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Neotectonics of Kashaf Rud River, NE Iran by Modified Index of Active Tectonics (MIAT)

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Abstract

Kashaf rud river is located in border zone of East Alborz and Kopet Dagh physiographic provinces in the north east Iran. Geomorphic indices are useful tools to show the neotectonic regimes. These indices have got the advantage of being calculated from Arc GIS and remote sensing packages over large area as a useful tool to identify geomorphic anomalies possibly related to active tectonics. In this research, seven geomorphic indices (stream-gradient index, valley floor width-valley height ratio, mountain-front sinuosity, drainage basin asymmetry, hypsometric integral, drainage basin shape and transverse topographic symmetry factor) were calculated along the Kashaf rud river. Then, based on a new index or modified index of active tectonics (Miat) values that calculated by average of seven geomorphic indices, relative tectonic activities levels were revealed. The low class of Miat is mainly in the sub-basins of No. 6, 10, 13, 14, 21, 22, 23, 24 & 28 while the rest of the study area has moderate tectonic activities in the other sub-basins. Our results show that the moderate value has located along faulted area, which shows 2 class of relative tectonic activity. These faults have been formed above an old suture zone between Cimmerian and Eurasian plates.

Keywords

1. Introduction

The study area is around of Mashhad city in the border zone of East Alborz and Kopet Dagh physiographic provinces in the north east Iran (**Figure 1**). Dominant structural trend in East Alborz province is NW-SE in eastern part. From tectonics view, it contains Binalod magmatic arc and its fore arc basin with volcanic activities

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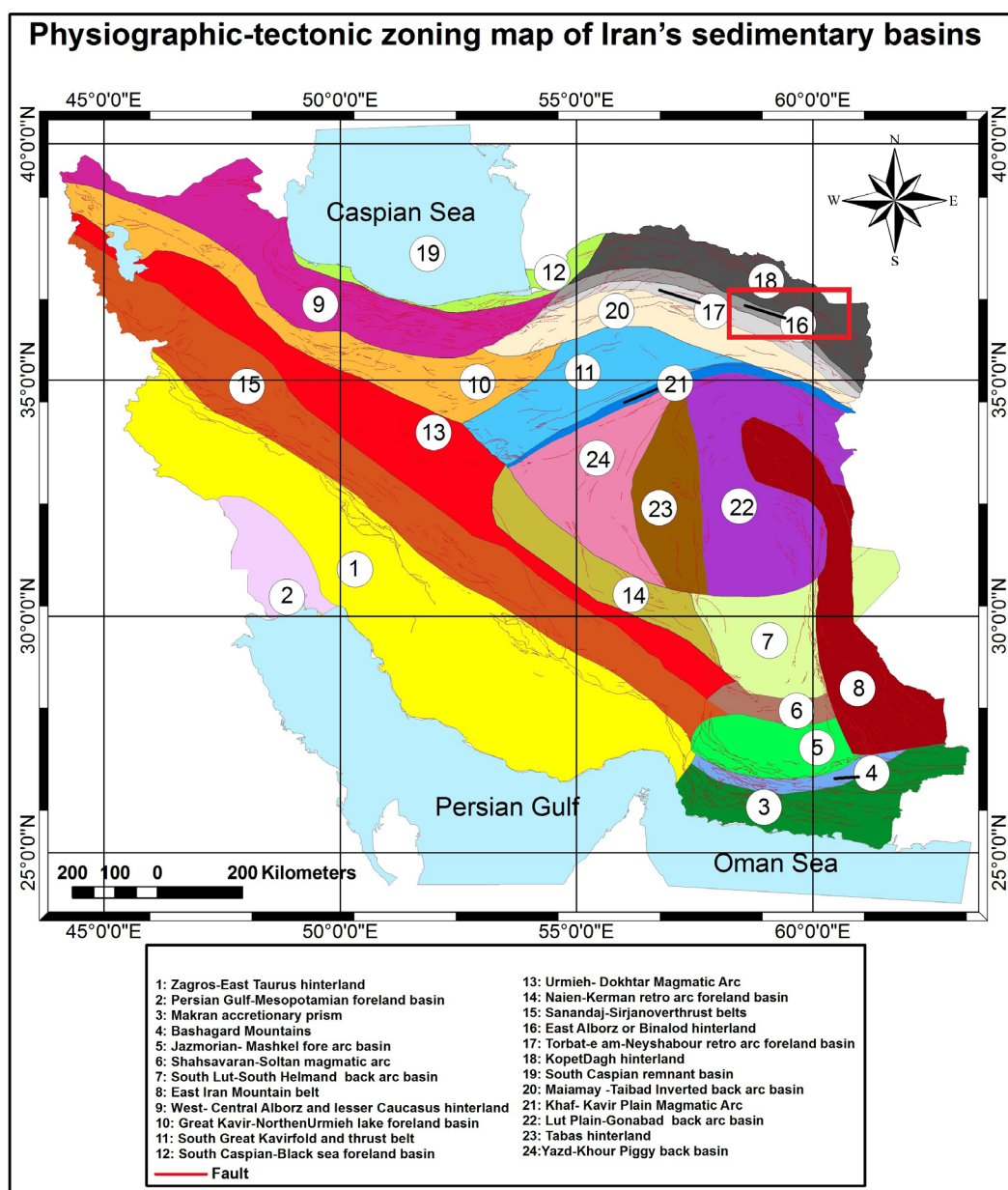**Physiographic-tectonic zoning map of Iran's sedimentary basins**

