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Evolution of valley-fill terraces in the Alaknanda Valley, NW Himalaya: Its implication on river response studies

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ABSTRACT

The present study attempts to understand the importance of place and local factors in the process of valley filling in an active mountain belt. The accumulation of sediments in a valley stretch depends upon the relationship between sediment carried from upstream by the main river entering into the stretch (q_i), locally derived sediments (i.e., from local streams (q_t), hillslopes (q_h), and glacial and periglacial processes (q_g)), and sediment exiting that stretch (q_o); these are in turn governed by other processes like tectonic activity, intensity of precipitation, and lithology.

As an example a valley stretch in the NW Himalaya is chosen in the Alaknanda River, one of the two uppermost tributaries of the Ganga River. This stretch is called as Pipalkoti Valley after the name of the main town; it is located close to the Main Central Thrust (MCT) and falls in the zone of orographic precipitation. Detailed geomorphic mapping reveals four surfaces and two terraces. Three debris-flow surfaces suggest their deposition by local mass flows and stream flows with very small contributions from the Alaknanda River. Terrace T2 occurs as a strath in some parts and is made up of fluvial and lacustrine sediments in others. The presence of lacustrine sediments suggests local damming of the river. Thick fluvial sediment is deposited in stretches of the rivers where it becomes wide due to the joining of a tributary. Synsedimentary deformation has been noted indicating that tectonic activity has affected sedimentation.

The results suggest that local processes played a dominant role in the accumulation of sediments in this valley stretch. A model is proposed showing the role of glacial activity, high intensity meteorological events, river width, active faults and landslide damming in the origin of valley-fill deposits of the Pipalkoti Valley. It is concluded that before correlating valley-fill deposits along the lengths of the Himalayan valleys, it is important to evaluate the role of various local processes that have operated in particular stretches.

1. Introduction

In active mountain belts, it is challenging to understand the response of a river to tectonic and climatic changes. One of the important archives that provides an opportunity to unravel this response are valley-fill deposits. The valley-fill deposits represent the final product of the processes occurring over a geological period. These deposits are often investigated to understand the conditions under which they were deposited, which in turn is governed by the climatic and tectonic activities of an area (e.g., Pratt et al., 2002; Pratt-Sitaula et al., 2004; Bookhagen et al., 2006; Meetei et al., 2007; Srivastava et al., 2008; Juyal et al., 2010; Ray and Srivastava, 2010). However, in tectonically active settings, the preservation potential of these deposits is limited, and these are preserved only in small spatial domains. In such cases, the investigation of these individual segments gives an idea of the response of the entire river system to past tectonic and climatic changes (e.g., Juyal et al., 2010; Ray and Srivastava, 2010). The distribution of valley-fill deposits depends on several parameters such as: (i) tectonically active structures (e.g., Parker et al., 2011), (ii) precipitation distribution (e.g., Wulf et al., 2010), (iii) spatial configuration of glacial fronts (e.g., Godard et al., 2012), (iv) sediment supply from different sources such as glaciers, landslides, tributaries and other hill slope processes (e.g., Parker et al., 2011; Godard et al., 2012), (v) valley shape, (vi) landslide vulnerability of the area and damming potential of these mass movements (e.g., Pratt et al., 2002; Pratt-Sitaula et al., 2004), (vii) vegetation cover (e.g., DiBiase and Lamb, 2013), (viii) tributary and trunk river relationship (e.g., Benda et al., 2004), and (ix) anthropogenic activities (e.g., Walling and Webb, 1996). In the case of rivers flowing — hundreds of kilometers — through the mountains, these factors may show strong variability in different stretches, thus emphasizing the role of place and local influence in sediment accumulation. Therefore, it is important to understand the role of these parameters in the sedimentation at a location (i.e., valley stretch) that will allow the determination of the processes involved in the valley filling.

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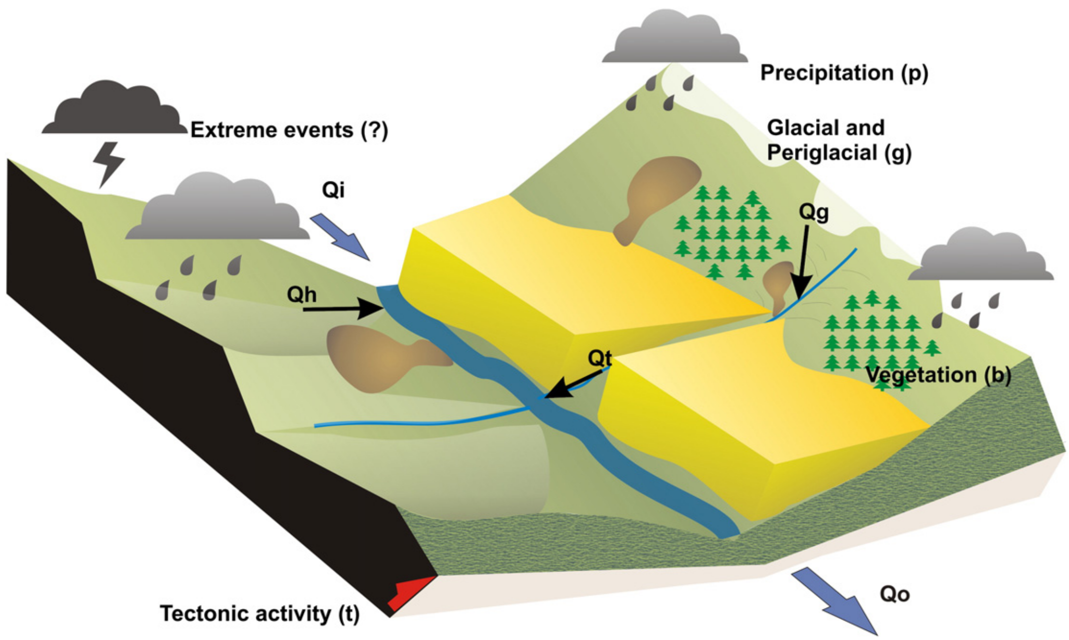

