



High sediment export from a trans-Himalayan semi-desert driven by late Holocene climate change and human impact

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Sediment export rates are sensitive to changes in climate, vegetation and human impact, but the direct response of a given landscape to such changes is difficult to unravel. Here, we report a strong landscape response to a disturbance of a stable, soil covered landscape in a trans-Himalayan valley, which was pushed over an eco-geomorphic tipping point resulting in fast and widespread erosion. We then identify potential drivers for this transition.

The upper Kali Gandaki (KG) river valley in Nepal drains the southern edge of the Tibetan plateau in the rain shadow of the High Himalayas, where a scarcely vegetated semi-desert is dissected by deep gullies. These badlands formed in a graben structure storing large amounts of unconsolidated sediments which provide a source of erosion product to the high stream-power river. Due to the high erodibility of this material, the region is particularly sensitive to changes in climate and land use. At the outlet of the upper valley, we estimate that river suspended sediment concentrations are up to two orders of magnitude higher for a given river discharge than downstream in the monsoon dominated High Himalayan river segment. Even though precipitation rates are low in the upper valley (160 mm/yr to 250 mm/yr) and discharges rarely exceed 100 m³/s, we show that modern erosion efficiency is around five times higher than in the steep and wet, landslide dominated southern part of the catchment.

In stark contrast to this modern setting, widespread occurrence of paleosol horizons reflects the persistence of geomorphologically stable conditions during the Holocene until 2.4 ka based on OSL and 14C ages. What pushed this landscape from a soil covered stable state into the erosional state observed today? We investigated human land use and climate change as possible drivers of this transition. Human impact on the landscape has been suggested from 5.4 ka onwards (Miehe et al., 2009) and an increased occurrence of archeological sites and evidence of grazing animals has been reported from 3 ka (Simons et al., 1994). We estimated paleo-hydrological conditions using the hydrogen isotopic composition of plant lipids (δD_{wax}) extracted from the paleosol horizons in the upper KG valley (3500 - 4100 m asl., n=24). δD_{wax} values range from 214 ‰ to 236 ‰ which is offset by 40 ‰ \pm 6 ‰ from the δD_{wax} values of modern shrub leaves sampled at the paleosol sites and modern topsoils sampled along the wetter fringes of the valley. This strongly suggests that soil formation took place under substantially wetter conditions, i.e. an enhanced monsoonal precipitation in the past. The subsequent Late Holocene drying trend combined with human land use likely reduced vegetation cover which then initiated the transition to badland development observed today. Current erosion rates suggest a catchment-average surface lowering rate of one meter per 1000 years, resulting in a strong and irreversible degradation of the landscape and its soils.

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