Figure 1. Physiographic-tectonic zoning map of Iran's sedimentary basins, modified from [1]. The study area is shown in the red rectangle.

(especially in Silurian) on northeastern of Cimmerian miniplate. Obduction of Mashhad ophiolite during late Paleozoic has been the result of subduction into beneath this province.

Dominant structural trend in Kopet Dagh province is NW-SE. From tectonics view, it contains the Kopet Dagh hinterland or Kopet Dagh fold and thrust belt that are formed in passive margin of Eurasian plate until late Triassic and then marine sedimentation on Kopet Dagh proforeland basin has continued to Eocene. Kopet Dagh hinterland has uplifted related to Karakorum foreland basin in northeast along Eshghabad fault [1]-[3]. In this research, area is divided into 28 sub-basins and the following indices are calculated: stream-gradient index (Sl), valley floor width-valley height ratio (Vf), mountain-front sinuosity (Smf), drainage basin asymmetry (Af), hypsometric integral (Hi), drainage basin shape (Bs) and transverse topographic symmetry factor (T). We use geomorphic indices of active tectonics, which are known to be useful for assessment of relative tectonic activities. Methodology for active tectonic studies [4]-[7] has been previously tested as a valuable tool in different

tectonically active areas, namely SW USA [8] the Pacific coast of Costa Rica [9], Zagros, Iran [10], but in this research, we have used a new index as modified index of active tectonics (Miat) that calculated by average of seven geomorphic indices.

2. Materials and Methods

The calculated geomorphic indices are suitable for assessment of tectonic activity of the study area. The geomorphic indices such as: stream-gradient index (Sl), valley floor width-valley height ratio (Vf), mountain-front sinuosity (Smf), drainage basin asymmetry (Af), hypsometric integral (Hi), drainage basin shape (Bs) and transverse topographic symmetry factor (T) are calculated in Kashaf rud river by using of topographic data and DEM (**Figure 2** and **Figure 3**).
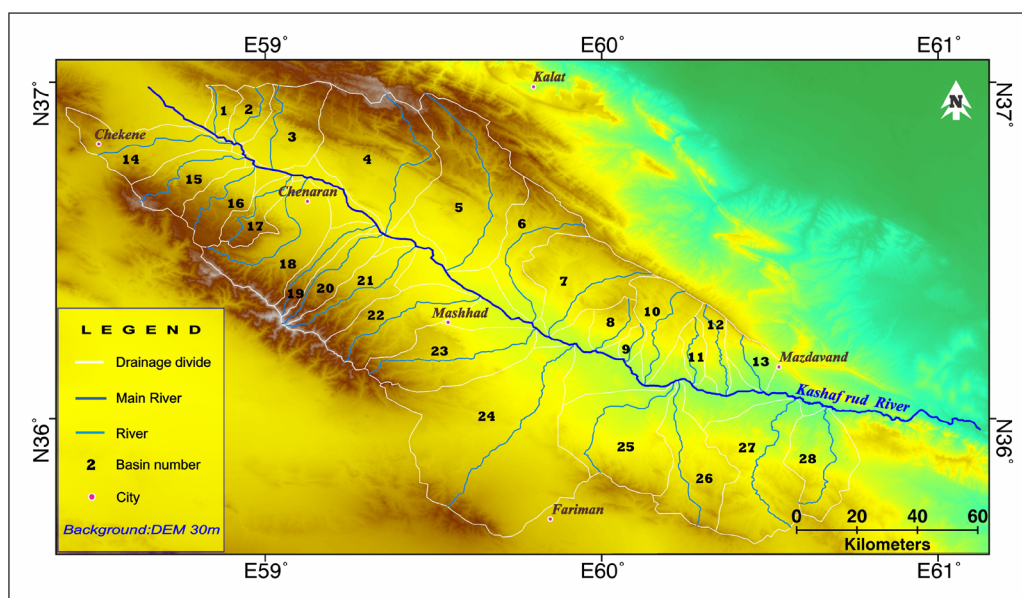

