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Analysis of controlling factors on boulder production on the hillslopes of the upper Bhote Koshi catchment, Nepal

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Landslides from mountainous bedrock hillslopes often contain boulders, the presence of which has been shown to influence landscape evolution by altering hillslope geomorphic processes and river erosion. Furthermore, the presence in various proportions of large grain sizes on hillslopes can amplify both landslide and flood hazards in largely unquantified ways. Boulders can have an immediate destructive potential on properties and infrastructure and can hinder response and recovery by blocking access routes, posing a challenge for removal. On entering the river network, they might have far reaching effects if remobilised in high flows, damaging or destroying key infrastructure such as hydropower plants and inducing significant knock-on effects on local economies. A fundamental step towards quantification of increased hazard potential is the understanding environmental controls on boulder production. Despite their potential to enhance hazard, the probability of large boulders being produced within different landslide types has not been directly accounted for in landslide hazard mapping.

Our study focuses on the upper Bhote Koshi catchment, northeast of Kathmandu (Nepal), characterised by extreme topographic gradients, seismicity and monsoonal climate, and subjected to frequent landslides and floods. This, coupled with increased population pressure and infrastructure growth, makes the area prone to natural disasters.

We used high resolution optical imagery to map more than 11300 boulders and analysed this large dataset in combination with lithology and topography, and well as structural and landslide data, to investigate controls on boulder production and grain size distributions in different lithological, structural and geomorphic settings of the landscape.

Lithology appears to exert a significant influence on boulder sizes, with statistically significantly larger boulders observed in crystalline rocks of the Higher Himalaya Sequence than in metasedimentary rocks of the Lesser Himalaya Sequence. We also observe that the spacing of the most pervasive fracture set, parallel to foliation, influences boulder size distributions in some lithologies, whilst other dominant regional fracture sets appear not to strongly correlate with mapped boulder sizes.

Although recent studies have shown the importance of structural control on boulder sizes, our large dataset reveals that for complex, high-relief landscapes, with high erosion rates, fracture characteristics do not fully explain grain size distribution.

The type of processes involved in boulder production and transport on slopes, before reaching the river network, also appears to exert a control over grain size distributions and boulder density, with rockfall processes appearing to be responsible for producing boulders with largest sizes as opposed to rockslides, where the high energy and mode of transport is likely associated with increased fragmentation.

Analysing lithological and structural characteristics alone may not be sufficient to explain the observed distribution and would thus only give a limited insight in the enhanced hazard levels posed by boulders across different sectors of a landscape and other factors, such as distance from source and mode of transport at shorter temporal scales, must be taken into account.