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Investigation of Neotectonics along Hazara Kashmir Syntaxis through Remote Sensing and GIS Analysis

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***Abstract*— The fatal earthquake of October 8, 2005 occured in Pakistani Himalayas and specifically within the Hazara Kashmir Syntaxis (HKS). The HKS is an active tectonic structure formed as a result of India-Eurasia collision. The unrelenting competition between tectonics, climate and erosional factors has created a very distinctive topography and thrust geometries in HKS. The aim is to constrain neotectonics and related active surface deformation based on semi-automated Digital Elevation Model derived morphometric parameters. The Shuttle Radar Topography Mission DEM with a spatial resolution of 90 m has been engaged for the generation of Hack gradient, steepness, concavity and relative uplift rate maps for the geomorphological analysis. The other surface dynamic indices such as drainage density, lineament density along with their rose diagrams were also generated automatically. A detailed stream profile analysis, lineament and drainage density, relative relief (incision map) revealed that the results obtained for the relative uplift rates and other geomorphic indices are consistent with the neotectonic activity along HKS. The relative uplift rates are higher in the NNE (2.35 mm/yr.) as compared to lower (0.01 mm/yr.) in the SSW part of study area. The steepness index and Hack gradients show more steepened regions and steep slopes NNE of HKS than SSW that is indicative of neotectonic activity. These results suggest tectonic control over the drainage network and the topography in the study area. The geomorphic indices and relative uplift rate maps also shows that the NNE is more deformed and uplifted region than the SSW. The inhomogeneous spatial distribution of variable relative uplift rates is a clear indication of complexity and severity of surface deformation in the HKS.**

***Keywords*— SRTM DEM, drainage network, neotectonics, Hazara Kashmir Syntaxis and Relative uplift rates.**

I. INTRODUCTION

These Most important controlling factors on the geomorphological features in a rugged mountain area are neotectonically influenced relative rock uplift, translational and upright crustal block motions,“change in climate, the rock strength to erosivity and stream incision development” [1]. “Stream profiles reveal the assimilation of manifold geological developments and tectonic factors, river profile is a substitute for recognizing areal distributions of differential relative uplift” [2,3,4,5]. River profiles respond to both climate changes by adapting the related watershed hydraulic and erosional conditions, but at the same time they illustrate effects, driven by orographic precipitation [4,5.6]. Stream profiles growth becomes composite as the rock strength varies spatially and it has a basic function in river incision, erosion and stream profile development and become a reason for the great inconsistency in stream profile growth [5,6,7,8,9]. This research is concerned with the extraction of active tectonic signals, streams-faults interrelationship in the HKS in the Northern flank of Pakistani Himalaya. This paper deals with the remote sensing investigation of active deformation and its inferences to know the differential relative uplift rates in the HKS and its outskirts. Mapping neotectonics is an important issue in order to assess seismic hazards and to understand the nature of deformation of the region.

This study is based on automated SRTM DEM derived drainage network. Digital elevation models present an opportunity to enumerate topographic surface dimensions in terms of its altitude variation and its offshoots. Neotectonic creeping all along the faults is frequently revealed by characteristic geomorphometric expressions such as elevation, stream offsets, slope breaks, landslides, moraines, fluvial terraces and the contributing drainage area. The HKS terrain is situated on the north-western margin of the Lesser Himalaya (Figure 1 and 2) and is one of the audacious tectonic scars, which actually separate this terrain from rest of the Himalaya. The main tectonic features sculpturing this terrain in the shape of folds and faults are: Hazara-Kashmir Syntaxis (HKS), Main Mantle Thrust (MMT), Main Boundary Thrust (MBT), Panjal Thrust (PT), Hazara Thrust (HT) and Indus Valley Faults (IVF), [6].

