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Investigation of Tilt Block Neotectonics in Gilgit-Baltistan-Pakistan: Implications from T-factor and fractal Analyses

Abstract

Fractal measures (F_{dim}, $D_{lac,}$ and D_{suc}) and Transverse-topographic-asymmetry-factor (T_{factor}) were used to assess the neotectonic deformation with aid of MATLAB algorithms and (GIS) techniques. This appraisal underlines the role of the tectonic geomorphometric processes for the basin asymmetry. Astore-Deosai-Sadpara watershed (ADSW) region in Gilgit-Baltistan was selected for this purpose as it lies between MKT and MMT which is experiencing surface topographic deformation (STD) caused by anti-clock-wise progression and subduction of Indian plate beneath Eurasia. To investigate neotectonism in the Astore-Deosai-region (ADSW), we identified geomorphic domains that show evidence of ground tilting during Quaternary time. T_{factor} and Fractal measures; fractal dimension, Lacunarity and Sucolarity (F_{dim}, $D_{lac,}$ and D_{suc}) were used to infer directions of topographic deformation (TD) and ground tilting. ASTER-GDEM based transverse basin profiles were converted to two-dimensional vectors that denote channel position with respect to basin mid-lines and divides. Quaternary activity is suggested for two thrust faults in ADSW-GB. The results obtained illustrates that (F_{dim}), Transverse-topographic-asymmetry-factor (T_{factor}) and Drainage density ($D_{density}$) show anomalies in the ADSW region that clearly represent a robust control of nearby MMT, MKT and KkF and highlights their significance to describe regions vulnerable to neotectonics and related deadly events threatening precious human lives and infrastructure damages. Results obtained reveal that geomorphometric investigation of $T_{factor,}$ F_{dim}, $D_{lac,}$ and D_{suc} proved efficient inspection tools in ADSW region.

Keywords: ASTER-GDEM, F_{dim}, $D_{lac,}$ and D_{suc}, T_{factor}, Neotectonics, ADSW, and Gilgit-Baltistan.

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Introduction

This research is about the topographic geometry of the Astore-Deosai-Sadpara watershed (ADSW) to examine its growth and development in association with the regional structural ADSW. The characteristic geometry and watershed boundary of the ADSW region (Figure 1) demonstrate important regional tectonic control, and neotectonic lineaments. Earlier investigations, like seismological, geophysical surveying or investigations did accumulate conventional datasets on the regional tectonics and structures (Cox, 1994; Garrote et al, 2006). The current research also employs indirect investigation technique on the basis of a principal geomorphometric parameter of a watershed, its stream network and particularly, basin T_{factor}. Fractal techniques significant in nature; fractal features having same F_{dim}, might be differentiated by D_{lac} (Melo, 2007; Gloaguen et al., 2007; Dong, 2009; Mahmood et al., 2009; Shahzad et al., 2010, Mahmood and Gloaguen, 2011). Consequently, D_{suc} have the capability to separate different fractal objects showing comparable F_{dim}, and D_{lac} values (Melo, 2006, Dog, 2009; Mahmood and Gloaguen, 2011) or vice-versa.

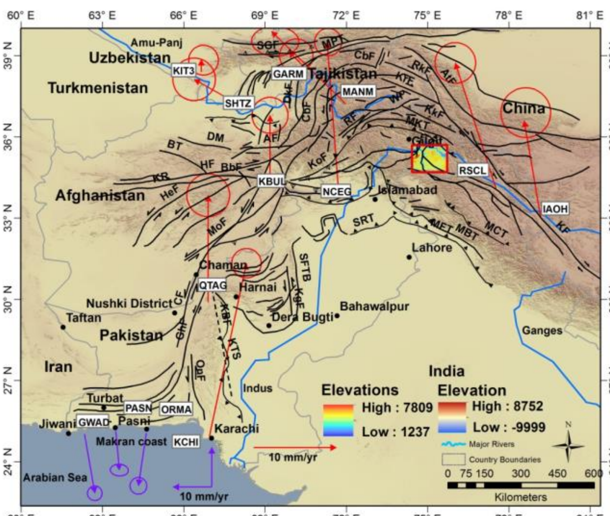

Figure1. The map showing regional tectonic structures with location map of the investigation site (Mohajder et. al, 2010, Mahmood and Gloaguen, 2011).