Figure 2. Digital Elevation model of the Kashaf rud river region.
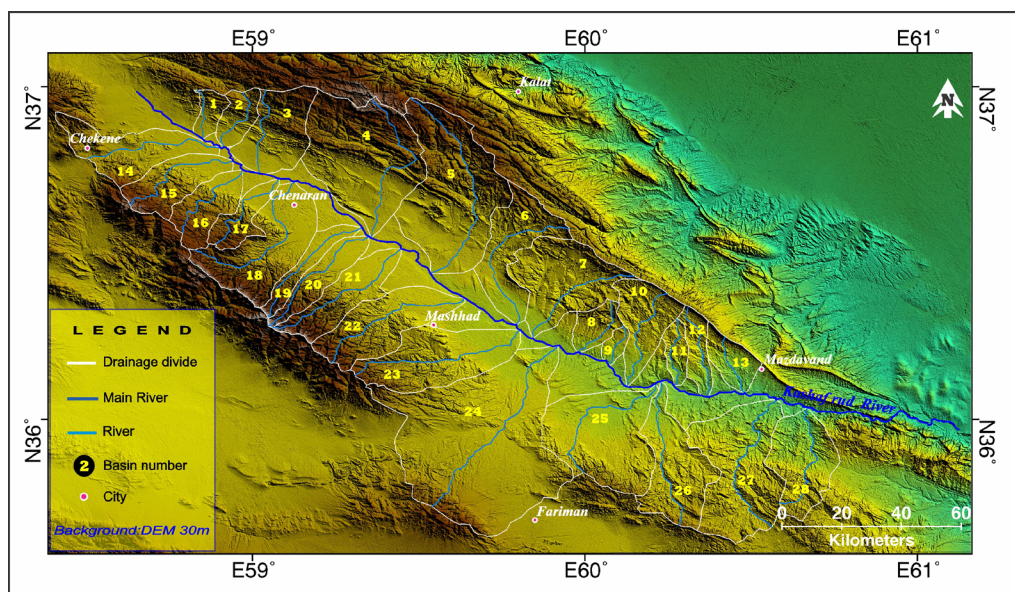

Figure 3. The relief of the Kashaf rud riverregion for identification of drainage pattern based on digital elevation model.

On the other hand, the area was divided to 28 sub-basins, and for each one, above indices were calculated, then all of the indices were combined to obtain index of active tectonics (Iat) by new method [11]. Therefore, sub-basins can be compared together. The study area is located between longitudes E58˚, 30′-61˚ and latitudes N35˚, 30′-37˚ in the Khorasan province, North East Iran. Based on previous work on the salt and mud diapirism [12]-[23] and neotectonic regime in Iran [24]-[29], Zagros in south Iran is the most active zone [30]-[47]. Then, Alborz [48]-[84] and Central Iran [85]-[100] have been situated in the next orders.

3. Results and Discussion

To study the indices, there is a formula which we turn to describe each one of indices. It is necessary to have some primary maps to calculate the indices, and the most important are: Digital Elevation Model (DEM), the drainage network and the sub-basins map of the Kashaf rud river that have been extracted from DEM (**Figure 3**). DEM extracted from a digitized topographic map (with 30 m intervals).

3.1. The Stream-Gradient Index (SL)

The rivers flowing over rocks and soils of various strengths tend to reach equilibrium with specific longitudinal profiles and hydraulic geometrics [101]-[103] defined the stream-gradient index (SL) to discuss influences of environmental variables on longitudinal stream profiles, and to test whether streams has reached equilibrium. The calculation formula is in this manner:

$$SL = (\Delta H/\Delta L) L$$

where ($\Delta H/\Delta L$) is local slope of the channel segment that is located between two contours and L is the channel length from the division to the midpoint of the channel reaches for which the index is calculated. This index is calculated along themaster streams of 28 sub-basins (**Table 1**). The SL index can be used to evaluate relative tectonic activity. An area on soft rocks with high SL values can be indicated for active tectonics. Based on our results, there are 2 and 3 classes (**Figure 4**).

