DEM BASED COMPUTATION OF TOPOGRAPHIC SURFACE ROUGHNESS TO REVEAL INCISION IN GILGIT-BALTISTAN,PAKISTAN

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ABSTRACT: This research investigates interrelationship between landscape evolution and neotectonics in the Gilgit-Baltistan (GB) region based on surface roughness (SR). We analyzed the topographic surface features such as flat area, surface area and surface ratio using Shuttle Radar Topographic Mission-Digital Elevation Model (SRTM DEM) with a spatial resolution of 90 meters. The objective is to make a SR map and to identify areas influenced by neotectonics. The DEM based spatial distribution of slope gradients and slope orientations along with the aspect map were combined to portray the vertical dissection. Lower values of vertical dissection indicate relatively flat topographic basins which generally mean a region of with intermediate slope gradient and slope orientation. Areas with high vertical dissection values correspond to sharp changes in the slope gradients and slope orientations, which could be due to abrupt scrap edges (possibly neotectonic or lithological control). Higher vertical dissection values in GB are wide spread and are oriented SE- NW in Ghanche, Skardu, Hunza, Gilgit and northern Ghizer districts along Karakorum, South Pamirs and Hindu-Kush ranges. While a few higher roughness values are aligned NE- SW in Diamir and Gilgit districts along the Raikot Fault. The surface roughness map is capable of identifying deeply incised valleys, tectonic uplifts and depressions.

Key words: DEM, Surface Roughness, Slope, Tangential Curvature, Incision, Gilgit-Baltistan.

INTRODUCTION

Surface roughness is a measure of the texture of a surface and, is quantified by the vertical deviations of a real surface from its ideal form. The surface roughness is a vital surface dynamic parameter, as it reveals tremendous information, such as nature of landforms(Hobson, 1983) amount of differential erosion and spatial distribution of landscape dissectivity (Grohmann, 2004; Grohmann and Riccomini, 2009).The topography of GB region in northern Pakistan is complex, compressional and strike slip tectonic deformation zone. The rugged topography of the GB region is a result of on-going and long-standing collision of India-Eurasia continental plates and consequent tectonic forcings and morphotectonic processes (Burbank and Anderson, 2001; Mahmood and Gloaguen , 2011)Such forces can generate huge mountain ranges, e.g., the Main Karakorum Thrust (MKT) in the study area is E-W oriented(Kazmi, 1979; Gaetani et al., 1995) and is principally influenced by the already present crustal structure and its direction. prior to such compressional periodic incidents, we can predict a topography, differentiated by a primeval flat surface which is then compressed, thrusted, folded, inclined and faulted along with the associated spatial patterns of drainage network rejuvenated. This research article investigates topographic surface roughness in the context of morph structural interactions. The objective is to assess the neotectonic signals regarding recent topographic development and to attach additional significance to active tectonics in GB region. Basically, the original topography is described by elevation raster data. This data were investigated using both ArcGIS 10 and MATLAB. Shuttle Radar Topographic Mission-Digital Elevation Model (SRTM DEM) with a spatial resolution of 90 m was used for the generation of slope gradients (in degrees), aspects, tangential curvature, hill shade, flat area and surface area maps. These maps permit for quick portrayal of tectonic topography and the analysis of morphotectonic relationships described by the interplaying tectonic forcing. Finally, the map of topographic surface roughness map was generated by using the method devised by (Grohmann, 2004), which is consistent with the incised rivers and valleys and associated spatial and differential uplifts (Masood et al., 2012, Qureshi et al., 2012).The surface roughness results suggest that the neotectonic relative uplift is significantly scheming the fluvial incision in the GB region except the Deosai Plateau. Digital mapping of the surface roughness can be a handy, rapid and cost free technique for demarcating neotectonic activities.

