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Geospatial Technology in Hypsometric Analysis of Mohand Anticline, Uttarakhand, India

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Abstract

Remote sensing and GIS serve as significant tools for studying morphometric characteristics of watersheds. Hypsometric analysis being a parameter of it is defined as the relationship between the horizontal cross-sectional area of the watershed and its elevation. The present study emphasizes on Hypsometric analysis of Mohand Anticline, Uttarakhand, India using Digital Elevation Model (DEM). This study takes into account the Hypsometric curves of watersheds developed over actively deformed Mohand anticlinal part of NW Himalaya. Hypsometric curves for each of the river basins close to Mohan Rao basin have been studied 30-meter ASTER GDEM. It has been observed that some river basins for example Mohan Rao and Khajnaur Rao basins over the anticline are relatively younger than the others and have been subjected to tectonic disturbances and rejuvenation.

Keywords: Digital Elevation Model, Hypsometric analysis, Mohand anticline, Himalaya, Active Tectonic

1. Introduction

Himalaya, being one of the most tectonically active Mountain Range on the Earth's surface, constitutes large number of faults which reflect the effect of Himalayan continental collision. The major thrusts of this area are Himalayan Frontal Thrust (HFT), Main Boundary Thrust (MBT), and Main Central Thrust (MCT). These thrusts are responsible for major earthquakes and landslides. The occurrence of a number of earthquakes between the MCT and HFT represent the continuing compressional stress regime in the region (Rautela and Sati, 1998). Identification of active faults in the Himalayas is extremely significant as these reflect the Himalayan continental collision. Hypsometric analysis is a crucial tool to assess and compare the geomorphic evolution of various landforms as it includes distribution of horizontal cross sectional area of a landmass with respect to elevation (Strahler, 1952). Climate, Tectonics and lithology play major role for the evolution of landscape (Singh and Sarangi, 2008). The different statistical characteristics of the hypsometric analysis which indicate important aspects of the geomorphological evolution of a basin such as indicated by the watershed development and differential erosion, make this technique an important method for the scope of the present study. These aspects are indicated by hypsometric curve, hypsometric integral (I) and hypsometric skewness (Strahler, 1952; Schumm, 1956; Ritter et al., 2002; Wei and Harlin, 2003). According to the hypsometric analysis, it has been observed that some of the basins in Mohand anticline have been uplifted or shifted to some extent and have been subjected to rejuvenation.

Hypsometric curve and hypsometric integral are used for watershed health indicator. In a tectonically active region, the basin topography is generally dynamic and its evolution responds to the stress regime of the region. The basin topography is also highly affected by the extent of erosional activities ongoing in the region. In Himalayan system, which is a highly active orogeny, the fluvial erosion plays a significant role in modifying the morphology. The quantification of this interplay of the tectonic uplift and subsequent erosion can be done in the form of a geomorphic index (Weissel et al., 1994). Based on the very same understanding of this interaction, several researchers have carried out hypsometric analysis to study the tectono-geomorphic evolution of different regions (Pandey et al., 2004; Singh et al., 2008a; Singh et al., 2008b; Sharma and Seth, 2010 and Sharma et al., 2011). The basins can be classified by analyzing the shape of hypsometric curves. These curves may be convex upward, S-shaped (concave upwards at high elevations and convex downwards at low elevations) or concave upward implying the youth, mature and peneplain stage of the basin, respectively (Strahler, 1952). The hypsometric integral value has applications for soil and water conservation measures also as it can be used to assess the erosion status of watershed (Singh et al., 2008). The present work involves study of role of active tectonics in channel modification and watershed geometry over Mohand anticline using morphometric tools.