3.2. Valley Floor Width-Valley Height Ratio (Vf)

Another index sensitive to tectonic uplift is the valley floor width to valley height ratio (Vf). This index can separate v-shaped valleys with small amounts from u-shaped valleys with greater amounts. The calculation formula is in this manner:
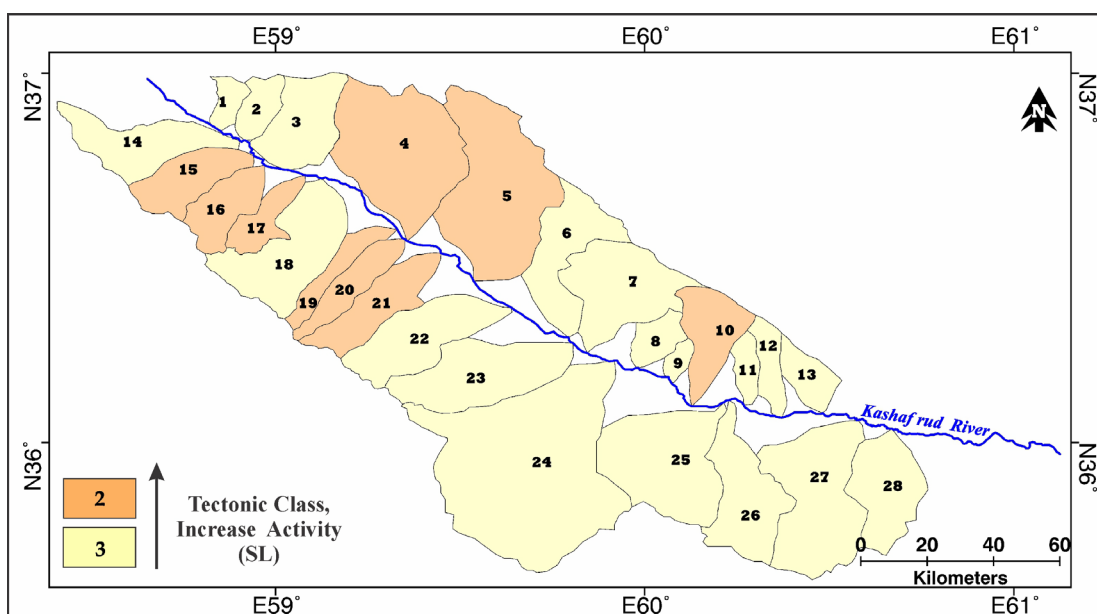

Figure 4. Classification of sub-basins based on stream length-gradient index.

Table 1. Values of stream length-gradient index for sub-basins No.1 and 28.

Stream Length-Gradient Index (SL), Length of Kashaf Rud River: More than 293.6 km					
Basin 1					
Points of Basin 1	**H (m)**	**L (m)**	**L (m)**	**SL (m)**	**Tectonic Class**	**Tectonic Class/Basin**
1, 2	50	2419	13,856	286.40	3	
2, 3	50	2545	11,447	224.89	3	
3, 4	50	1986	10,132	255.09	3	
4, 5	50	796	8958	562.69	2	
5, 6	50	1750	7799	222.83	3	
6, 7	50	377	7199	954.77	2	
7, 8	50	850	5651	332.41	3	3 (Low Activity)
8, 9	50	1914	4780	124.87	3	
9, 10	50	206	4387	1064.81	1	
10, 11	50	469	3962	422.39	3	
11, 12	50	361	1505	208.45	3	
12, 13	50	157	1230	391.72	3	
13, 14	50	1160	687	29.61	3	
Basin 28					
Points of Basin 28	**H (m)**	**L (m)**	**L (m)**	**SL (m)**	**Tectonic Class**	**Tectonic Class/Basin**
1, 2	50	5480	36,880	336.50	3	
2, 3	50	3060	33,539	548.02	2	
3, 4	50	3200	29,259	457.17	3	
4, 5	50	4615	25,915	280.77	3	
5, 6	50	2297	22,498	489.73	3	
6, 7	50	2602	19,908	382.55	3	
7, 8	50	3715	16,654	224.15	3	
8, 9	50	2134	13,634	319.45	3	
9, 10	50	2809	10,997	195.75	3	3
10, 11	50	1949	8836	226.68	3	
11, 12	50	2145	6718	156.60	3	
12, 13	50	1823	4657	127.73	3	
13, 14	50	1127	3171	140.68	3	
14, 15	50	1196	2165	90.51	3	
15, 16	50	384	1396	181.77	3	
16, 17	50	800	839	52.44	3	
17, 18	50	304	279	45.89	3	

SL classification→1 (High Activity): > 1000, 2 (Moderate Activity): 500 - 1000, 3 (Low Activity): <500

$$Vf = 2\,Vfw/(Eld + Erd - 2Esc)$$

where Vfw is the width of the valley floor, and Eld, Erd and Esc are the altitudes of the left and right divisions (looking downstream) and the stream channel, respectively [102]. [4] found significant differences in Vf be-

tween tectonically active and inactive mountain fronts. Also, they found significant differences in Vf between tectonically active and inactive mountain fronts, because a valley floor is narrowed due to rapid stream down cutting.

Vfw value is obtained by measuring the length of a line which cuts the river and limits to two sides of a contour through which the river crosses (**Table 2**). In this research, Vf values are divided into 3 classes: 1 (Vf < 0.5), 2 (0.5 < Vf < 1), and 3 (Vf > 1). Therefore, all of the valleys are in 1 class and show V-shape valleys (**Figure 5**).