There exists a valid relationship among larger channels and their connection with the local tectonics is broadly established (Potter, 1978; Schumm, 1986). Despite of higher discharges and evident potential to decide their itineraries, main rivers are prone to neotectonics due to lower gradients simply influenced by small variations. Though stream investigation is a primary tool to interpret neotectonics, evaluation of stream performance is not simple because of variabilities in channel influence (Schumm, 1986). Within a basin with uniform geologic setting, stream dimension and power computes the extent of a channel response to neotectonics. Consequently, different Strahler order streams may have diverse geomorphological geometries either due to their own developing capabilities or various tectonic contributions. To examine this inconsistency in the ADSW region, T_{factor} investigation has been executed to different order stream subbasins. The T_{factor} (Cox, 1994) is significant both in demarcating tilt-block tectonics in region of higher seismicity, and in zones of lower seismicity, neotectonic blocks that earlier escaped other methods of investigation (Cox, 1988, 1994; Fisher et al., 1994; Cox et al., 2001; Csontos, 2002; Garrote and Garzon, 2002). This research deals with a proficient GDEM based semi-automatic analysis that acquires the T_{factor} geomorphometric index. From T_{factor} datasets, different spatial domains in ADSW region are drawn, representing subbasin with unlike tilting directions. To obtain complete and supplementary information for the test site, the results of ADSW have been evaluated with other complementary geomorphometric indices. Therefore, this multi-index technique alongwith (F_{dim}, $D_{lac,}$ D_{suc}) reveals variations in channel patterns and geospatial distributions that decipher distinctive regions of topographic evolution.

Study Area

The investigation site (Figure 2) demonstrates intense climate set-up with unexpected weather inconsistency due to the presence of lofty adjoining great mountain ranges. East of the ADSW region, the north-western Himalayan flanks exit. Higher summer temperatures remain between 25-30° C while lowest in winter ranging below -08 to -10° C. Maximum rainfall occurs as 30-35 mm as snow from February-March. The topographic relief rises from 3000-5000 m. The ADSW regions display moderate to steep slopping trends with almost very less vegetation land cover. The Indus, Astor, Kala Pani, Bara Pani and Sadpara are main rivers that ultimately join Indus River that in the region. Asian monsoon rarely penetrates ADWS region and the majority of the precipitation/rainfall is from western disturbances, with 45-50% only from March-May with iso heavy in April that ranges from 1050-1950 mm similar to rainfall on mountain tops as freezing snow-fall. While, in lower down the valley regions stay dry with 225-330 mm of rain every year. Deosai Mountains on west of Ladakh consists of younger granites and Precambrian-rocks (Figure 3). Deosai pleateau (world second largest, extends 125-185 km from the Indus river at Bunji toward Karcha-Suru River, that disconnects it from Zaskar-Range) consists of Deosai volcanics (Desio, 1978). These volcanics are similar to tholeiites-to-calc-alkalines, Dras-volcanics in occupied Kashmir of Late-Jurassic-to-Cretaceous period (Sharma and Gupta, 1983; Searle, 1983). They are associated with the Chalt-volcanics in Kohistan-island-arc with similar chemical composition (Searle, 1999). Late Cretaceous Burji-La-Formation north of Deosai plateau overlies Deosai volcanics (Desio, 1978).

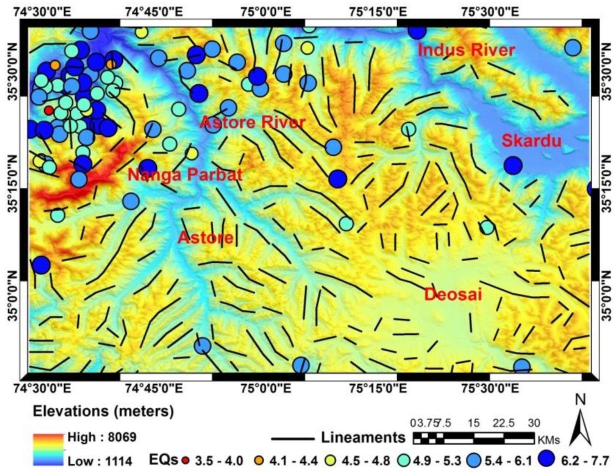

Figure 2. Map showing study area, with local lineaments and seismic events.