Study area: The GB is a newly establishing province in the northern area of Pakistan, bordering India, China, and Afghanistan (see Figure 1). In the North-South, the Gilgit-Baltistan makes one of the most significant parts of

Hindukush-Karakorum-Himalaya (HKH) in the context of its geotectonic, topographic and geomorphic development. Numerous geomorphological expressions (landforms) such as huge glaciers and glacial retreat traces, fluvial/alluvial erosion, slope instability and landslide/rockslide hazards. The salient and prime segment of the Karakorum Range is situated inside Pakistan and bridges a connection flanked by the NW Himalaya, the Hindukush and the Pamir in the West. The spatial location of GB region lies geographically within 71^o – 75^o E Longitudes and 32^o – 37^o N latitudes. Pakistan in general and GB in particular, is characterized by extensive zones of high seismicity and contains several seismotectonic features generated by an integrated network of active faults. In the central Karakoram the E-W trending Upper Hunza Fault (Kazmi, 1979; Gaetani et al., 1995; Zanchi, 1993) is an E-W oriented thrust fault that runs along the depression formed by the Chapursan and Upper Yarkhun Valleys (see Figure 2). The strike-slip Karakoram Fault forms the eastern termination of the Karakoram block and comprises a nearly 500Km long fracture that appears vividly on satellite images as a spectacular linear feature. Right- lateral displacement of 200 to 250 Km has been suggested along this fault (Burtman et al., 1963; Srimal, 1983).

The short names of faults in the (see Figure 2) are AM, Alburz Marmul, CbF, Central Badakhshan Fault, HF, Herat Fault, CF, Chaman Fault; MoF, Mokar Fault, GzF, Gardez Fault, KoF, Konar Fault, MBT, Main Boundary Thrust; MFT, Main Frontal Thrust, MMT, Main Mantle Thrust, SRT, Salt Range Thrust, MKT, Main Karakoram Thrust, RF, Reshun Fault, SF, Sarobi Faultand ST, Spinghar Thrust (Mahmood and Gloaguen, 2011).

Data sets and methods: This research uses SRTM DEM, (version. 4) data with a spatial resolution of 0.0008333 x 0.0008333 degree (~ 90 x 90 meter). The geographic image dimension for the study area spans between latitude min: 34.30^o N max: 37^o N longitude min: 72.30^o E max: 77.30^o E and employs the Map projection Latitude/ longitude (WGS84).In a DEM based square grid data, the surface roughness can be described as the arithmetic proportion between flat area and real surface. The DEM grid size can be variable in a context of variable spatial resolution of the DEM used and the study area of interest.

The diagrammatical and arithmetical correlation of the flat area and the real surface area is shown in the (see Figure 3).The flat area is computed by the product of the spatial resolution of the DEM or topographic data with the length of each and every square of grid generated from the SRTM DEM. The real surface area of all the grids can be calculated from the mathematical relationship as shown in the (see Figure 3). The real surface area within a single grid cell may be affected by the slope variability and it corresponds to tangible neotectonic deformation of the relative relief. From this method, we obtain a map that can be exploited in a GIS environment to make further classification showing spatial distribution of surface roughness variability.

