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Hillslope-channel coupling in the Nepal Himalayas and threat to man-made structures: The middle Kali Gandaki valley

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ABSTRACT

In mountain areas, the confinement of valleys favours landslide interaction with rivers, causing channel changes or short-lived dams and lakes that may threaten trails, roads and human settlements. Their impacts may occur successively in space and time, and they affect randomly the functioning of the sediment fluxes. The present study focuses on the interaction patterns between unstable mountain slopes and the Kali Gandaki River, in the Nepal Himalayas. In this valley, the deepest on earth, a road linking the Myagdi and Mustang districts has been under construction for the past 5 years, either cutting into the bedrock or crossing areas affected episodically by debris slides, earth flows, debris flows and rock slides. On the basis of the geomorphic evolution observed over the last three decades, we assess the potential threats that now arise following completion of the road. We mapped three areas of recurrent mass wasting features characteristic of the most frequent situations encountered in this valley. We analyzed the combination of the hydro-geomorphic processes involved. With the use of a DEM, we assessed the volume and spatial impact of temporary river dams on infrastructure located along the valley floor. We estimated hydraulic parameters to document the geomorphic efficiency of river flooding after dam breaching. We reconstructed the spatial extent of (1) areas threatened by backwater flooding upstream of the dams and (2) areas threatened by the collapse of the dams. We describe the current geomorphic and sedimentary adjustments still at work along the valley sides. Our findings confirm that in the High Himalaya, medium scale landslides (10^{5-6} m^3) play a major role in the overall process of denudation and sediment transfer. They highly influence the transient nature of bedload transport in the channel. In reducing the residence time of sediments in temporary, spatially limited traps of the valley bottom, they enhance the vulnerability of land and people attracted by a roadside location.

1. Introduction

Landslides are a major hazard in mountainous regions throughout the world. In the Himalayas, tectonically active mountains characterized by rapid uplift and river incision rate, mass wasting features are common features, triggered either by heavy rain or/and by earthquakes, and favoured by steep terrain and locally by weak bedrock. Each year during the summer monsoon, landslides and debris flows cause high levels of economic losses and fatalities, a figure that increases with demographic growth and development of infrastructures (Froehlich and Starkel, 1987; Gerrard, 1994; Sah and Mazari, 1998; Starkel and Basu, 2000). According to Upreti et al. (2008), 35% of the global death due to landslides occurs in the Himalayas, and this represents about 30% of the world's total landslide-related damage value. Nepal Himalaya is particularly affected because of the current process of development as occurring through urbanization and construction of roads across a country that is still rural and remote for most of its part (Petley et al., 2007).

Landslide hazard is particularly acute across the Greater Himalaya, where the confinement of valleys favours landslide interaction with rivers. Landslide impacts may occur successively in time, depending on their magnitude and their capacity to act or not as a barrier; they are often responsible for off-site hazards such as channel diversions, short-lived dams and impounded lakes, hence outburst floods, all processes that threaten trails, roads and human settlements, as reported in many Himalayan valleys (Brunsden et al., 1981; Yagi et al., 1990; Marston et al., 1998; Higaki et al., 2000; Weidinger and Ibetsberger, 2000; Naithani, 2001; Paul et al., 2000; Bhattarai et al., 2005; Gupta and Sah, 2008).

The context of our study is the road linking the Myagdi and Mustang districts (and indirectly connecting China to India) that has been under construction for the past 5 years. The road follows the same design as the old salt-trade-route. Its construction has not proceeded without difficulty. It has been necessary either to cut into the bedrock or to cross areas affected episodically by natural debris

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slides, earth flows, debris flows and rock slides, the runout of which may potentially dam the valley. This contribution aims at illustrating interaction patterns between unstable mountain slopes and Kali Gandaki river (Nepal Himalayas), at short (10^2 years) to very short (10^{-2} years) time scale, in a context of road development. We selected three sites where blockages of different types and duration have occurred. First, we mapped the areas of recurrent mass wasting features and analyzed the combination of the hydro-geomorphic processes involved. Second, with the use of a DEM, we calculated the volume of sediment dams and deduced the spatial extent of (1) areas threatened by backwater flooding upstream of the dams and (2) areas threatened by the collapse of the dams. Third, on the basis of a multi-temporal approach, we try to assess the potential threats that now arise following the completion of the road.