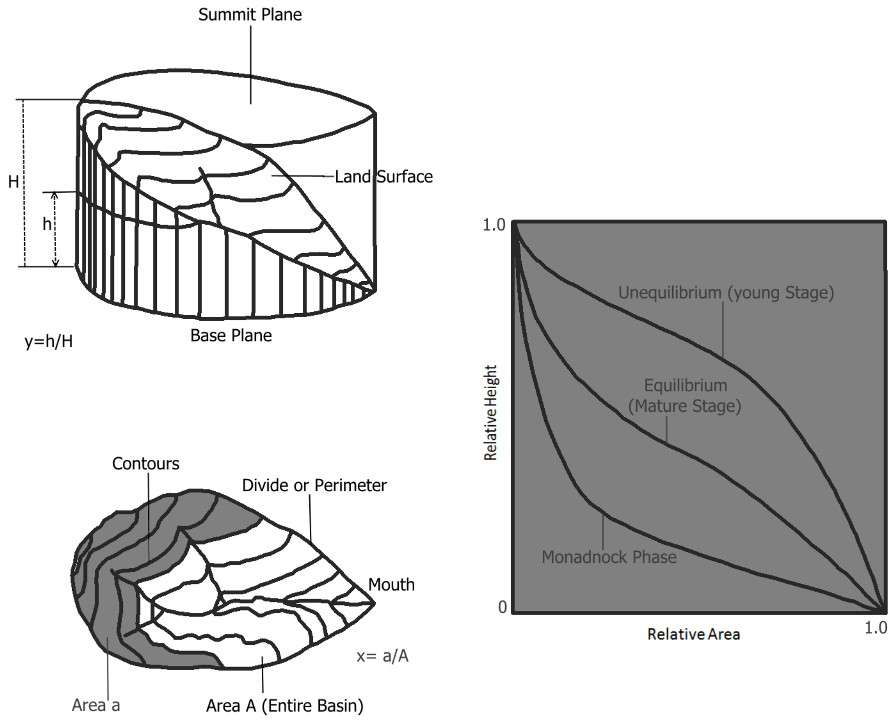

Figure 1: The Concept of Hypsometric Analysis and the Model Hypsometric Curves. Hypsometry is a measure of the relationship between elevation and area in a basin, watershed, or catchment (modified after Ritter et al., 2002).

2. Study area

The selected study area covers part of Sub-Himalayan belt in Dehradun, Northern India. The fold belt constitute many structural depressions commonly known as 'duns'. (Nossin, 1971). Actively growing anticlines manifested as frontal ridges striking almost parallel to the Himalayan Frontal Thrust (HFT) bound these duns from the south. New streams have been developed due to the growth of these ridges. These new streams are known as neo-drainage as they are linked directly to neo-tectonic deformation. The Mohand anticline that forms the focus of the present study comprises a system of ephemeral streams draining the southern flanks of the frontal ridge formed by anticlinal growth (Figure 1).

The area receives plenty rainfall of approximately 1600mm/year, mostly due to southwest monsoon. During the summers, the temperature ranges between 36°C and 16.7°C. In winters, the temperature lies in between 23.4°C and

5.2°C. The other significant aspect of the climate of Dehradun is the monsoon. Dehradun gets an average rainfall of 2073.3mm annually. Dehradun receives the rainfall in between June and September (Mohindra et al., 1992; Wesnousky et al., 1999).

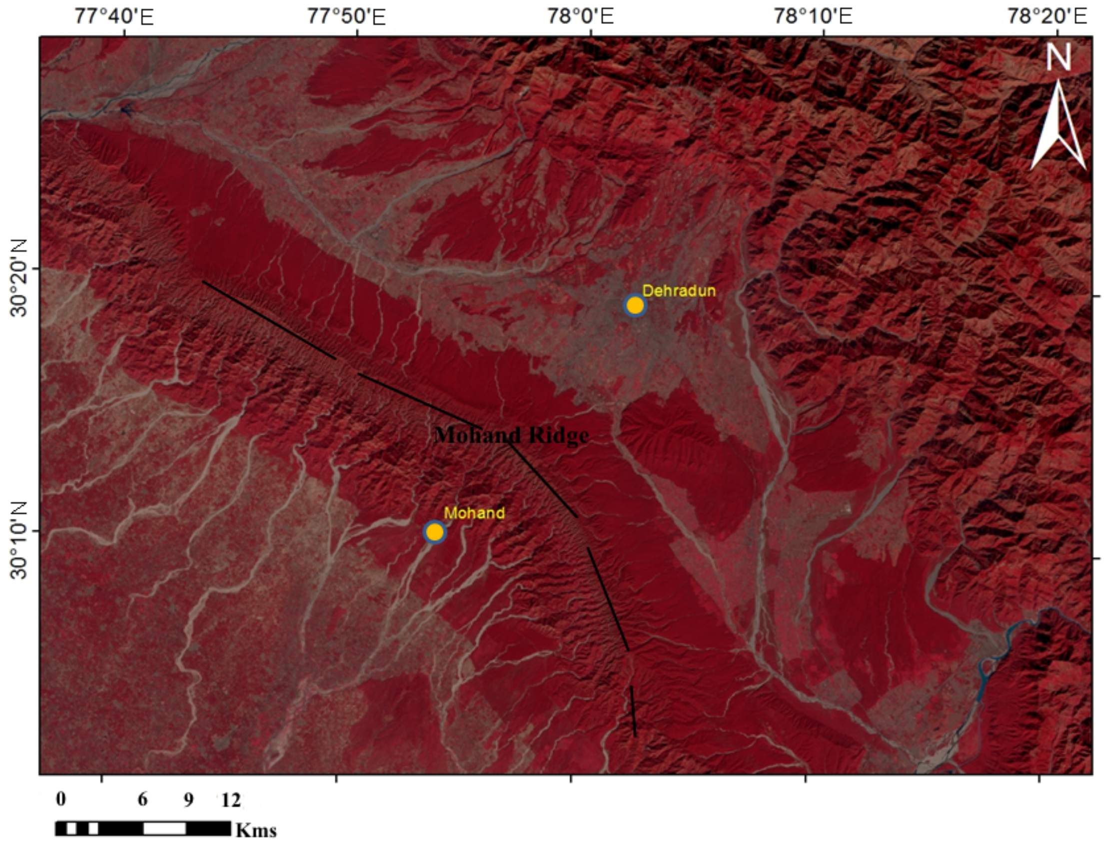

Figure 2: Study area showing NW-SE trending Mohand ridge along with streams in the southern part.

