Hydrology, hillslope processes and suspended sediment transport in the central Himalayas of Nepal

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Suspended sediment load in rivers is a primary proxy for present-day mean catchment denudation rates (Dadson et al., 2003). In active mountain belts denudation is generally thought to be dominated by hillslope mass wasting. In the Himalayas, strong relief and intense monsoonal rainfall provide favourable conditions for mass wasting (Korup and Weidinger, 2011). On the other hand the suspended sediment fluxes in rivers, draining such large orogens, are mainly controlled by the transport capacity of these rivers and by the contribution of material from the adjacent hillslopes, for example by landsliding. In the Himalayas the spatio-temporal distribution of precipitation has numerous consequences for surface processes, water availability and transport capacities of the rivers. The very clear seasonality - monsoon and non-monsoon - exerts a very distinct annual cyclicity bounding surface processes almost exclusively to the monsoon season, when high rainfall feeds pore water pressures in steep hillslopes that are already prone for failure. In particular, the occurrence of mass wasting and associated highly concentrated suspended sediment fluxes in rivers are closely tied to monsoon season (Andermann et al., 2012a). However, the transfer of precipitation into rivers involves temporary water storage in reservoirs such as soils, groundwater, snow and glaciers, where different transfer times influence the hydrological cycle (Andermann et al., 2012b).

In this contribution we discuss first the interlinkage between suspended sediment concentration, river hydrology and precipitation, on the example of the three major drainage basins (Karnali, Narayani and Koshi) of the Nepal Himalayas. And secondly, we present a new unpublished and highly resolved dataset from the Kali Gandaki River where we infer hillsope processes from the grain-size distribution of the suspended load, supported by satellite imagery based landslide mapping.

For the three major drainage basins the dataset consist of daily suspended sediment and river discharge measurements from 12 hydrological stations across the Nepal Himalayas. All records are daily measurements, spanning several years (i.e. 4–6 yr) between 1973 and 2006, but are not always complete. Precipitation information is derived from the APHRODITE (Asian Precipitation- Highly-Resolved Observational Data Integration Towards Evaluation of Water Resources) precipitation dataset, the best available spatial data for this region (Andermann et al., 2011). The suspended sediment records vs. river discharge plots display seasonal clockwise hysteresis loops. By separating the discharge hydrograph into its different discharge components and only plotting direct runoff (short response time) against suspended sediments the hysteresis collapses to a linear relationship. This demonstrates that the fast flowing discharge component, caused by intense rainfall provides material from the hillslopes to the river. From the clear relationship between direct discharge and sediment fluxes we propose a new sediment transport rating model, allowing us to deduce basin wide denudation rates from the river discharge record, ranking from 0.1 to 5.9 mm/yr. Last we discuss these denudation rates in the context of basin characteristics and we propose a new conceptual model of mobilization and transportation of material within the monsoonal discharge cycle.

The second, more highly resolved dataset incorporates equally suspended sediment and river discharge measurements from two gauging sites along the Kali Gandaki River, one of Nepal's major trans-Himalayan rivers. These two strategically located gauging stations provide the opportunity of tracing at-a-station variations in discharge, sediment fluxes and potential delivery processes on either side of the

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Himalayan orographic divide. The upstream station at Lete village (2500 m asl) has an upstream area of 3450 km^2 and is located at the transition between the arid Southern Tibetan Plateau Margin in the north and the monsoon-influenced southern Himalayan front. At Lete suspended sediments have been measured twice daily (morning and evening) over two years (2011-2012). The downstream station is situated at the water intake of a run-of-the-river hydropower facility at Mirmi (520 m asl) with an upstream area of 7580 km^2. At Mirmi the data is available for seven consecutive years (2006-2012). For the first time, for both stations grain size distribution information is available in addition to the bulk suspended load. In order to examine broad scale patterns we compare the sand-to-mud ratio between the upstream and downstream station. The sand fraction clearly shows a stronger sensitivity to external forcing. We observe a distinct coarsening of the sediment flux during monsoon at the downstream station while the sediment ratio at the upstream station remains all year around constant. We attribute this coarsening to precipitation driven mass wasting during monsoon that is contributing coarse sediments to the rivers. This interpretation is confirmed by landslide mapping from Landsat Satellite image time series, indicating that landslides occur exclusively during monsoon and more than ten times more frequent in the south facing monsoon influenced part of the catchment.

Our results demonstrate that the transport of sediments in the Himalayas depends to first order on the contribution of sediments supply from the hillslope and the availability of water, rather than from in channel sediment storage. We show that erosion in the Himalayas is strongly coupled with the magnitude–frequency distribution of precipitation expressed in the fast river discharge fraction. Furthermore, the downstream coarsening of suspended load along the Kali Gandaki River is likely to be linked to sediment input by hillslope mass wasting processes preferentially occurring at the southern front of the Himalayas. Since our denudation rates are derived from a dataset of continuous contemporary sediment flux, they provide a field-based benchmark for denudation studies across multiple timescales.

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