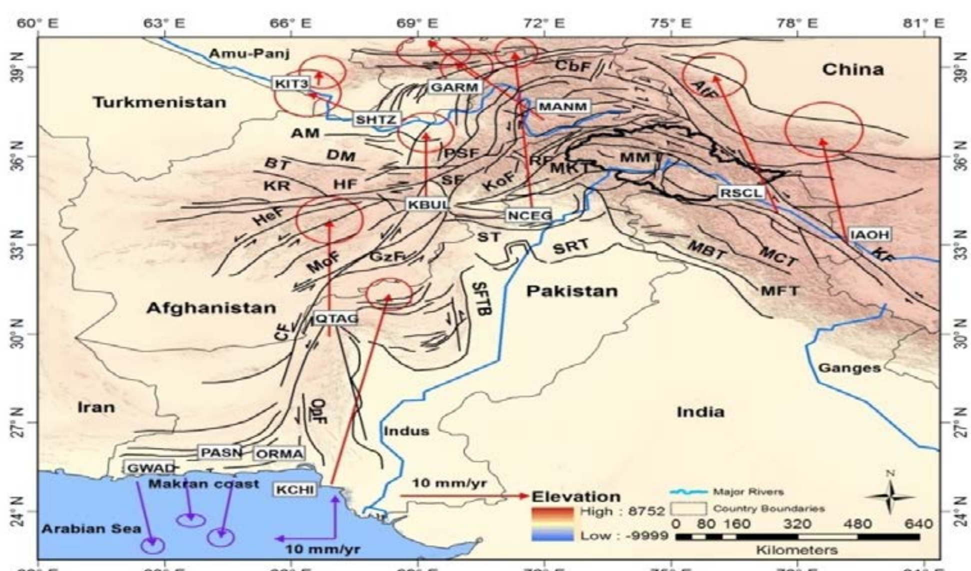

Figure1: Tectonic map of the Pakistan and neighboring countries illustrating published and recently interpreted structures/faults.The black and bold shape file represents the province of Gilgit-Baltistan. Global Positioning System red arrows w.r.t fixed frame of reference (Eurasia), whereas the purple arrows are transformed w.r.t fixed India (Mohadjer et. al., 2010).

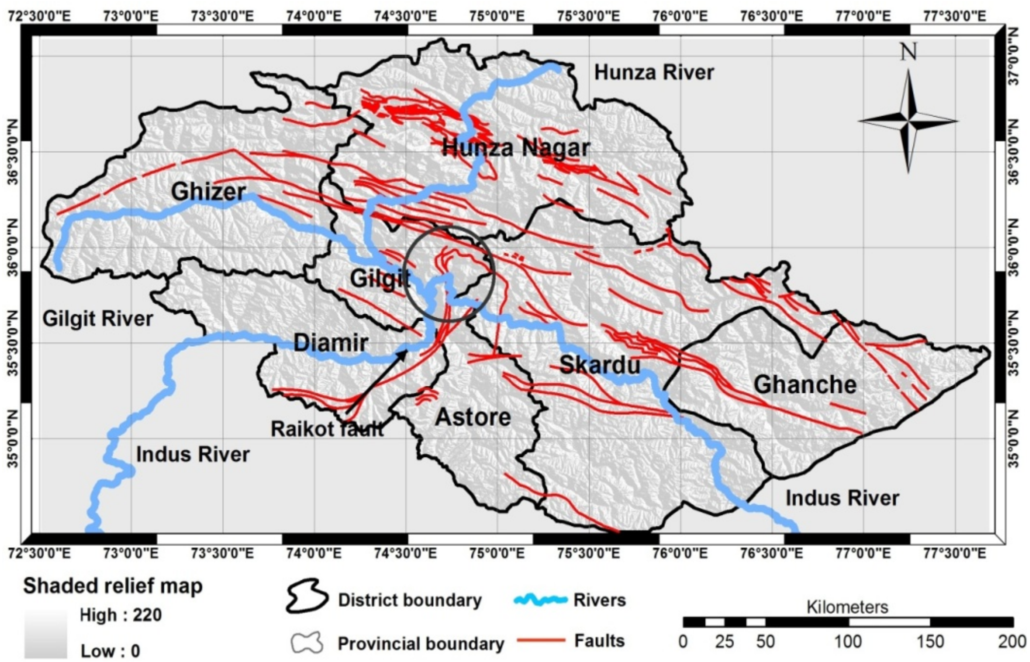

Figure 2: Location of study area of Gilgit-Baltistan region (northern Pakistan) with shaded relief map along with major rivers (Indus, Gilgit and Hunza), district and provincial boundary.

