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# Morphometric properties of the trans-Himalayan river catchments: Clues towards a relative chronology of orogen-wide drainage integration

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ABSTRACT

The geomorphological evolution of the Himalayan mountain belt both in terms of crustal deformation and concomitant erosion by surface processes has been suggested to have a profound influence on a number of earth system processes and has been extensively researched through a number of different techniques. The huge catchments of the trans-Himalayan rivers are the product of long-term fluvial erosion of the landscape. This work attempts to understand their evolution through a study of drainage network, morphology, and internal organization of the smaller watersheds nested within each catchment.

Using morphometric techniques applied to an orogen-wide digital elevation data grid, we characterized the drainage network structure and catchment of all the 18 trans-Himalayan rivers situated between the exits of the Indus and Brahmaputra rivers and constructed rectangular approximations of the catchment geometries. With the help of catchment dimensions measured transverse and parallel to the strike of the orogen, and by analyzing the dimension and spatial dispositions of the rectangular approximations, we demonstrate that the trans-Himalayan catchment shapes cannot be explained only as a product of the headward enlargement of drainage networks on a topographic slope, or orogenic taper. Within individual catchments we identified the existence of drainage components (watersheds) that are organized in a systematic manner with respect to the first-order physiographic features of the Himalayas, formed at different periods of geological time. Each of them shows distinct morphometric characteristics that are indicative of differences in processes and / or time scale involved in their formation. The hypsometric properties of the watersheds occupying the upper part of the catchments suggest that they are the remnants of pre-orogenic drainage that became confined to the leeward side of the Himalayas before the advent of monsoon circulation. The shape and organization of the transverse watersheds occurring in the middle of the catchments resemble a series of small drainage basins formed on the precursor topography of the modern Himalayas. The lower parts of the catchments were shaped instead by drainage diversions induced by deformations related to the frontal thrust. We show how the shape of the catchments represents an integration of processes such as headward drainage enlargement, capture of pre-existing drainage, and diversion of drainage in response to crustal deformation at successive stages of Himalayan mountain growth. We further show that there is a systematic change in the morphological characters and organization of the watersheds, nested in the catchments, from the middle towards the flanks of the Himalayas indicating the variations in relative influence of different drainage evolution processes and the orogen-scale heterogeneity in tectonic style.



## 1. Introduction

Surface processes, and predominantly the action of rivers, have carved out large valley systems on the Himalayan topography. A huge population of rivers, very large to small, drains the southern slope of the Himalayas and flows out into the foreland alluvial plains after crossing the southern mountain front (Burrard and Hayden, 1907; see also Fig. 1 in Brookfiled, 1998). The smaller streams cross only the lower part of the southern slope, whereas the larger rivers traverse the entire southern slope as well as small regions lying to the north of the topographic divide (Fig. 1). These rivers are termed trans-Himalayan in this work. In contrast, the two syntaxial rivers, the Indus and Brahmaputra originate in the Tibetan Himalaya. They flow parallel to the orogen behind the Himalayas for hundreds of kilometers towards the west and east, respectively (Fig. 1). Their tributaries drain the region lying between the northern slope of the orogen and the southern edge of the Tibetan Plateau (Fig. 2). These two rivers turn south at the western and eastern syntaxial bends to cut across the mountain belt and exit in the foreland plains.

The catchments of the modern trans-Himalayan rivers are very large (Table 1, Fig. 1). It would require continuous erosion for a few tens of

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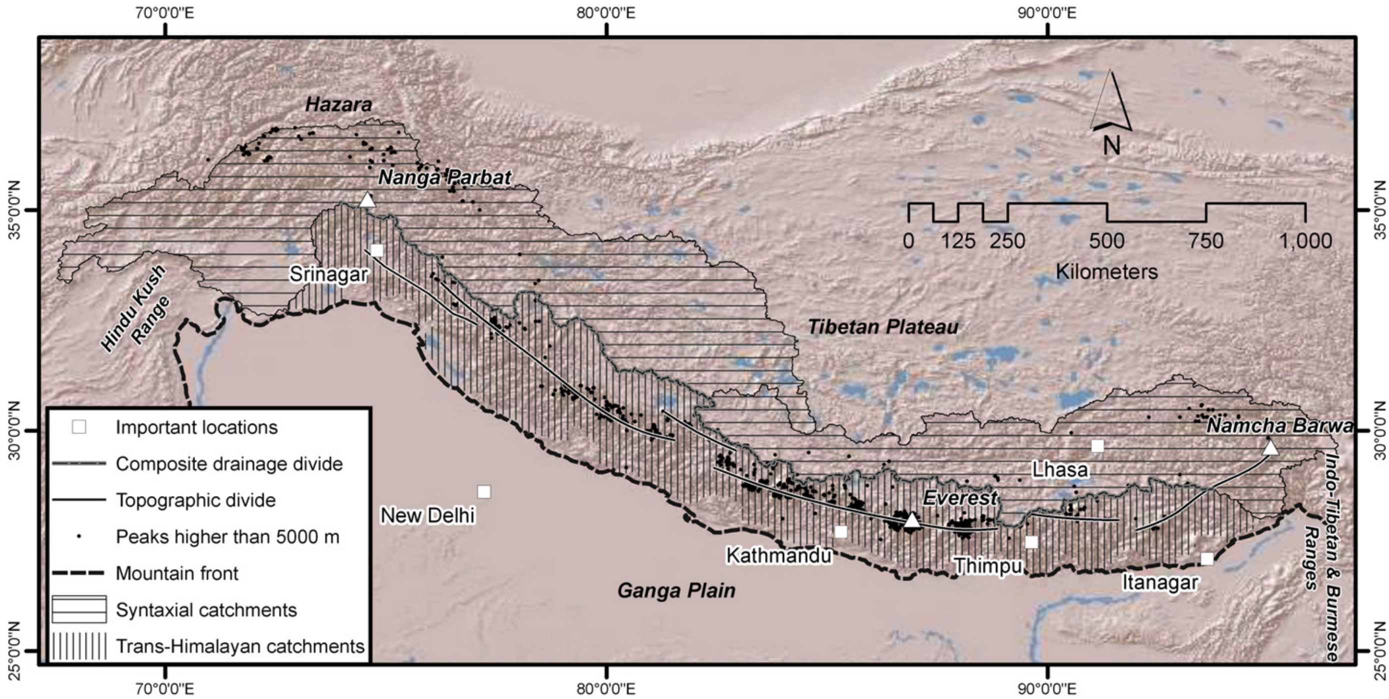


