DEM AND GIS BASED HYPSOMETRIC ANALYSIS TO INVESTIGATE NEOTECTONIC INFLUENCE ON HAZARA KASHMIR SYNTAXIS

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ABSTRACT: North-South oriented neotectonic activity, abrupt slope and stream length gradients in Hazara Kashmir Syntaxis (HKS) make it an ideal natural laboratory and provide an important opportunity to investigate neotectonic and lithological influence on its landscape evolution. In this research, geomorphometric characteristics of HKS in northern Pakistan are evaluated through DEM based hypsometric analysis of different Strahler order subbasins. Twenty eight Strahler order six subbasins and 134 five order subbasins were extracted from SRTM 90 m using D8 algorithm. Hypsometric integrals (HIs) and hypsometric curves (HCs) for each individual subbasin were calculated to evaluate the degree of erosional stages and the factors controlling it. HIs and HCs were computed using zonal statistics by exploiting the maximum, minimum and mean elevations. The convex up curve shows less eroded subbasins and they are located along and the NE of the Muzaffarbad anticline which is an indication that HKS is tectonically active, while the S-shaped curves represent the intermediate erosion stage and they are located north of the HKS. The concave down curves indicate maximum erosional stage and they are located east and west of HKS. Higher values of HIs and shape of the HCs correspond to neotectonic control of the landscape of HKS.

Key words: DEM, GIS, Hypsometry, Neotectonics and HKS: lithological influence

INTRODUCTION

The hypsometric analysis to investigate neotectonics is one of the emergent disciplines in geosciences. The results of regional studies on neotectonics are significant for evaluation and management of natural hazards, land use developments and populated areas. The eventual goal of our investigation is to understand tectonic history from topography by inferring the effects of tectonism on landforms and geomorphic processes. The morphology of the Earth is a result of interactions between tectonics, climate and geology (Luo et al., 1994; Burbank and Anderson, 2001; Keller and Pinter, 2002; Mahmood and Gloaguen, 2011). Therefore the study of neotectonics requires a multi-disciplinary approach, integrating data from remote sensing imagery, geomorphology, structural geology, stratigraphy, geochronology, seismology, and geodesy. The HI is one of the key parameters in morphometry and is used to infer the temporal stages of geomorphic development (Weissel et al., 1994). Hypsometry (or area-altitude analysis) describes the distribution of the horizontal cross-sectional area of a landmass with respect to different elevations and can be calculated using the HI (Strahler, 1952). Mathematically, it represents a line plot between elevation ratio (h/H) and area ratio (a/A) in a given basin, as shown in Fig. 1 and can be computed by the equation 1. The shape of this curve represents the development history of the concerned basin (Strahler, 1952). S shaped curves represent intermediate basins while curves above the mid line are convex up curves representing the younger basins and vice versa. The hypsometric curves have been used to infer the stage of development of the drainage network in the HKS and also are a powerful tool to discriminate between tectonically active and inactive areas (Mayer, 1990; Hurtrez and Lucazeau, 1999).

Study area: The HKS is a comlex tectonic zone in the northern Pakistan, between Mirpur and Muzaffarabad. The broader geological structures of the NW-Himalayas formulate an abrupt hairpin bend as if "they were bent rounded a pivotal point obstructing them" (Wadia, 1928, 1930, 1931, 1934). Its axial zone is well-defined by a stack of thrust faults which form a loop around its axis. Precambrian to Neogene sedimentary, volcanic and metamorphic rock and Cambrian or earlier granitic rocks are exposed in the syntaxial zone and its environs. The axial zone of the syntaxis has a NNW orientation and is largely covered by Murree formation (Oligocene? to Miocene). This formation comprises reddish siltstone and shale and is at least 1,700m thick. Near Muzaffaraabad, Precambrian to Cambrian and Paleocene sedimentary rocks are exposed in an anticline, which is crossfolded, overturned and thrust southwest along the Muzafferabad

