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An Active Tectonics Study Using Remote Sensing SRTM DEM: A Case Study of Parachinar Syntaxis – NW Pakistan

S.A. Mahmood[1]*, U. Alvi [2], J. Sami[3], J. Qureshi[4], A. Masood[5], Sahar Mirza[6], S.M.H. Raza[7]

[1,2,3,4,5,7]. *Department of Space Science, University of the Punjab, Lahore, Pakistan.*
[6] *Institute of Geology University of Punjab, Lahore, Pakistan.*

*Corresponding Author (amerpakistan@gmail.com)

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ABSTRACT

North-East and East-West oriented neotectonic activity, abrupt slope and differential erosion in Parachinar Syntaxis (PCS) make up a perfect natural laboratory and deliver a significant prospect to examine neotectonic influence on its landscape evolution. In this research, geomorphometric characteristics of PCS in north-western Pakistan are assessed through DEM-based hypsometric analysis of Strahler order 5 subbasins. One hundred and eleven Strahler order 5 subbasins were extracted automatically from SRTM 90 m using D8 algorithm. Hypsometric integrals (HIs) and hypsometric curves (HCs) for each singular subbasin were computed to estimate the gradation of erosional stages and the elements governing these changes. HIs and HCs were computed using zonal statistics through the maximum, minimum and mean elevations. The convex up curve shows less eroded subbasins and they are located along and the Spinghar Thrust and North-west margins of Khowst Plateau which is an indication that PCS is tectonically active, while the S-shaped curves represent the intermediate erosion stage and they are located within and south-east of the HKS. The concave down curves indicate maximum erosional stage and they are located near Kabul Block. Higher values of HIs and shape of the HCs correspond to neotectonic control of the landscape of PCS.

Keywords: Remote Sensing, SRTM DEM, PCS, Hypsometry, Neo-Tectonics And Spinghar Thrust.

1. INTRODUCTION

The Important part of tectonic geomorphology is portrayed by a constant race between the tectonic processes that incline to build topography and surface processes that tend to break them down (Burbank, Anderson, 2001).Tectonic geomorphology has been replaced with the progression of many improved techniques for deciding the ages of the landscape features, rates of geomorphic processes and assigning the functions and illustrating the rates of crustal movements. Now it has become possible to evaluate how rapidly a given section is shifting with respect to the others and how these rates of corresponding divergence and convergence are partitioned among various folds and faults at the scale of millimeters (Burbank et al. 2001). The main motivation of this research comes from the fact that the study of strong ground movement, earthquake hazard, and risk plays a significant role in modern seismology. It is of such great societal importance (e.g., Bilham et al., 2001; Bilham, 2006). In this study Shuttle Radar Topographic Mission digital elevation model (SRTM DEM) data with spatial resolution of 90 m is used which is available free of cost from the USGS website for the extraction of automatic drainage based on Strahler order. Geomorphic indices like hypsometric integral have been extracted to develop spatial thematic maps. These maps are important as they can highlight zones of neotectonic activity.

This is the study of the active tectonics along the Parachinar syntaxis and the related neotectonic deformation in Parachinar area of Federally Administered Tribal Area (FATA) of Pakistan and Spinghar Thrust (Tora Bora Mountains or Sufaid Koh) which has experienced many low and large scale earthquakes that not only has caused a threat of damage to life and built-up environment but also has jumbled the landscape through fracturing, cracking and rocksliding. This is the first attempt of DEM based semi-automated geomorphic index analysis in the region of Parachinar using remote sensing and GIS techniques and it will help researchers working in this region specially in the field of active surface deformation. The objectives of this research are to constrain and highlight zones of neotectonically vulnerable zones using hypsometric analysis through hypsometric integral and hypsometric curves and a spatial thematic map to have a quick view of the deformed zones.

The DEM based hypsometric investigation to examine neotectonics is one of the growing disciplines in geosciences. The results of recently active tectonics are important to evaluate and manage the natural disasters, land use developments and populated areas. The ultimate goal of our study is to determine tectonic antiquity from the evolving topography by deducing the effects of active tectonics on landforms and geomorphic developments. The present Earth' morphology is a direct consequence of climate, geology and tectonics (Keller and Pinter, 2002; Mahmood and Gloaguen, 2011). Consequently, the neotectonics investigation needs multi-faceted approaches, assimilating records from satellite imagery, geomorphology, geological structures, stratigraphy, seismology, and geodesy. The "Hypsometric integral (HI)" is one of the main factors that is quite capable of inferring the time-series based stages of geomorphic growth (Weissel et al., 1994).

Hypsometry or "area-altitude analysis" labels the dissemination of the flat cross-sectional area of a landform with respect to contrasting "variable elevations" and can be calculated using the hypsometric integral. Arithematically, it signifies a line plot between cumulative height (h/H) and cumulative area ratios (a/A) in a certain watershed as shown in (Fig. 1).