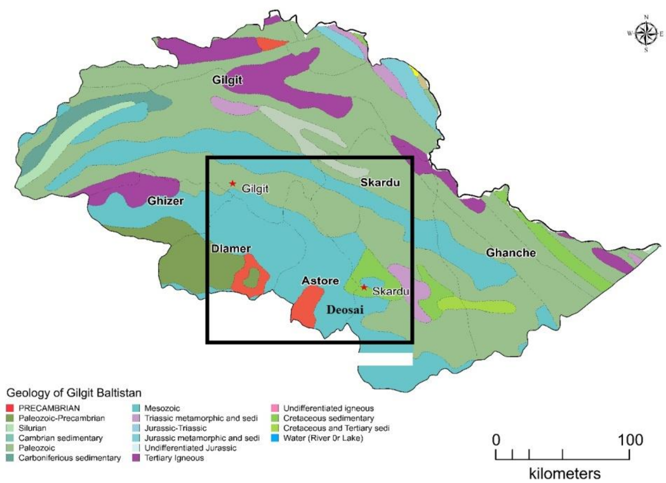

Figure 3. Geology map of the Gilgit-Baltistan with inset showing location of ADSW region (source, USGS).

Materials and methods

Earlier investigations show that, numerous attempts have been performed to inspect the fractal measures for geomorphometric surfaces with higher slopes, stream networks, coast-lines and regional-topographies (Tarboton et al. 1989; Melo at el., 2008; Mahmood and Gloaguen, 2011). A binary image from GDEM was generated, D8-filling algorithm by (O'Callaghan and Mark, 1984, Jenson and Domingue, 1988). This analysis provides prediction of river linearization as the topography is robustly affected by impacts of ongoing neotectonism. The F_{dim} shows the complication of a channel texture and conceals the channel pattern interpretation. To reveal this potential information, the D_{lac}-D_{suc} techniques (Figure 4) are utilized to decode and discriminate channel textural properties (Mandelbrot, 1983; Melo and Conci, 2006, 2008; Mahmood and Gloaguen, 2011).

For a known channel segment, the stream asymmetry (for cross-valley) of its watershed is a ratio (Da/Dd), while Da represents the distance of the channel to basin mid-line (calculated at right angle to a straight-line-segment befitting to the stream), and Dd represents space from the watershed divide to the basin mid-line (Figure 5). For instance, if the channel segment flows along the basin mid-line, then Da = 0, and the ratio Da/Dd = 0 (a symmetrical channel basin). As a river deviates laterally across the basin mid-line flows towards the watershed divide, the value Da/Dd=1. For every Da/Dd computations, the azimuth angle (compass angle) of lateral changing at right angle to the channel segment is documented, and jointly these datasets represent the magnitudes of (Da/Dd) and azimuth angles of a 2-D vector (T_{factor}). These $T_{factors}$ can be treated statistically as vector-fields. To evaluate potential relationships of $T_{factors}$ to Quaternary deformation in context of neotectonic activities, study field and its boundaries were compared with the geospatial locations of mapped fault and to earthquake epicenters.

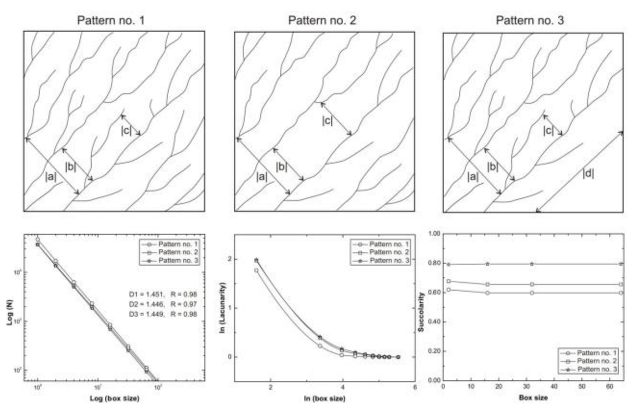

Figure 4. Schematic diagram showing calculations of DEM based F_{dim}-D_{lac}-D_{suc}.

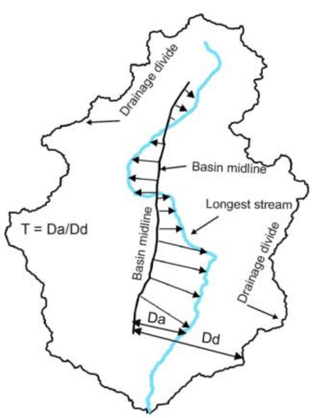

Figure 5. Diagram showing schematic representation of computation of T_{factor}.

