Identifying areas of differential uplift using steepness index in the Alaknanda basin, Garhwal Himalaya, Uttarakhand

A. K. Tyagi¹, Shipra Chaudhary², N. Rana², S. P. Satinya², a and N. Juyal¹

¹Physical Research Laboratory, Ahmedabad 380 009, India
²Department of Geology, H.N.B. Garhwal University, Srinagar 246 174, India

In this paper an attempt has been made to identify places of high surface uplift in the Alaknanda valley using the steepness index method. Locations that are undergoing faster surface uplift are marked by convex river profile and high steepness index (k) values. Conventionally, the Main Central Thrust (MCT) is known to be the zone of high uplift (incision), which accords well with our analyses. The second zone of relatively higher surface uplift is identified south of the MCT around Chamoli, Nandprayag and Karnprayag. These locations are traversed by the Chamoli, Nandprayag and the Alaknanda faults respectively. Our preliminary study suggests that for future earthquake risk evaluation, detailed geomorphological and seismotectonic studies should be undertaken in this area.

Keywords: Alaknanda basin, differential uplift, river profile, steepness index.

Evolvement of landscape in tectonically active mountain regions is intrinsically related to the combination of endogenic (crustal deformation) and exogenic (surface) processes. In such areas, rivers play an important role due to their ability to incise, which ultimately sets the rate of lowering of a landscape and therefore mass removal in actively rising mountainous regions. Two major factors that modulate bedrock incision rate are climate and tectonics. In a steady state condition, when climate (the long-term sediment supply and transport capacity are balanced) and the rate of uplift is equal to the rate of incision, the longitudinal profile of a river would be graded. However, if the river bed uplift rate exceeds the incision capability, then the convex longitudinal profile develops. Therefore, in order to ascertain the fluvial response to terrain instability (stability), longitudinal river profile provides a first order approximation towards the role of endogenic and exogenic processes. Towards this, empirical studies were found quite useful to assess the spatial variability in surface uplift (endogenic) in active orogen. The general equation for the river profile evolution can be written as

\[ \frac{dz}{dt} = U(x,t) - KA''S^n, \]  

where \( \frac{dz}{dt} \) is the rate of change of channel elevation, \( U \) is rock uplift rate relative to fixed base level, \( K \) is erosion coefficient, \( A \) is channel drainage area, \( S \) is channel gradient, and \( m \) and \( n \) are the constants depending on the basin lithology, river channel geometry and erosion process.

In such studies (for steady state condition), erosion is balanced by uplift, and the longitudinal profile of a river can be represented by a power law function in which the local channel slope (S) of a stream is a function of the stream drainage area (A) and can be represented as \( S = kA^{-d} \).

Here \( k \) is the steepness index and \( \theta \) is the concavity. If there is no differential uplift, the value of \( k \) should remain constant for a given stream. However, if the river basin is undergoing differential uplift, \( k \) can change from one segment to another. Considering that the channel slope is inversely proportional to drainage basin area, therefore, as the drainage area increases, the slope of the river profile decreases. However, in areas where differential uplift is going on, the proportionality of drainage area and slope does not hold. The areas where differential uplift is higher, oversteepening of the river profiles should occur, and can be ascertained by changes in \( k \).

However, in this equation, it is assumed that the role of lithology, channel geometry and sediment variability has limited influence. This is reasonable considering that in the study area there is no significant lithological variation, river dominantly flows on the bedrock, and hence variable sediment supply may not have much influence on erosion coefficient. Therefore, changes in \( k \) can be used to ascertain the variation in the uplift. Here we would like to mention that the equation can be used in areas where insignificant variations in lithology, sediment supply and channel width exist. In the Himalayas a good correlation exists between erosion-resistant lithology and high river gradient and vice versa, implying that the role of differential erosion is secondary to the role of tectonics in shaping the profiles of Himalayan rivers. Further, channel geometry and sediment supply would have insignificant influence on the river profile development because of the confined nature of river channel and bedrock-dominated flow characteristics. In the present study, longitudinal profile of the Alaknanda river in the Central Himalaya was investigated using the given expression in order to identify areas of differential uplift. The Alaknanda river drains through three major lithologies, from north to south; these are the Trans-Himalayan Sedimentary (THS), the Higher Himalayan Crystalline (HHC) and the Lesser Himalayan Metasedimentary rocks (LHM). The orographic and lithological discontinuities are differentiated by the Trans-Himadri Fault (THF) and the Main Central Thrust (MCT) respectively. In addition to this, the Alaknanda river traverses the MCT at Helong, the Alaknanda fault (AF) at Karnprayag and the North Almora Thrust (NAT) at Srinagar before meeting the Bhagirathi river at Devprayag in the Lesser Himalaya.