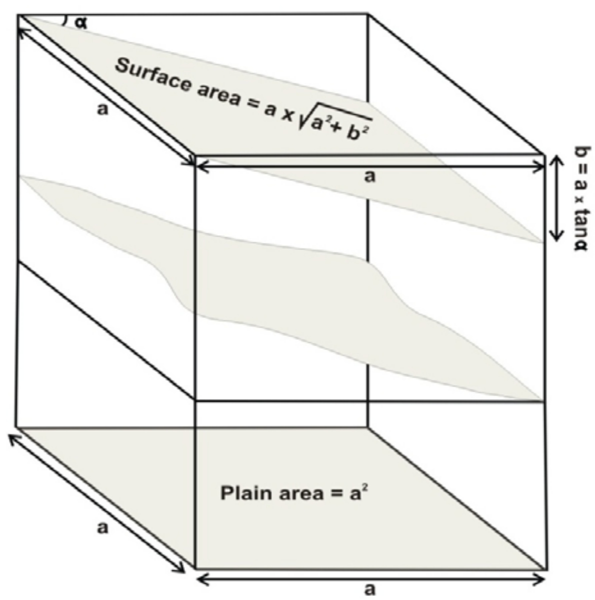

Figure 3: Diagram showing mechanism of calculation of surface roughness or vertical dissection, modified after (Grohmann, 2004).

RESULTS AND DISCUSSIONS

The results obtained show a strong relationship between GB landscape evolution and neotectonics. The existing topography of the GB can be depicted as a tectonically controlled landscape. DEM based slope analysis (see Figure 4c) shows that the average slope angle is ~45°along upper Hunza fault (UHF), Main Karakorum Thrust (MKT) and Raikot Sassi fault (RSF)for most of the GB region except for the Deosai Plateau where it is as low as 0°-7°. Besides, the higher and medium slope angles (30°-90°) are frequent and can be observed in entire Ghanche, upper Skardu, Hunza, upper Gilgit, Astore, lower Diamir and upper Ghizer, which typically corresponds to high and medium gradients. These high to medium gradients explicates the high fluvial incision in the GB region which is also in agreement with the high to medium surface roughness values. Due to higher slope angles, the hill slopes becomes unstable and the hill slope processes (Rock and landslides etc.) become dominant are therefore easily and rapidly modifiedby mass movements. For example, the presence of high angle slopes near Attabad (Hunza) caused a huge lake on the Hunza River in northern Pakistan due to a massive landslide on January 5, 2010 (see Figure 6).The tangential curvature map (see Figure 5c) also suggests that the steepest gradients exist almost in every district of GB except in Deosai Plateau in south-west Skardu. The positive values or convexity of the curvature suggest that water will diverge as it flows over the central high (uplifting area or less eroded areas), while the negative values or concavity suggest that water will converge as it flows over the central low (more eroded areas, less uplifted areas).