Fault or Balakot Bagh fault (BBF) shown in Fig. 2. This fault dips 20-25 degree E and has moved the older rock westward over Paleocene limestone and Murree rock (Calkins et al., 1975). Bossart et al., 1988) suggest that the core of the syntaxis is comprised of a deformed dome which developed by "layer compression" sub-perpendicular to a southwestward over-thrust direction. Near Muzaffarabad the sediments have been metamorphosed to prehnite-pumpellyite grade (Greco, 1991). The axial zone of the syntaxis, with its Eocene molasse cover (Murree Formation), is in continuation of the Sub-Himalayan zone to the southeast continues from the Sub-Himalayan zone northward into the core of the syntaxis and is terminated against the MBT (Baig and Lawrence, 1987). North of Balakot, the axis of Hazara-Kashmir Syntaxis bends northeastward and continues up till Paras into Kaghan valley and beyond, into the Nanga Parbat-Haramosh region, where some workers call it "the Nanga Parbat Syntaxis" (Coward, 1986). This eccentric position of the Nanga Parbat Massif is attributed by Desio (1979) to a possible clockwise rotation. On westwrn side of Hazara-Kashmir Syntaxis there are several arcute, south verging thrust fault which terminate in the Jhelum Fault at an acute angle between Balakot and Kohala.

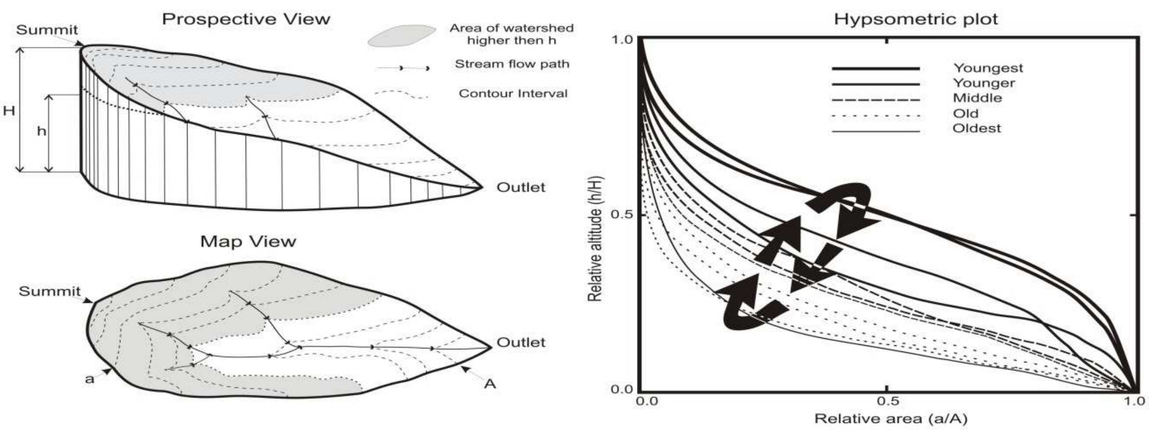

Fig. 1 A typical HC (modified after Keller and Pinter, 2002). Area below the HC is known as the HI. Total elevation (H) is the relief within the basin, total area (A) is total surface area of the basin, and area (a) is surface area within the basin above a given altitude (h).