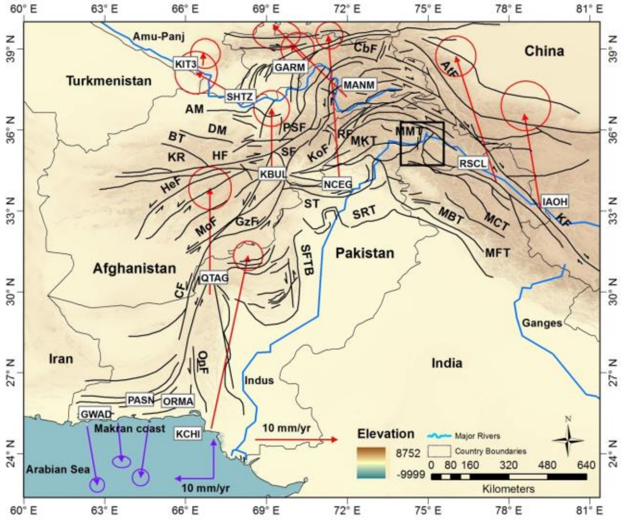


Figure 1: Regional tectonic map of the Hindu Kush-Himalaya-Pamirs-Karakoram, with black box showing the study area location shown in (Figure 2.1). "Red and purple vectors show GPS velocities w.r.t Eurasia and India fixed respectively" [7].

II. TECTONICS OF HAZARA KASHMIR SYNTAXIS

The HKS is one of the most important structural features of the region and displays prominent scars [10]. The southern range of Himalaya extend northward in a gentle unbroken curve of northern India, continue into Kashmir and Hazara districts of Pakistan, where the form the eastern limb of the Syntaxis [10]. The two main boundary faults wrap around the Syntaxis are considered equivalent to the Punjal and Murree Faults [11]. The foreland fold and thrust belt of the Sub-Himalayas extends in the external zone of HKS up to Paras in Kaghan Valley (Figure 2). There is formation of Muzaffarabad Anticline which has been affected by N-S trending thrust faults called KBT and it is west verging thrust. Along this thrust many neotectonic features are present. As a result of the progressive incursion of the NW flank of Indian plate in Eurasian/Kohistan Island Arc, the consequent penetration of HKS caused right lateral rotation of the thrust direction by 75° relative to the India cratonic block, [10.11,12,13,14]. The rock patterns and formations present on the footwall of MBT characterizes a part of the Fold and thrust belt of the Indian foreland [14]. The core of the HKS contains Murree formation which is in contact with (a) The Precambrian igneous and metamorphosed rocks near Balakot due to which sedimetary zone of Hazara basin is completely missing. Because of the Joining of the two thrusts, MBT and PT.

However, near Muzaffarbad, a classic outcrop of MBT is exposed between Murree and Hazara formations. The Muzaffarbad anticline displays paleogenee rocks which unconformabley overlies Abbottabad formation of Cambrian age.

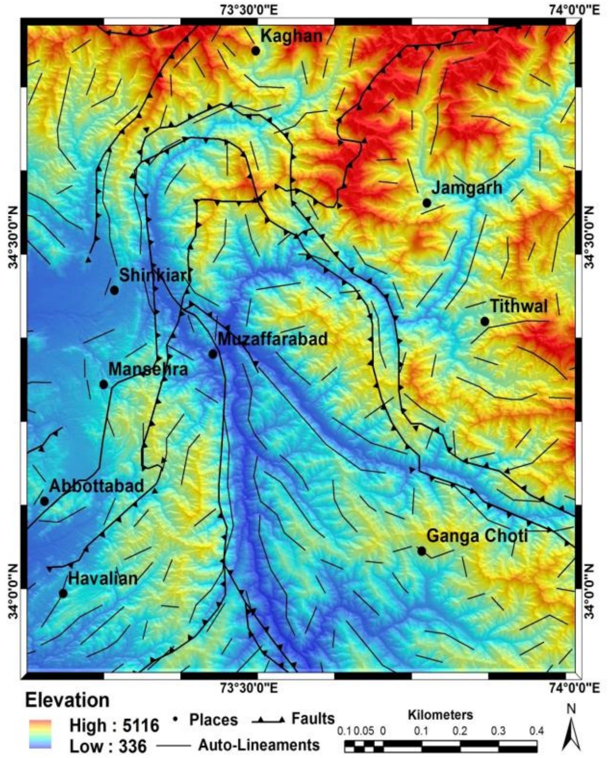


Figure 2: Digital elevation model of the Hazara Kashmir Syntaxis and its surrounding region with prominent places, digitized faults from published geological maps and automatic lineaments extracted from SRTM DEM swathed over shaded relief map