The Mohand ridge is a folded anticline and comprises Siwalik group of rocks. Here mostly middle Siwalik rocks are present in the frontal Himalaya and upper Siwalik rocks have been completely eroded (Powers et al., 1998; Mukhopadhyay and Mishra, 2004). This anticline extends for about 78 km with maximum width of 14 km. This anticline forms a well-defined ridge bounded by Ganga and Yamuna tear faults at the southeast and northwest sides respectively.

The Siwaliks of the Himalayan ranges forms the youngest and southernmost ranges. This fold belt has come into existence owing to the regional tectonic activities operated during the Himalayan orogeny. The collision of the Indian plate with the Asian plate during late Cretaceous to early Eocene lead to the upliftment and marking of first orogeny of the Himalayas. The event is evident from the northern margin of Indian plate stacking over the south propagating intra-crustal thrusts (Molnar, 1984). From north to south these principal intra-crustal thrust are the Indus Tsangpo Suture Zone (ITSZ), Main Central Thrust (MCT), Main Boundary Thrust (MBT) and Himalayan Frontal Thrust (HFT). The HFT separates the Indo-Gangetic plains from the sub-Himalayas and MBT separates sub-Himalayas from the Lesser Himalayas on the north (Figure 3). It is suggested that the convergence in the Himalayan belt has migrated southwards marked by formation of thrusting younger initiation southward (Thakur, 1992). During the Tertiary period, the Himalayan front witnessed the deposition of molassic sequences in the foreland basin. It formed the murree/Dharamshala and Siwalik groups of Oligocene and Neogene age, respectively. Several longitudinal valleys, called Duns, developed in sub-Himalayas with the southward propagation of the fold thrust system.

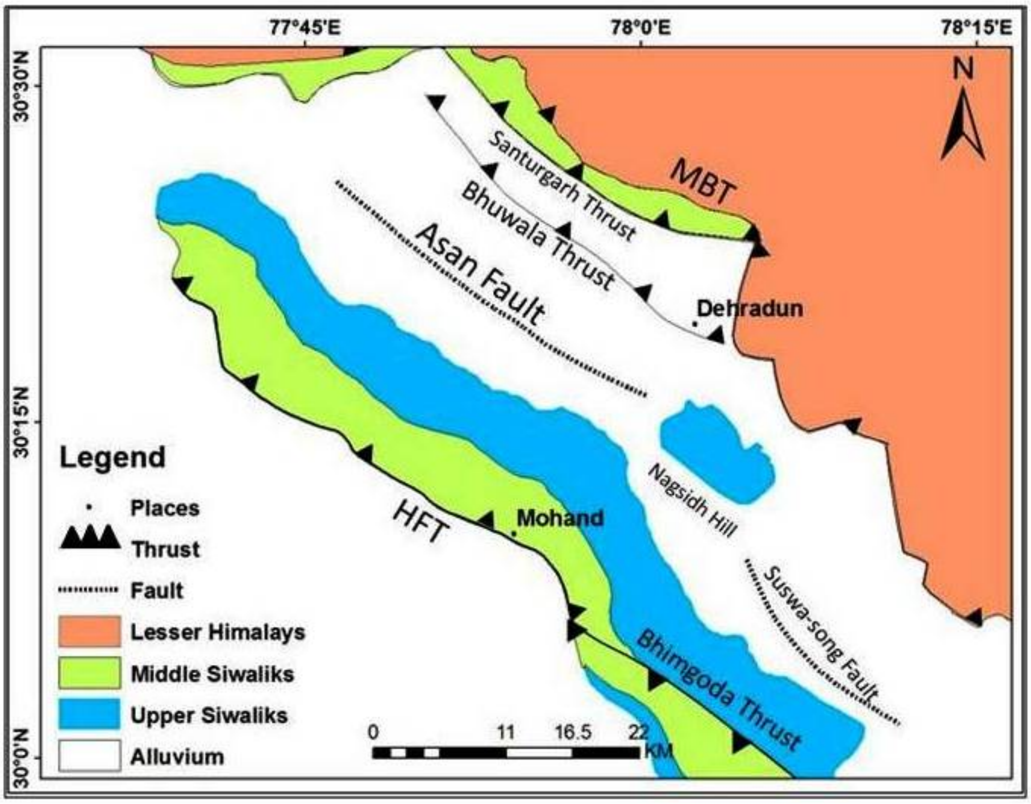

Figure 3: Geological set up of Mohand anticline and Dehradun region. Mohand anticline is surrounded by HFT in the south and MFT in the north (after Raiverman et al., 1990 and Thakur et al., 2006).