3.3. Mountain-Front Sinuosity Index (Smf)

This index represents a balance between stream erosion processes tending to cut some parts of a mountain front and active vertical tectonics that tend to produce straight mountain fronts. Index of mountain front sinuosity [3] is defined by:

$$Smf = Lj/Ls$$

Table 2. Values of Vf index for sub-basins No.1 to 4.

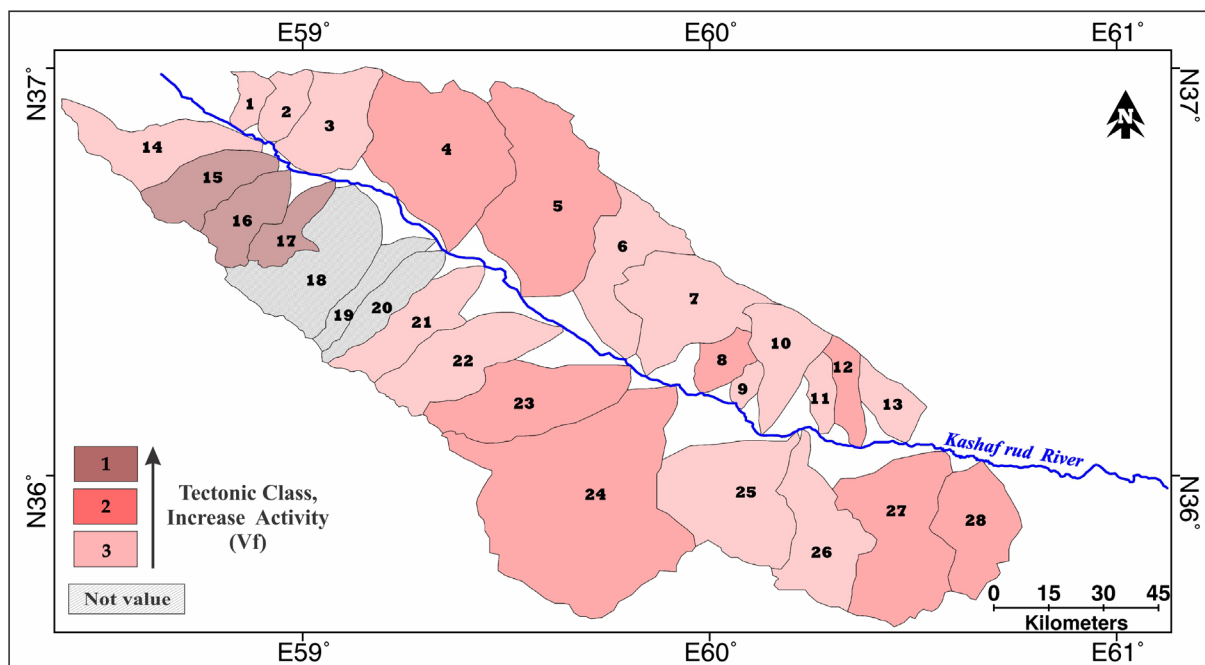| Basin	Number	V_{fw} (m)	E_{ld} (m)	E_{rd} (m)	E_{sc} (m)	V_f (m)	Tectonic CLASS	Tectonic Class/Basin
1	P1	70	1433	1410	1382	1.77	3	3 (Low Activity)
2	P1	200	1286	1281	1254	6.78	3	3
	P2	8	1236	1235	1233	3.20	3	
3	P1	80	1277	1289	1258	3.20	3	3
4	P1	20	2937	2900	2891	0.73	2	2 (Moderate Activity)
	P2	100	2781	2571	2325	0.28	1	
	P3	70	2336	2145	2155	0.82	2	
	P4	60	2513	2437	2301	0.34	1	
	P5	70	2158	2195	2005	0.41	1	
	P6	100	1601	1555	1451	0.79	2	

Figure 5. Classification map for the valley floor width to valley height ratio.

