Himalaya mass-wasting: impacts of the monsoon, extreme events, and road construction

Joshua N. Jones[1,2*], Sarah J. Boulton[2], Georgina L. Bennett[3], Michael R. Z. Whitworth[4], Martin. Stokes[2]

* @joshjones06 /joshua.jones@plymouth.ac.uk / Joshua.N.Jones@uea.ac.uk

[1]School of Environmental Sciences, University of East Anglia, [2]School of Geography, Earth and Environmental Sciences, University of Plymouth, [3]School of Life and Environmental Sciences, Geography, University of Exeter, [4]AECOM Ground Engineering

A) Introduction

Quantifying mass-wasting is vital for understanding landscape evolution / improving hazard management.

There is a need to understand how extreme events and human activity perturb background mass-wasting rates.

Here, a 30-year inventory of mass-wasting events (figure 1) is used to quantify mass-wasting magnitudes in Nepal due to the monsoon, extreme events and road building.

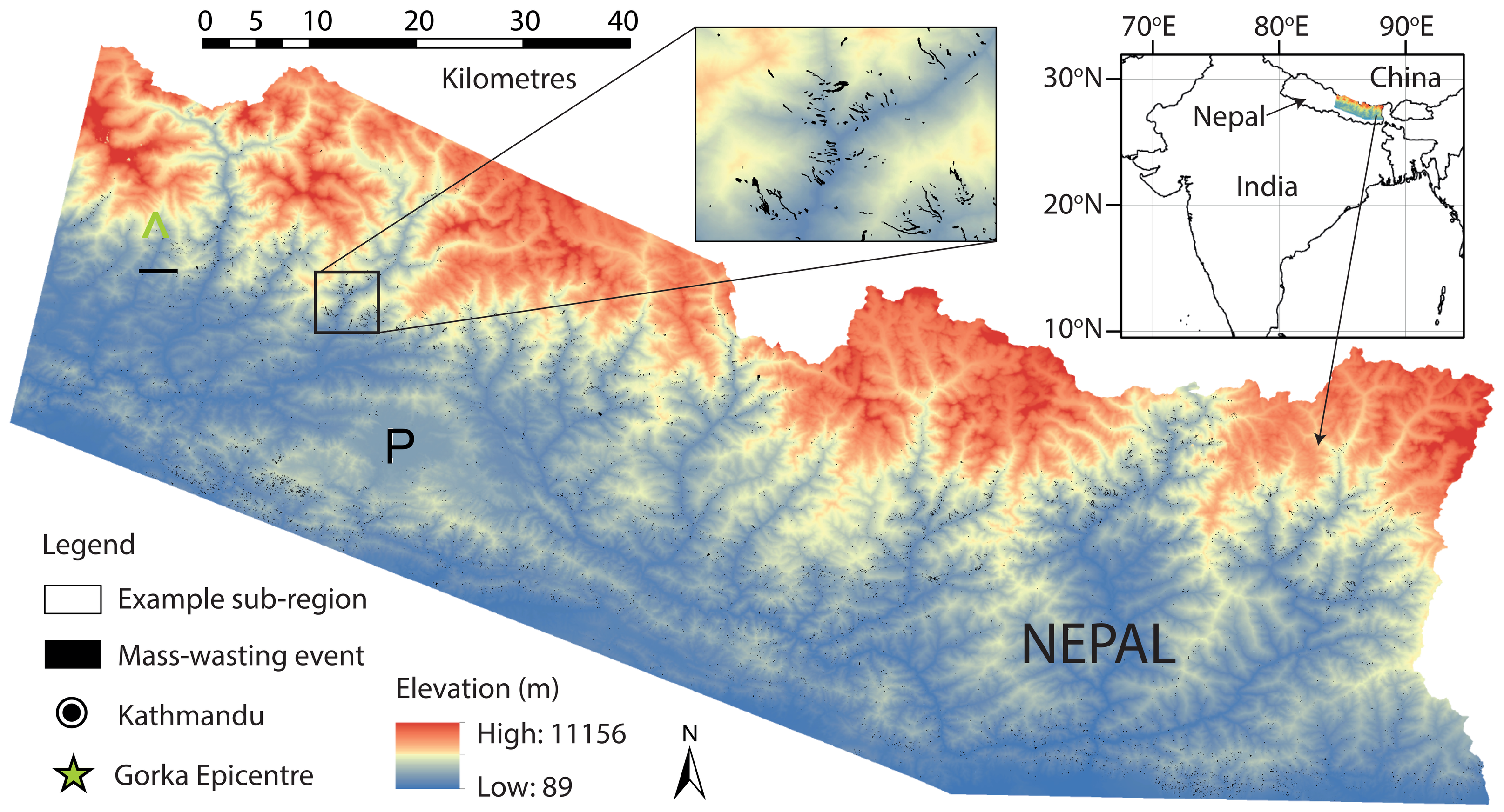


Figure 1: Location of study region and > 15,000 monsoon-triggerred and road associated mass-wasting events mapped across 30 monsoon seasons from LandSat Imagery

B) Methods

1. Calculate yearly total and scar mass-wasting volumes from mapped polygons using empirical relationships (Larsen et al., 2010; Marc et al., 2018).
2. Obtain relationships between mass-wasting volume and monsoon-strength for all pre-earthquake years (figure 2). This defines the "background" rate of monsoon -triggered mass-wasting across the study region.
3. Derive a monsoon-strength normalised rate of mass-wasting by calculating the ratio of the actual mass-wasting mapped in a given year to the mass-wasting predicted based on the total rainfall relationships from 2 (figure 3).

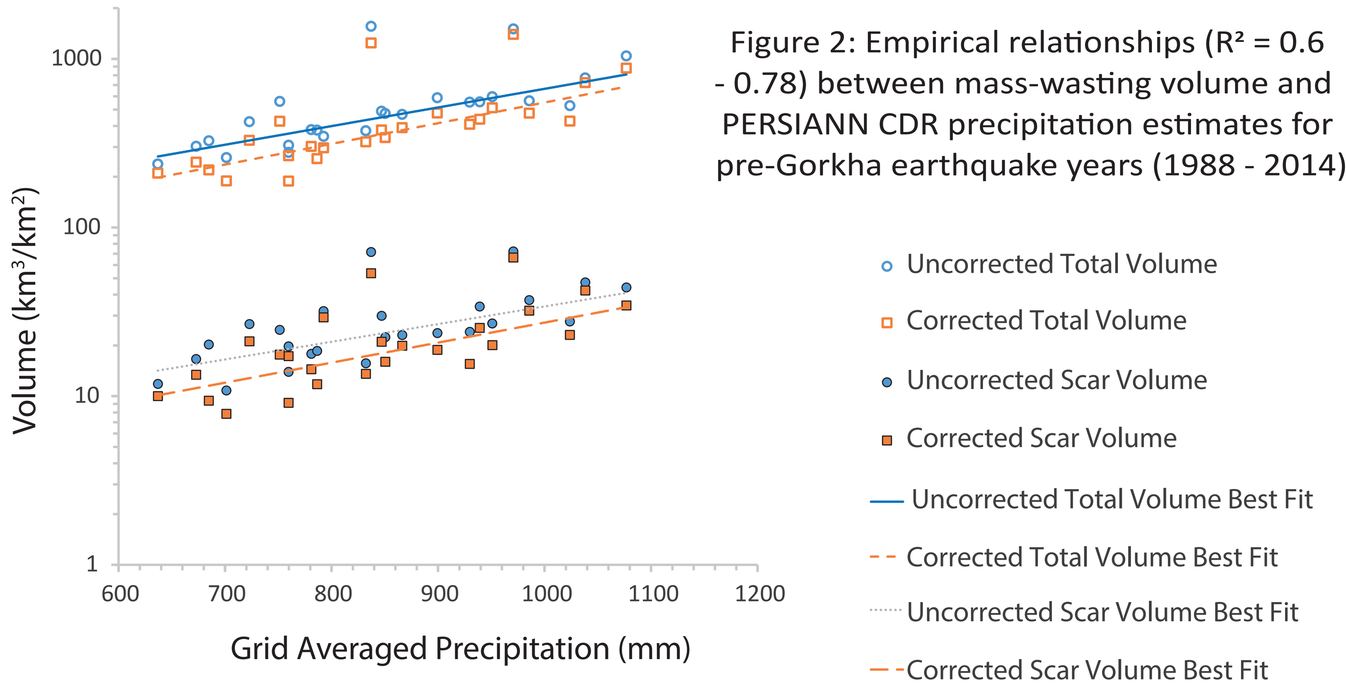
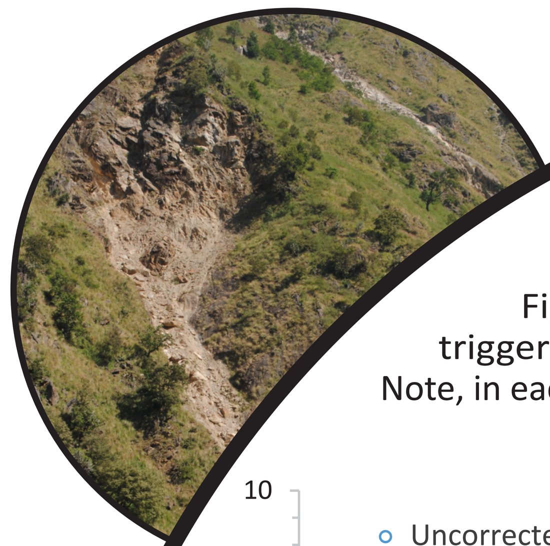