2. Geomorphic setting

2.1. Regional context

The Kali Gandaki river originates from the southern edge of the Tibetan Plateau, and cuts across the >8000 m high peaks of Dhaulagiri and Annapurna Himal, forming the deepest gorges (>6000 m) in the world (Fig. 1). It drains all the different Himalayan lithotectonic units before joining the Ganges alluvial plain: the Tethyan sedimentary series and Mustang–Thakkhola graben (Fort et al., 1982; Colchen et al., 1986), then the High Himalayan Crystalline Series (mostly gneisses) and the Lesser Himalayan Series (mostly quartzites, limestones and schists) (Colchen et al., 1986), then the Siwalik molasses (Delcaillau, 1986). These structural units correspond to a series of

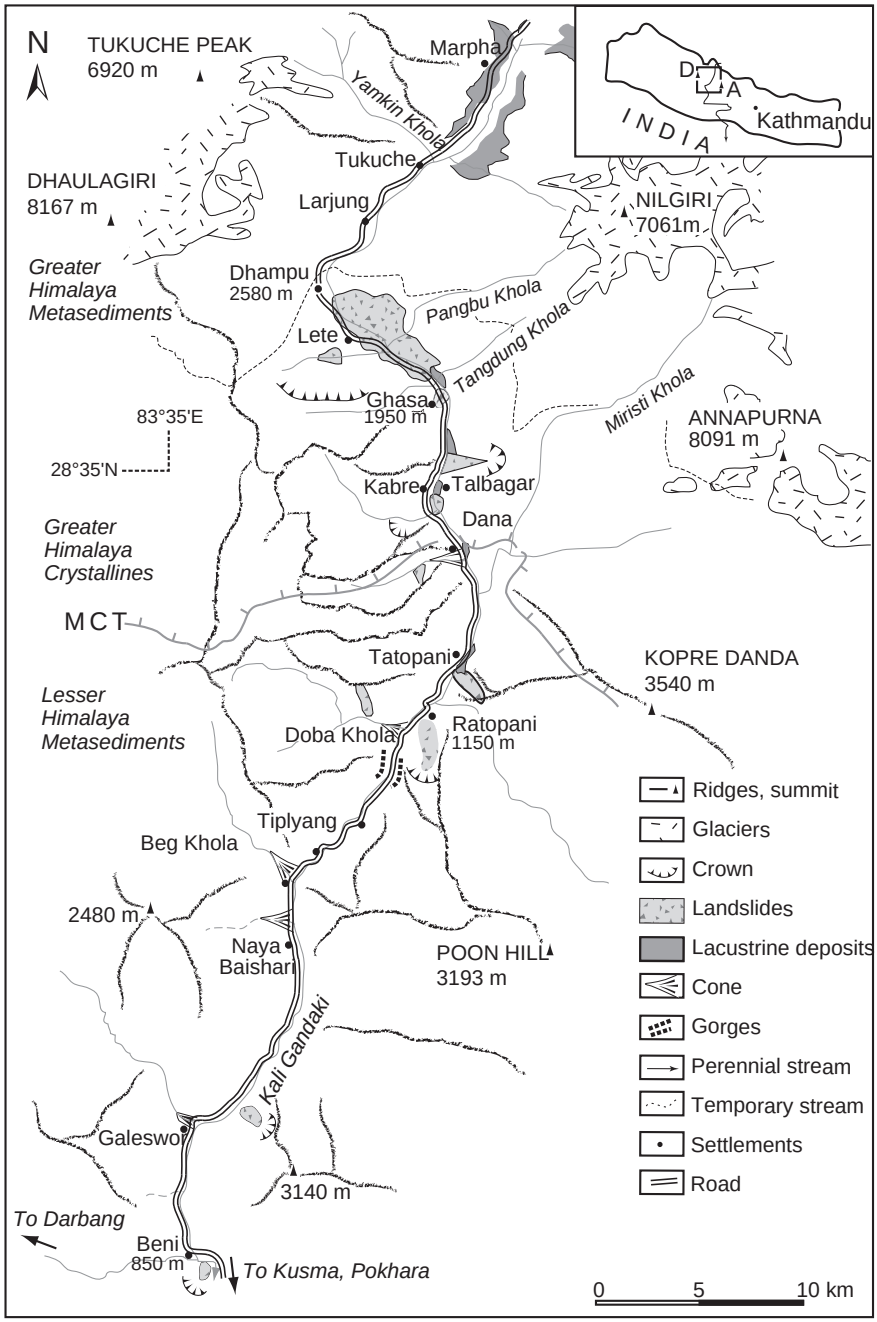

Fig. 1. Location map of the middle Kali Gandaki valley. The river cuts across three main Himalayan structural units (the Tethyan sedimentary series, the Higher Himalayan Crystalline and the Lesser Himalayan units) in a deep and narrow gorge. The valley is locally obstructed by mass wasting features of different ages, the material of which is a permanent threat to the new road (opened in 2008).