III. MATERIALS AND METHODS

A. Hack Gradient Index

The streams length-gradient index (SL index) correlates to streams power [14]. It is related to the ability of a particular reach of stream to erode its bed and transport sediment [14, 15]. The SL gradient is determined at the middle of every segment that is actually defined by the equal contouring (equal division of individual streams in the drainage network) and is expressed as:

$$\text{Stream Length gradient} = (\Delta H/\Delta L) * L$$

$\Delta H/\Delta L$ is the slope of the channel, ΔH is the elevation variation between the two consecutive reaches of adjacent segments of the stream, ΔL is the distance between two consecutive segments measured at the middle of the total segment (see Figure 3), and L is the distance between the drainage divide and the middle of the segment of the channel [14, 15].

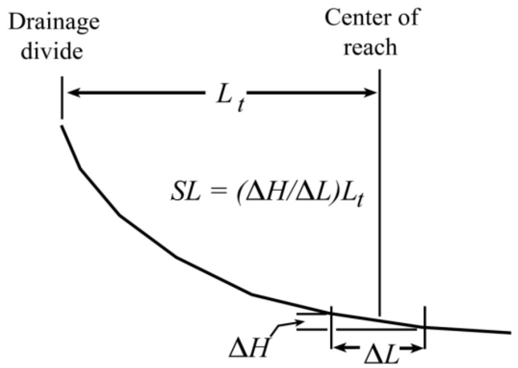


Figure 3: Schematic diagram showing the method to calculate the hack gradient index.

B. *Stream Power Analysis*

The drainage network of PP is extracted from DEM by calculating using D8 algorithm. The direction of the drainage flow is reliant on upstream and basin area. Stream delineation algorithm can affect stream parameters (e.g. slope, contributing area, local elevation, and distance of down slope and Strahler order). The selected individual streams are formulated in ASCII layout for more analysis. The selected streams have always a few errors therefore; some smoothing computer codes are used that depend upon number of nodes (i.e. the smoothing factor). The River Longitudinal Profile Investigation Analysis was used on every individual stream to calculate vital data that depends on the detachment limited incision model. This model tells that the steady state channels do not monitor the coverage of sediments continuously, even if the flow is low due to identical stream gradients according to stream power law (see Figure 4). The faults scarp or lithologic contrast helps the streams to reach in a new equilibrium. Mathematically we can write:

$$\frac{dz}{dt} = U - E \qquad (1)$$

Here U means uplift and E stands for erosion rates. We can write equation (1) as follows:

$$\frac{dz}{dt} = U - KA^m S^n \qquad (2)$$

Here K is constant relating to erosion, strength and sediments. A represents the upstream drainage area and S stands for channel slope. The m and n are constants and depends on water shed hydraulics, basin geomatics and wear and tear process [15, 16], dz/dt is the rate of change of elevation based on time and if the topography is in equilibrium under dynamic equilibrium form then dz/dt will be zero. Therefore we can re-write equation (2) as follows:

$$S = \left(\frac{U}{K}\right)^{1/n} A^{m/n} \qquad (3)$$

Where the coefficient (U/K)1/n is steepness of the river profile while m/n is the concavity of the profile. The stream power law is represented as:

$$S = k_s A^{-\theta} \qquad (4)$$

Where ϴ and ksn are concavity and steepness indices respectively and can be calculated directly by regressional analysis on the area slope data shown in the eq.(4) [5]. From equations (3 and 4), the following relation is formulated to calculate relative uplift rates.