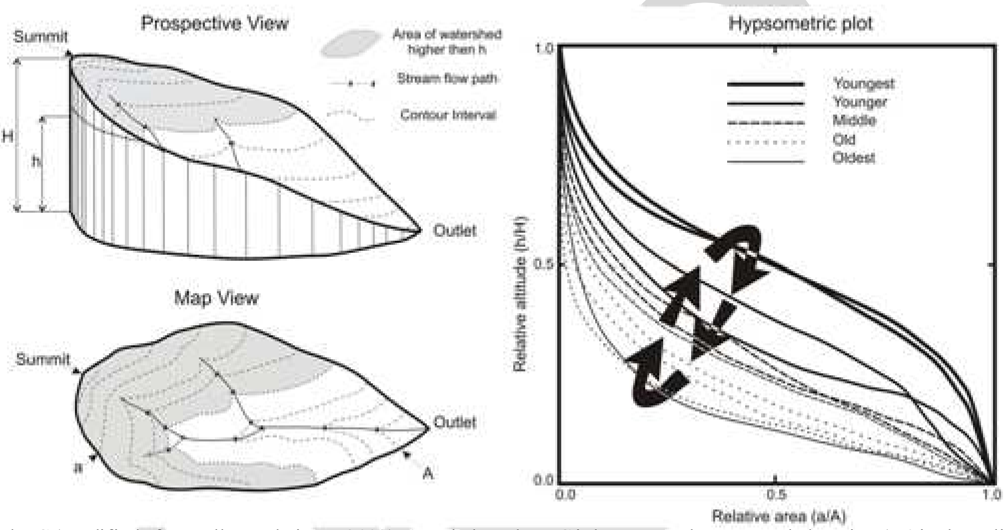


Fig 1. A typical HC (modified after Keller and Pinter, 2002). Area below the HC is known as the HI. Total elevation (H0 is the relief within the basin, total area (A) is total surface area of the basin, and area (a) is surface area within the basin above a given altitude (h).

The profile of this curve characterizes the progress and evolutionary past of the certain watershed. The hypsometric curves (HCs) exhibiting "S-shape (convex and concave)" epitomizes intermediary watersheds whereas curves above the mid line are convex up curves representing the younger basins and vice versa. The HCs have been used to deduce the various temporal stages of developments of the drainage watersheds in the Parachinar syntaxis. The hypsometric analysis is also a commanding geomorphic index to distinguish between tectonically active and quiescent areas (Mayer, 1990; Mahmood and Gloaguen, 2001).

2. THE STUDY AREA

The research focused on the Parachinar region of Federally Administered Tribal Area (FATA) of Pakistan and some regions Pak-Afghan border. This region is comprised of the Kurram-Cherat-Margalla fold-and-thrust belt. Accurate and narrow (20 to 30 km wide) thrust belt lies to the north of Kohat-Potwar fold belt. From near Balakot (Hazara Kashmir Syntaxis), it extends southwest-ward through Margalla Hills, Attock-Cherat and Kalachitta Ranges to the Sufaid Koh Range on Afghanistan border, a distance of about 350 km. It is an intensely deformed and tectonised belt with isoclinal folds and several south-verging thrust sheets. Eastward it has been cut by the Jhelum Fault. Southward it has been thrust over the Kohat-Potwar fold belt. This thrust zone is now being referred to as the MBT (Lillie et al. 1987, Yeats and Hussain 1987, Burbank et al. 1988, McDougall and Hussain 1991, Abbasi and McElroy 1991). The Waziristan-Kurram stretch at the western fringe of the Kohat Plateau in the North West Himalayan foreland inclination NNE-SSW, roughly at the right angle to Himalayan trend in the north (Meisner et al., 1975; Beck et al., 1996), making a regional syntaxial bend referred to as the Kurram Reentrant. This variation in the orographic trends obligated to two different but coincidental collisional tectonic systems; India-Kohistan-Karakoram collision in the north (Coward et al., 1988) and India-Afghan collision in the west (Beck et al., 1995; 1996).Three different tectonic blocks are in connection with one another in the Kurram-North Waziristan region; Kurram-Waziristan in the south Spinghar block in the north, and in the middle western Samana block (Figs. 2 and 3)

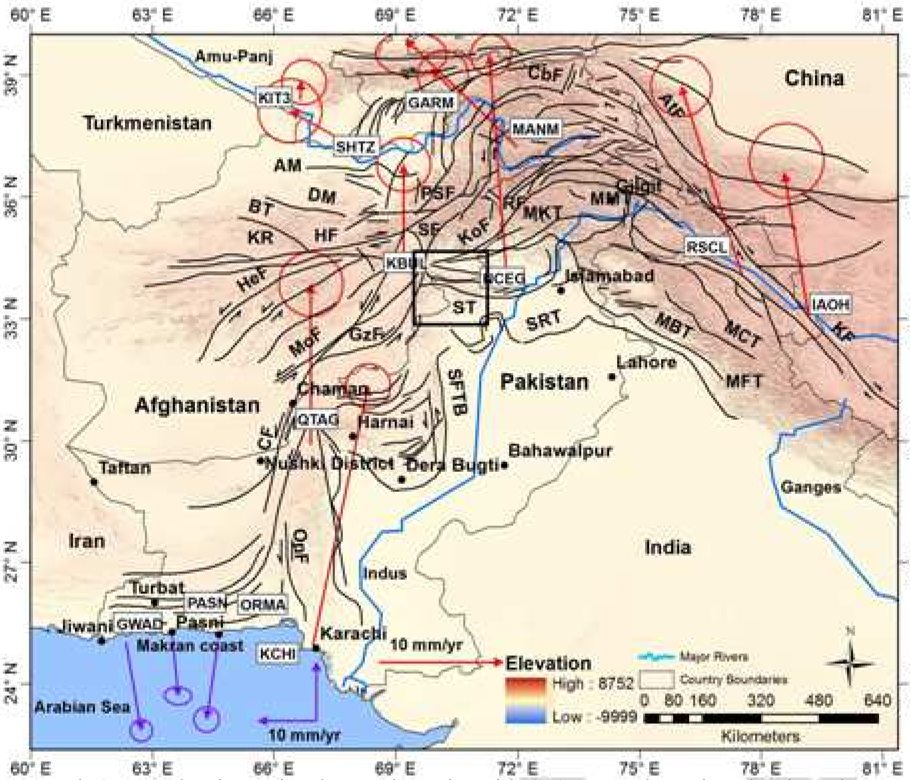


Fig 2. Map showing regional tectonic setting with GPS vector shown in red and purple.