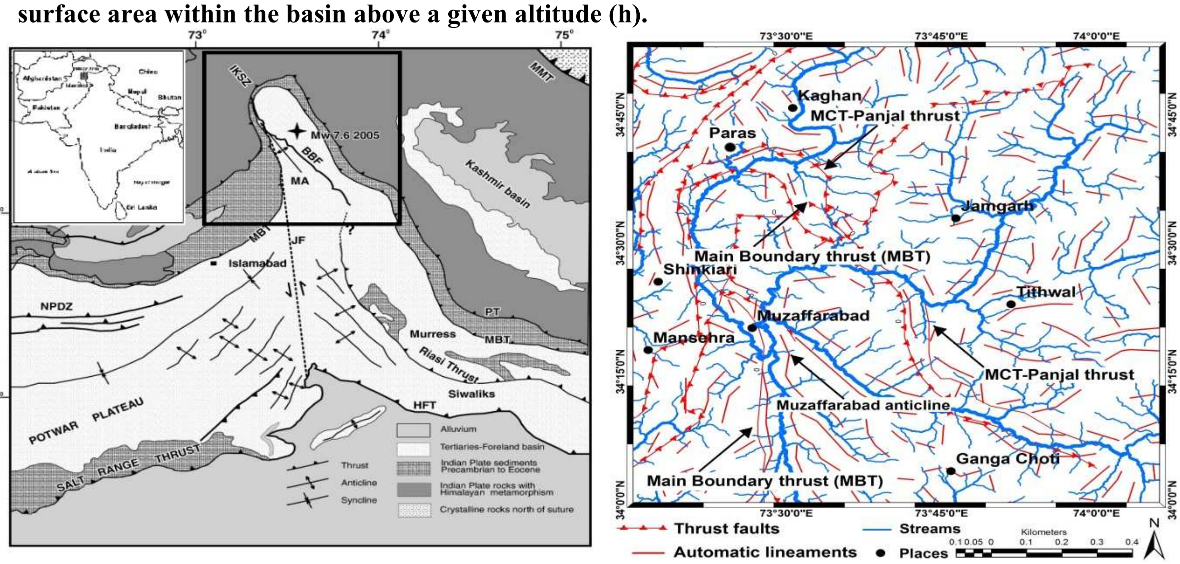

Fig. 2 Map on the left shows NW flank of Himalaya (HKS) with two different tectonic settings indicative of contrasting compression directions. The eastern flank of HKS is dominated by NW–SE trending fold and thrust belts, whereas the western flank shows NE–SW trending, separated by active sinistral Jhelum fault. Abbreviations in both maps: MMT, Main Mantle Thrust; PT, Panjal Thrust; MBT, Main Boundary Thrust; HFT, Himalayan Frontal Thrust; BBF, Balakot–Bagh Fault; MA, Muzaffarabad Anticline; JF, Jhelum Fault; NPDZ, Northern Potwar Deformed Zone; IKSZ, Indus–Kohistan Seismic Zone (Blisniuk et al., 1998). Map on the right shows local drainage in blue, thins red automatic lineaments and thick published faults.

Datasets and Methods: We use NASA Shuttle Radar Topography Mission (SRTM, version 4) 3 arc second digital elevation model (DEM) data with a spatial resolution of 90 m. This data is currently distributed free of charge by USGS and is available for download from the National Map Seamless Data Distribution System, or the USGS ftp site. The vertical error of this DEM is reported to be less than 16 m. It is an accurate and robust DEM that covers most parts of the world. At First, the DEM is pit-filled using ArcGIS 10 generic tools in order to fill possible voids. The D8 flow grid algorithm applied by specially designed Matlab algorithm that extracts the drainage network from DEM. The D8 algorithm calculates possible flow directions at each cell towards the 8 neighboring cells. The least cost algorithm is used to connect the stream flow directions in order to generate a continuous network of streams. All streams were vectorized and are assigned with a unique Strahler order, and the desired watersheds are extracted. We exploited zonal statistics to compute maximum, minimum and mean elevations over the extracted watersheds of different Strahler order in order to get HI values for each watershed.

$$HI = \frac{H_{mean} - H_{\min}}{H_{\max} - H_{\min}} \qquad (1)$$

RESULTS AND DISCUSSION

In this research HI and HC analyses are applied in the subbasins of HKS in northern Pakistan. According to generated results convex, S shaped and concave hypsometric curve are observed in the area indicating differential erosional stages and level of neotectonic activity in the study area. High HI values of the majority of the watersheds and their subbasins indicate the youthful stage (convex up curves) of HKS except a few, east and west of HKS that are moving towards the S-shaped (intermediate stages) and maturity stages (Fig.3).

