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Neotectonic activity in Quetta-Ziarat region, northwest Quetta City, Pakistan

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Abstract: Geomorphic parameters are very helpful as they can quickly explain the concerned area, which is going through a tectonic adjustment. For this purpose, four indices were applied to examine the active tectonics in the Quetta-Ziarat region. These indices include: sub-basins asymmetry (Af), transverse topography (T-Factor), hypsometric integral (HI) and stream-length gradient (SL). The calculation of the three indices as denoted by Af, HI and SL show low active tectonics, whereas T-Factor suggests moderate to high level of tectonic activity. While index of active tectonics (IAT) indicated a low to moderate level of active tectonics. In addition, these indices are compared with lithological and climatic consequences to detect the final neotectonics judgement.

Keywords: Neotectonics, asymmetry factor, T-factor, hypsometry, stream-length gradient.

Introduction

In the active tectonic evaluation, geomorphic parameters are very helpful since they may quickly explain the concerned area that is going through a tectonic adjustment (Keller, 1986). To regulate the level of tectonic activities, geomorphologic parameters are used. Geomorphic indices identify drainage basins variances brought by localized tectonic processes such as uplift (Hamdouni_et al, 2008). Application of geomorphologic indicators aids in gathering crucial data in regions where active tectonics are causing deformation. It provides an explanation for how a specific landscape evolve (Bull and McFadden, 1977; Keller and Pinter, 2002 and Zovoili et al. 2004). The drainage pattern is impacted by tectonic processes including folding and faulting, which also cause asymmetries in the catchment and phenomena like faster river incision and river diversions (Cox, 1994; Jackson, et al. 1998 and Pérez-Peña, et al. 2010). To evaluate topography, drainage patterns, and geomorphic features, one can use recent tectonic activity (Azor, et al. 2002; Keller, et al. 2000 and Pérez-Peña, et al. 2010). In these investigations, DEM, aerial photos, and topographic maps can be used to obtain evaluation-related data. Present study is an attempt to investigate the neotectonics activities in the Quetta-Ziarat region by means of geomorphic parameters.

The geological map is acquired by the Geological Survey of Pakistan published by Kazmi and Rana in 1982 and re-examined for this study (Fig. 1). The drainage basin covers an area of about 2040 km^2. The forty-year annual rainfall of the research zone ranges from 0.11 mm to 1.90 mm with average of 0.56 mm (Fig.1). Five major units fall in the study area i.e., post-orogenic, orogenic and pre-orogenic.

The post-orogenic units comprise unfolded sedimentary covers. These are composed of sedimentary deltaic, lacustrine, aeolian and alluvial coverings. They have not been altered tectonically. In the research region, they form valley fill. The age of these units ranges from Upper Pleistocene to Recent (Bakr and Jackson, 1964; Hunting Survey Corporation, 1960 and Kazmi and Rana, 1982). Late Himalayan orogenic units fall in fold belt. Continental deposits that were laid down on tilted and eroded lower Miocene or earlier rocks are among the formations. In early Pleistocene, the folding and faulting of the rocks occurred. These rocks have an age of Miocene to Pleistocene (Bakr and Jackson, 1964; Hunting Survey Corporation 1960 and Kazmi and Rana, 1982). The middle Himalayan orogenic units (fold belts) are lateritic and conglomeratic beds at the base which be continental to shallow marine sedimentary rocks. They have gypsum and coal in the formations. The rocks deposited atop Palaeocene that have been tilted or degraded. Early to Mid-Oligocene uplift partially raised these rocks, and succeeding orogenic stages severely impacted these rocks. They denote an age ranging from Middle Eocene to Lower Oligocene (Bakr and Jackson, 1964; Hunting Survey Corporation 1960 and Kazmi and Rana, 1982). The early Himalayan orogenic units of sedimentary deposits range from shallow marine to continental. They settled on Mid-Jurassic rocks that were inclined and degraded. early Palaeocene and mid-Eocene Eras are regarded as some of their uplift. Throughout the Early to Mid-Oligocene, they were initially folded and faulted. The age range of these units is Upper Jurassic to Lower Eocene (Bakr and Jackson, 1964; Hunting Survey Corporation 1960 and Kazmi and Rana, 1982). The Jurassic to Eocene include sedimentary rocks from the continental shallow marine. Occasionally interspersed with coloured mélange and volcanic rocks of Cretaceous. They have substantial ophiolite blocks in them, which were partially uplifted during the late Cretaceous in the form of a small volcanic island, and then during the late Palaeocene or early Eocene, the area was thrust, obducted, and ophiolites were deposited. Throughout the late orogenic stages, they have further distorted (Bakr and Jackson, 1964; Hunting Survey Corporation 1960, and Kazmi and Rana, 1982). The Pre-orogenic units of sedimentary rocks range from marine to continental. They first rose around the middle to late Jurassic.