where Lj is the planimetric length of the mountain along the mountain-piedmont junction, and Ls is the straight-line length of the front. The Mountain fronts map of the study area has drawn in **Figure 6**. Smf is commonly less than 3, and approaches 1 where steep mountains rise rapidly along a fault or fold [102]. Therefore, this index can play an important role in tectonic activity. Considering that mountain fronts sites are independent from basins places, chances are some of them have various fronts (**Table 3**). Values of Smf are readily calculated from topographic maps for sub-basins. In this research, Smf values are divided into 3 classes: 1 (Smf < 1.53), 2 (1.53 < Smf < 2.3), and 3 (Smf > 2.3) and in the study area most of the obtained values are in 3 class (**Figure 7**).
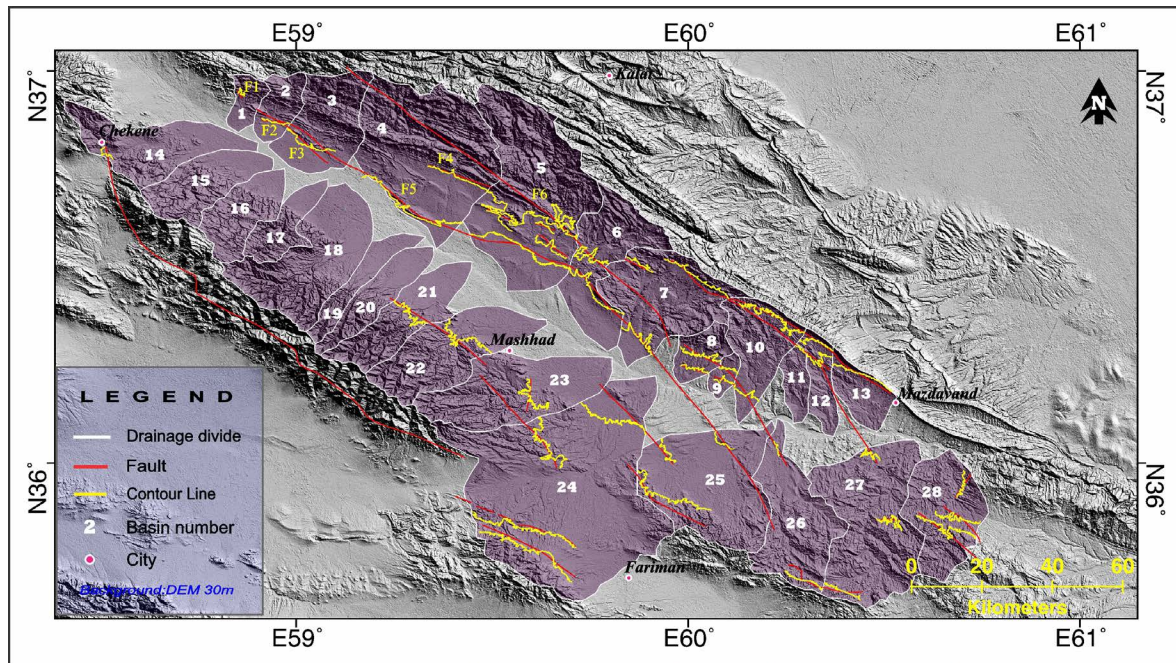

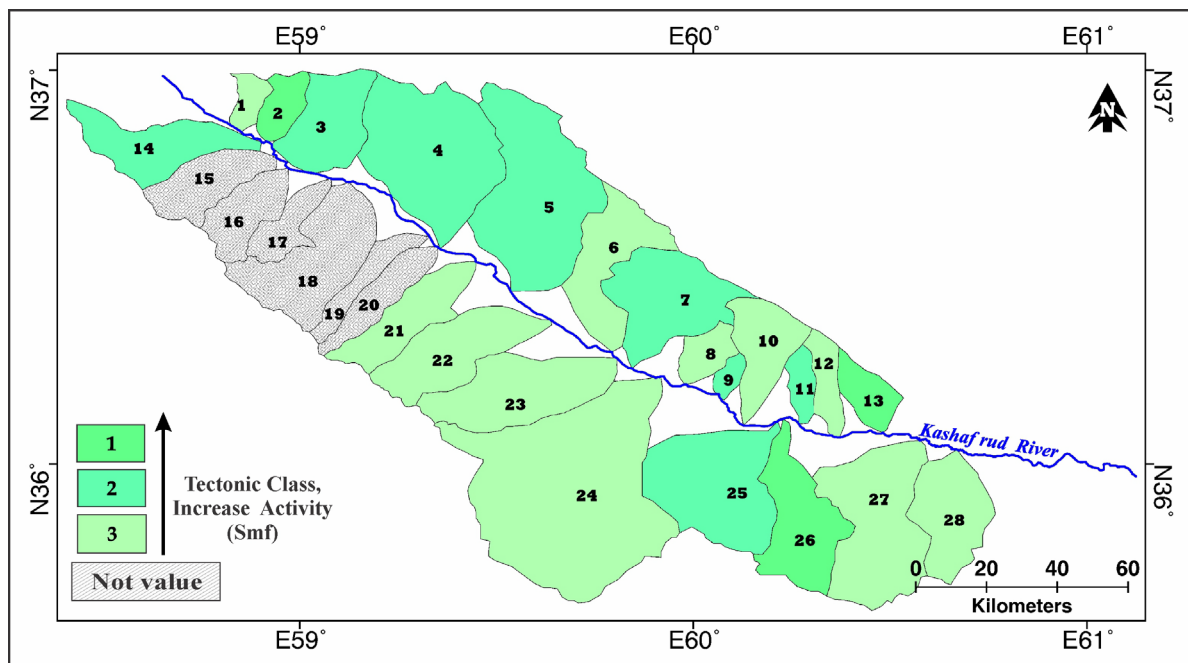**Figure 6.** Position map for Mountain-fronts of study area.

