
Surface Deformation of NPHMZ through Geospatial Technologies

Imran Siddique Kaukab

Syed Muhammad Hassan Raza

Syed Amer Mahmood

Among all the continental faults in the world and especially in Asia, Nanga Parbat (NP) is one of the younger and highly uplifting topographic unit in the context of Indian-Eurasian collision. In this paper, the Rate of Deformation (ROD) over the area of Nanga Parbat has been studied using a Remote Sensing technique based on Digital Elevation Model (DEM). The results obtained reveal that NP is uplifting at a rate of 14-16 mm/year with unique relative relief. Satellite remote sensing technique is a significant tool to constrain active zones that are vulnerable to natural disasters like earthquake etc.

Introduction

Geomorphology or Geomorphometry - The combination of earth sciences with computer sciences, engineering and mathematics furnish ground surface measurements (GSF) which further helps in the monitoring of terrain analysis and modeling (TAM). The branch of tectonics geomorphology has wide range of applications from planetary explorations to hydrology, sea-floor mapping to tectonics and geo-hazards. The father of modern geography, Alexander Humboldt (1769-1859) and Carl Ritter (1779-1859) a German geographer – together laid the foundation of the field of modern geographical sciences (MGS) and transformed this field in the 20th century through computer and DEMs that enabled to cover and differentiate large areas of ground (Maune, 2000; Arbaret *et al*, 2000; Hildebrandet *al*, 2001). While the morphometric alterations over these large land segments are studied by Geographic Information System (GIS) (Whittington *et al*, 1995; Weinberget *al*, 2000; Eastman, 2002). Talking about the geography of the area under consideration, Nanga Parbat - the world's 9th highest mountain and therefore

locally known as 'Diamir' (king of mountains) flanks from the south-west to north-east part of the eminent Himalayan massif overwhelming glaciers and steep rocky surfaces. Some three kilometer away from the Nanga Parbat there is another peak i.e. the 'North Peak' some 7,816 m high. On the northern side of the apex of Nanga Parbat, flows the august and most primeval River Indus. The vertex is tri-facial (three faced), the Diamir face (glaciers zone) is on the western side, the southern face i.e. the Rupal face is a geographic marvel in itself as it is the world's tallest vertiginous face, stretching up-to 4,600m. While the opposite northern Raikot face is much simpler than the southern one (Figures 1a and 1b). One of the most famous area on the summit is 'The Mazeno Wall' which is actually a 10km long ridge-line lies on the southern part with eight other subservient peaks.

The tectonic activity undergoing in the region delineate youngest geomorphic land forms in the Northwest Himalayan region. The crustal deformity due to the tectonic activity induces two major structural bends in the north-east north part of the Himalayas (that also inundates two main valleys of the territory; The Indus valley in the north and the Astore valley in the south), 1) the Nanga Parbat syntaxis and 2) the Hazara Kashmir syntaxis. The former deforms the main mantle thrust (MMT) and is the most tectonically active domain in the world while the latter is termed as the main boundary thrust (MBT). The most active fault of the region is Sassi-Raikot-Fault-Zone (SRFZ) that lies between the Raikot and Sassi realms from north to south. Other faults that are present include Stake fault and Raikot fault but these are generated anti-formally (Masek *et al* 1994; Searle and Khan, 1999; Treloar *et al.* 2000). Another proof of the seismic activities in the area is the presence of domes (anti-clinal folds) shown in Figure 1 with structures usually generated over the areas of convergent zones (Whittington, 2000; Bishop *et al.*, 2003; Khwaja, 2003). Now, relating the seismicity to the outflow nexus - As it is said, that tectonic activity and drainage network (along with the climate) of an area are in a relentless contest with each other similarly, in this particular area the Indus River flows with all its glory in the east west direction incising the faults and uplifting the massif. Moreover, the highly compressed drainage network of the area agrees with the regional uplifting rates i.e. 7mm per year (Abbott *et al.*, 1997; Kazmi and Jan, 1997; Searle and Khan, 1999). This uplifting process is responsible for the folding and fracturing of the surface are in a stable way (Argles, 2000; Burg *et al.*, 2000; Burkank and Anderson, 2001). However, the purpose of this research is to highlight the relative uplift rates in Nanga Parbat Haramosh (NPHMZ) Massif Zone through RS/GIS techniques.