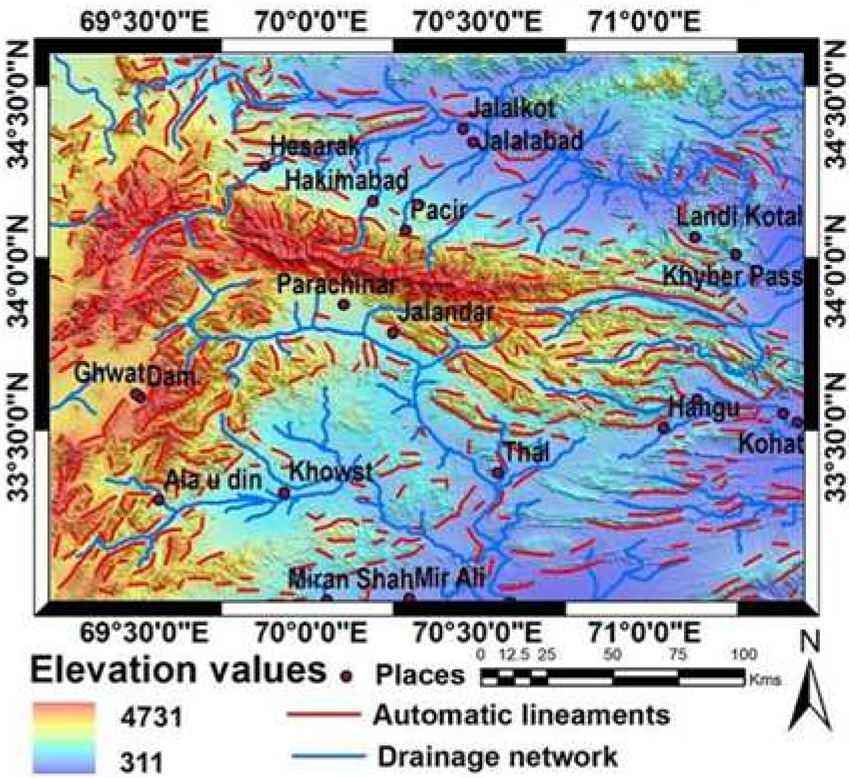


Fig 3. Location of the study Area

3. MATERIAL AND METHODS

We used Shuttle Radar Topography Mission (SRTM, version 4) 3 arc second digital elevation model (DEM) data from NASA, with a 3-D spatial resolution of 90 m. This data is presently disseminated 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 was 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 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.

The HI is generally derived for a specific drainage basin and is an index that is not dependent on the basin area. The HI is an index that demonstrates the allocation of elevation of a particular area of a landscape, specifically a drainage basin (Strahler, 1952). The index is defined as the area below the hypsometric curve and thus expresses the volume of a basin that has not been eroded. The simple equation that may be used to calculate the index (Mayer, 1990; Keller and Pinter, 2002) is equation 1.

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

This index is similar to the SL index in that rock strength as well as other factors affect the value. High values of HI generally mean that not as much of the uplands have been eroded, and may propose a younger landscape (Fig. 4a), possibly produced by active tectonics. High HI could also result from recent incision into a young geomorphic surface formed by deposition. In our analysis of HI, we suppose that if part of the HI is convex in the lower portion, it may relate to uplift along a fault. High HI values are possibly related to young active tectonics and low values are related to older landscapes that have been more eroded and less impacted by recent active tectonics (Fig. 4b). Using Eq. (1), we computed HI for each sub-basin. It ranges from 0.24(sub-basins 2) to 0.64 (sub-basin 30). Then HI values were grouped into three classes with respect to the convexity or concavity of the hypsometric curve: Class 1 with convex-up hypsometric curves (0.41 - 0.63); Class 2 with concave–convex hypsometric curves (0.31 - 0.40) and Class 3 with concave-down hypsometric curves (< 0.30) as shown in (Fig. 4c).

