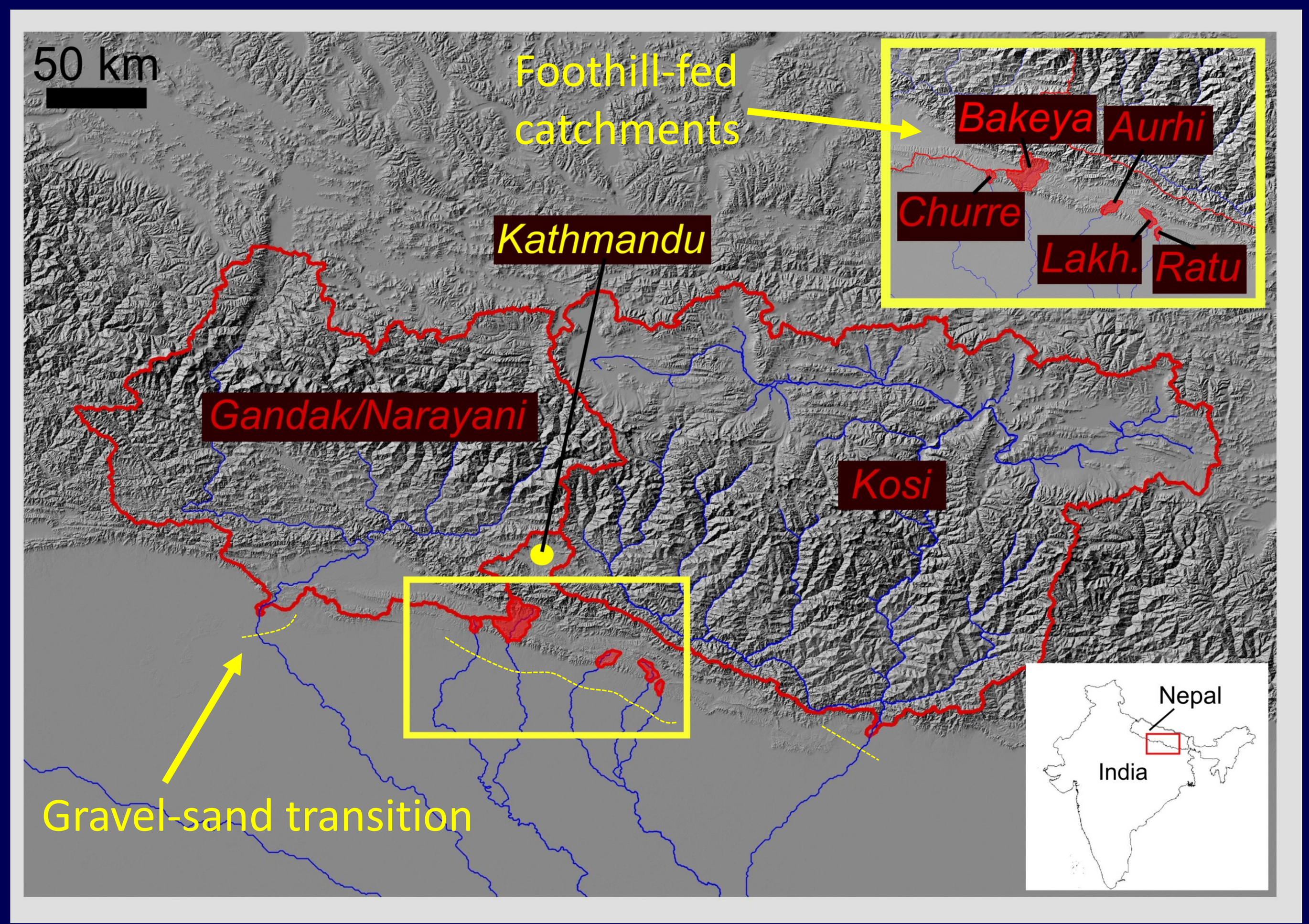
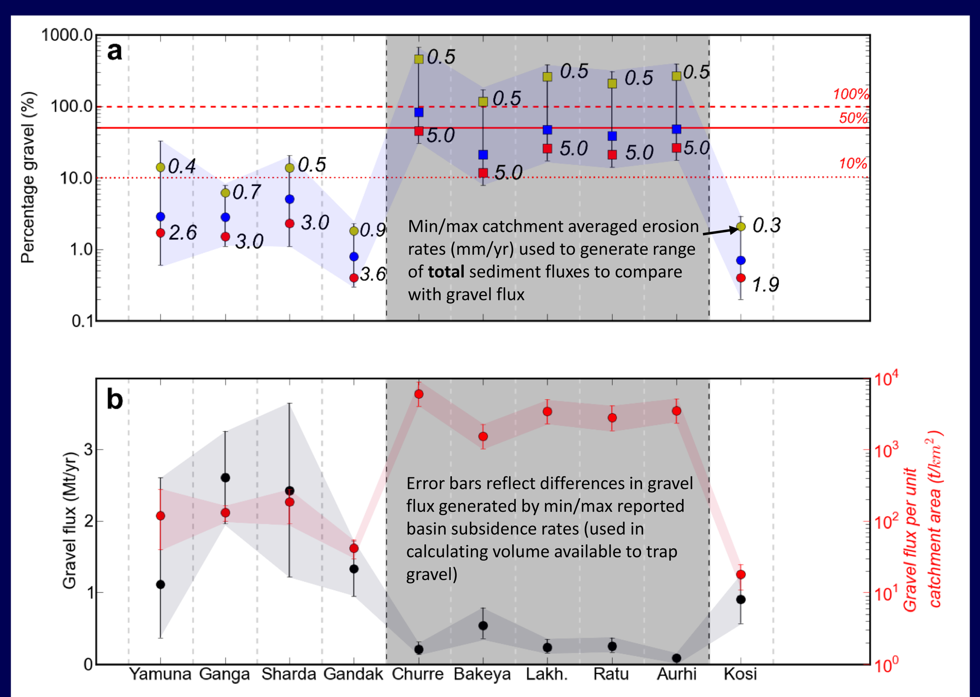
Rivers sourced in the Himalayan mountain range carry some of the largest sediment loads on the planet, yet coarse gravel in these rivers vanishes within approximately 12-40 kilometres on entering the Ganga Plain. Understanding how sediment is transported out of the mountain catchment is vital to determining how large inputs of coarse sediments (such as those triggered by storms or earthquakes) are translated downstream into sedimentary basins, and onto densely inhabited floodplains. Here, we examine controls on the gravel flux (where the term 'gravel' is used for grain sizes greater than 2 mm) out of the Himalayan mountains through an analysis of fan geometry, sediment grain size and lithology in the Ganga Basin.