$$U = k_{sn}{}^{n} K \qquad (5)$$

Where ksn^n is the normalized steepness index. Eq.(5) gives the relative erosion rate for the study area under

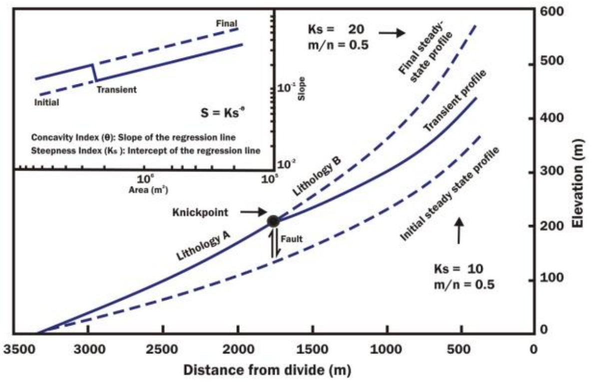


Figure4. Mechanism showing process of river longitudinal profile investigation (RPLI)

dynamic equilibrium conditions for topography evolution selecting suitable values for m, n and K. For each individual stream RPA is performed on the chosen segments to calculate geomorphic indices (concavity and steepness indices) after doing log area-log slope analysis through regression models for each and every chosen segment on the stream (Figure 5 and 6).

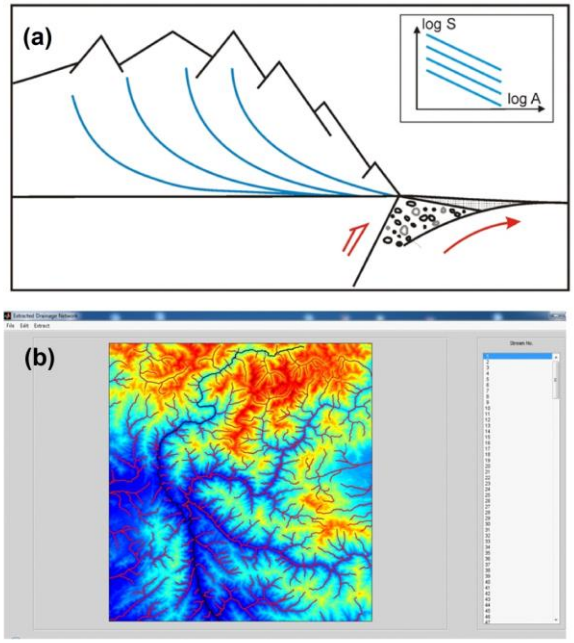
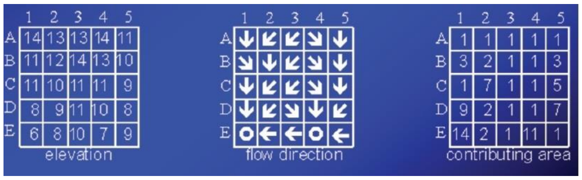


Figure 5 (a) Right hand inset shows log slope-log area plot, [19], (b) The screenshot of the Matlab based graphic user interface showing DEM and selected streams used for the stream profile analysis for the region of Hazara Kashmir Syntaxis and its outskirts.