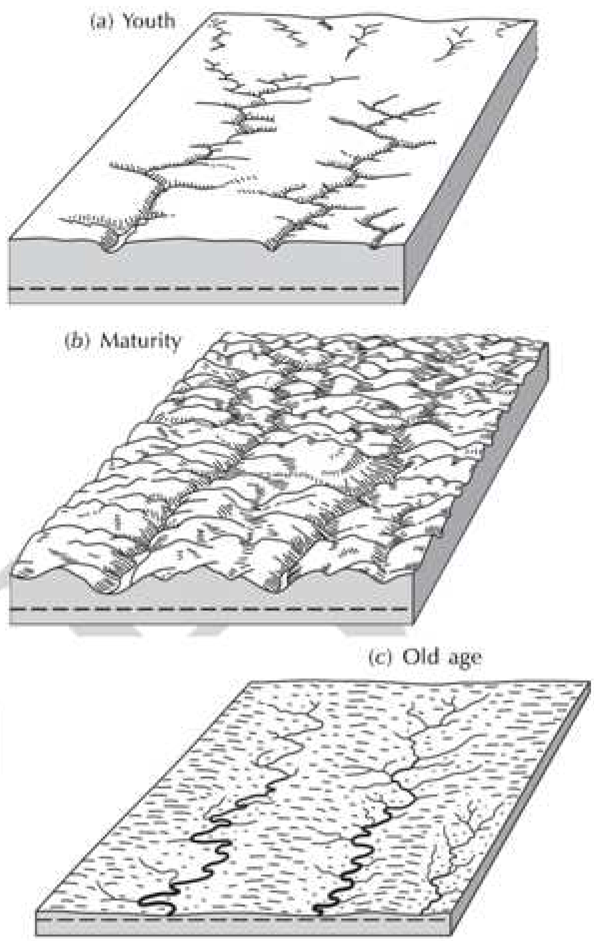
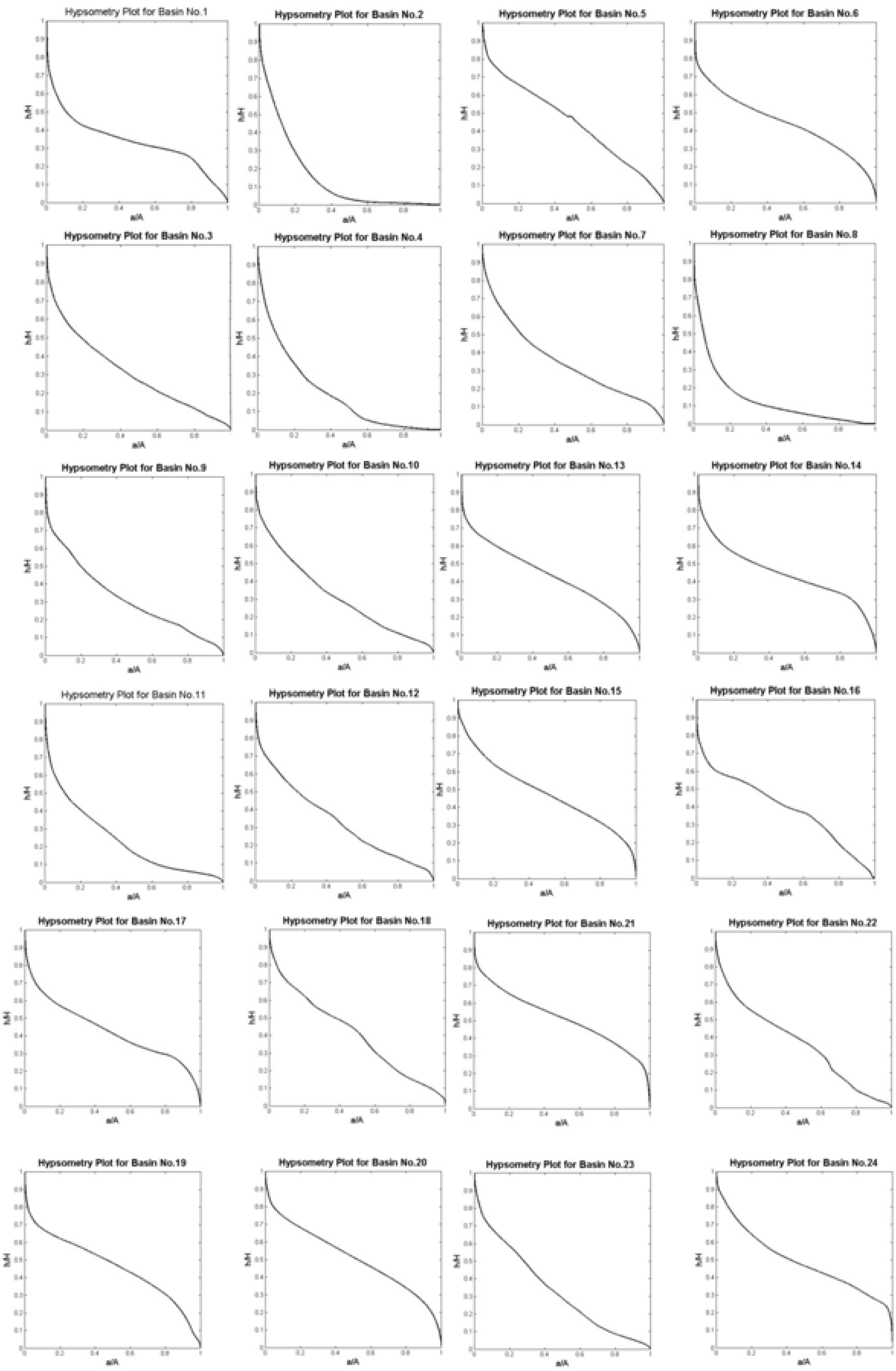


Fig 4. Willian Morris Davis's Geographical cycle in which a landscape evolves through "life- stages" to peneplain. (a) Youth, (b) Maturity, (c) old age, source, adapted for Holmes (1965, 473)

4. RESULTS AND DISCUSSION

In this research HI and HC analyses are applied to the subbasins of Parachinar PCS in NNW Pakistan. Conferring to the generated results, convex-up, S-shaped and concave-down HCs (Figs. 5.1 to 5.14) are observed in the study area signifying differential erosional stages and level of neotectonic activity in the PCS region.