Figure 2: Empirical relationships (R^2 = 0.6 - 0.78) between mass-wasting volume and PERSIANN CDR precipitation estimates for pre-Gorkha earthquake years (1988 - 2014)

C) Results



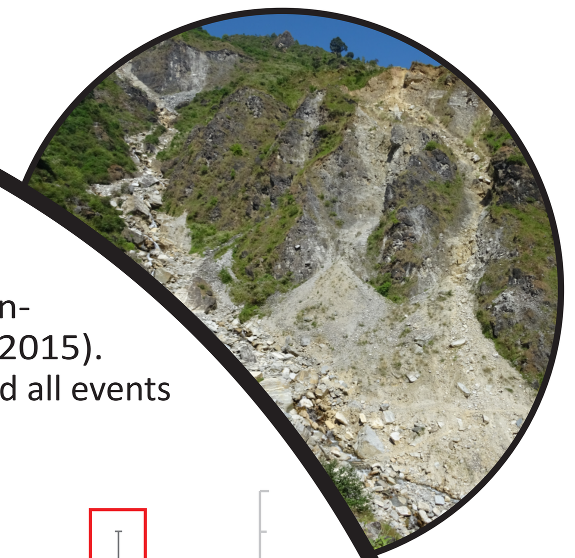
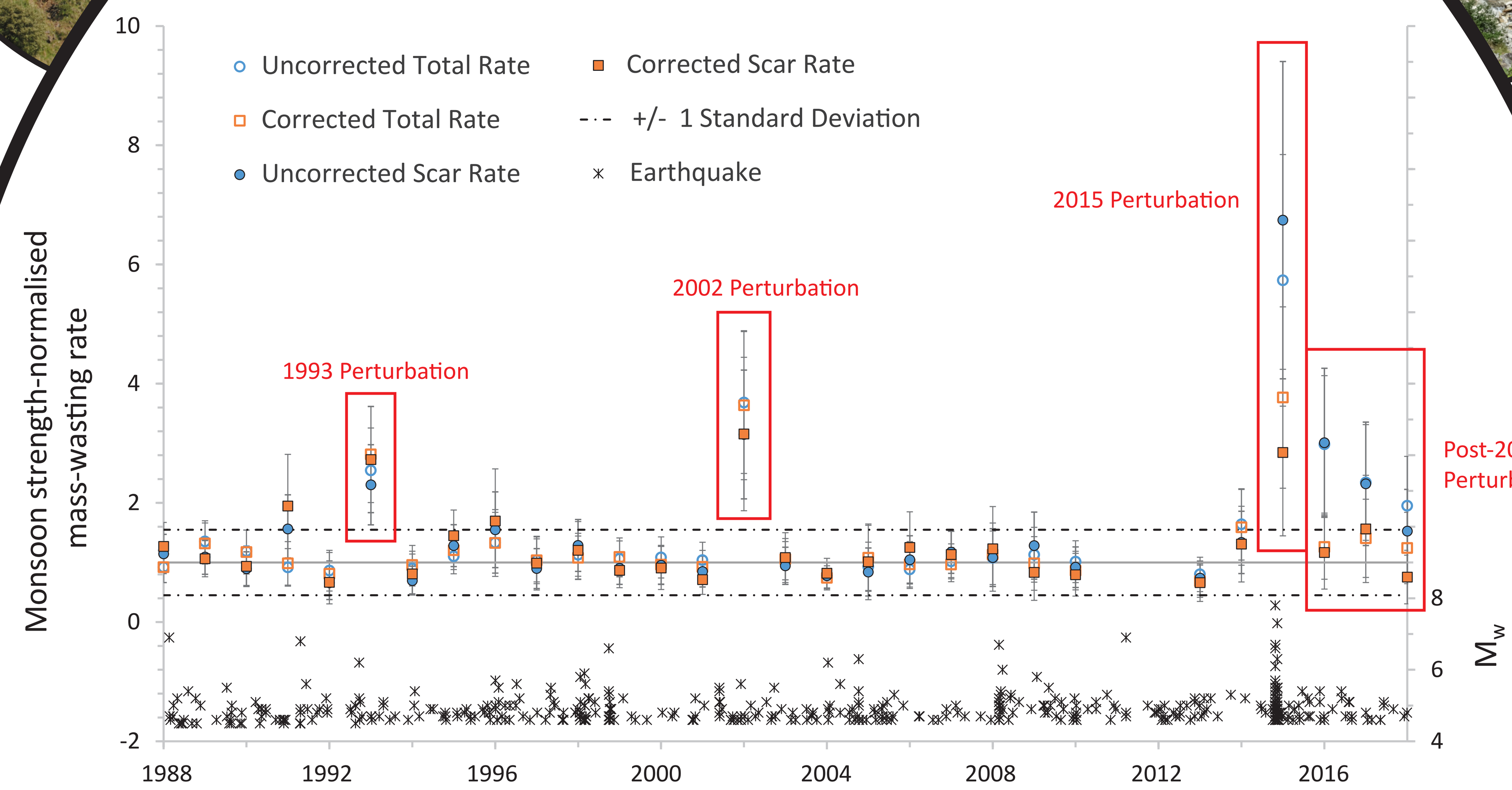
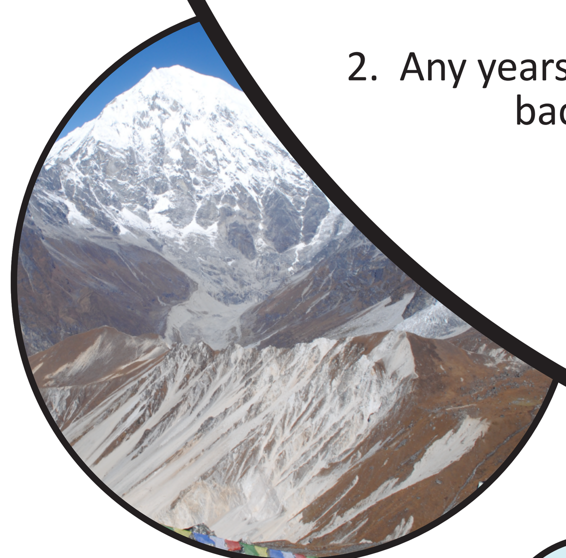


Figure 3: Monsoon strength-normalised rate of monsoon-triggered mass-wasting following the method of Marc et al. (2015). Note, in each case, rates were obtained for all events (uncorrected) and all events minus road-associated and reactivated events (corrected).



1. Most years fall within +/- one SD of the background 'normal' and so are explainable by the monsoon-strength alone.
2. Any years with normalised rates perturbed above the monsoon-triggered background rate must be partially attributable to another extreme event or human activity.
3. The magnitude of each perturbation above the background can be used to quantify the relative magnitudes of each perturbation



D) Impacts of extreme events

The 1993 and 2002 perturbations were caused by cloud outburst storms that deposited over 540 and 300 mm of rainfall in 24 hours.

These two perturbations caused mass-wasting equivalent to 4.3 average background monsoon-seasons.

In 2015, the Gorkha earthquake caused monsoon-triggered mass-wasting equivalent to 2.1 average monsoon-seasons.

Analysis of 2015 coseismic mass-wasting (Roback et al., 2015) reveals that the Gorkha earthquake caused coseismic mass-wasting equivalent to 23 average monsoon seasons.