Throughout several phases of the Himalayan orogeny, they were folded and faulted. They show an age ranging from Permian to mid-Jurassic units (Bakr, Jackson, 1964; Hunting Survey Corporation 1960) and Kazmi and Rana, 1982).

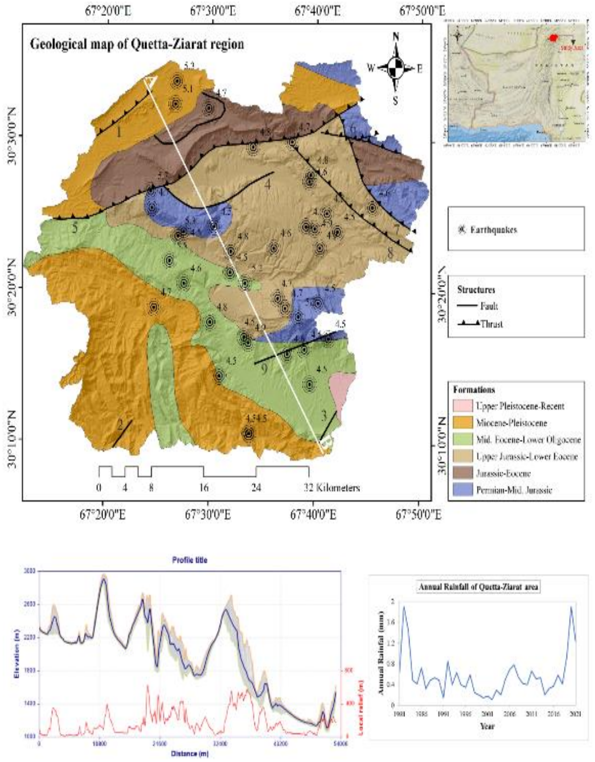

Fig. 1. Demonstrating the geology with cross-sectional Swat-profile of Quetta-Ziarat region. The numbers denote faults: 1. Sarian-Saran Tangi 2. Johan 3. Mushkaf 4. Bibai 5. Gogai 6. Malik Salar 7. Mana 8. Ziarat and 9. Khalifat

Materials and Methods

Using a DEM with a 30m resolution, the area's geological characteristics have been meticulously mapped and digitalized. According to Strahler's stream order system, the drainage basins are categorized as 3rd, 4th, 5th, and 6th order (Strahler, 1952). The stream orders overlain on hillshade map is shown in Figure 2. The geomorphologic parameters used in this study are, Asymmetry (Af), Transverse topography (T-Factor), Hypsometric integral (HI) and Stream length gradient index (SL). ArcGIS v.10.5 and Matlab functions were applied to extract these parameters. Af indices were calculated manually by sketching the right trunk of the main streams of the sub-watersheds in ArcGIS environment. T-Factor and HI were acquired using Matlab scripts. Whereas, the stream length-gradient indices were achieved by SLiX (an ArcGIS extension toolbox).

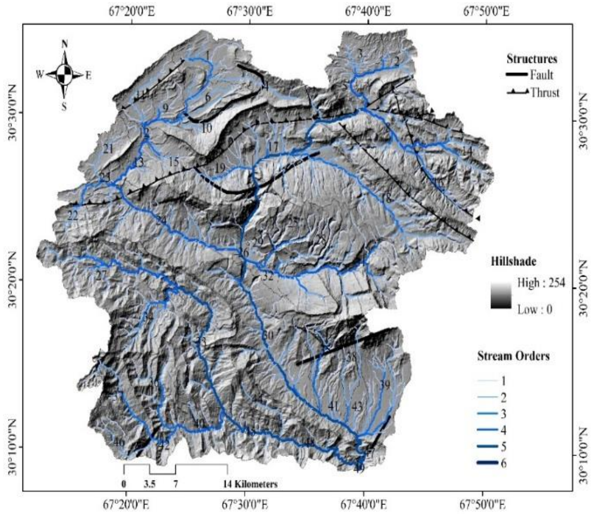

Fig. 2. The hillshade map of the study area overlain by stream orders.

Asymmetric factor (Af) is utilized in detecting tectonic tilting. The parameters are on a drainage basin scale. Additionally, it is useful to a sizable region (el Hamdouni et al. 2008; Hare Paul and Gardner Thomas, 1985, and Keller and Pinter, 2002). It is calculated by;

$$Af = \left(\frac{Ar}{At}\right) \times 100$$

Ar: the portion of the basin to the right of the main stream (looking downstream).
At: the drainage basin's entire area.