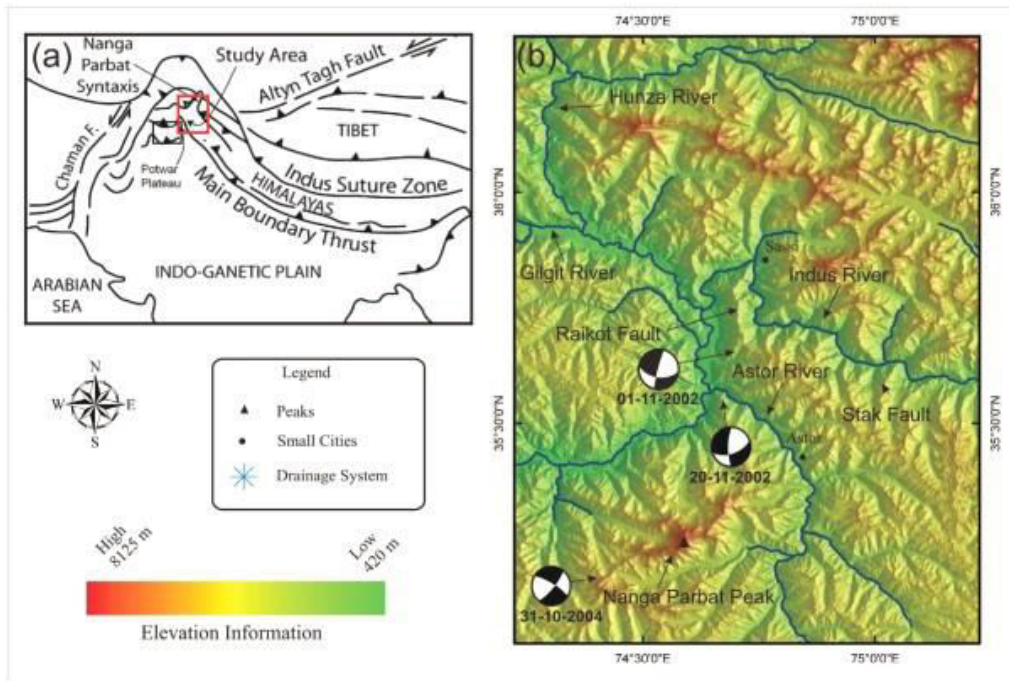


Figure No. 1(a): Figure showing location of study area in the context India-Eurasia collision.

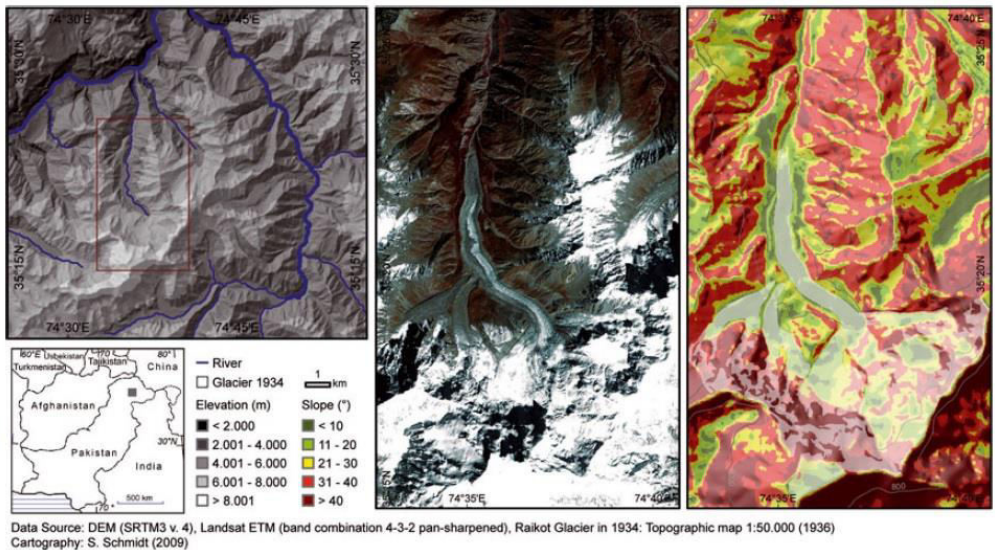


Figure No. 1(b): Nanga Parbat region in northern areas of Pakistan (left) and Raikot Glacier at the northern declivity (centre and right); Landsat scene from 2001 showing the Raikot Glacier catchment (centre) along raikot fault; glacierized area

according to R. Finsterwalder in 1934, Schmidt and Nu`sser, 2009 combined with a map of slope angle and altitude (right).