	1	2	3	4	5
A	14	13	13	14	11
B	11	12	14	13	10
C	11	10	11	11	9
D	8	9	11	10	8
E	6	8	10	7	9

elevation

	1	2	3	4	5
A	↓	↙	↙	↘	↓
B	↘	↓	↙	↘	↓
C	↓	↙	↙	↘	↓
D	↓	↙	↘	↓	↙
E	○	←	←	○	←

flow direction

	1	2	3	4	5
A	1	1	1	1	1
B	3	2	1	1	3
C	1	7	1	1	5
D	9	2	1	1	7
E	14	2	1	11	1

contributing area

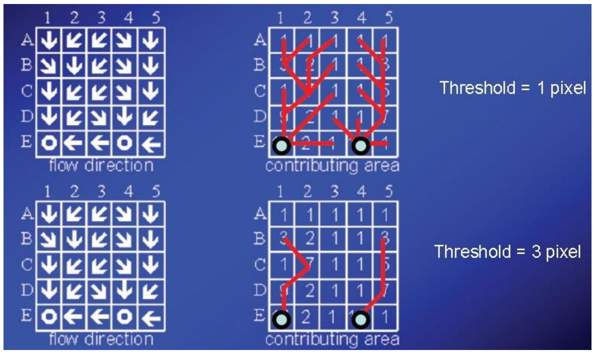


Figure 6 (a) Diagram showing D8 algorithm method, e.g., for pixel A1, there are three surrounding cells (A2, B1 and B2) and the least of among them is B1, so the flowpath southward and downward. For pixel, C3, the least of all 8 nearby pixel is D2, so the flowpath is southwest towards lower-left. Cells E1 and E4 don't have lower neighbors there are thus "sink". (b) For the river network extraction, the threshold can be roughly considered as the minimum amount of water required to produce a stream. Based on this, the streams are defined according to the flow grid.

IV. RESULTS AND DISCUSSIONS

The analysis of geomorphic indices and Hack gradient index in the Hazara Kashmir Syntaxis (HKS) and adjoining regions provides an insight into the evolution of the landscape, uplifting and ground tilting influencing the entire region. The stream longitudinal profile analysis was performed on approximately 309 small and large channels of the SRTM DEM based extracted streams to calculate the concavity (θ) and steepness (ks) indices using stream power law. To dig out neotectonic signals from stream profiles, we found that, the steepness and concavity data concede akin details: a downstream change between different steepness values (or two convex up segments) is generally bridge by a high or low concavity (Figs. 7 and 8). Such a changeover zone is because of spatially varying rock uplift rates, or spatially variable lithologies. The non-equilibrated stream profiles display several prominent knickpoints (Figure 7) and some of them are migrated upstream by the channel response due to increased channel incision, channel narrowing, increased sediment removal and the erosion of tectonics units. These profiles exhibit a disequilibrated behaviour due to the neotectonic activity along the fault trace that causes a reasonable step in the direction of downstream.

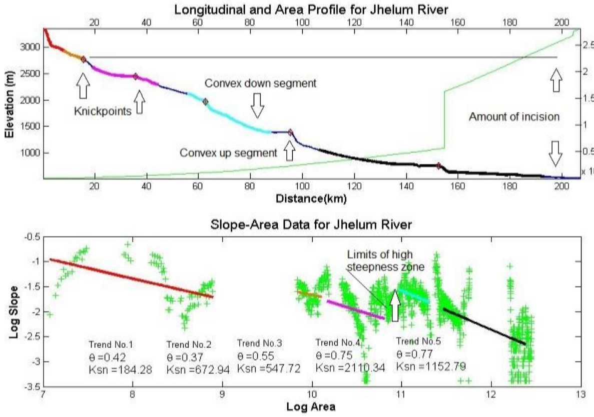


Figure 7. Stream longitudinal profile investigation for the Jhelum River with elevation distance profile (a), log area-log slope data with best fit regression line (b), up arrows show the convex up segments (uplifted bedrock) while the down arrows show concave down segments (more eroded parts of the river. Five knick points are due the interaction of the river with neotectonic features.