The range to find the active tectonics is <35 to > 65 for high tectonic activities (Class 1), 57 to < 65 or 35 to < 43 for moderate tectonic activities (Class 2) and 43 to < 57 for low tectonic activities (Class 3).

The method used to determine the transverse topography (T-Factor) is;

$$T = Da/Dd$$

Dd: the distance from the midline to the basin limit.
Da is the distance between the drainage basin's midline and the active belt's midline.

(Cox, 1994) referred that T = 0 in a basin that is perfectly symmetrical, and T approaches the value of 1.0 as asymmetry rises. Furthermore, *T-Factor* is assigned with three classes to distinguish the tectonic activities. Class 1 ranges from > 0.40, Class 2 ranges 0.20 to 0.40 and Class 3 is < 0.20. (Strahler, 1952) first used the Hi index to designate a certain area or landscape's elevation. The Hi index was computed using the following formulae (Mayer, 1990; Pike and Wilson, 1971).

$$HI = (Hmean - Hmin)/(Hmax - Hmin)$$

The HI is assigned with 3 classes as; >0.50, 0.40 to 0.50 and <0.40 for Class 1, 2 and 3 respectively.

The SL parameter can be applied to detect any variations in longitudinal profile of channel that is caused by local lithology, neotectonic activities, or climate variations (Hack, 1973). Hack (1973) outlined the definition as;

$$SL = \left(\frac{\Delta H}{\Delta L}\right) \times L$$

ΔH/ΔL: the slope of channel slope.
ΔH: the change in elevation.
ΔL: the reach's length.
L: the length from the reach's mid-points to the divide.

The SL is categorized into >600, >500 to < 600 and < 500 for Class 1, 2 and 3 respectively.

Numerous indicators were employed in earlier studies quantify the level of neotectonic activities such as valley floor and mountain front sinuosity. Among them, (Bull and Mcfadden, 1977)) and Silva et al., 2003) allocated distinct tectonic activity classifications based on these two indicators. Instead of focusing on the regional assessment of neotectonics activities, these methodologies concentrated on the active tectonic analysis in mountainous regions (el Hamdouni, et al. 2008). By averaging the several classes of geomorphological indexes, (el Hamdouni, et al., 2008) created IAT (Index of Active Tectonics) to examine neotectonics activities. The range of IAT neotectonics activities are shown in Table 1.

Table 1. The representative ranges of IAT index to quantify the neotectonics activities.

Class	Range	Intensity
1	1.0 <1.5	extremely high
2	≥1.5 - <2.0	High
3	≥2.0 - <2.5	Moderate
4	≥2.5 – 3.0	Low

Results and Discussion

Af of the sub-drainage basin showed almost equally classed. The Class 1 of the drainage basin is 32.65% with 16 out of 49 sub-basins. Class 2 resembled 28.57% with 14 sub-basins and 38.78% with 19 sub-basins belonged to Class 3 (Table 2; Fig. 3A). The classified results show low to high tectonic activities in the Quetta-Ziarat section.

Table 2. Table expressing the calculated four parameters with their classes are Quetta-Ziarat region.