Hypsometry Plot for Basin No.1
Hypsometry Plot for Basin No.2
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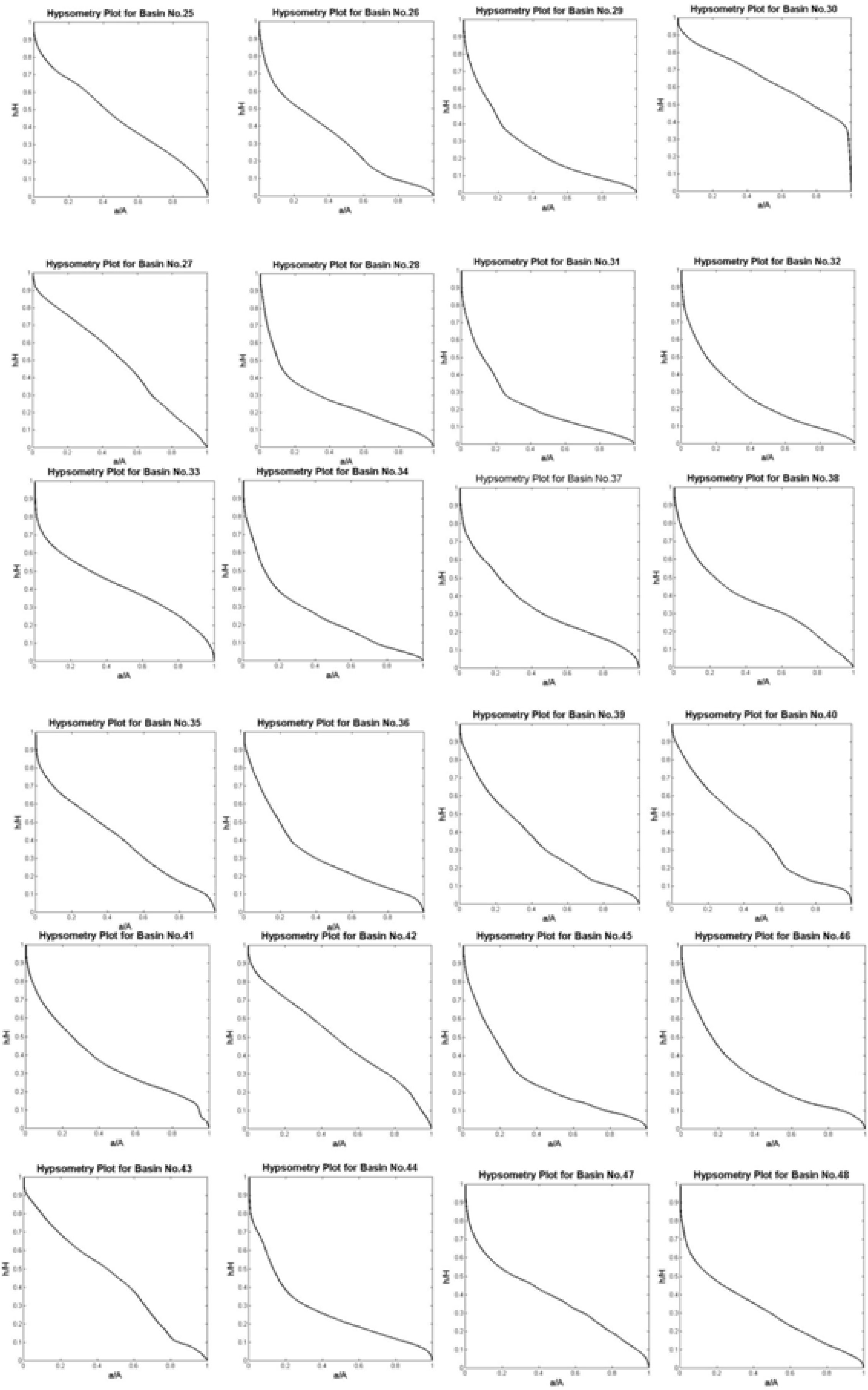
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