Photo 1 (left): Small debris flow of reactivated 2015 coseismic material, Arniko Highway, Nepal

E) Impacts of road buiding

As the 2016 - 2018 perturbation is only evident in the uncorrected rates, it is likely due to reactivations (e.g. photo 1) or road-building (e.g. photo 2).

There is a large increase in road -associated mass-wasting in 2008 (figure 5), with road-associated events causing >45% of all mapped mass-wasting by 2018.

Photo 2: Mass-wasting due to road tipping, Arniko, Nepal

In total, road construction caused mass-wasting equivalent to 3.6 average monsoon seasons.

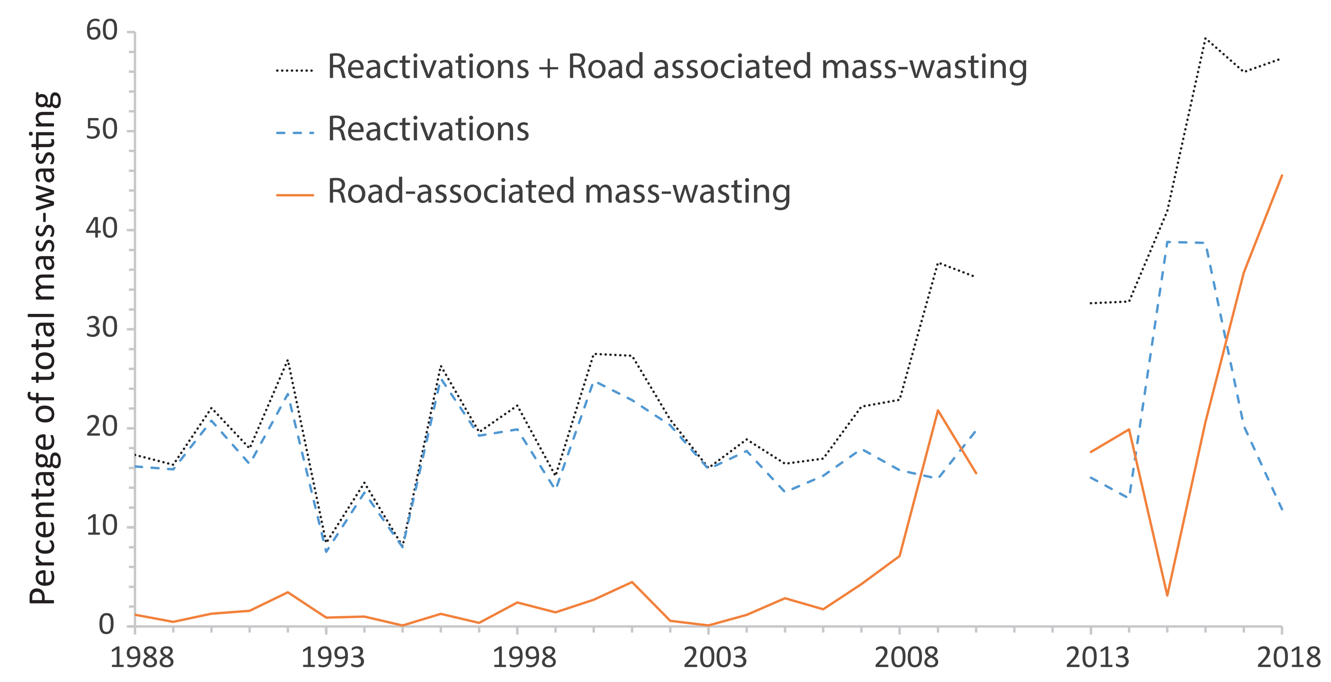


Figure 5: Proportion of inventory composed of reactivations and road-associated mass-wasting

F) Implications and Conclusions

Implication 1: Our new empirical relationships between monsoon-strength and mass-wasting could assist quantitative assessments of potential future changes.

Implication 2: Our results show that extreme events can cause transient mass-wasting perturbations. This highlights the need for time-dependent mass-wasting susceptibility models.

Extreme storms caused mass-wasting equivalent to 4.3 average monsoon-seasons .

The Gorkha earthquake caused coseismic and monsoon-triggered mass-equivalent to 23 and 2.1 average monsoon-seasons.

Road construction caused mass-wasting equivalent to 3.6 average monsoon-seasons.

Acknowledgements and References

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