The rocks of the Krol group override the Siwaliks through the NE dipping MBT running at the base of Mussoorie range. The hills of ~800 m elevation belonging to the frontal Siwalik range mark the southern limit of the Dun. This Siwalik range is separated from the adjoining alluvial plain towards its south by HFT, which is locally known as the Mohand thrust. The sudden elevation difference between the middle Siwaliks and the Holocene sediments of alluvial plain demarcates the HFT in the region which dips moderately by an amount of ~30° due NE direction. Near Mohand at Khajnaur Rao (stream) and further west in the stream sections, steeply dipping, both N and S, middle Siwalik sandstone abuts against the recent alluvium.

3. Methodology

The watersheds over Mohand anticline region were delineated from Aster GDEM and the hypsometric integral was derived. The hypsometric integral provides basic idea regarding the distribution of elevation data in the area. The higher the values, the larger is the proportion of the total land surface present at higher altitude and whereas smaller the values the smaller is the proportion of area present at higher altitude. Hypsometric curves show high-medium hypsometric integrals/elevation relief ratios indicating different stages of landscape development.

Use of elevation Relief Ratio

The elevation relief ratio method proposed by Pike and Wilson (1971) is given as

$$E \approx H_{si} = \frac{Elev_{mean} - Elev_{min}}{Elev_{max} - Elev_{min}}$$

Where E is elevation relief ratio equivalent to hypsometric integral Hsi; Elevmean is the weighted mean elevation of the watershed estimated from the identifiable contours of the delineated sub-watersheds; Elevmin and Elevmax are the minimum and maximum elevations within the sub-watershed.

Table 1: Calculated Hypsometric integral values of all 10 watersheds. Out of these 10 basins Mohan Rao and Khajnaur Rao basins are showing high hypsometric integral.

Sub Watersheds	Area (Km^2)	Perimeter (Km)	Max. Elev. (m)	Min. Elev. (m)	Total Relief (m)	Hypsometric Integral	Geological Stage
Bakala Rao	33.69	35.69	868	298	570	0.38	Late Mature
Shanasra Rao	50.02	38.51	861	309	552	0.23	Late Mature
Kothri Rao	32.93	38.51	834	302	532	0.33	Late Mature
Rai Singh Rao	41.10	46.79	890	305	585	0.38	Late Mature

Shahajahanpur Rao	47.43	44.44	870	308	562	0.27	Late Mature
Khajnaur Rao	46.12	31.77	883	343	540	0.45	Mature
Mohan Rao	96.74	60.62	872	292	580	0.41	Mature
Chillawala Rao	64.31	53.15	870	303	567	0.33	Late Mature
Andheri Rao	32.74	33.35	900	305	585	0.37	Late Mature
Dhokhand Rao	51.74	40.64	907	347	560	0.30	Late Mature