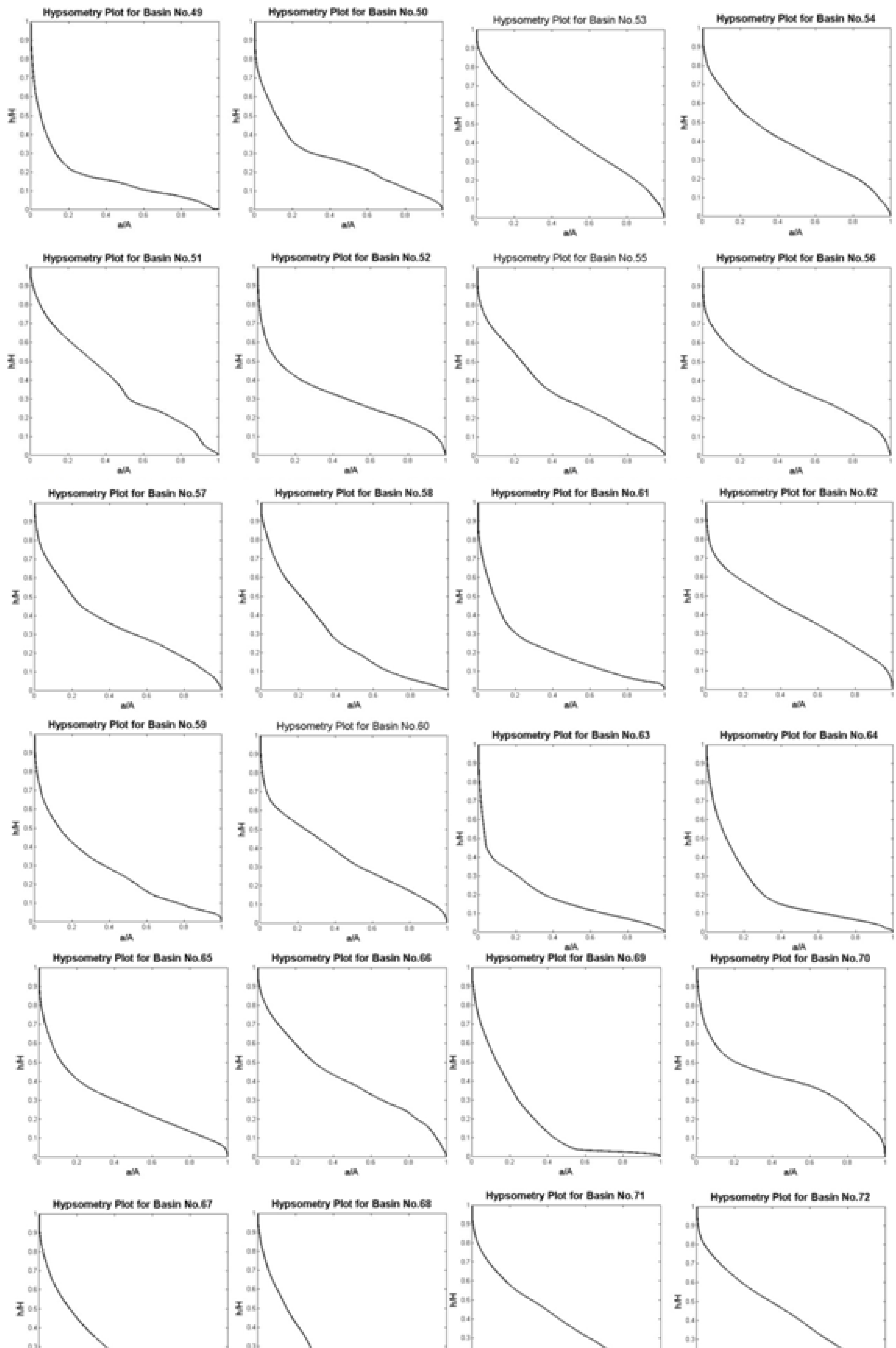
Hypsometry Plot for Basin No.48
h/H
a/A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Hypsometry Plot for Basin No.72