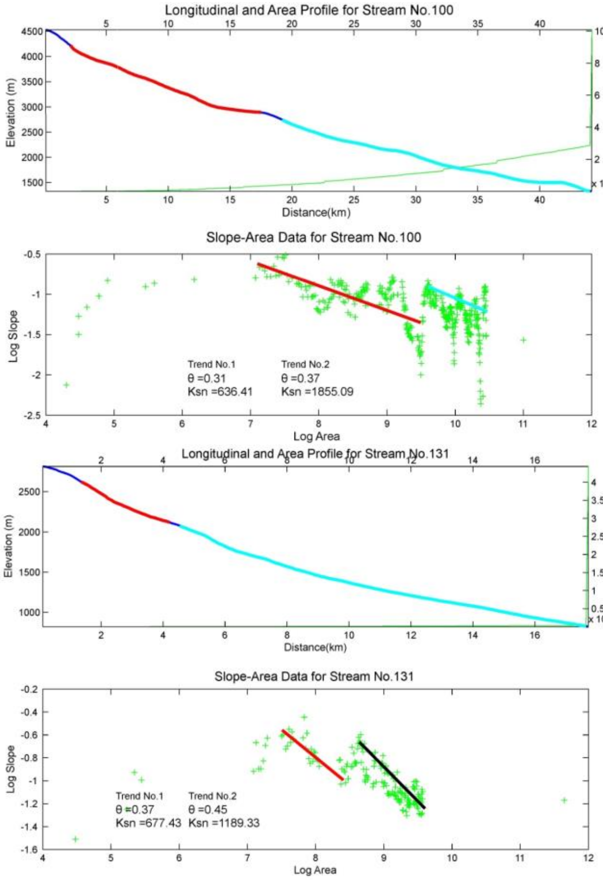


Figure 8 River profile analysis for the Jhelum River, Stream # 100 and 131, showing knickpoints and convex up and concave down segments of the profiles.

The interpolated concavity index map (Figure 9) shows that the HKS shows relatively more erosion on both side and north of the syntaxis as compared to the as compared to lower part within the syntaxis, except in zone north of Muzaffarbad. This is why, because that the streams in these region show relatively more smooth profiles as compared to those region which displays less concavity index due to uplifted and disrupted profiles which is an indication of active tectonics. The hack gradient index map (Figure 10) shows steeper gradients in Kaghan valley, Jamgarh sector, Tithwal sector, NE-Shinkiari, NE of Ganga Choti and the apex and within the HKS. These steeper gradients are consistent with the presence of neotectonics both along the east and west of the syntaxix and also more pronounced on east of the HKS. This is why, we observe more landslides and slope instabilities both due to neotectonic activity and monsoonal effect (that are responsible for the intense episodes of erosion due to torrential rains.

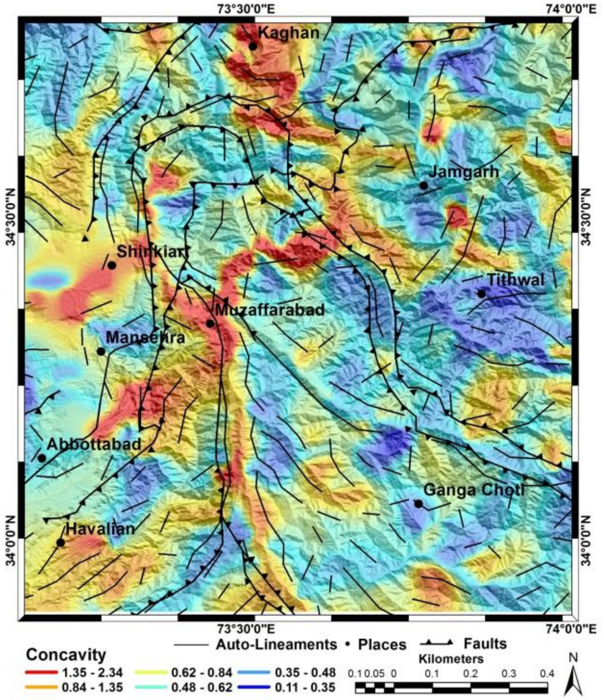


Figure 9. Interpolated concavity map (θ) for HKS. Thick black lines with teeth symbols show published geological faults. Streams on the west of the MBT and northeast of apex of the HKS tend to have relatively.