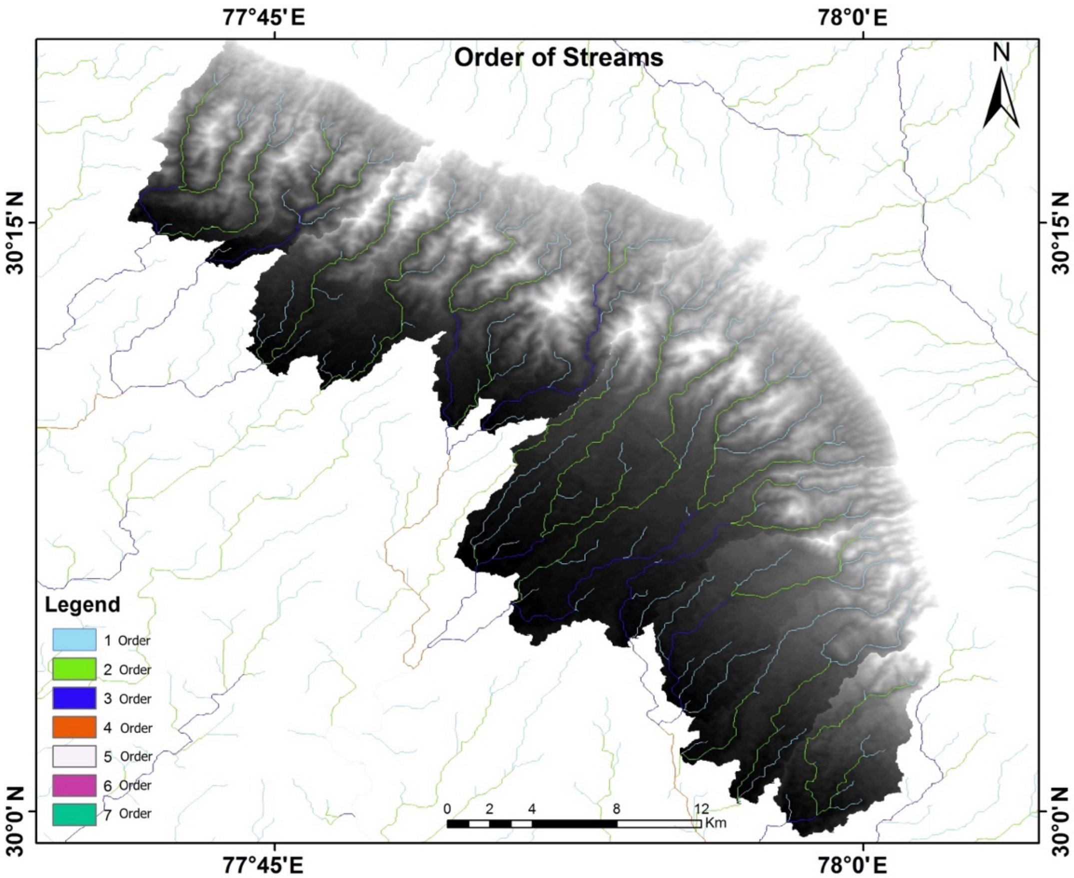

Figure 4: The order of streams for all basins derived from Aster GDEM while employing surface hydrological modelling technique in GIS. The DEM derived streams have been modified using Toposheets (1:50k) to match with natural streams orders. Stream orders of all basins shows similar signature of slope except Mohand Rao and Khajnaur basin which shows different signature comparison to rest of the basins. Second order stream on Mohand and Khajnaur basin starts at a much higher elevation than the others.

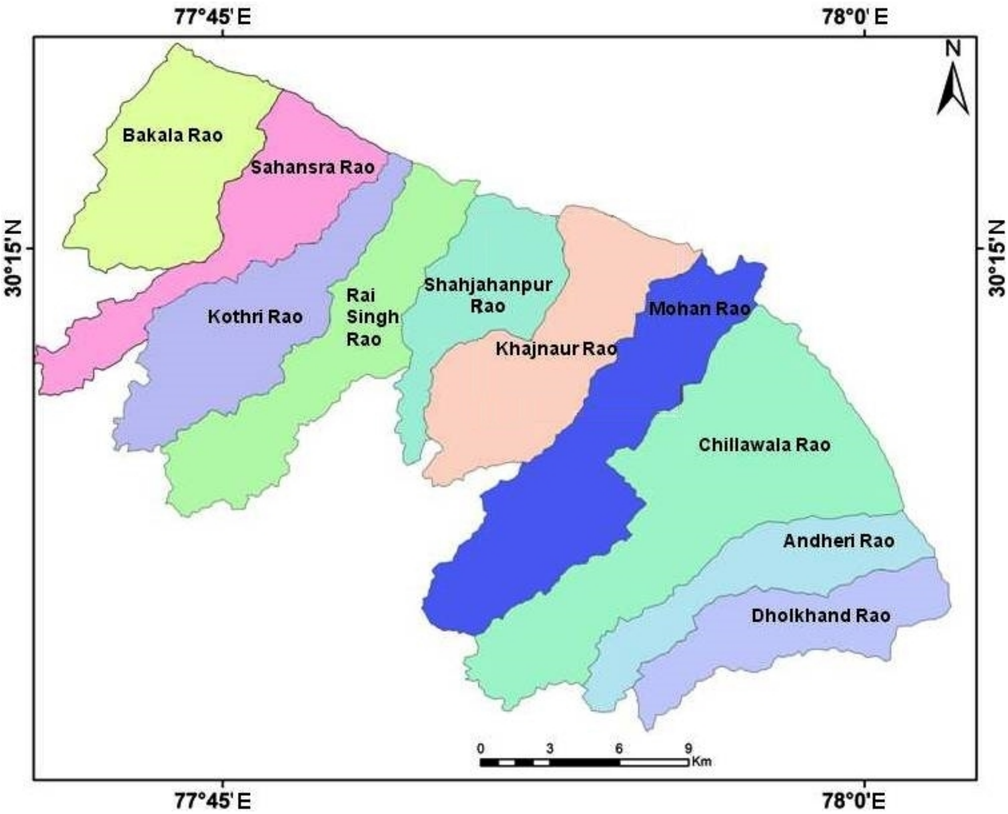

Figure 5: Distribution of watersheds over Mohand Anticline.

