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

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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.

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 polygons using empirical relationships (Larsen et al., 2010; Marc et al., 2018).
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).

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 1.6 average monsoon-seasons.

E) Impacts of road building

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.

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

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.

Acknowledgements and References

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Especially in the case of the Gorkha earthquake, the potential for future changes needs to be considered.

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

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

Figure 2: Empirical relationships (R² = 0.6 - 0.78) between mass-wasting volume and PERSIANN-CDR precipitation estimates for pre-Gorkha earthquake years (1988 - 2014).

Image 3: Example sub-region

Figure 4: Percentage of total mass-wasting due to reactivations and road-associated mass-wasting.