Fig. 1. A conceptual model of factors affecting sedimentation in a valley segment and sources of sediment supply.

In order to investigate the controls of various parameters on sedimentation, we first offer a simple model for valley filling, and later test this model for a valley stretch with thick valley-fill deposits in the NW Himalaya. This study is qualitative and it discusses the possible relative roles of these processes in this stretch.

2. A conceptual model for valley-fill deposits

A conceptual model demonstrating sedimentation in any valley segment is presented in Fig. 1. Since we have carried out a coarse resolution study and the timescale of this study is much larger than that involved in human transformations, the anthropogenic controls are ignored. Also, controls of vegetation on the sedimentation could not be investigated due to lack of data. Further, rock strength is not considered because of limited lithological variations in the study area. However, it would be an important parameter if several stretches are compared.

In general, the following parameters influence the sediment supply and depending on the tectonics and climate of an area, the intensity of these governing factors may vary:

(i) Tectonic activity: In general it causes either uplift or subsidence that influences the rivers flowing in the area. The river may aggrade or erode depending on how it interacts with the new topography. It may also trigger landslides (e.g., Parker et al., 2011). These landslides can suddenly increase the sediment flux, and at times they may choke the large rivers. A sudden increase in sediment flux changes the river dynamics in response to which a river may aggrade.

(ii) Glacial and periglacial processes: The glacial fronts advance or retreat with changing climate that leads to change in sediment availability in an area. For example, when the glacial front advances, it covers certain areas that were previously available for erosion (e.g., Rahman et al., 2009); however, when the glacial front retreats it leaves behind a large amount of sediments (moraines) available for erosion (e.g., Ray and Srivastava, 2010). These paraglacial sediments are worked upon by the rivers when the glaciers retreat (e.g., Ray et al., 2011). Sediments are also generated by periglacial processes, and therefore, these inputs need to be considered at elevations where they are most active.

(iii) Rainfall distribution: Rainfall has a direct control on erosion (Wulf et al., 2010). Thus, its spatial variability also plays a dominant role in the amount of sediment moved from an area. It is also an important factor in triggering landslides. Moreover, sediment transportation is mostly dependent on the amount of rainfall, especially in humid areas.

(iv) Tributary influence: The tributaries joining the trunk river play an important role in aggradation and erosion because they change the sediment to water ratio of the trunk river after joining it. Thus, the stream power of the trunk river may be modified resulting in aggradation or erosion. Occasionally, a catastrophic event in a tributary may result in sudden increase in sediment flux that may choke the trunk river temporarily, leading to episodic aggradation.

(v) Hillslope processes: Apart from landslides, other processes such as sheet wash, creep, solifluction, and biogenic processes also affect the sediment contribution from the hillslope. These processes are governed by tectonics, climate and lithology of an area.

The valley-fill deposits in a river stretch are a function of (a) sediment load of the river entering in to that stretch (q_i); (b) sediment delivered by tributaries to that segment (q_t); (c) sediment delivered by the hillslopes (q_h); (d) sediment contributed by glacial and periglacial processes (q_g); and (e) sediment load of the river exiting out of that segment (q_o) (Fig. 1). Within the segment q_t, q_h, and q_g are dominantly influenced by the climate, whereas q_h and q_t are also influenced by the tectonics of the area (landslides are important hillslope processes that can get triggered by tectonic activity and moreover, the bed load of the tributaries draining the hillslopes that are not directly in contact with the major rivers is also influenced by such events). It should also be noted that, at a smaller scale, similar sediment delivery would be seen for the tributary. Now, if we assume the valley stretch of the area to be in steady state, then, $q_i + q_t + q_h + q_g = q_o$ (Fig. 1) and in this case, no sedimentation would be seen in the stretch. However, if $q_i + q_t + q_h + q_g < q_o$, it would mean that incision is occurring in the stretch and if $q_i + q_t + q_h + q_g > q_o$ then, it would mean