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Geomorphic evolution of a non-glaciated river catchment in Lesser Himalaya: Response to tectonics

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ABSTRACT

The study discusses detail valley formation and sedimentation processes in the monsoon dominated non-glaciated catchment of the Ramganga river in the Lesser Himalaya. The geomorphic and sedimentological studies in this basin indicates phases of massive aggradation that was controlled mainly by channel bound processes and debris flows/landslides. The luminescence chronology of the fill sequences suggests that the valley filling occurred mainly in response to the enhanced monsoon after the Last Glacial Maxima (LGM), during Medieval Warm Period (MWP) and Little Ice Age (LIA). This phase is common in both glaciated and the non-glaciated catchments of Himalaya.

The Ramganga River that flows through various tectonic structures of the Lesser Himalaya shows development of wide valleys with thick fill deposits in the fault zones. Chaukhutiya Fault (CF) and Binau-Bhikiyasain-Naurar Fault (BBNF) are the two main transverse faults where the evolved geomorphology pertains to their tectonic activity. The computed morphometric variables such as Ratio of valley floor width to valley height (Vf) and Stream Gradient Index (SL) show higher values in the transverse fault zones. Basin asymmetry vectors along the South Almora Thrust and BBNF are characterized by preferred stream migration in NE and SW direction suggesting BBNF with dip slip movement. Thick clay deposits at different sites along the Ramganga River resulting from blocking of the river, particularly along the BBNF, also point towards tectonically induced landslide and channel blockage. Later phase of tectonic activity, bracketed between 27 and 24 ka, is evident from deformed fluvial deposits in the form of folds and faults. Evidences of tectonic activity in the form of soft sediment deformation structures (SSDS) generic to seismic activity in layers comprising alternation of clay and sand are observed in the Himalayan Frontal Thrust (HFT) zone. The diagnostic features such as dykes, faults and folds suggests that the shaking event took place between 38 ka and 30 ka.

1. Introduction

The rivers that originate in Lesser Himalaya are non - glaciated catchments and are generally fed by groundwater and southwest monsoon. Major river systems that originate in higher and Tethys Himalaya are generally fed by glaciers in their source areas. Rivers like the Ganga, the Sutlej, the Yamuna and the Brahmaputra, etc originating from the elevation of >4000 m amsl and fed by several hundreds of large and medium sized glaciers located in the Higher Himalaya are extensively studied (Srivastava and Misra, 2008; Srivastava et al., 2009; Sinha et a., 2010; Dutta et al., 2012) for the genesis and climatic significance of fluvial terraces, debris flows, alluvial fans, landslides, epigenetic gorges, and paleo-flood. Fluvial and glacio-fluvial landforms in these river systems have been widely investigated to understand relationship between palaeoglaciation, monsoon variability and fluvial dynamics (Church and Slaymaker, 1989; Ray and Srivastava, 2010; Juyal et al., 2010; Srivastava et al., 2013,Pratt-Sitaula et al., 2004). Further, the Himalaya is cut across by an extensively active fault system (Nakata et al., 1984; Nakata and Kumahara, 2002) along with southward

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progression of Himalayan orogenic front, it produced series of faults namely Main Central Thrust (MCT), Main Boundary Thrust (MBT), Himalayan Frontal Thrust (HFT) from north to south separating major geological units of the Himalaya (Gansser, 1964; Valdiya, 1980). It has been observed that they played an important role in evolution of landforms in the Himalaya particularly in Lesser and Outer Himalaya.

The catchments of the Lesser Himalaya are yet to be explored through integrated studies exploring landform evolution as proxy to tectonic-climate interaction having implications for the role of extreme events. Very few efforts have been made to understand the landscape development of non-glaciated catchments of Himalaya. Studies so far either focused on morphometric variables (Farooq et al., 2015; Asthana et al., 2015) or effects of neo-tectonics on fluvial or colluvial landforms (Valdiya et al., 1984) largely treating these in isolation. Major questions, like (i) what processes, play important role in building up their landscape if not glaciation-deglaciation (ii) Do non - glaciated catchments also aggrade and incise in-tandem to their glaciated counterparts, and (iii) role of tectonics in the development of landforms are yet to be answered.

The present study is undertaken in the Ramganga catchment – a tributary of Ganga, in north-west Himalaya. The Ramganga river originate at 3100 m amsl, a region devoid of glaciers in the Lesser Himalaya, and is fed mainly by the groundwater recharged by the SW Indian monsoon and negligible amount of snow melt. The geomorphic processes in the catchment are modulated by the temporal changes in the Indian Summer Monsoon (ISM). The study presents geomorphology, character of sedimentary fills and chronology from the river Ramganga (Fig. 1). All the landforms viz., the fluvial terraces, debris flow deposits, alluvial fans, paleo-landslide deposits, flood deposits and epigenetic gorges are studied as complete assemblage to comprehensively understand the response of fluvial system to the tectonic and Late Quaternary climate variability. The geomorphic indices have been used to understand the role of the Lesser Himalayan tectonic elements in shaping up the landscape of the Ramganga river. The first order geomorphic survey of these rivers does not reveal presence of any paleoglacial features, like moraines, etc. Further, the catchments is not affected by long and short term geological responses of the Main Central Thrust zone (MCT) and the rapid exhumation and erosion of the Higher Himalayan Crystallines (HHC). Therefore, this study provides an opportunity to understand the role of the Lesser Himalayan Geology and tectonic framework on its fluvial landscape evolution and aggradation phases.

