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High K and Ca chemical erosion triggered by physical erosion in a watershed of the High Himalaya of Nepal

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Abstract

The Khudi river in Nepal is an example of a basin undergoing intense physical erosion by landslide under very wet monsoonal conditions. Although under such a regime, dissolved element concentrations are expected to during the monsoon, we observe marked increases in dissolved K and Ca during flood events. These peaks in K and Ca concentrations are well correlated with increases of suspended load by an order of magnitude. The data suggest that release of K and Ca is enhanced by physical erosion and rock disaggregation events during sediment transfer.

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1. Introduction

The influence that physical erosion exerts on chemical erosion by enhancing the reactive surface between mineral and surface water is an intuitive relationship because the increase of fresh mineral surface in contact with surface

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water leads to a potential increase of total weathering flux. Thus, it has been invoked that at the continental scale, orogenic phases that boost physical erosion could trigger global cooling[1]. There are clear examples of direct correlations between physical and chemical erosion approximated by sediment and solute exports of river[2]. However, West et al.[3] showed that when physical erosion become very high, weathering might be kinetically limited. Through a modeling approach, Gabet & Mudd[4] proposed that where erosion rates are greater than 100 $t/km^2/yr$ ($\approx$ 0.04 mm/yr), increase in erosion rate leads to progressive decrease in weathering rate because maximum production rate of regolith is overtopped by physical erosion. These approaches are however hampered by the difficulty to define the effective soil thickness and to take into account weathering occurring outside of the soil zone such as weathering in fractured bedrock or in landslide areas[5].

The Khudi khola (river) in Central Nepal Himalaya is one example where physical erosion exceeds 2 mm/yr, where physical erosion appears to be much higher than chemical erosion, and where chemical erosion should be kinetically limited. However, in this study we present a daily survey of both physical and chemical erosion of the Khudi river during monsoon 2010 showing that dissolved fluxes of K and Ca are triggered by very high physical erosion events. These data are compared with earlier record of the river in 2002 by Wolf-Boenish et al.[6] when physical erosion was weaker. Additional sampling from July 2013 is also considered.

2. Study area and sampling

The Khudi khola is a 150 km^2 watershed draining the south flank of the Lamjung massive in Central Nepal. Elevation ranges between 800 and 4900m and no glacier is present. The watershed is exposed to heavy rainfall, up to 4 m during the three months of the monsoon[7]. The basin is undergoing intense physical erosion estimated around 1.5 to 3 mm/yr by suspended load x discharge measurements[8]. Recent survey of the basin reveals that most of the sediment flux originates from 2 active landslides present in the higher part of the basin and which show almost continuous sediment supply during the monsoon[9].

During 2010 monsoon, daily water and sediment sampling was performed from a bank of the intake station from the Khudi hydropower plant. Daily, two litres of water were sampled. Samples were then filtered so that sediments concentrations and dissolved element concentrations could be measured. Since 2012, the basin has been equipped with turbidity and conductivity probes. Rain gauges in different locations of the basin also provide an estimate of rainfall. In addition, suspended sediment and water sampling was performed using a one litre horizontal double opening bottle. Because of the high velocity and turbulence of the stream, the sampler was operated on a vertical rail installed on the wall of the intake station from a hydropower installation. This system allowed sampling in reproducible conditions and at the surface and ca. 40 cm above riverbed. Discharge was estimated using a theoretical rating curve, i.e. the relation between water stage and discharge at the Intake river section, using the HEC-RAS model (1D hydraulic model). In 2010, we use the limnimetric record of the power station and in 2012 the pressure gage record. We controlled the computed total discharge integrated over the year to be roughly equal to the annual precipitation falling upstream minus the mean yearly evapotranspiration.

3. Monsoon 2010 data.

Data are presented in figure 1. From the onset of the monsoon in June to its climax at the end of July, discharge increased from $\approx$3 to 15-30 m^3/s and gradually decreased at the end of the monsoon. Daily rainfall events generally occurring over night generated daily discharge peaks which increased the base discharge by a factor 2 to 10. Discharge and suspended sediment concentrations were clearly related. Sediment concentrations varied from 0.5 to 5 g/l under steady conditions and reached values higher than 50 g/l during peak discharge.