Results and Discussions

T_{factor} Analysis

We explain the results achieved from this investigation into two following groups: 1) results from T_{factor} calculation; and 2) results in association F_{dim}- D_{lac}-D_{suc} techniques over ADSW regions. The T_{factor} results yield details regarding magnitude and direction of 2nd-SOSs DBA in the ADSW region. T_{factor} show geospatially localized sub-watersheds and construct vector fields that comprises zones of favored DBA and may be demarcated. The stream power behavior on DBA is attuned by standardizing the T_{factor} vectors in the context of stream behavior within its sections through mean average spatial statistical investigation (Garrote et al., 2006) for the resultant field with average vectors. The last phase is significant in those regions or watersheds that are geologically influenced. T_{factor} computations with no normalized stage (Csontos, 2002) give up a field with vectors robustly controlled by stream behavior, particularly in a smaller investigation with less number of streams (Salvany, 2004). Ultimate result is a map with average vectors showing a spatially distributed corresponding the magnitudes and directions of DBA (Figure 6). We can interpret these datasets, the cause of DBA, which may correspond to monoclinal shifting, changes in lithologies (erosion), neotectonic features, or combination of both in the investigation of larger regions or watersheds. The ADSW is suitable for T_{Factor} investigation as the rivers are not limited to bedrock watersheds and remain free to sinistral or dextral migration with low dip angles structurally and are nearly horizontal. At localized scale the watershed may display broad diversity of types of sediments, while at regional scales it may be represented as uniform lithological watershed. Consequently, it may be assumed that variations in DBA (watershed morphometry) over the ADSW are mainly controlled by neotectonics. T_{Factor} index analysis (TIA) was performed over various Strahler-order-streams (SOSs), principally spotlighting on the DBA of SOSs with 2nd-order. Third and 4th SOSs were also examined to evaluate different SOSs and consequently the control of fluvial dynamics and stream power. A T_{Factor} spatial map was generated for every stream with a pre-defined order. 2nd and 3rd SOSs results show the average-vector-field (AVF) after application of the running AVF. Variations in magnitudes or orientations of average-vectors (AVs) were employed to illustrate watersheds domains. The initial noteworthy attribute on DBA map is a factor in eastwards directions that entails 2nd-SOS-MVs pointing upward of the main channels. T_{Factor} study of 3rd-SOS watersheds was overlaid onto 2nd-SOS boundaries so as to evaluate results. (Figure 6b) represents a close connection among lower SOSs and DBA, while higher order domains/boundaries explain an important differentiation in asymmetry trend, roughly 40°. This research shows that evolution of 2nd and 3rd SOSs has been influenced by the similar events/processes. Additionally, these results explain u that for such SOSs, DBA-values are autonomous for the flow orientations of the major streams. To substantiate the systematic distribution of DBA vectors, 4th-SOS basin boundaries have been tested as diverse sub-areas within each field or domains. For this, we have computed 2nd-SOS DBA within each 4th-SOS watershed. DBA results show a positive association with western (sub-watersheds including 1-7, 9-12 and 14 within Astore region), central (13, 15-