Study Area – East Ganga Basin



1. Calculating gravel flux

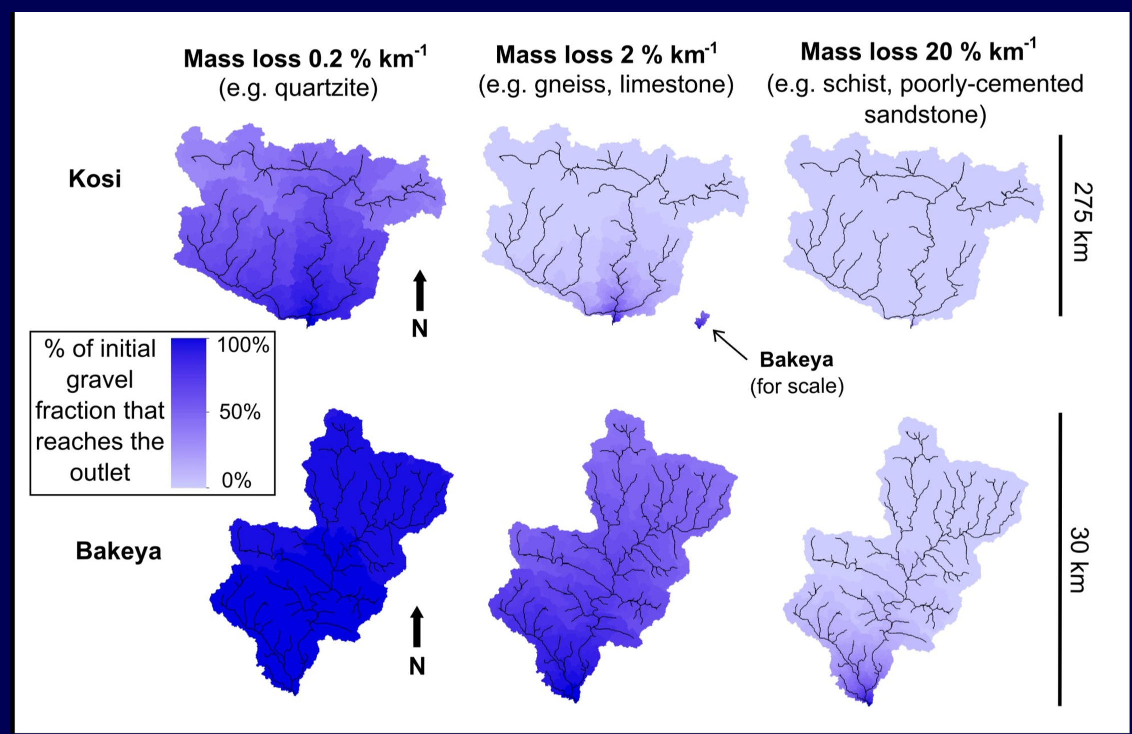
We first calculated the mass of gravel trapped between the mountain front and the gravel-sand transition. This was done for the trans-Himalayan Gandak and Kosi catchments where the gravel-sand transition has previously been mapped[1,2], and in five foothill-fed catchments (<250 km^2).