Geology and Tectonics of Study Area

Being one of the highly active seismic regions of the world, Nanga Parbat has always been an attraction for the geologist/geomorphologists around the world. Butler (1998) explained the active structures illustrating the extent of uplift and structural evaluation of syntaxis. Schroeder and Bishop (2000) found that the rapid crystalline uplifting complex is a cause of high relative relief of 6000 m of Nanga Parbat and claimed that uplift and erosion are both due to tectonic surge response. They also mapped the erosion and uplift of the area for the future by examining the temporal adjustments in remotely sensed data (RSD). The crystalline rocks (Figure 2) dominant on the lesser Himalayas are parts of Indian plate that have impinged into the Nanga Parbat were found out by (Whittington, 1997), when he performed a chemical examination using isotopic data. The topographic evolution that took place in the north-west frontiers of Pakistan was described by (Hildebrand, 2000, 2001) in which he also documented that suturing of Kohistan into Asia was analogous to a major late Mesozoic deformity. He also explained another historic event Oligocene-Miocene-metamorphism in which Kohistan terrain was inundated into Asia followed by its collision with India (Figure 3).

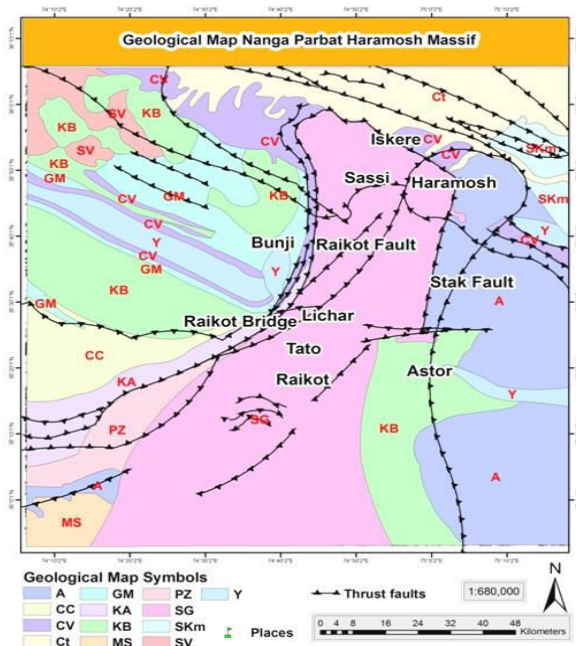


Figure 2 Geology and tectonic map of Nanga Parbat Haramosh Massif Zone.