18 in Deosai region) and eastern (19-23 in Skardu region) sub-watersheds of ADSW (i.e., Astore-Deosai-Skardu) as shown in (Figure 6). This investigation shows that ADSW region can be understood as a plateau type (Deosai, the world second largest) with west and east margins (Astore and Skardu) having homogeneously compressed and non-homogeneous asymmetric subbasins. A homogeneous compressed strip of subbasins (3 and 6) (Figure 6) is located near Nanga Parbat Zone in the NW of the investigation site that differentiates relatively non-homogeneous band of subbasins (2 and 4) in the west of Astore River from where, another non-homogeneous band that follows the subbasins in Deosai plateau (13,15-18). Non-homogeneous subbasins may reveal differentiations in the context of basin development among lower and higher SOSs in the basins, which might be of structural or lithological origin. More remarkable differentiations among lower and higher SOSs and DBA are placed in the Deosai Plateau and Skardu region. Commonly, 5^{th}- SOS asymmetry as deduced from (Figure 6) shows a good relationship with main rivers DBA, such as Astore, Bara Pani and Indus River watershed (Figure 6). That shows there are obvious variations among the lower and higher-SOS sub-watersheds and evolutionary developments. Which DBA developed first (lower or higher SOSs), and which one predates the other is a significant research question. Yet, we presuppose that lower-SOSs subbasins contain greater choice to flow sinisterly or dextrally, one should think that channel development is reliant on numerous factors, like sub-surface lithologies, slope variations and channel release (essentially the factors scheming the stream power). Steep slopes in a lower-SOSs case can endorse quick topographic development in lower-SOSs, but water release (smaller in lower-SOSs) might have a reverse influence. It is also quite probable that higher-SOSs DBA reveals the governing long-lasting development for ADSW region and lower-SOSs in east direction DBA is because of a more current phase-of-ground-tilting (PGT). Subsequently, when higher-SOSs flow sinisterly or dextrally and re-form its subbasin, it would generate terraced features and detain new vicinities as upward-dip of watershed summit drifts. If higher-SOSs DBA is at youthful stage, then the DBA of lower-SOSs will absent in the new regions. Our comparison of western, central and eastern subbasins shows that homogeneous and non-homogenous asymmetries in the ADWS are due to a neotectonic tilting phase. The eastwards ground tilting in ADSW may be influenced by NW–SE trending MKT and the NNE-SSW MMT features influencing the Indus and Astore Rivers. It is noteworthy bearing that shows the displacements of series of crustal ripples as described by (Mahmood and Gloaguen, 2011). One of these NNE–SSW displacements coincides with the Astore River, which is related to numerous anomalies in our geomorphometric investigation. Its route, most likely neotectonically controlled, having a milder crisscross spatial pattern alternating between NNE and SSW directed and aligned with MMT. Finally the rose and polar plots for the 5^{th}-SOSs subbasins were Matlab generated to see the orientations and positions of their spatial locations in various quadrants. The Western ADSW region (a) shows moderate to low surface deformation in the context of ground and subbasin tilting as the 5^{th}-SOS are being tectonically controlled by the NNE-SSW propagation of the MMT, its active splays and DBA (Figures 1, 2 , 6 and 7). This impact is also because of the major uplifting and thrusting of Nanga Parbat Zone (NPZ) feature in the Eastern ADSW region. The central ADSW region (b) shows moderate deformation comprising of

Deosai pleateau which has higher margins towards the Harmaosh massif zone (HMZ) in the North, Skardu Basin in the NE and Astore in the NW with milder inclination towards the Kargil-Batalik -Dras (KBD) sections in the SE directions as indicated by the rose vectors in the combined rose plot (d) due to the overall tilt of the Deosai pleateau in a NW-SE along the Bara Pani river. The Polar plots for the Western (a), central (b), Eastern (c) and ADSW region (d) showing displacements of 23 subbasins and their spatial locations and orientations, Magnitude at Center = 0 and 1 at margin of the polar plot. The presence of DBA data in first and fourth quadrant (Figure 8) is an evidence that the Deosai Plateau is showing ground tilting towards NE (Sakardu basin) and SE towards KBD sections due to the relatively more uplift and steepness from the NPZ and HMZ as compared to Eastern and SE KBD sections.