Major dissolved element species displayed contrasted evolutions. Na and Si both progressively decreased throughout the monsoon corresponding well to a "dilution" effect due to the increase of rainfall and direct runoff. [Na^+] reduced from 90 to 50 µmol/l and [Si] from 150 to 100 µmol/l. On the contrary, [K^+] and [Ca^{++}] showed an overall increase during the monsoon and displayed sharp variations. [K^+] base level stayed stable around 70 µmol/l and peaked up to 250 µmol/l during some flood events. [Ca^{++}] base level decreased from 280 to 180 µmol/l and peaked up to 600 µmol/l. [Mg^{++}] overall decreased during the monsoon but also displayed moderate peaks correlated with K^+ and Ca^{++} fluctuations. K^+ and Ca^{++} peaks were well correlated and also corresponded to peak discharge and suspended sediment concentrations (Fig. 2).

4. Discussion

Such high K^+ and Ca^{++} rich waters were not observed before in Nepal rivers[10] nor during the first survey of the Khudi river in 2002[6]. However, physical erosion of the Khudi river was notably lower during that period. As a matter of fact, 2002 Khudi waters were significantly less concentrated in K^+ than 2010 waters: 40-55 μmol/l during 2002 compared to 55-85 μmol/l for 2010 base values.

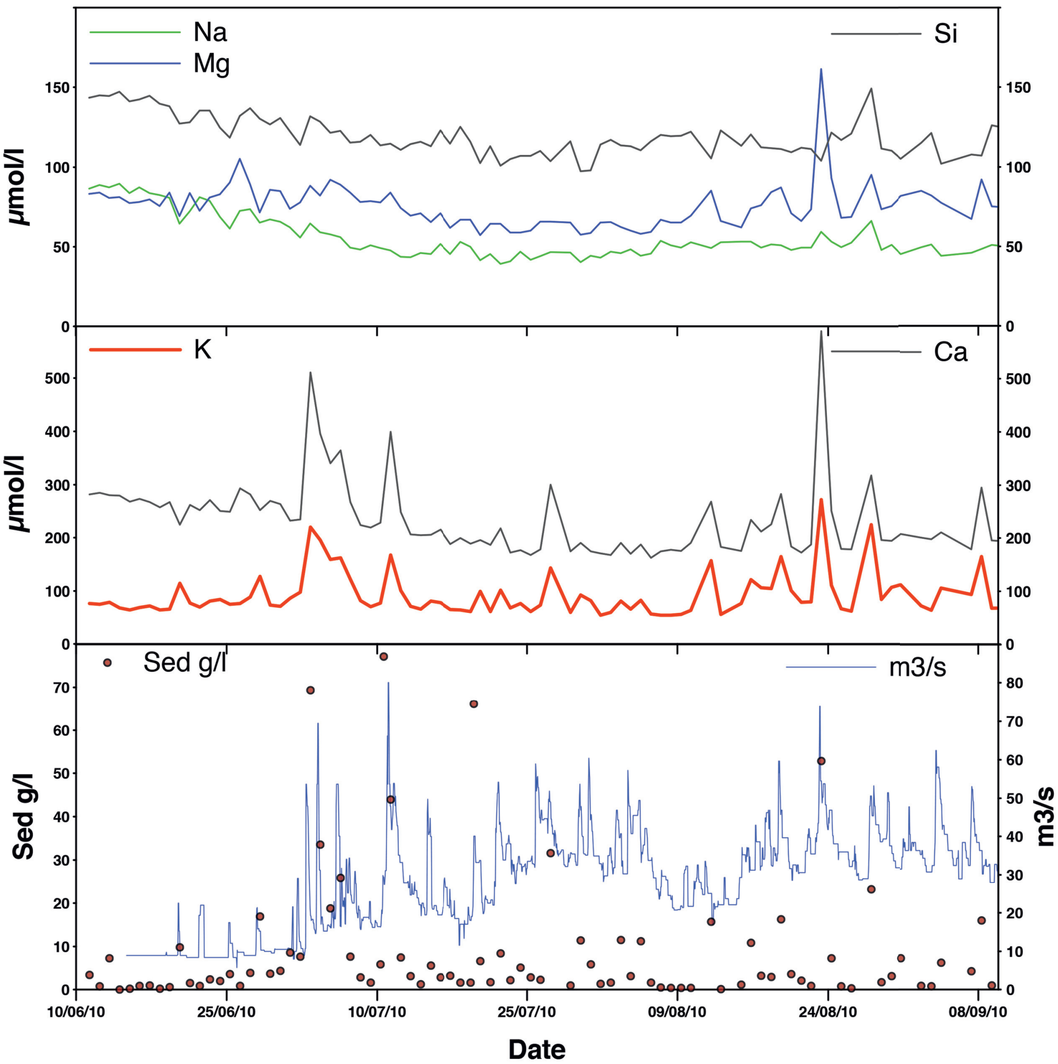

Fig. 1. Khudi record during monsoon 2010 for: discharge & suspended sediment concentration (bottom); dissolved K & Ca (middle); dissolved Na, Mg & Si (top). Suspended sediment and dissolved element concentration were determined from the same samples taken daily at 08h00.