Basin	AF	Class	T Factor	Class	HI	Class	SL	Class	Σc	Σc/N	IAT
1	66.11	1	0.46	1	0.21	3	138.18	3	8	2.00	3
2	64.29	2	0.38	2	0.35	3	355.40	3	10	2.50	4
3	89.13	1	0.71	1	0.28	3	123.29	3	8	2.00	3
4	57.24	2	0.24	2	0.38	3	247.41	3	10	2.50	4
5	48.12	3	0.28	2	0.23	3	181.37	3	11	2.75	4
6	48.15	3	0.20	2	0.27	3	191.44	3	11	2.75	4
7	65.52	1	0.12	3	0.36	3	399.75	3	10	2.50	4
8	36.34	2	0.57	1	0.43	2	307.96	3	8	2.00	3
9	41.19	2	0.26	2	0.23	3	170.31	3	10	2.50	4
10	29.22	1	0.32	2	0.43	2	270.48	3	8	2.00	3
11	49.86	3	0.36	2	0.33	3	224.45	3	11	2.75	4
12	35.81	2	0.37	2	0.17	3	131.00	3	10	2.50	4
13	46.70	3	0.44	1	0.22	3	150.46	3	10	2.50	4
14	68.83	1	0.26	2	0.38	3	247.59	3	9	2.25	3
15	61.30	2	0.46	1	0.36	3	258.88	3	9	2.25	3
16	49.12	3	0.21	2	0.40	2	245.82	3	10	2.50	4
17	78.14	1	0.24	2	0.31	3	388.39	3	9	2.25	3
18	52.48	3	0.38	2	0.52	1	410.69	3	9	2.25	3
19	46.62	3	0.13	3	0.37	3	289.41	3	12	3.00	4
20	69.74	1	0.54	1	0.51	1	636.36	1	4	1.00	1
21	55.53	3	0.32	2	0.20	3	167.77	3	11	2.75	4
22	52.49	3	0.61	1	0.32	3	233.33	3	10	2.50	4
23	45.68	3	0.67	1	0.24	3	-	-	7	2.33	3
24	45.27	3	0.28	2	0.33	3	358.96	3	11	2.75	4
25	77.39	1	0.77	1	0.60	1	728.87	1	4	1.00	1
26	76.30	1	0.98	1	0.21	3	-	-	5	1.67	2
27	55.70	3	0.14	3	0.34	3	431.34	3	12	3.00	4
28	73.98	1	0.62	1	0.55	1	790.58	1	4	1.00	1
29	40.73	2	0.30	2	0.27	3	1080.55	1	8	2.00	3
30	49.24	3	0.15	3	0.28	3	327.46	3	12	3.00	4
31	26.81	1	0.41	1	0.47	2	853.53	1	5	1.25	1
32	35.33	2	0.56	1	0.40	2	623.98	1	6	1.50	2
33	50.49	3	0.23	2	0.51	1	503.65	2	8	2.00	3
34	50.61	3	0.25	2	0.28	3	358.45	3	11	2.75	4
35	43.07	3	0.49	1	0.33	3	489.01	3	10	2.50	4
36	42.09	2	0.30	2	0.42	2	364.21	3	9	2.25	3
37	59.67	2	0.25	2	0.45	2	818.62	1	7	1.75	2
38	76.11	1	0.53	1	0.34	3	471.44	3	8	2.00	3
39	60.06	2	0.52	1	0.18	3	269.29	3	9	2.25	3
40	45.26	3	0.65	1	0.36	3	310.12	3	10	2.50	4
41	48.23	3	0.18	3	0.25	3	126.43	3	12	3.00	4
42	76.61	1	0.54	1	0.35	3	150.94	3	8	2.00	3
43	67.30	1	0.37	2	0.28	3	207.92	3	9	2.25	3
44	34.14	1	0.47	1	0.39	3	440.88	3	8	2.00	3
45	61.48	2	0.45	1	0.34	3	338.67	3	9	2.25	3
46	44.40	3	0.18	3	0.54	1	990.73	1	8	2.00	3
47	29.71	1	0.28	2	0.34	3	181.12	3	9	2.25	2
48	42.11	2	0.15	3	0.28	3	250.40	3	11	2.75	4
49	36.36	2	-	-	0.38	3	-	-	5	2.50	4
Mean	**53.18**	**2.06**	**0.39**	**1.73**	**0.35**	**2.61**	**374.72**	**2.63**	**8.84**	**2.26**	**3.20**
Maximum	89.13	3	0.98	3	0.60	3	1080.55	3	12	3	4
Minimum	26.81	1	0.12	1	0.17	1	123.29	1	4	1	1

The T-Factor was analysed within 48 out of 49 sub-basins and were divided into three above said classes. Where, 41.67% belong to Class 1, 43.75% belong to Class 2 and 14.58% belong to Class 3 (Table 2; Fig. 3B). The results denote a moderate to high tectonic stage in the Quetta-Ziarat section.

The calculated 49 sub-basins were examined and their HI values were categorized into three classes.12.24%

belong to Class 1, 14.29% belong to Class 2 and 73.47% belong to Class 3 (Table 2; Fig. 3C). The HI results indicate low to moderate active tectonics in the area.

The SL 46 out of 49 sub-basins were calculated. The examined results were categorized accordingly as; 17.39%, 2.17% and 80.44% for Class 1, 2 and 3, respectively (Table 2; Fig. 3D). These results indicate low tectonic activities in the area.

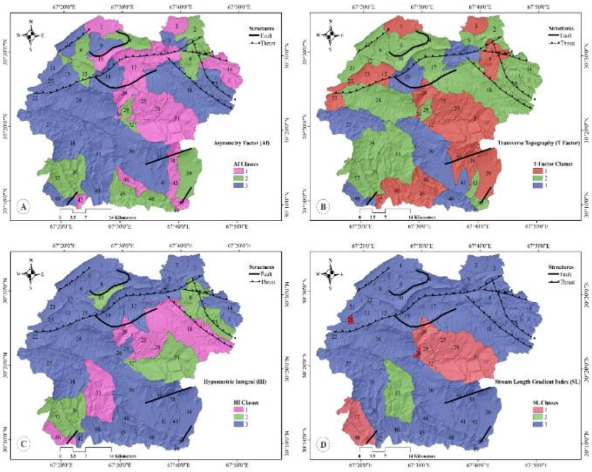

Fig. 3. Maps showing the calculated four geomorphologic parameters. (A) Asymmetry Factor, (B) T-Factor, (C) Hypsometry and (D) Stream-Length Gradient.