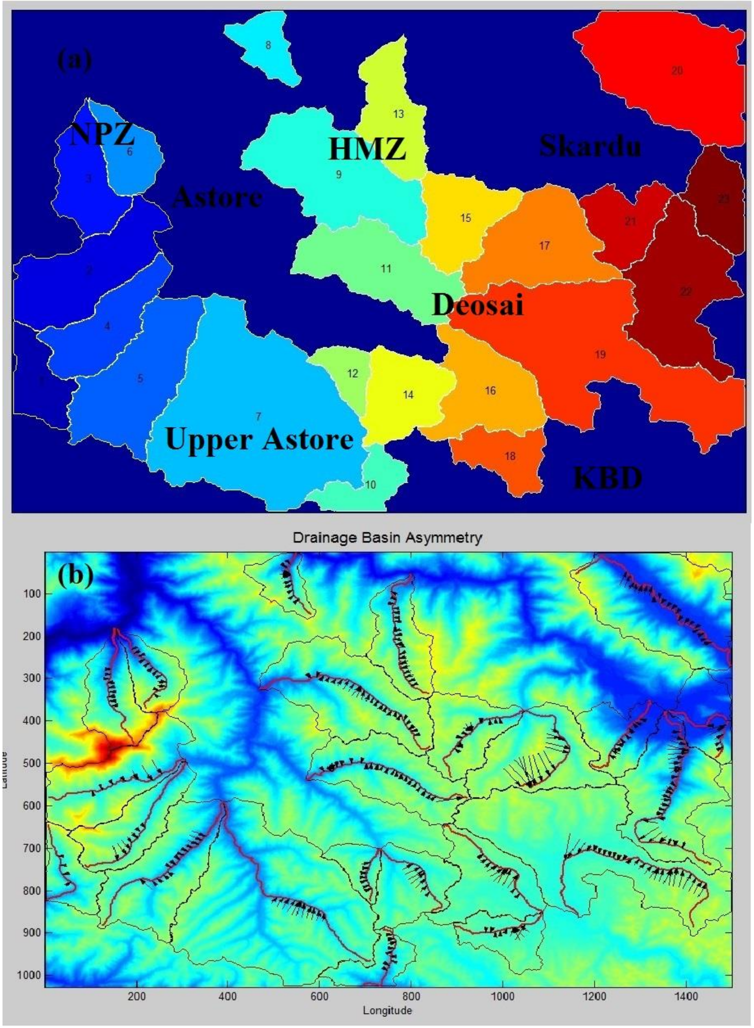

Figure 6. Higher-SOS (5th order) DBA referenced to the primary stream network of the investigation region.

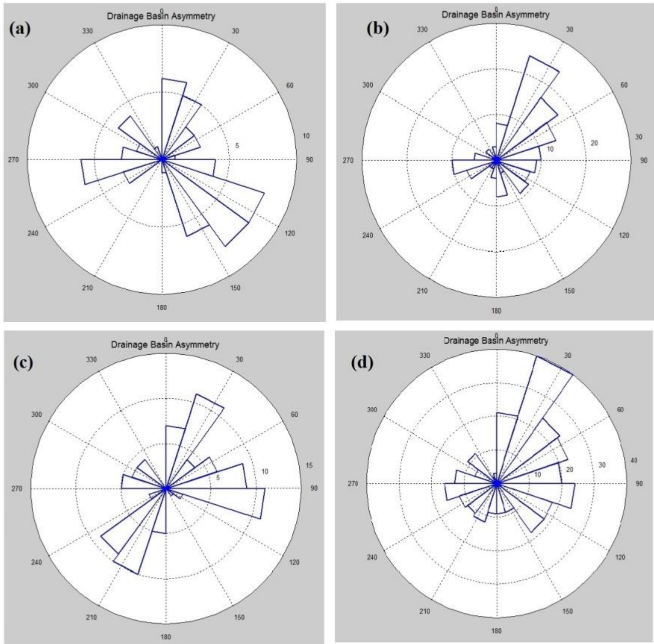

Figure 7. Rose plots for Western (a), central (b), Eastern (c) and ADSW region (d) showing displacements of 23 subbasins and their spatial locations and orientations.

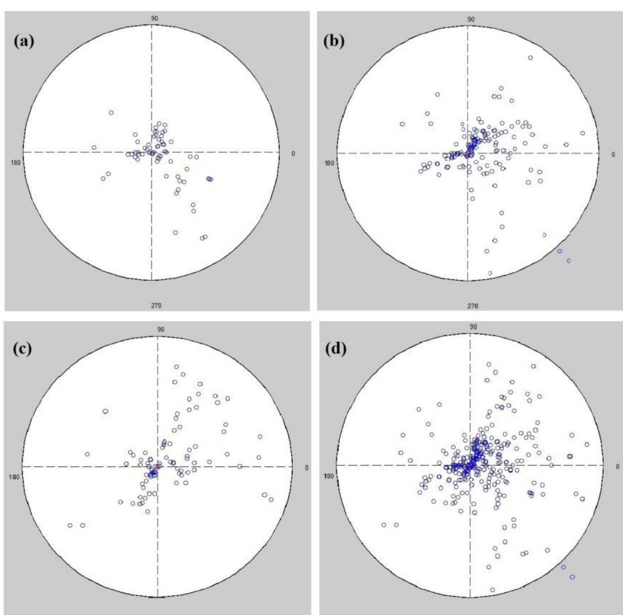

Figure 8. Polar plots for Western (a), central (b), Eastern (c) and ADSW region (d) showing displacements of 23 subbasins and their spatial locations and orientations, Magnitude at Center = 0 and 1 at margin of the polar plot.