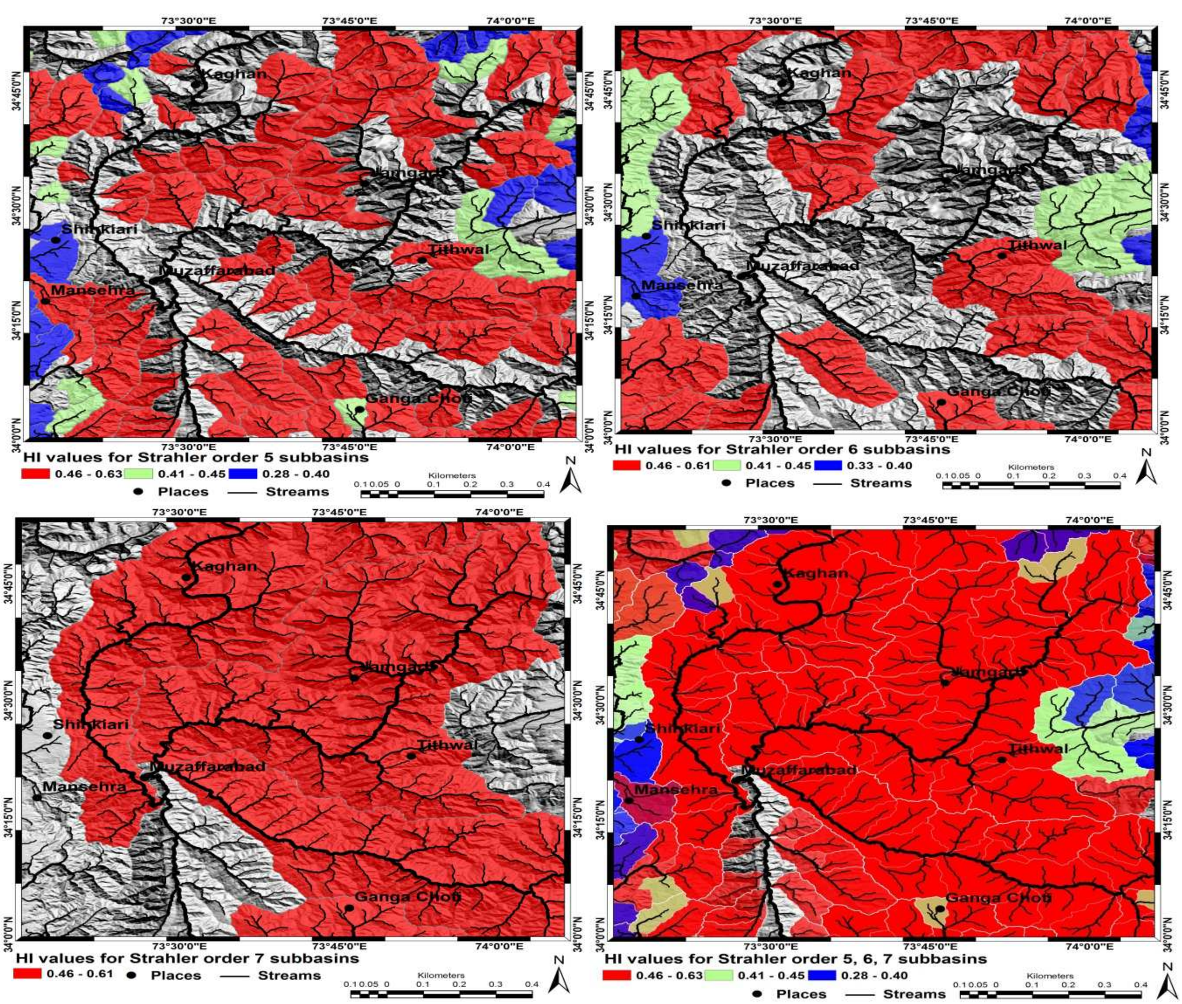

Fig. 3 Maps showing different Strahler order subbasins (i.e., order 5,6 and 7 and their superimposition in the fourth map respectively, red colour stand for the less eroded (young), green colour means intermediated stage and blue means more eroded (mature) subbasins.

Lower HI values signify mature and more eroded areas and evenly dissected drainage subbasins. High HI values also show that most of the HKS topography is high relative to the mean, such as even upland surface cut by deeply incised streams representing young evolving and less eroded areas that are still under geological development. However, subbasins east of HKS on the Sri Nagar (Kashmir basin) valley side are impending towards monadnock (less vulnerability to erosion) stage and attributed mainly to human interventions in the form of construction of houses, roads, agricultural practices and deforestation activities. High values of HI along HKS in the Kunhar, Neelam and Jehlum watersheds and their subbasins, explain their late youthful stages, and therefore, these subbasins are also prone to subsequent erosion activities and need appropriate soil and water conservation measures.

Hypsometric analysis has been broadly employed for topographic analyses and is very sensitive to diverse forcing factors in the landscape development. The HI values calculated for the different Strahler order subbasins are different, For example, HI values are usually high, where the drainage area is small and hillslope processes are active. In such cases, the HCs would be convex up with a HI value close to one (Fig. 4). On the contrary, in case of subbasins with intermediate size, with increased contributing drainage area, the importance of river processes become dominant; the HC becomes concave down with a HI close to zero (Fig. 4).