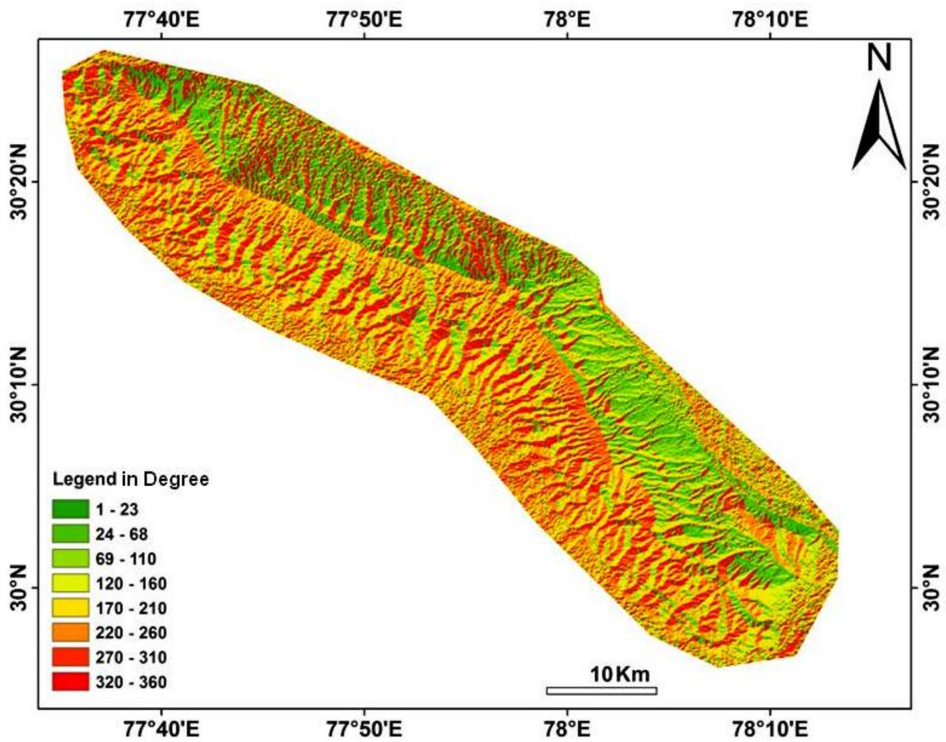

Figure 6: Aspect map (derived from Aster-GDEM) of the Mohand anticline shows the different variations between northern part and the southern part of the Mohand Anticline.

Aspect measures the direction of steepest slope for a location on the surface. The DEM data were processed in ArcGIS to extract aspect map of the Mohand anticline. The aspect map allows a visual support to determine if the direction of the slope is affecting the orientations observed in the streams and faults. Slope is the steepness of the surface at any particular place. The DEM data were processed in ArcGIS to extract slope map.

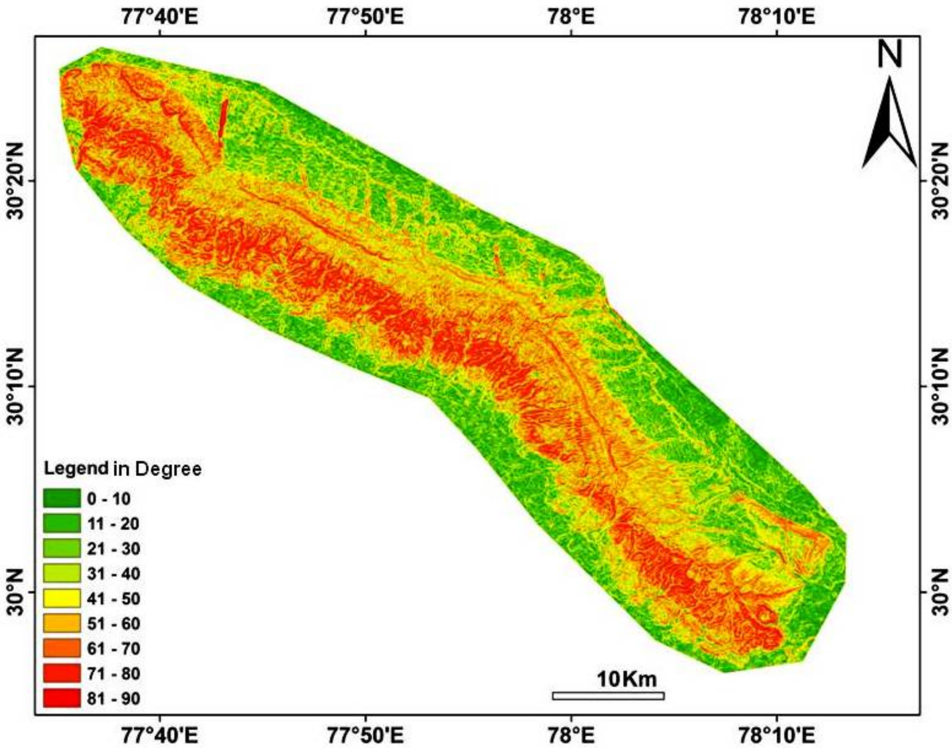

Figure 7: Slope map (derived from Aster-GDEM) of the study area. The southern part of the Mohand Anticline is highly dissected compare to northern part. The northern slope of the ridge is less dissected and exhibits smooth or gentle slope.