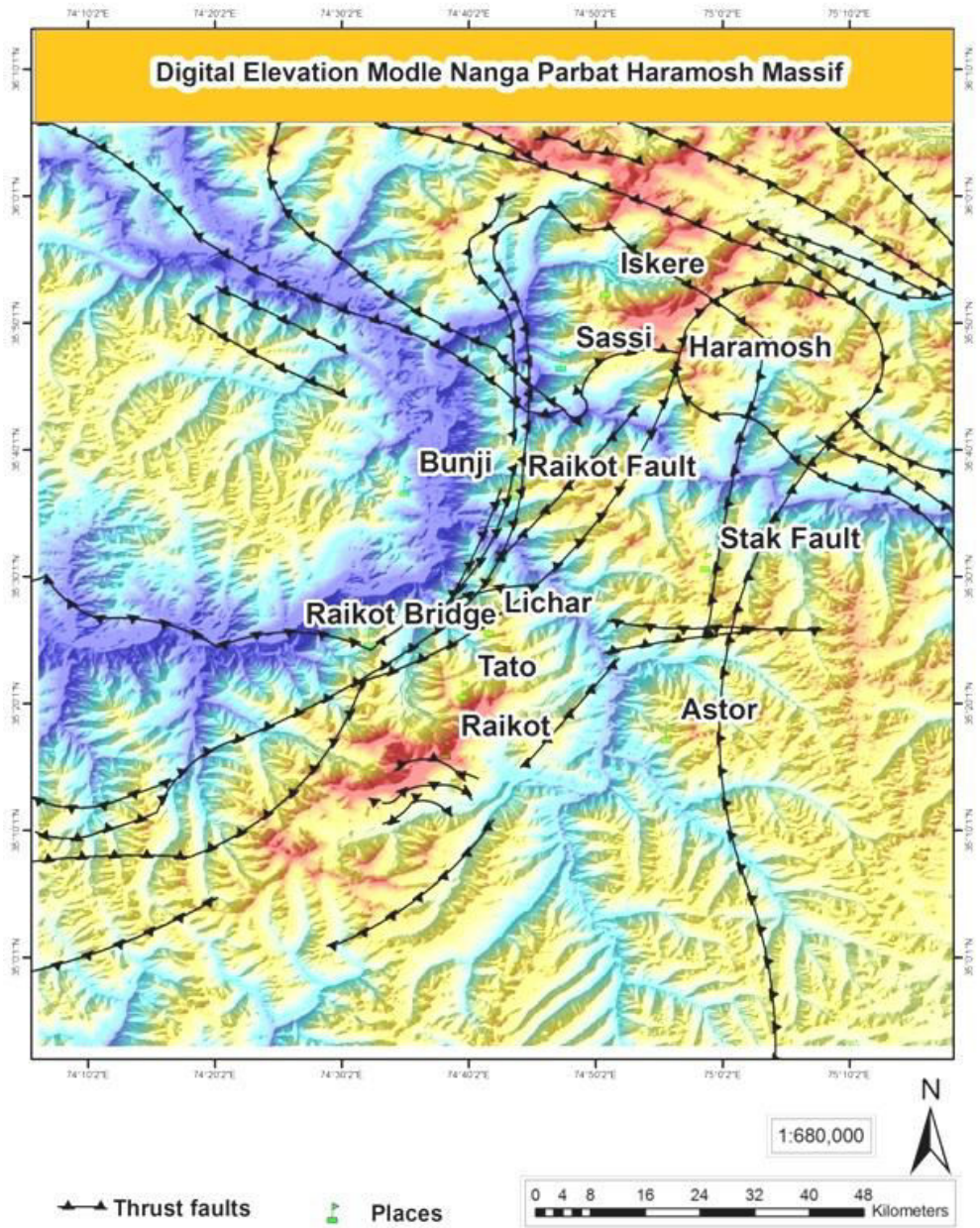


Figure 3: Tectonic setting of Nanga Parbat Haramosh Massif Zone draped over the SRTM DEM with prominent geographical places

Materials and Methods

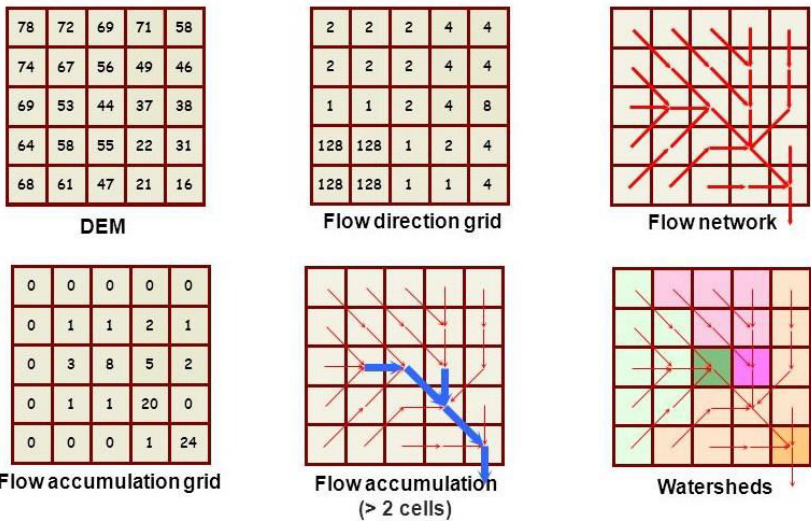
The data used to map the deformation rates in the NPHMZ are of two types;

- 1) Vector data
- 2) SRTM DEM data

DEM or digital elevation model is a particular database that presents the elevation information along with the 2D-ground surface data of a region. The other two models used are Digital Surface Model (**DSM**) that encompasses the earth with all its natural and built-up features and Digital Terrain Model (**DTM**) that captures the bare earth with reference to a vertical datum along with the elevation.

Longitudinal River Profile Analysis (LRPA)

The river profile exhibits the renditions that a river undergoes in its downstream altitude and gradient as it flows from its source to mouth. The analysis is done by the simplest D8 algorithm in which flow from each pixel is allocated to one of its eight neighbors in the course of the steepest slope (Figure 4). But first of all a grid is to be generated and therefore DEM becomes abonus dataset for this purpose. A depression-less (DEM with no sinks) DEM is generated from an original DEM. Then by applying ‘imposed gradient’ method, flow direction of the planes is extracted. The pixels with a flow code of 0 are termed as basin outlets which comprises of four edges of the DEM. The biggest advantage of this algorithm is that the output file received is in vector form that captures data in a single or numerous



sub-basins.

Figure No.4: Example of a DEM and the flow directions are indicated with arrows.

Calculation of Concavity and Steepness

Channel concavity is explained as a lateral change in the channel slope of the reach and is the most frequently used landscape metric to analyze river profile geometry (RPG). The steepness of the channel is calculated by normalizing channel gradient through contributing drainage area.

$$dz / dt = U(x,t) - K A^m S^n \quad (1)$$

Where, dz / dt is rate of change in channel elevation and U describes the uplift rate. A is the upstream drainage area and K is the dimensional co-efficient of erosion. S gives the channel gradient at local level while the powers m and n are positive constants whose dependency lies on erosion rates of A and S .