The IAT index of (el Hamdouni, et al. 2008) was applied by summarizing the four calculated parameters. The summarized results of IAT were according to above said classes to detect the level of neotectonic activities (Table 2; Fig. 4). Among them, Class 1 comprises 8.16% occupancy, Class 2 with 8.16% occupancy, Class 3 with 38.78% occupancy and Class 4 with 44.90% occupancy. These results summarized a Class 4 to Class 3 range i.e., low to moderate level of tectonic activities.

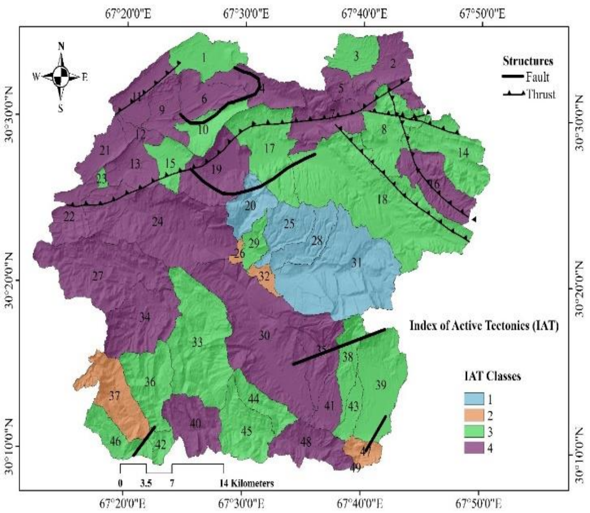

Fig. 4. Expressing the summarized four IAT classes of the Quetta-Ziarat region.

The geomorphologic indication adds additional proof and measure of neotectonic activity to the fragments of evidence indicating the region's tectonic activity. The area possesses erodible lithology, a very low annual precipitation range (0.11-1.90 mm), and a tropical climate. It might not be the cause of some indicators that show the region to be less tectonically active. However, occasionally floods are caused by this lower rainfall range. Increased erosion is a result of such lithology and climatic circumstances. The result may be impacted by the higher erosion rate since it may partially erase tectonic activity evidence. The obvious tectonic traces are obscured by circumstances like excessive precipitation, flooding, and weak lithology, which also affected the geomorphic indices result.

Identification of the tilting direction is aided by the Af and T-Factor indices. The Af and T-Factor analyses point to the area's activity. Because of the research area's comparatively strong uplift, tilting values are significantly greater and the T-Factor is frequently medium to high asymmetry (>0.20-0.40 and >0.40), it can be said that the majority of sub-basins are almost asymmetric. However, the majority of the basins' Bs are round (Supplementary: S1). Because of the channel's strong headward erosion caused by lithology or climatic dependencies, the basins exhibit circular properties. Since many of the deposits with examined area are shale, marl, or weaker sedimentary materials, lithology is to blame for the lowest SL ratios. Because volcanics are so exposed within some limited regions, the presence of rocks like basalt, andesite, rhyolite, and tuff has an impact on the increasing trend of the SL index in Jurassic to Eocene rocks (Fig. 1). The HI values are comparable to those of the SL index due to similar active tectonics and other lithological conditions (Fig. 1).

One of the best methods for identifying an area of uplift or subsidence in a basin is to use the HI and SL indices. These uplifted/subsided positions denote tectonic movement or lithological interaction. The study's cluster of HI and SL points indicates less neotectonic activities as an average in the area. The IAT is calculated using all measured geomorphic indices (IAT). The area is classified as moderately to highly active according to IAT's computation, which includes T-Factor and Af. But classify the location into a less active class when all the parameters are taken into account. Although the IAT results indicate that the region has less tectonic activity, there are several pieces of data and signatures that support the region's tectonic activity such as faulting and frequent earthquake occurrences.

Conclusion

The geomorphological indices helped concluding that, range of Af indicated almost an equal division of classes but an increasing level of low active tectonics.

The T-factor suggested an active tectonic level of moderate to high.The HI expressed a range of low to moderate level of tectonic activities.The SL index showed a low active tectonic class in the area.The summarized IAT index quantifies a level of low to moderate level of tectonic activities.

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