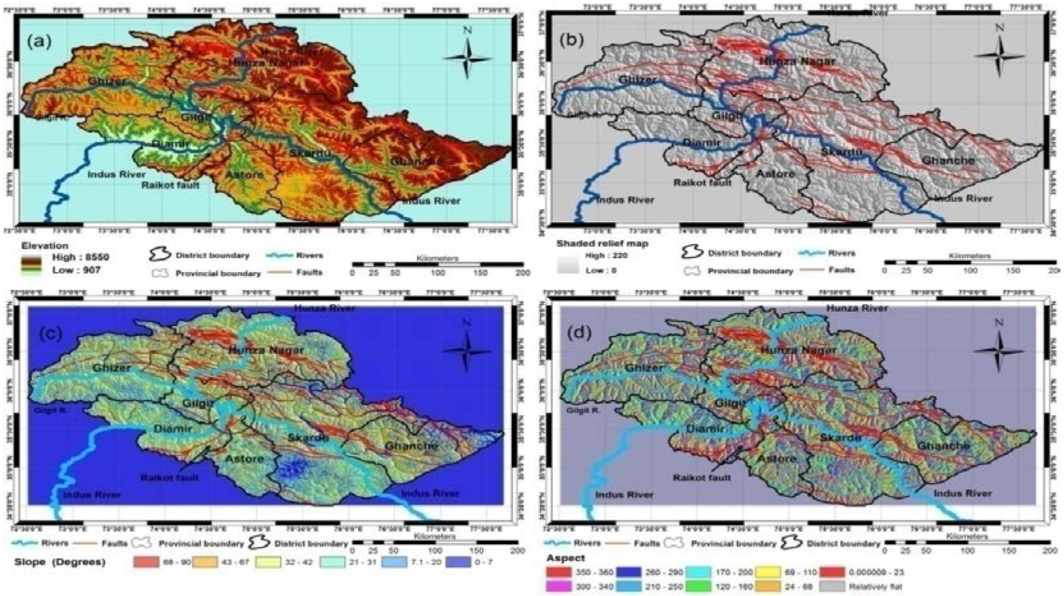

Figure 4:(a) Digital elevation model, **(b)** Hill shade map, **(c)** Slope map showing variable gradients and, (**d)** Aspect map showing direction and steepness of the slope for the GB region.

DEM based investigation and resultant topographic surface roughness map (see Figure 5d) indicate higher values (strong river incision) in the districts of Ghanche, upper Skardu NE of Deosai Plateau, upper Hunza, junction of Diamir-Gilgit-Astore along Raikot Sassi Fault (RSF) (indicated by a circle), northern Ghizer in the GB province,signifying a possible neotectonic activity and current relative uplift episodes. The enhanced surface roughness or river incision may also be due to partially forced by an isostatic rebound as a result of orogenic assemblage processes, particularly allowing this orogenic sequence development. This mountain chain development is a result of crustal thickeningas a result of collision between Indian and Eurasian platesand consequently strong variable fluvial incision chiefly caused the differential relative uplifts with the exception of Deosai Plateau and flood plains and, hence these uplifts may be regarded as a result of neotectonic activity. It is logical to propose that the swift incision in majority of the GB region reveals a blend of spotlighted incision, maybe a consequential from neotectonic activity.

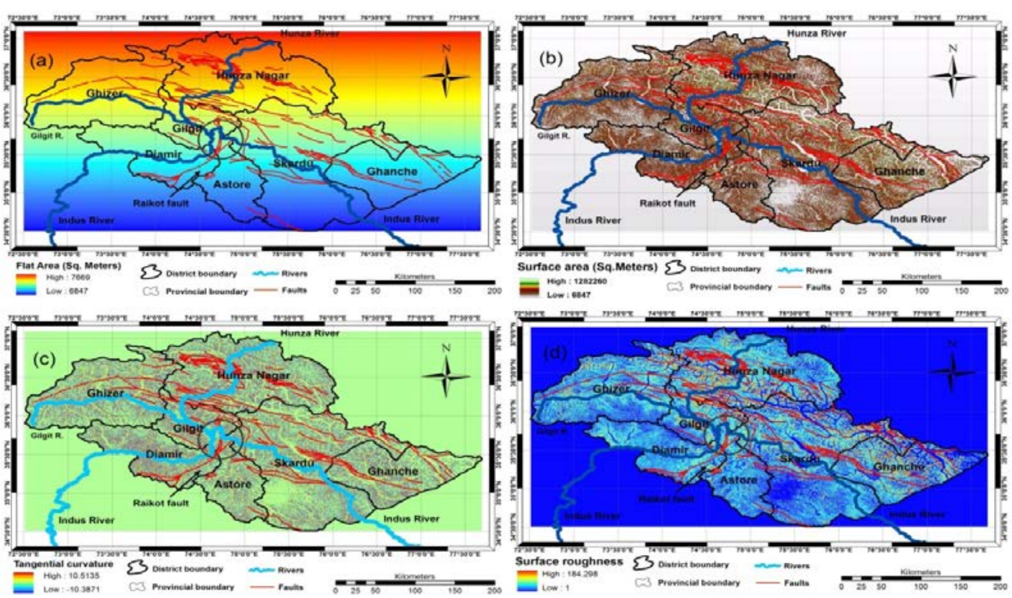

Figure 5:(a) Flat area map generated from DEM, **(b)** Surface area map, **(c)** Tangential Curvature map (**d)** and surface roughness map calculated by taking the ratio of surface area and flat area.