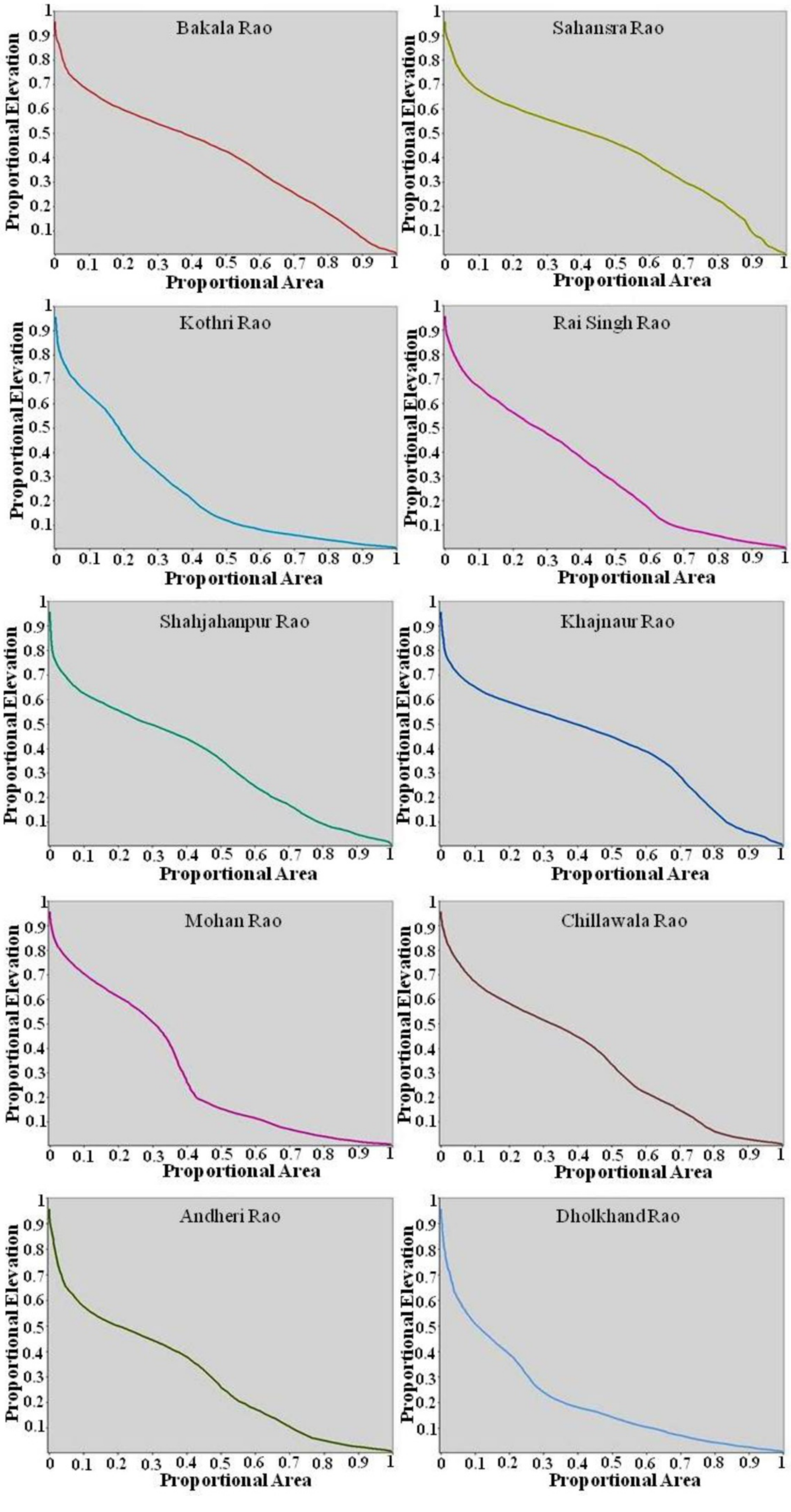
Bakala Rao
Sahansra Rao
Kothri Rao
Rai Singh Rao
Shahjahanpur Rao
Khajnaur Rao
Mohan Rao
Chillawala Rao
Andheri Rao
Dholkhand Rao
Proportional Elevation
Proportional Area

Figure 8: Hypsometric curves of Bakalo Rao, Sahansra Rao, Kothri Rao and Rai Singh Rao, Shahjahanpur Rao, Khajnaur Rao, Mohan Rao, Chillawala Rao, Andheri Rao and Dholkhand Rao basins. According to the hypsometric curves of watersheds, it is observed that Khajnaur Rao and Mohan Rao watersheds are having more influence of some tectonic effect.