The fan geometry and published subsidence rates[1] were combined to calculate a gravel volume which was converted to a mass of quartzitic gravels to calculate a gravel flux. This was also compared to the range of **total** sediment fluxes, calculated from published ^{10}Be erosion rates sampled at the mountain outlets[3,4]. There are higher proportions of gravel in the small foothill catchments, but relatively similar total gravel fluxes between trans-Himalayan and foothill-fed catchments despite order of magnitude differences in upstream catchment area.

2. Abrasion modelling

Three pebble erodibility values are used, representative of Himalayan lithologies to test the effect of abrasion on gravel survival at the mountain outlet[5]. The intermediate abrasion rate used (2 %/km) is typical of the majority of Himalayan lithologies. In this figure, each DEM pixel in the mountain catchment of the Kosi (trans-Himalayan) and Bakeya (foothill-fed) rivers are coloured to reflect the % of gravel supplied to the river at that pixel that reaches the catchment outlet as gravel, under different pebble erodibilities.

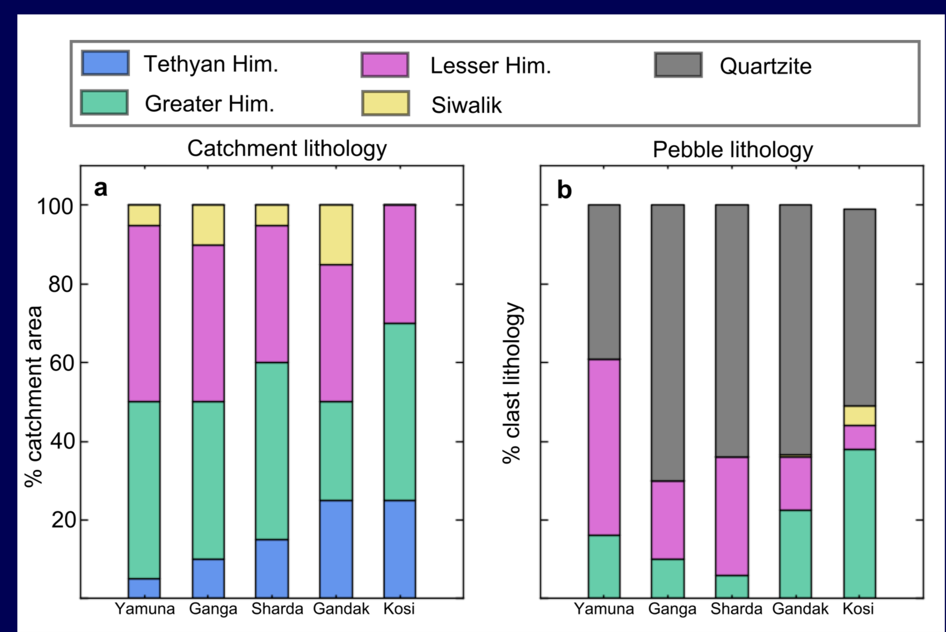


The remaining % represents the mass loss by abrasion, assumed in this case to be sand and finer sediment. More than 50 % of the gravel supplied by pixels in dark blue colours reaches the outlet as gravel; almost all of the gravel (>80 %) supplied by pixels in pale lilac colours has been turned into sand and finer products by the time it reaches the outlet. Importantly, this figure demonstrates that increasing catchment area doesn't always increase the gravel flux out of the mountains.