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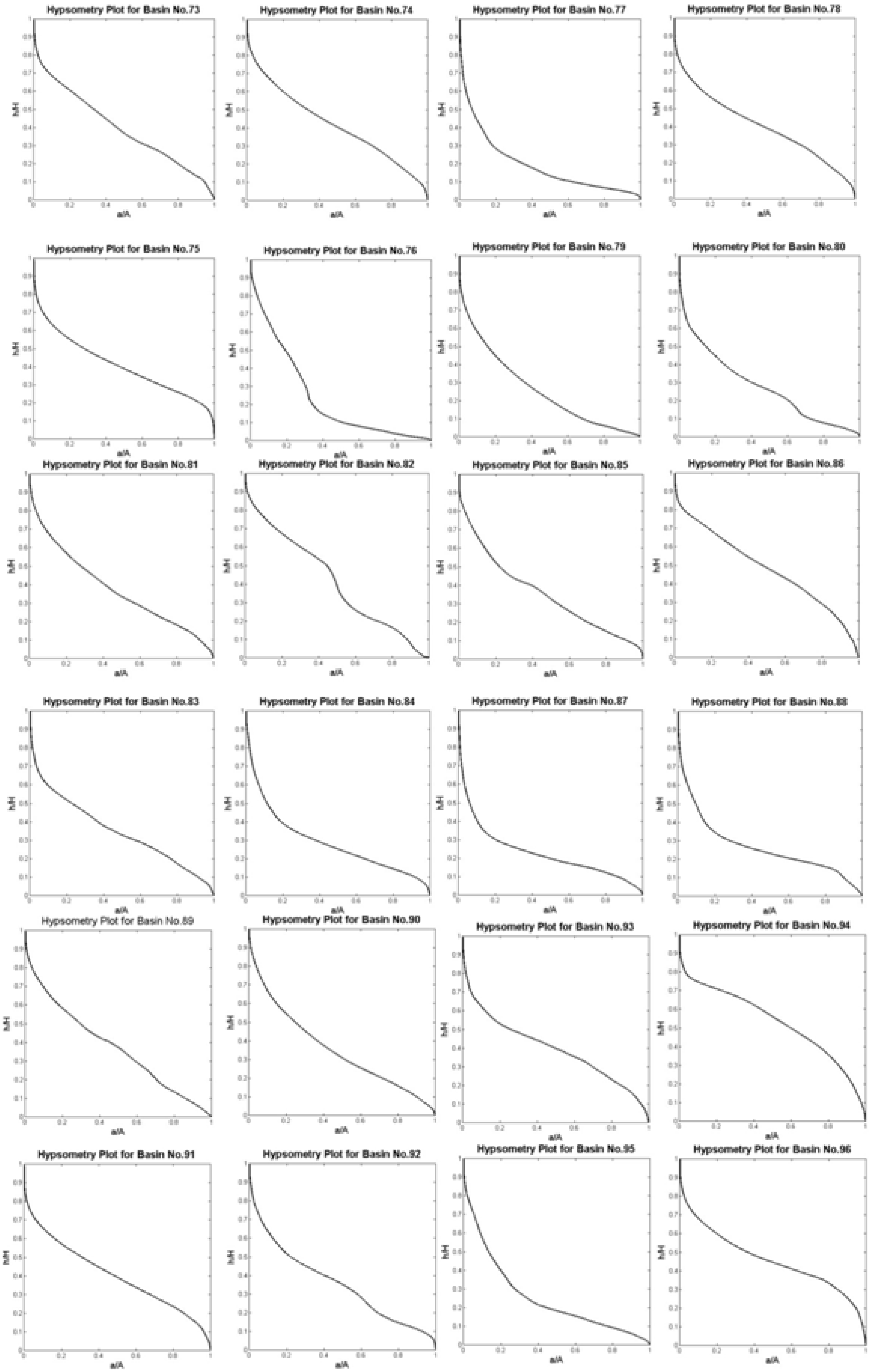
Hypsometry Plot for Basin No.73
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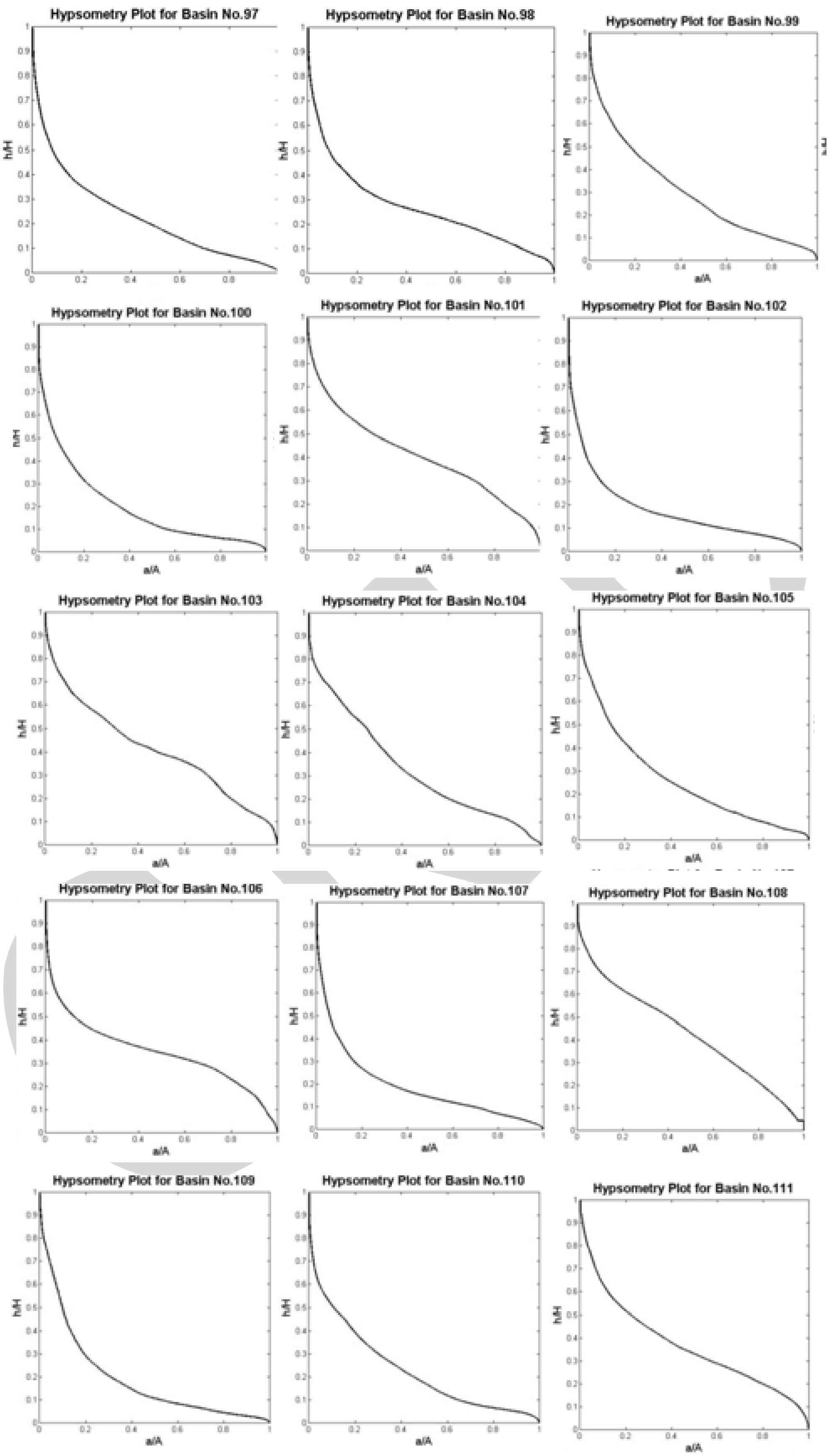