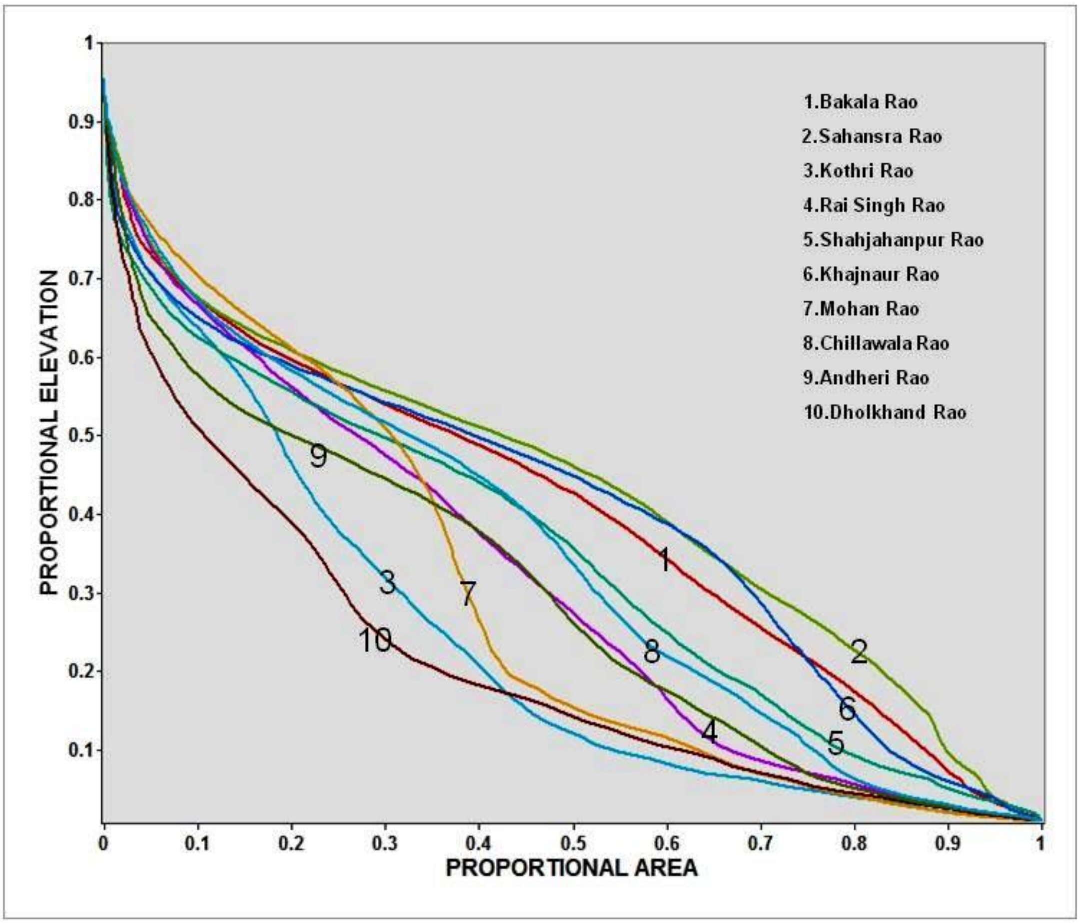

Figure 9: Comparison of hypsometric curves for all basins. Hypsometric curves show low medium high hypsometric integral/elevation relief ratio indicating old to mature and mature to youth stages.

4. Result and Conclusion

This study deciphers the importance of Hypsometric analysis in observing the activity of the basins associated with the stream channels. According to the analysis some basins over Mohand anticline shows clear influence of active tectonics on watershed geometry and channel morphology. Study also interpret that study area (Mohand anticline) having some ongoing tectonic activity. Hypsometric analysis of the study area also shows significant changes in all basins. Hypsometric curves of watersheds show that Khajnaur Rao and Mohan Rao watersheds are influence by a tectonic activity. Hypsometric curves of these basins show signatures of rejuvenation of the watershed caused by active tectonics (Figure 9) According to hypsometric integral values of all the watershades lies on the Mohand Anticline showing different geological stages. Hypsometric integral (HI) of Khajnaur Rao watershed and Mohand Rao is 0.45 and 0.41 respectively. This also indicates that Mohand Rao and Khajnaur Rao watershed are more prone to erosion in comparison to other watersheds adjacent to it.

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