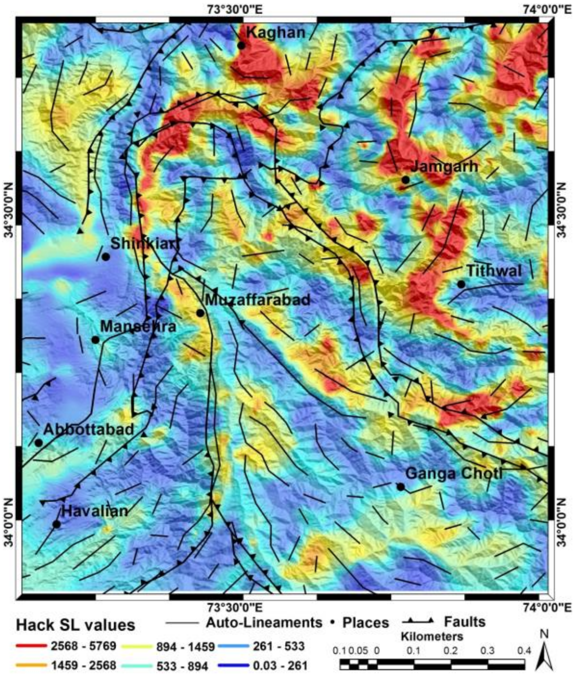


Figure 10. Interpolated map of Hack indices (SL) determined for channels in HKS. Note that the gradients are more steeper NNE east of the HKS.

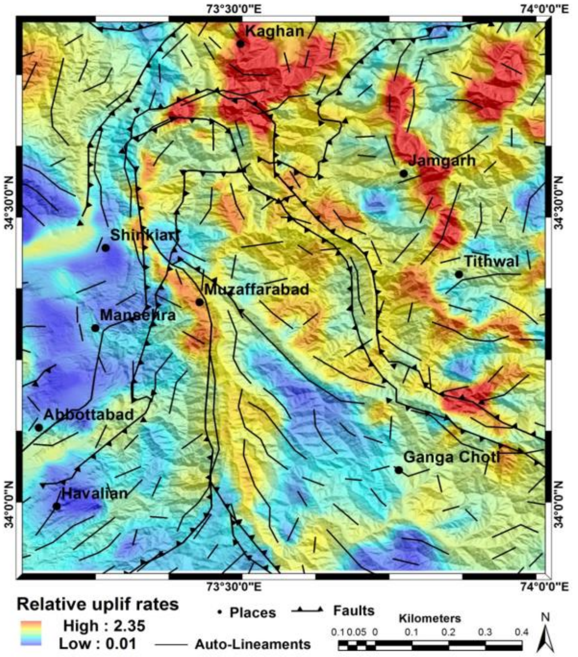


Figure 2.11. Interpolated map of relative uplift rates prepared from the automated DEM derived channels in HKS. Note that channels developed NE of the MBT and northeast of the apex of the HKS tend to have relatively more uplifted conditions.

V. CONCLUSION

Neotectonic surface deformation in a rugged terrain of Hindu Kush and its outskirts caused breaks in scaling of topographic slope, thus adjusts the channel slopes and stream lengths gradients. The stream longitudinal profiles emerge as much easier and faster approach to delineate sites of influenced by recent tectonic activity. The analysis of stream profiles reveals a systematic spatial distribution of channel steepness index to yield variable differential and relative rock uplift rates. The high values of Ks are spatially associated with the recently reactivated fault zones along MBT and PT, this zone confined within a band of ~50-100 km width during the last earthquake of 2005. Within the central and north- east of the HKS, the drainage network reflect the higher relative uplift rates as dictated by the channel steepness and Hack gradients (Figs. 10 and 11). This is why; the inside and NNE side is the HKS is uplifting more with respect to SW side of HKS. Higher gradients are spatially connected with the elevated topography along the HKS and its margins indicating that the channels set much of the relief structure of tectonically active HKS. The major advantage of DEM based stream profile analysis is that no information is lost and it allows the explanation of preferred directions of lateral stream migration as a result of recent tectonism such as differential uplift.

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