Fig 5. 5.1 to 5.14 HCs along with their respective HI values for the subbasins along PCS, the convex up shapes and their Higher HI values indicate that the PCS, iss still emerging as youthful stage of topography.

Higher HI values for more than about 55 % of the total watersheds and their subbasins in the PCS specify the youthful stage (convex-up curves shown in red), about 40 % watersheds south and southeast of the PCS that are advancing towards the S-shaped (intermediate stages shown in light green shades) and rest of the about 5 % watersheds show concave down with light blue colours indicating peneplain or older stages (Fig.6).

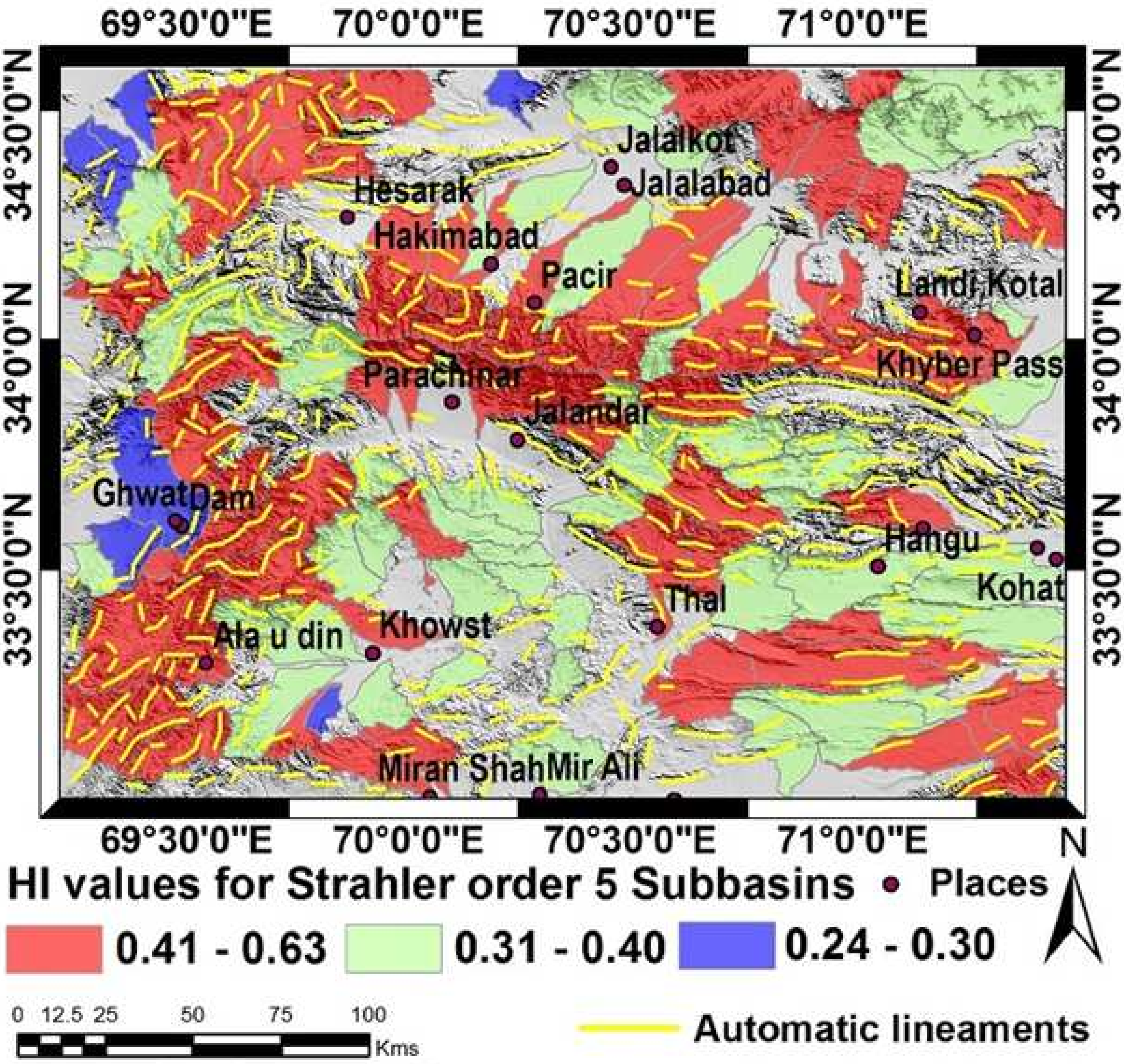

Fig 6. Map showing HI values for Strahler order 5 sub-basins

Low HI standards indicate intermediate and more eroded zones and consistently divided and highly dissected drainage subbasins.

High HI values also show that most of the PCS topography is highly relative to the mean, such as even upland surface cut by deeply incised streams demonstrating young developing (emerging landscapes) and less eroded regions that are still under geological growth.

Though, subbasins east of PCS on north-west of Jalalabad, near Ghwat Dam side and in some part of Kabul block 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.

Higher values of HI along PCS are along the Tora Bora Mountains (Koh-e-Sufaid or Spinghar Thrust north of Parachinar, north-west of Parachinar near Sarobi Fault and the north-east extension of Gardez Fault (part of the Chaman fault) watersheds and their subbasins, explain their late, most recent youthful stages which is an evidence of neotectonic activity giving rise to the birth of new syntaxes and younger plateau like Khowst Plateau along Pakistan-Afghanistan border, and therefore, these subbasins are also prone to subsequent erosion activities and need appropriate soil and water conservation measures.

Hypsometric analysis has been indirectly engaged to topographic analyses to highlight the active tectonics and is very delicate to miscellaneous constraining dynamics in the landscape development.

The HI values calculated for the different Strahler order subbasins are dissimilar, For example, HI values are typically high, where the drainage area is trivial and hillslope processes are active. In such cases, the HCs would be convex-up with a HI value close to one. On the contrary, in case of subbasins with intermediary size, with increased contributing drainage area, the significance of river processes become prevailing; the HC becomes concave-down with a HI close to zero.

5. CONCLUSIONS

Analysis of HIs and HCs subbasins enunciates the difficulty 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 PCS region is less prone to erosion in contrast to those subbasins, which lie west or north-west of the PCS. It simply means that in the areas of less erosion within the PCS, 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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