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Basin-scale sediment transport and sediment concentration-discharge relationship modeling in a permafrost-dominated basin

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Permafrost degradation by ongoing climate warming has expanded the erodible thermokarst landscapes, enhanced the thermal erosion, and altered the sediment transport processes in cryosphere basins. Thermal-activated sediment sources and enhanced sediment export due to developed hillslope-channel connectivity can increase the annual sediment flux and accelerate the sediment response to hydroclimatic disturbances, thus complicating suspended sediment concentration (SSC) and discharge (Q) relationships and forming various hysteretic patterns. Yet, the commonly used sediment rating curve ($SSC=a \times Q^b$ with a and b as static fitting parameters) is unable to capture the SSC-Q hysteretic patterns and most single-event-scale hysteresis models mainly emphasize the pluvially enhanced sediment transport (e.g. rainstorms), but overlook the thermally-erosional processes.

To rebuild dynamic SSC-Q relationships and hysteresis in sediment transport in cryosphere basins, we propose a Sediment-Availability-Transport (SAT) model by extending traditional rating curves to incorporate the time-varying sediment availability regulated by thermal-fluvial processes and long-term storage exhaustion. In the SAT-model, increased thermal erosion is represented by basin temperature; enhanced fluvial erosion is represented by runoff increase; sediment transport capacity is represented by total runoff. Specifically, thawing permafrost as temperature rising can enhance sediment generation by forming active layer detachment, retrogressive thaw slump, and thermal erosion gully from hillslopes, and fluvio-thermal erosion along the riverbank, associated with a time-lag in the sediment response due to the time for temperature accumulation to melt cryosphere and long-travel distance from thermal-activated sediment sources to the basin outlet. A surge in basin water supply during intense rainfall and excessive melting with a certain time-lag can increase sediment availability and fluvial erosion by flushing the erodible slope and scouring the river channel. Moreover, sediment storage is assumed to be continuously depleted throughout a hydrological year and leads to sediment exhaustion.

With the support of multi-decadal daily SSC and Q in-situ observations (1985-2017), the SAT-model can be parameterized and validated in the permafrost-dominated Tuotuohe basin on Tibetan Plateau. In Tuotuohe, thermal erosion processes are found to be best captured by an eight-day average temperature, associated with an exponential amplification of SSC. Fluvial erosion is best captured by a two-day runoff increase and shows a linear amplification of SSC. Moreover, the

warming-wetting climate over the past decades has expanded the thermokarst landscapes and boosted the slope-channel connectivity by thermal gullies, which leads to the significant inter/intra-annual variation in SSC-Q relationships and reduces the performance of the sediment rating curve. Yet, the SAT-model can robustly reproduce the long-term evolution, seasonality, and various event-scale hysteresis of SSC, including clockwise, counter-clockwise, figure-eight, counter-figure-eight, and more complex hysteresis loops. Overall, the SAT-model can explain over 75% of long-term SSC variance, outperforming the sediment rating curve approach by 20%, with stable performance under an abrupt hydroclimate change.

Part of the results is also published in Water Resources Research: Zhang et al., 2021. Constraining dynamic sediment-discharge relationships in cold environments: The sediment-availability-transport (SAT) model.;. Li et al., 2021. Air temperature regulates erodible landscape, water, and sediment fluxes in the permafrost dominated catchment on the Tibetan Plateau.