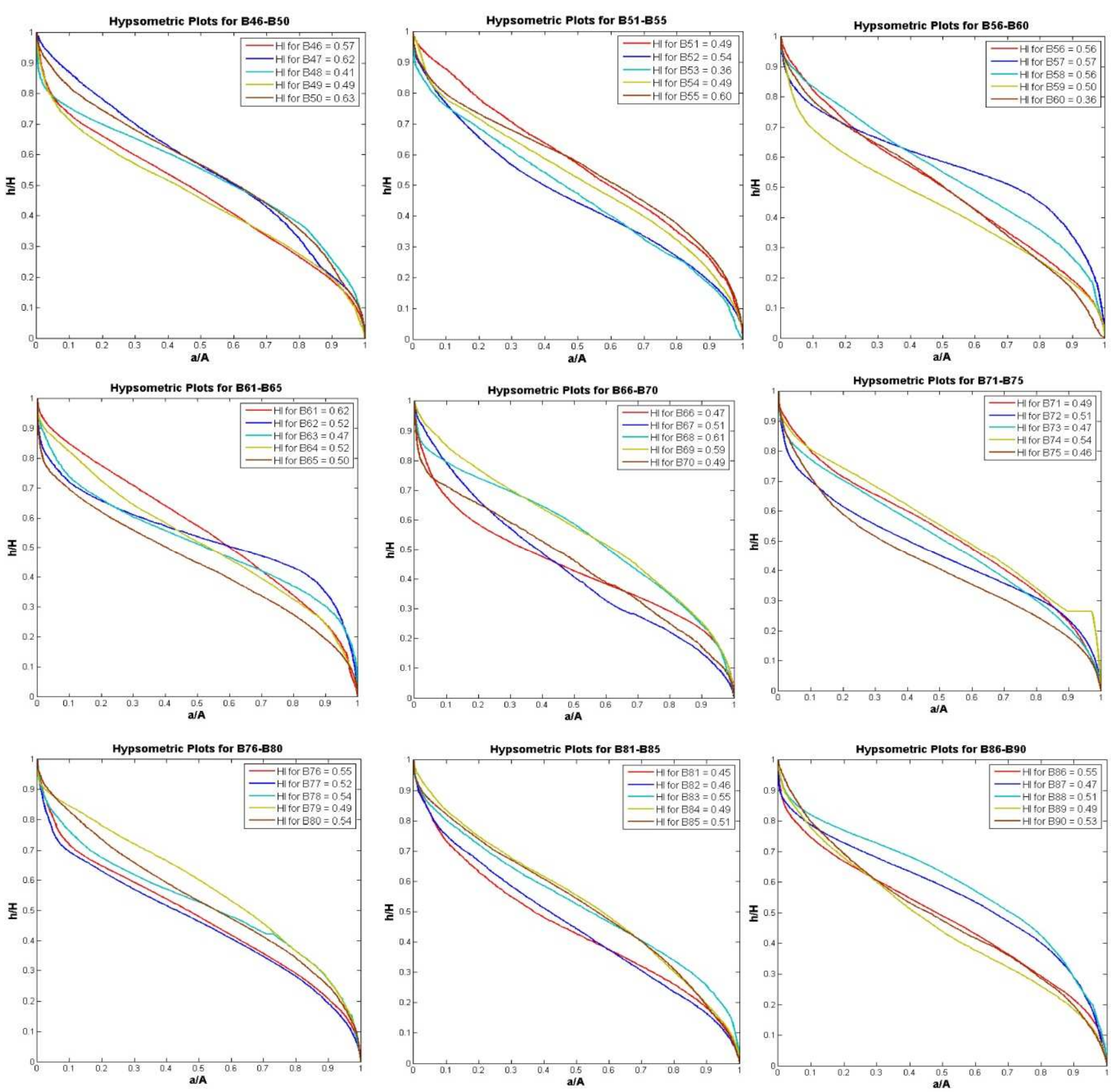

Fig. 4 HCs along with their respective HI values for the 45 subbasins along HKS. The convex up shapes and their Higher HI values indicate that the HKS is still emerging as youthful stage of topography.

Conclusion: Hypsometric analysis of subbasins articulates the complication of stripping processes and the rate of morphological changes. Hence it is a handy tool to understand the continuous and existing erosion conditions of the subbasins in the context of taking immediate and appropriate measures for the conservation of soil and water. Nevertheless, one should be extra careful regarding the interpretation and comparison of HCs because of the composite nature of its calculation. The results of HI values show that the subbasin within the HKS region (Between PT and MBT) is less prone to erosion in contrast to the subbasins, which lie east or west of the HKS. Due to tectonic domination over erosion and climate, this region has uplift rates of about 2-3 mm/year and differential erosion is also active here due to recent neotectonic activity in Kashmir, and due to plentiful precipitation both in summer and winter. It simply means that means that in the areas of less erosion within the HKS, we can ensure soil and water management easily at suitable sites within the various subbasins to detain the sediments removal and safeguard water resources. In addition, the subbasins having HI values more than 0.45 (young stage and emerging landscapes) require building of both vegetal and automated measures to protect soil and water for integrated basin and subbasins management and vice versa. The hypsometry is a geomorphic parameter, which is extremely responsive to both surface and sub-surface processes coupled with landscape development. The landscape controlling factors (neotectonics, erosional processes and climate) in conjunction with stream and hillslope processes (lithology) can be decoded via HI and HCs analyses.

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