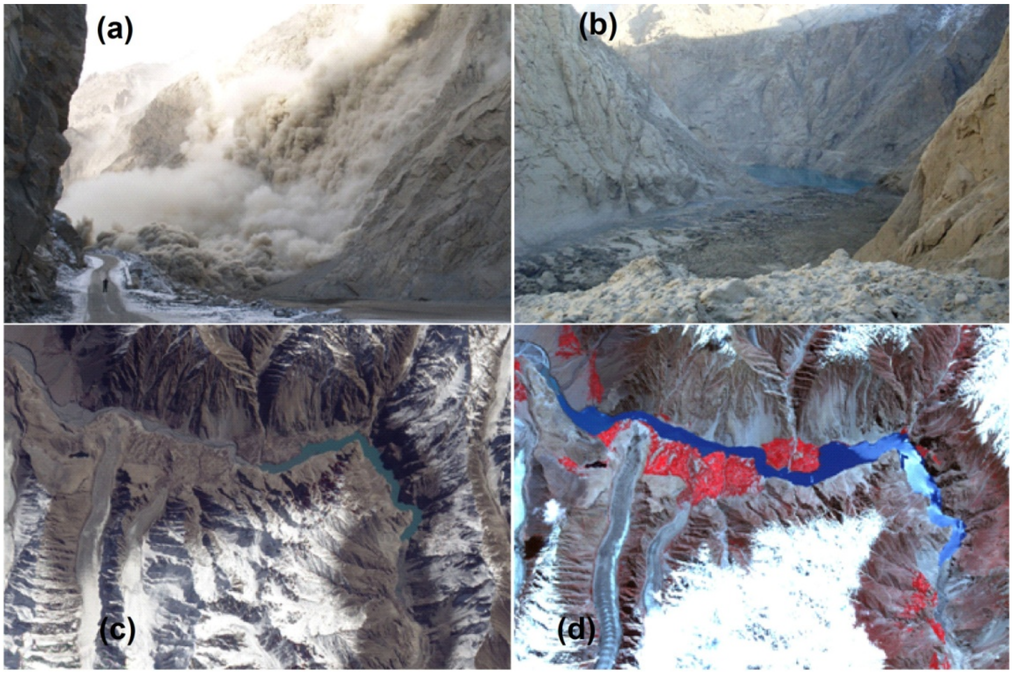

Figure6:(a) A landslide in Hunza River on Jan. 2010,**(b)**Temporary lake as a result of damming of Hunza River, **(c)**ALI (EO-1) satellite image on Mar. 16, 2010, highlighting the Hunza damming,**(d)** The ASTER false-color composite image of June. 1, 2010,Water in varying bluish tones, reddish vegetation, and rocks in varying brownish-grayish tones(Courtesy of NASA).

Conclusions: The topographic surface roughness analysis of theGB (N. Pakistan) and DEM derived aspect, slope, tangential curvature, flat area, surface area and the surface area ratio maps reveal that areas with high surface roughness correspond to rapid variations in slope gradients and orientations.These abrupt variations in the GB region are due to the extremely incised valleys of Hunza, Ghanche, upper Skardu, Ghizer and near RSF in upper Astore with the exception of Deosai Plateau having less incised areas. The higher surface roughness represents enhanced incision that appears to reflect differential and uplift vertical incidents, which appears to be very significant in majority of the GB region, especially along the upper Hunza fault (UHF), Karakorum fault, MKT and along RSF. Regional topographic features such as UHF and MKT are E-W oriented while the RSF is SW-NE oriented and clearly explains the higher slopes, high surface roughness values and positive tangential curvature values. The DEM based surface roughness computation is an efficient and a quite a handy tool that provide a quick map view to highlight the neotectonic features.

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