1.1. *Geology of the Ramganga valley*

The Ramganga river catchments lies south of the Main Central Thrust, in the Lesser Himalaya and Siwalik terrain (Rupke, 1974; Valdiya, 1980). It originates from the southern slopes of the Lesser Himalaya at Dudadholi and joins the Ganga in the middle Ganga Plains (Farukhabad). The Lesser Himalaya is composed largely of the sedimentary and low grade meta-sedimentary sequences (Fig. 1). In the inner Lesser Himalayan zone it comprises of granite and gneisses of Almora and Ramgarhgroups, the Calc zone of Pithoragarh (Rautgarha, Gangolihat limestone and Sor Slates) and the Berinag Formation (quartzite) (Valdiya, 1980). This is followed by North Almora Thrust (NAT) that forms the northern boundary of the Almora Nappe which also defines the boundary between the inner and outer Lesser Himalaya. The Almora Nappe is a thick synclinal sheet of metamorphics intruded by trondhjemitic suite of granites (Valdiya, 1980; Joshi, 1999; Goswami and Pant, 2008).Towards south, the Almora Nappe is bounded by South Almora Thrust (SAT). South of the SAT lie the Ramgarh (crystallines comprising schists, gneisses and granites), Nagthat (argillaceous), Blaini (glacial tills), Krol and Tal (Shallow marine argillaceous and limestone package) formations of middle Proterozoic to Cambrian age (Valdiya, 1980). These in turn are thrusts over the Tertiary rocks along the Main Boundary Thrust (MBT). Sub-Himalaya is the outermost belt of Himalaya that comprises the marine Subathu Formation and the Siwalik succession consisting of fluvial sandstone, siltstone, mudstone and conglomerates deposited in a foreland basin of Middle Miocene to Middle Pleistocene age (Karunakaran and Ranga Rao, 1979; Raiverman, 2002) (Fig. 1).The Sub-Himalaya is defined by number of closely spaced intraformational thrusts (Raiverman, 2002).Apart from the major structural boundaries such as NAT, SAT, RT, MBT and the HFT, the Ramganga River cuts few transverse faults namely; Chaukhutiya (CF) and Binau-Bhikiyasain-Naurar faults (BBNF)where sudden change in landform is observed (Valdiya, 1976). The landform development is affected by continued movements along the North and South Almora Thrust and other transverse faults such as BBNF and CF.

2. Materials and methods

The methodology adopted to address geomorphic evolution in the Ramganga basin comprises morphometric analysis of landscape, field study of landforms and channel characteristics and TL/OSL dating of fluvial deposits.

The morphometric measurements of the landscape developed in the Ramganga River basin were carried out on Survey of India toposheet at 1:50,000 scale. The calculated geomorphic indices include Transverse Topographic Symmetry Factor (T), Stream Longitudinal profile and Stream Gradient Index (SL), and ratio of valley floor width to valley height (Vf). The Topographic Symmetry Factor 'T' is defined by $T = Da/Dd$; where Da is the distance from the midline of the drainage basin to the midline of the active channel and Dd is the distance from the basin midline to the basin divide. It is assumed that $T = 0$ where the basin is perfectly symmetric. So any value greater than 0 indicates the migration of steam channels, which is an indication of possible ground tilting in that direction (Cox, 1994). The obtained T values are plotted in polar diagram and rose diagram to know the trend of migration. Stream having higher order streams (>5) were considered for analysing the transverse topographic symmetry (T). For computing stream longitudinal profiles and SL indices, topographic maps of 20 m contour spacing were used. The SL index was developed by Hack (1973) to decipher the relationships amongst stream power, channel morphology and bedrock resistance to erosion. This index is defined as $SL = (\Delta H/\Delta L) L$, where ΔH is the change in elevation along the channel reach, ΔL is the length of the reach and L is the total channel length from the midpoint of the reach of interest upstream to the highest point on the channel (Hack, 1973; Merritts and Vincent, 1989). The V_f is given by $V_f = 2V_{fw}/[(E_{ld} - E_{sc}) + (E_{rd} - E_{sc})]$, where V_{fw} is the width of the valley floor, E_{ld} and E_{rd} are elevations of the left and right valley divides and E_{sc} the elevation of the valley floor (Bull and McFadden, 1977). This ratio helps in differentiating broad canyons defined by high values of V_f from that of V-shaped valleys with low V_f values. High V_f ratios suggest less tectonic activity while those with low ratios and V-shaped cross-sections resulting from stream incision, may indicate tectonic activity.

In the field, channel characteristics and geomorphic features like narrow gorges, wide valleys and terraces were studied. Terraces were studied for their configuration, sedimentary architecture and chronology. Terraces, with thick sedimentary fill and thin or no underlying bedrock benches were designated as cut and fill type and those with thin alluvial cover and thick underlying bedrock bench as strath type (Bull, 1991; Srivastava and Misra, 2008). Terrace thickness was precisely measured by a measuring tape.

The sedimentary fill of terraces along the Ramganga valley was

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