By keeping the rate of change steady i.e. ($dz/dt = 0$) and taking U and K uniform also keeping the exponents (m and n) constant in equation 1; an expression for equilibrium can be achieved which helps in calculating channel gradient and drainage area for natural landscapes.

$$S = (U/K)^{1/n} A^{-(m/n)} \quad (2)$$

Where, $(U/K)^{1/n}$ represents the channel steepness and the value of ratio (m/n) achieved by assuming K and U as constants and the channel concavity which is equals to actual concavity θ . Further calculation of second equation gives;

$$S = k_s A^{-\theta} \quad (3)$$

Taking log on both sides of the above equation gives;

$$\text{Log } S = -\theta \text{ log } A + \text{log } k_s \quad (4)$$

Where, the concavity is represented by θ , steepness by K_s , regression by $-\theta$ and intercept is $\text{log } k_s$.

Results

The relative relief and surface uplift in the topography of Nanga Parbat Haramosh Massif Zone (NPHMZ) is represented by steepness and relative-uplift-rate maps. Steepness and concavity maps of the NPHMZ revealed 116 small and large stream linkages that were limited by incision detachment model (IDM) and channel profile analyses were carried out by regression model in the first place (Figure5). The concavity index map (CIM) reveals that streams near Bunji and Astore regions of the study area are flowing with relatively low gradient with (low concavity index) and have intermittent profiles mostly affected by erosion in their vicinity which are clear signs of relatively older surface. The following statement has a proof as the regions have Raikot fault in their north and Stalk fault in the east.

Steeper and elongated profiles are detected along the western, north-western and north-eastern parts of Sassi Raikot fault (SRF). Similarly, higher uplift rates i.e. 12-14 mm/ year (reddish-orange-yellowish region in the map, Figure6) are observed along the western and north western part of Nanga Parbat (near Saasi-Haramosh, northwest of Bunji, near Raikot-Nanga Parbat section, Tato and west of Astore) which is considerably highest ever recorded Uplift rates. And this is why; the greatest shear zone is present in the Lichar thrust region of the study area. The highest uplift rate map indicates south-east (SE) part to be a relatively down than the north east (NE) which implies that more bedrock erosion has taken place in the lower portion of the region. By interpreting all the maps of the area, the lithology can be justified to be equivalently distributed. The high values in Figure7 show relatively uplifted areas (along Indus River) and correspond to metamorphic rocks with more lineaments while, the lower values indicate relatively flatter regions with less density of lineaments. Some field photographs are show below for the study area in Figure 8.

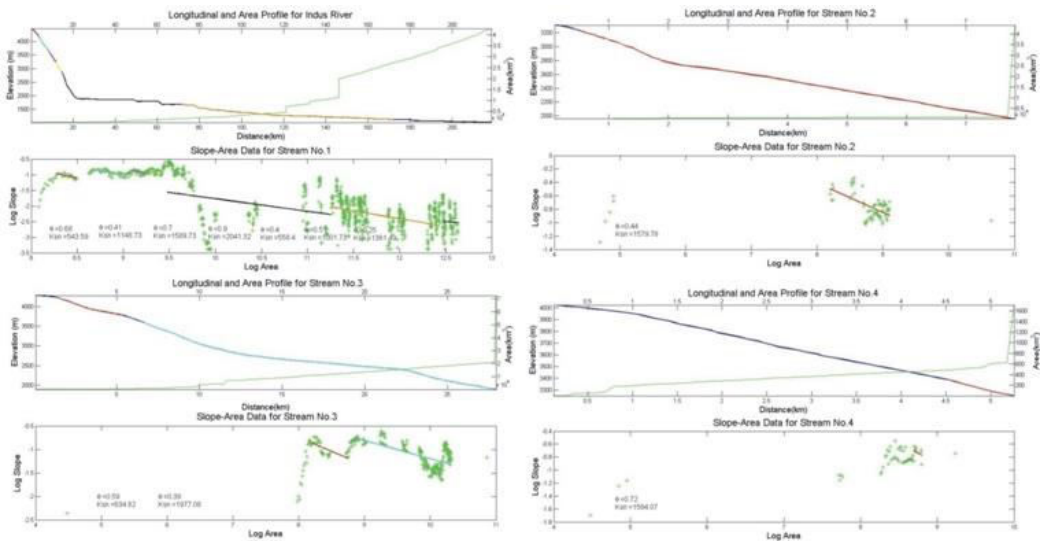


Figure No. 5: Stream longitudinal profile investigation for the Indus River with elevation distance profile and log area-log slope data with best fit regression line.