Geospatial channel follow the basic fractalizing character, stay constant and are alienated by diverse fractal technique, i.e, F_{dim}, $D_{lac,}$ D_{suc} (Figure 9a) Low F_{dim}-values in ADSW region suggest the neotectonic processes on the topographic evolution of ADSW (Mahmood and Gloaguen, 2011). F_{dim} map yields that greater part ADSW region is describe by low-to-lowest F_{dim}-values that demonstrate that ADSW region as high-to-medium in ruggedness and local tectonics are conniving regional channel network. High F_{dim}- values are found in the NE of Skardu as the channel exhibit non-linear fashion because of steady glaciers and permanently snow packed regions. Higher F_{dim}- values are indicative the dendiritic stream patterns under the influence of glacial processes lower tendency to surface deformation. SW of upper Astore valley, snow deposits, glaciers and dendiritic geometry exists and is represented by Higher F_{dim}- values. The regions with similar F_{dim}- values can be discriminate based on their behaviour in terms of their translational invariance (TIB). For this reason, we utilize D_{Lac} that distinguishes zones with F_{dim}- values neotectonic control. High D_{Lac}-values are found NNE of ADSW (Figure 9b) and decipher tectonic signals which means high variations from TIB of the textural channels. Divergence from TIB regarding channel geometry for assorted regions demonstrates that they are under the geological influence temporally (Mahmood et al., 2008, 2009 and 2011). When channel network exhibits the correspondent style of bridging gaps among the network and TIB, then D_{suc} computes the possibility of orientation and percolation of stream geometries and explain to their additional classifications. Justification of D_{suc}-map to categorize relative vulnerability to active deformation in regions with same F_{dim} and D_{Lac} values. In our case, it is the direction of the channel textures. Locations of F_{dim}-D_{Lac}-D_{suc} values for ADSW region are steady with the regional active structures and their bearings. For instance, NNE-SSW orientated Sassi-Raikot-fault zone (SRFZ) with low and high-D_{suc}-values summarize a predictable boundary of SRFZ (Figure 9c). The low D_{suc}- values correspond to lesser deformed regions and vice versa.

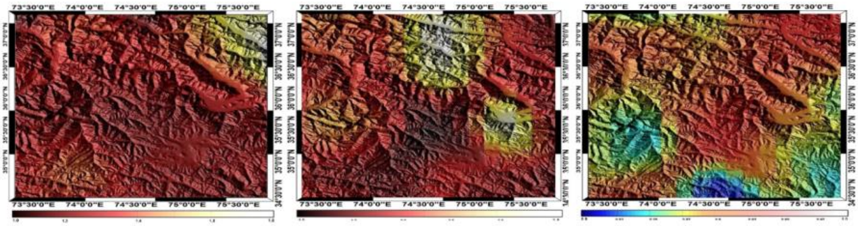

Figure 9. Distribution of F_{dim}-map of the ADSW region, (a). The low values of F_{dim} correspond to highly deformed areas. D_{Lac}-distribution map of the study area where high D_{Lac}-values stand for the regions with high susceptibility of surface deformation (b). D_{suc} distribution map with high values highlighting the severely deformed regions. The low values of D_{suc} indicate less deformed regions (c).

Conclusion

Regional investigation of T_{factor} is a invaluable mechanism to identify potential active tectonic elements, it is prudent to vigilantly review all indicators of neotectonism at the plate margins. We recommend that the MKT and MMT in

ADSW region are compliant of important portion of thrusting in the NW near NPZ, in middle as Deosai Plateau and in north as HMZ. T_{factor} permits characterization of favored orientations and directions of sinistral/dextral channel relocation, which might be a result of either by neotectonism, lithologies (dip azimuth or dip) relative uplifts or subsidence. While interpreting, the mean location of main rivers or big channels would be managed alongside morphostructural controlled zones in a NW, NNE, NE direction of the ADSW. Eastward-trending channels in ADSW will crisscross and detain the previous streams arriving from the central ADSW when entrenchment progresses, supporting channel relative relief influenced by the SSE tilt block tectonics, in this case, the KBD region. 3-fractal examinations (F_{dim}-D_{lac}-D_{suc}) are significant to guess the relative allocations of topographic severe deformation (TSD). The channels in ADSW reveal parallel, dendritic ,disconnected patterns that are indicate recent neotectonism in ADSW region. The ADSW region evolving and being uplifted due to shift of rotation of Indo-Pak continental plate against Eurasia (from clockwise anti-clockwise direction). ADSW region represents the most highest ever uplift-rates recorded over NPZ and is facing TSD.

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