Because peak concentrations in K^+ and Ca^{++} correlate with suspended sediment concentrations, we initially suspected that post sampling exchange or weathering of the sediment load could have occurred because samples taken in 2010 were stored for variable time before filtration. However subsequent sampling in 2013 performed with immediate filtration during a large flood event replicated the same observation (Fig. 2). We are therefore confident that these data reflect real variations in K^+ and Ca^{++}. In addition, combined conductivity measurements and discharge in 2012 and 2013 show flood events accompanied by conductivity increase, although this relationship is not systematic.

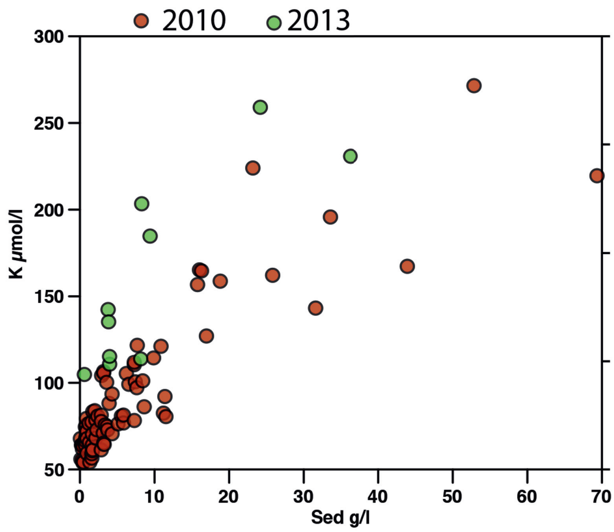

Fig. 2. Relationship between suspended sediment concentration and dissolved K+ concentration in 2010 and 2013 samples.

Flood events are usually correlated with decreases of the dissolved load due to dilution by direct runoff. In some cases, release of leachable element stock in soils can lead to initial increase of dissolved load. But such effects are unlikely in the case of intra-monsoon flood event as the upper soil reservoirs are saturated and thoroughly leached. One sample of soil water taken in July 2011 showed lower concentrations than any of those recorded in the river. None of the other known sources of dissolved elements seem to fit with a combined increase of K and Ca. Hydrothermal springs are characterised by high Na concentration and are likely diluted during the monsoon. Groundwaters sampled from springs during dry season in the upper basin reveal no composition compatible with those observed during floods of the Khudi river. Therefore the main implication is that the release of dissolved K and Ca is associated to physical erosion processes. High sediment fluxes in the present Khudi river are associated to continuous creeping in the active landslide area that delivers sediments to the river (Gallo et al., submitted). As a consequence, the average suspended sediment concentration recorded in 2010 was 8 g/l, whereas it was 1.5 g/l during the 2002 monsoon season[8]. The processes and reactions associating K and Ca release with peaks in sediment discharge are matter for discussion. The more direct sources of K and Ca are biotite and calcite respectively. Biotite is very abundant in the gneisses and shows traces of transformation to vermiculite. Calcite is present in very small proportion ($\approx 0.1\%$) in the gneisses. Processes that deliver cations to the river require high dissolution kinetic (e.g. calcite dissolution) or leaching of exchangeable cations. Fresh exposure of mineral surfaces by rock crushing during the flood event may trigger the release of these cations. Partially ground landslide material is stored in deposits at the outlet of the landslide area and undergoes weathering for days until it is flushed during the next flood event. Overall this process appears as a significant source of dissolved K and Ca to the river. Although the relationship between discharge and dissolved load is not straightforward when we observe time-series, if we consider a base concentration of 70μmol/l for K and 180μmol/l for Ca, we can estimate that at least 50 to 75% of dissolved K and 35 to 70% of dissolved Ca in the river are due to this prompt process during major flood events.

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