**Fig. 1.** Map showing the first-order physiographic features of the Himalayan mountain belt. The area drained by the two syntaxial rivers, Indus and Brahmaputra, as well as that by the trans-Himalayan rivers are marked.

millions years to produce erosional features of such dimensions (Shroder and Bishop, 2004). Capturing insights into the history of these catchments could, therefore, provide scope for better understanding the erosional history of this orogen on a time scale of $10^7$ years and, in turn, for better constraining links between orogen-scale denudation and global changes. However, relying on clues contained among the complex geomorphic features of landscapes such as those of the trans-Himalayan river catchments is possible only on condition that their mode of formation can be clearly understood. Apart from a few earlier studies on the evolution of the Himalayan drainage systems (e.g., Gupta, 1997; Brookfiled, 1998; Friend et al., 1999) a comprehensive understanding of the evolution of these huge geomorphic features is not available.

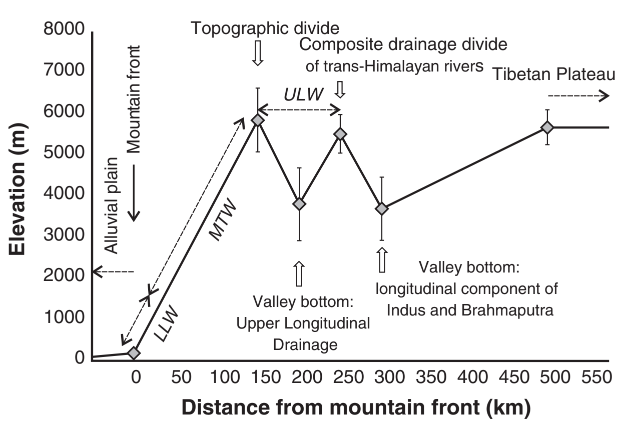


**Fig. 2.** Generalized physiographic profile of the Himalayan mountain belt along a traverse extending from the mountain front in the south to the edge of the Tibetan plateau in the north. The average elevation of the main topographic divide, the composite drainage divide of the trans-Himalayan rivers and the southern edge of the Tibetan plateau are plotted against distance from the mountain front. The distances are averages of measurements made along a number of orogen transverse lines in the western and eastern Himalayas. Vertical bars represent the standard deviations. The elevations were measured at the outlets of the trans-Himalayan rivers for the mountain front; at the peaks, higher than 5000 m, for the topographic divide; along the trunk streams for the upper reaches of trans-Himalayan rivers; along the composite drainage divide, along the trunk streams of the Indus and Brahmaputra and along the northern catchment boundaries of the two syntaxial rivers.

Global surveys of the drainage networks in linear orogens and footwall uplands (Hovius, 1996; Talling et al., 1997; Purdie and Brook, 2006; Walcott and Summerfield, 2009) indicate that the drainage outlets of the range-scale catchments are regularly spaced along the mountain front irrespective of scale, slope, lithology, climate or tectonic setting. It has been also noted that the outlet spacing (s) maintains a consistent relationship with the width of the orogen (w). For many orogens, the spacing ratio (w/s) takes a value of about 2 (Hovius, 1996; Walcott and Summerfield, 2009). This consistency among spacing ratios has been attributed to an expression of Hack's Law (Hovius, 1996), which states that the length of the trunk stream maintains a power law relationship with the drainage area (Hack, 1957) during the growth of the drainage network. Despite being more or less regularly spaced, unlike other orogens the spacing ratio of outlets of the trans-Himalayan drainages has been found to be much less, about 1.7 (Hovius, 1996; Walcott and Summerfield, 2009). This would indicate that the catchment-evolution process, in this case, is different. Large, tectonically active and widening orogens like the Himalayas have a complex history of physiographic evolution due to variations in tectono-climatic forcing over a millennial time scale. It is expected that, in such cases, additional factors and mechanisms will affect drainage development (Gupta, 1997; Friend et al., 1999; Castelltort and Simpson, 2006). It has been argued that drainage reorganization induced by currently ongoing tectonic deformation at the frontal part of this active orogen produces an unstable arrangement of the basins (Walcott and Summerfield, 2009), which gives rise to a computed spacing ratio smaller than 2. However, the mechanics of catchment evolution that might explain the present-day shape and organization of the trans-Himalayan basins remains to be fully investigated. It is possible that known mechanisms such as enlargement of the basins into the hinterland (Densmore et al., 2005; Perron et al., 2008), accretion of the foreland (Castelltort and Simpson, 2006), and annexation (capture) of antecedent river catchments have interacted at different stages to give rise to the modern-day configuration. However, identification of