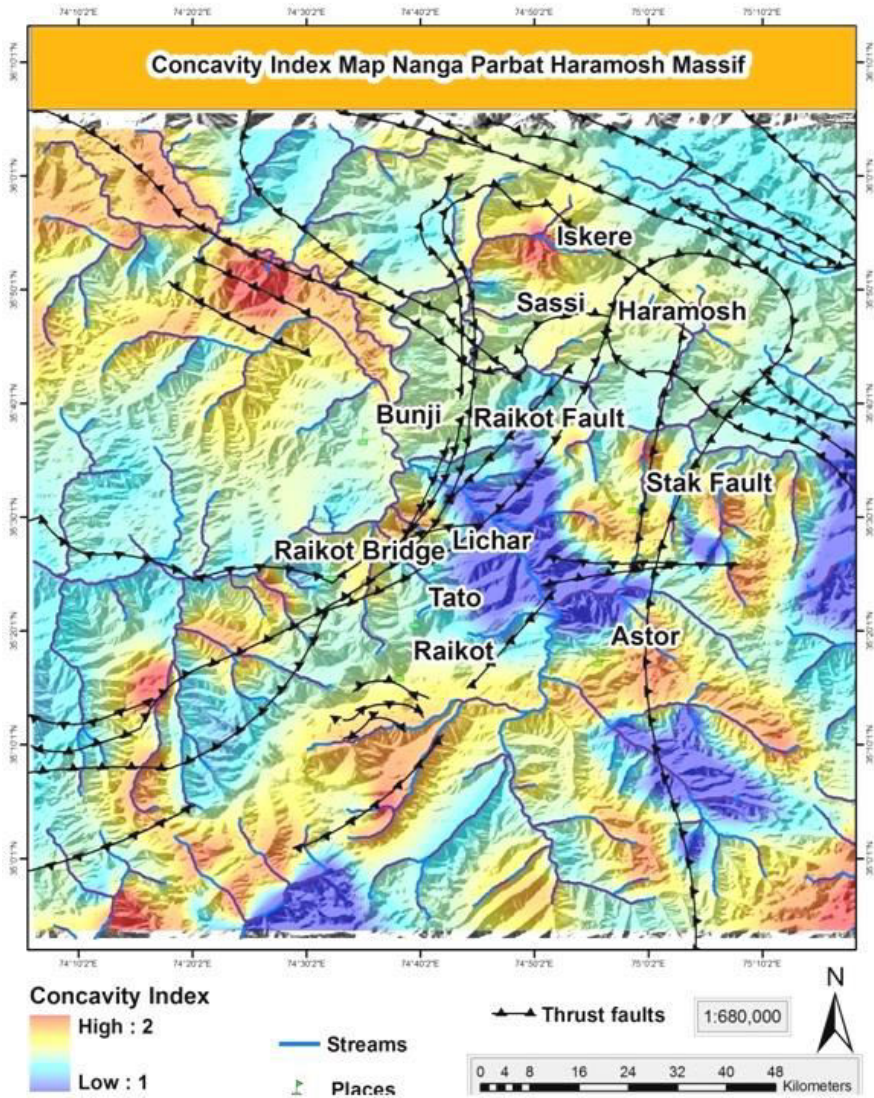


Figure No. 6: Interpolated concavity map (θ) for NPHM. Thick black lines with teeth symbols show published geological faults.