Figure 7. Classification map for Mountain-front sinuosity index.

Table 3. Values of Smf index for sub-basins No. 1 to 4.

Basin	Fault	Segment	L_{mf} (m)	L_s (m)	S_{mf}/segment	Average of S_{mf}/Basin	Tectonic class
				Mountain Front Sinuosity (Smf)			
1	F1	1 (1490 m)	6400	1626	3.94	3.94	3 (Low Activity)
2	F2	1 (1250 m)	8600	6540	1.31	1.31	1 (High Activity)
3	F3	1 (1220 m)	20,930	12,640	1.66	1.66	2 (Moderate Activity)
4	F4	1 (1330 m)	20,660	15,360	1.35	1.60	2
	F5	1 (1130 m)	48,530	26,080	1.86		

3.4. Asymmetry Factor (Af)

This index is related to two tectonics and none tectonic factors. None tectonic factors may relate to lithology and rock fabrics. It is a way to evaluate the existence of tectonic tilting at the scale of a drainage basin. The index is defined as follows:

$$Af = (Ar/At) \, 100$$

where Ar is the right side area of the master stream basin (looking downstream) and At is the total area of the basin that can be measured by GIS software. To calculate this index in the area At and Ar are obtained using the sub-basins and the master river maps. Af is close to 50 if there is no or little tilting perpendicular to the direction of the master stream. Af is significantly greater or smaller than 50 under the effects of active tectonics or strong lithologic control. The values of this index are divided into three categories. 1: (Af > 15) 2: (7 < Af < 15) and 3: (Af < 7).

Among the obtained values (**Table 4**), a map has prepared that it shows Asymmetry factor of study area (**Figure 8**).

3.5. Basin Shape Index (Bs)

Relatively young drainage basins in active tectonic areas tend to be more elongated than their normal shape to the topographic slope of a mountain. The elongated shape tends to evolve into a more circular shape [4]. The horizontal projection of the basin shape may be described by the basin shape index or the elongation ratio, Bs [7]. The calculation formula is:

$$Bs = Bl/Bw$$

where Bl is the length of the basin measured from the headwater to the mount, and Bw is basin width in the widest point of the basin.

To calculate this index in the area, Bl and Bw are obtained using the sub-basins (**Table 5**) and the master river maps then the values are divided into 3 classes. 1: (Bs > 4) 2: (3 < Bs < 4) 3: (Bs < 3), based on [11]. According to **Figure 9**, this index has calculated and the maximum value belongs to sub-basin No. 19 (Class 1 in **Figure 10**).

3.6. Hypsometric Integral Index (Hi)

The hypsometric integral (Hi) describes the relative distribution of elevation in a given area of a landscape particularly a drainage basin. The index is defined as the relative area below the hypsometric curve and it is an important indicator for topographic maturity. H_{max}, H_{min} and H_{ave} are calculated on DEM. This index is calculated to all sub-basins in the area. The hypsometric integral reveals the maturity stages of topography that can, indirectly, be an indicator of active tectonics.