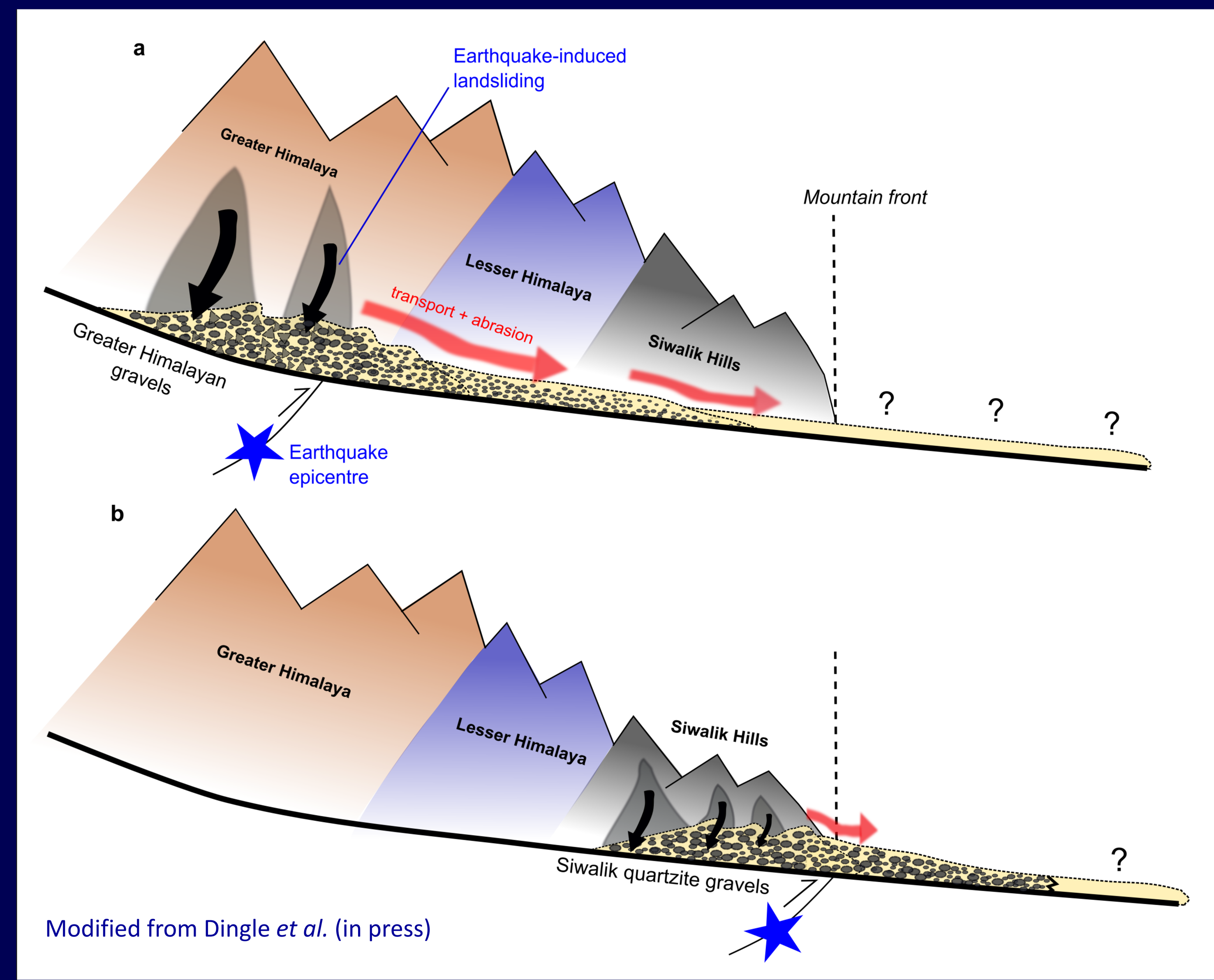
3. Catchment Vs pebble lithology

Pebble lithologies were determined along a number of exposed gravel bars between the mountain front and gravel-sand transition, and compared to the upstream catchment lithologies. The proportion of major geological units in trans-Himalayan catchments upstream of the mountain front are shown on the left (a), and average clast lithology composition recorded on exposed gravel bars upstream of the gravel-sand transition are shown on the right (b).

Foothill-fed catchments (not shown here) are exclusively underlain by recycled quartzite pebbles of the Siwalik Group. Quartzites are considered separately in pebble lithology (b) as they are distributed within each of the contributing units (a) but cannot be traced back to any of these units. Quartzite typically represents a small fraction of the rocks exposed in the catchments, (less than 10%) but makes up the majority of pebbles (~40-70%) sampled downstream of the mountain front.



4. So…where is all the gravel?



Beyond a critical transport length upstream of the mountain front, gravel delivered to the fluvial network is abraded into sand and finer sediment before reaching the Ganga Plain. This transport length is dependent on pebble erodibility, which is a function of lithology. Most gravel delivered to the Ganga Plain originates within ~100 km upstream of the mountain front, or from regions dominated by quartzitic lithologies. The amount of gravel transported out of the Himalaya by these rivers is largely insensitive to catchment size. Our results suggest that over the length scale of trans-Himalayan rivers, abrasion facilitates the downstream translation and dispersion of coarse sediment pulses through the transformation of gravel to more mobile sand.

References
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