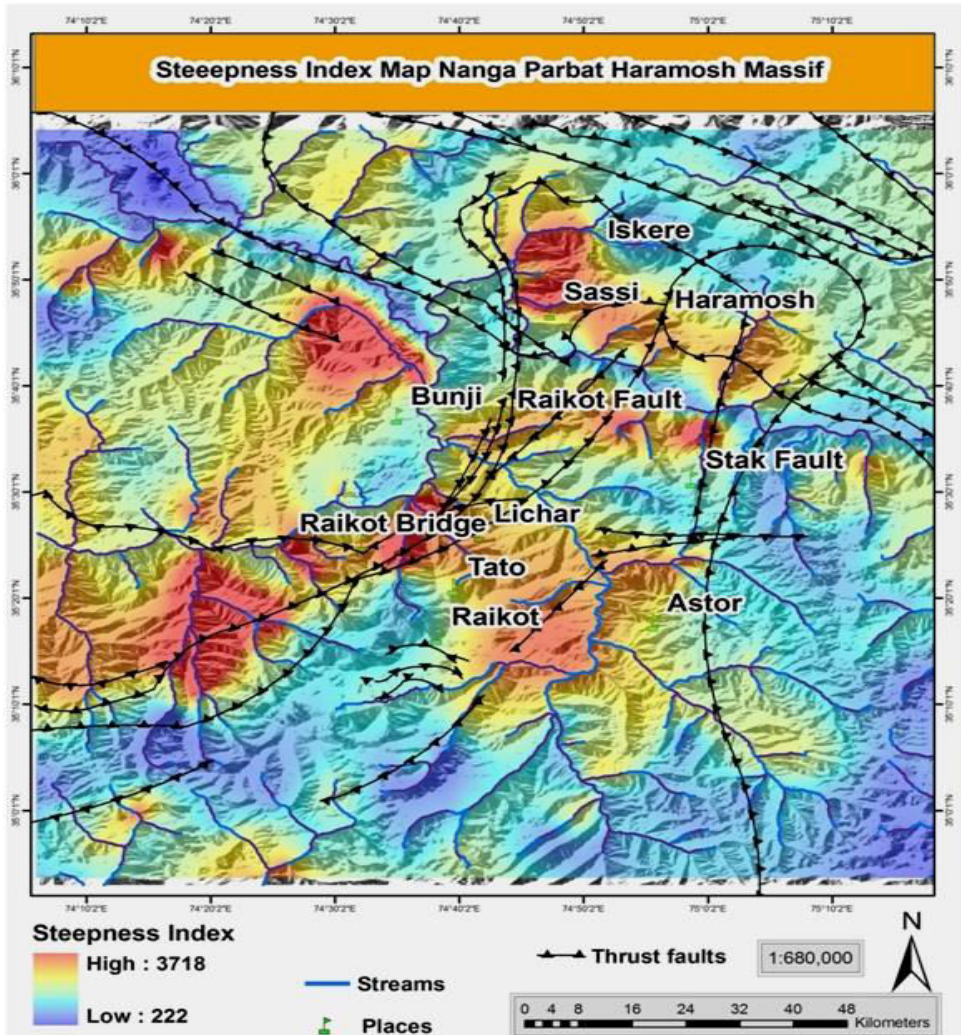


Figure No. 7: Interpolated maps of Relative uplift rates prepared from the automated DEM derived channels in NPHM. Note that bedrock channels developed along the Saasi Raikot fault, west of Sassi Raikot fault and west of Astor tend to have relatively more uplifted conditions than north-west, south and south-east region of the study area.



Figure No. 8: Nanga Parbat facing north (a), Scarps at Dassu with view to the northeast of an alluvial fan built onto the Sassi till plateau at Dassu village. The toe of the fan is truncated by a scarp along the Sassi-Dassu fault (b) and Scarp at Hanumal with view to the north of a glaciofluvial terrace astride the Sassi-Dassu fault at Hanumal. A scarp approximately 15 m high cuts the terrace (Schmidt and Nusser, 2009).

Conclusion

This study concludes that erosion/uplift rates with active surface deformation are evaluated by using surface dynamics maps (SDMs) in terms of CIM and Relative uplift map. These maps help in revealing the signals of tectonic activity are stronger in the area than the erosion rate or in the context of steady state equilibrium (in case of no climate change). The fact that the area is neo-tectonically active is demonstrated by higher uplift rates extracted using stream power law. The uplift rates like 14mm/year extracted from remote sensing technique are in agreement with other studies (Zeitler, 1985; Whittington, 1995; Anderson et al, 1996, 1998). This research also highlights the utility of open source SRTM DEM and efficient MATLAB algorithms to automatically generate graphs and maps for quick evaluation and demarcation of active faults and zones that may trigger sudden landslides, glacial outbreaks and earthquakes.

Notes and References

1. Azor, A., Keller, E.A., Yeats, R.S., 2002. Geomorphic indicators of active fold growth: Oak Ridge anticline, Ventura basin, Southern California. *Geological Society of America Bulletin*, 114(6): 745-753.
2. Burnett, A.W., Schumm, S.A., 1983. Active tectonics and river response in Louisiana and Mississippi. *Science* 222(4619), 49-50.
3. Bull, W.B., 2007. *Tectonic Geomorphology of Mountains: A New Approach to Paleoseismology*. Wiley-Blackwell, Oxford. 328 pp.
4. Burbank, D.W., Anderson, R.S., 2001. *Tectonic Geomorphology*. Blackwell Science, Oxford. 247 pp.
5. Burtman, V.S., Molnar, P., 1993. Geological and Geophysical Evidence for Deep Subduction of Continental Crust beneath the Pamir, vol. 281. GSA, Colorado. 1-76.
6. Cox, R.T., 1994. Analysis of drainage-basin symmetry as a rapid technique to identify areas of possible Quaternary tilt-block tectonics: an example from the Mississippi Embayment. *Geological Society of America Bulletin*, 106(): 571-581.
7. Dehbozorgi, M., Pourkermani, M., Arian, M., Matkan, A.A., Motamedi, H. Hosseiniasl, A., 2010. Quantitative analysis of relative tectonic activity in the Sarvestan area, central Zagros, Iran. *Geomorphology* 121 (3-4), pg. 329-341.
8. Doebrich, J. L., Wahl, R.R., 2006. Geological and mineral resources map of Afghanistan, version 1, compiled by USGS.
9. Hildebrand, P.R., Searle, M.P., Shakirullah, Khan, Z., van Heijst, H.J., 2000. Geological evolution of the Hindu Kush, NW Pakistan: Active margin to continent-continent collision zone, *Geological Society (London) Special Publication* 170: 277–293.
10. Hildebrand, P.R., Noble, S.R., Searle, M.P., Waters, D. J., Parrish, R.R., 2001. Old origin for an active mountain range: Geology and geochronology of the eastern Hindu Kush, Pakistan. *Geological Society of America Bulletin*, 113(5): 625-639.
11. Keller, E. A. and Pinter, N., (Eds.) 2002. *Active Tectonics: Earthquakes, Uplift, and Landscape*, 2nd ed., 362 pp., Prentice Hall, Upper Saddle River, N. J.
12. Lawrence, R. D., Khan, S. H., DeJong, K. A., Farah, A. & Yeats, R. S., 1981. Thrust and strike-slip fault interaction along the Chaman fault zone,

- Pakistan. In: Thrust and Nappe Tectonics (edited by McClay, K. R. & Price, N. J.). Spec. Publ. geol. Soc. Lond. 9,363-370.
13. Lifton, N.A., Chase, C.G., 1992. Tectonic, climatic and lithologic influences on landscape fractal dimension and hypsometry: Implications for landscape evolution in the San Gabriel Mountains, California, *Geomorphology*, 5(1-2): 77-114.
 14. Mahmood, S. A and Gloguen, R., 2011b. Analysing spatial autocorrelation for hypsometric integral to discriminate neotectonics and lithologies using DEMs. in *Journal of Giscience and remote sensing*, (in Press).
 15. Mohadjer, S., Bendic, R., Ischuk., S., Kuzikov, S., Kostuk, A., Saydullaev, U., Lodi, S., Kakar, D.M., Wasy, A., Khan, M.A., Molnar, P., Bilham. R., Zubovich, A.V., 2010. Partitioning of India-Eurasia convergence in the Pamir-Hindu Kush from GPS measurements, *Geophysical Research Letters*, 37(LO4305): 1-6.
 16. Ohmori, H., 1993. Changes in the hypsometric curve through mountain building resulting from concurrent tectonics and denudation. *Geomorphology*, 8(4): 263-277.
 17. Pegler, G., Das, S., 1998. An enhanced image of the Pamir-Hindu Kush Seismic Zone from relocated earthquake hypocenters. *Geophysical Journal International*, 134(2): 573-595.
 18. Rockwell, T.K., Keller, E.A., Johnson, D.L., 1985. Tectonic geomorphology of alluvial fans and mountain fronts near Ventura, California. In: Morisawa, M. (Ed.), *Tectonic Geomorphology. Proceedings of the 15th Annual Geomorphology Symposium*. Allen and Unwin Publishers, Boston, MA, pp. 183–207.
 19. Ruleman, C.A. 2005. Annotated bibliography for Quaternary faulting and geomorphic tectono-morphic development of Afghanistan - Progress Report for Afghan Geologic Hazards Activities: U.S. Geological Survey Internal Report, p. 12.
 20. Schumm, S.A., Dumont, J.F., Holbrook, J.M., 2000. *Active Tectonics and Alluvial Rivers*. Cambridge University Press, Cambridge. 276 pp.
 21. Searle, M., Hacker, B.R., Bilham, R., 2001. The Hindu Kush seismic zone as a paradigm for the creation of ultrahigh-pressure diamond- and coesite-bearing continental rocks. *Journal of Geology*, 109(2): 143-153.
 22. Shahzad F, Gloaguen R. 2010. TecDEM: A new tool for Tectonic Geomorphology, Part 2: Surface dynamics and basin analysis. *Computer and Geosciences*. DOI: 10.1016/j.cageo.2010.06.008.

23. Silva, P.G., Goy, J.L., Zazo, C., Bardají, T., 2003. Fault generated mountain fronts in Southeast Spain: geomorphologic assessment of tectonic and earthquake activity. *Geomorphology*, 50(1-3): 203-225.
24. Tapponnier, P., Mattauer, M., Proust, F., Cassaigneau, C., 1981. Mesozoic ophiolites, sutures, and large-scale tectonic movements in Afghanistan. *Earth and Planetary Science Letters*, 52(2): 355-371.
25. Wells, S.G., Bullard, T.F., Menges, C.M., Drake, P.G., Karas, P.A., Kelson, K.I., Ritter, J.B., Wesling, J.R., 1988. Regional variations in tectonic geomorphology along segmented convergent plate boundary, Pacific coast of Costa Rica. *Geomorphology* 1(3): 239-265.