In general, high values of the hypsometric integral are convex, and these values are generally > 0.5. Intermediate values tend to be more concave-convex or straight, and generally have values between 0.4 and 0.5. Finally, lower values (<0.4) tend to have concave shapes [11]. We can consider class 1 for Hi > 0.5, class 2 for Hi between 0.4 and 0.5 and class 3 for Hi < 0.4 and so, sub-basin No.11 shows younger topography (**Table 6**, **Figure 11**).
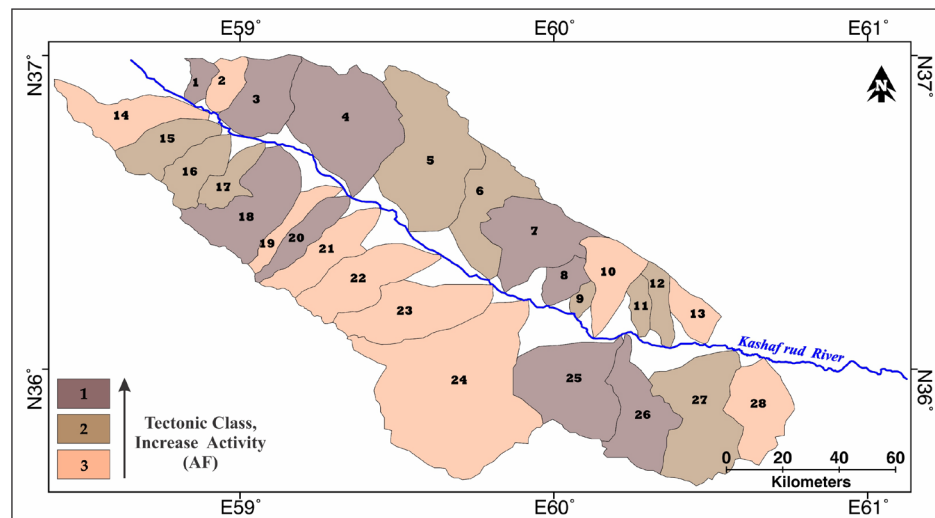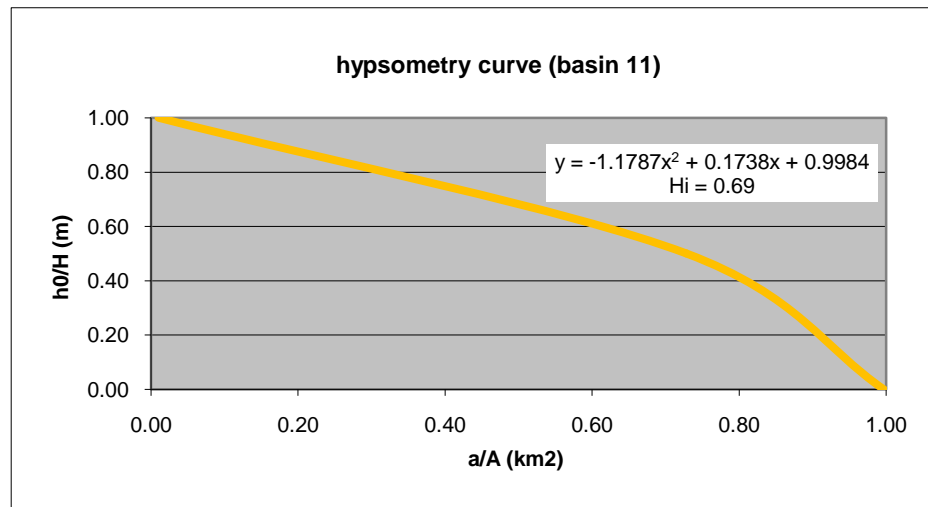
Table 4. Values of Af index for sub-basins No. 1 to 6.

			Asymmetry Factor (AF)		
Basin	A_r (sq km)	A_t (sq km)	AF	Tilting Part	Flow Direction of River	Tectonic Class
1	22.19	97.55	22.75	west	N→S	1 (High Activity)
2	80.27	155.93	51.48	east	N→S	3 (Low Activity)
3	99.7	431.5	23.11	west	N→S	1
4	786.6	1023.7	76.84	east	N→S	1
5	696.5	1098.7	63.39	east	N→S	2 (Moderate Activity)
6	311.2	498.6	62.41	east	NE→SE	2

Table 5. Values of Bs index.

	Drainage Basin Shape (Bs)			
Basin	BI (m)	BW (m)	Bs	Tectonic Class
1	16,580	8430	1.97	3 (Low Activity)
2	21,400	9850	2.17	3
3	32,350	16,670	1.94	3
4	47,180	34,380	1.37	3
5	59,070	25,880	2.28	3
6	47,710	26,670	1.79	3
7	34,380	30,860	1.11	3
8	19,670	12,660	1.55	3
9	13,790	6520	2.12	3
10	35,040	20,540	1.71	3
11	22,480	6930	3.24	2 (Moderate Activity)
12	31,370	8410	3.73	2
13	26,100	11,600	2.25	3
14	34,130	30,700	1.11	3
15	31,620	16,970	1.86	3
16	30,060	15,920	1.89	3
17	28,510	14,390	1.98	3
18	40,390	27,540	1.47	3
19	39,570	6390	6.19	1 (High Activity)
20	39,910	8330	4.79	1
21	43,500	14,090	3.09	2
22	41,240	17,940	2.30	3
23	47,830	20,770	2.30	3
24	63,390	61,390	1.03	3
25	38,620	37,440	1.03	3
26	50,780	18,930	2.68	3
27	49,160	24,170	2.03	3
28	38,040	20,500	1.86	3

Table 6. Values of Hi index for sub-basin No. 11.

Hypsometric Integration of Basin 11					
h (m)	h_0 (m)	h_0/H (m)	a (km^2)	A (km^2)	a/A (km^2)
900	0	0.00	29.21		1.00
1200	300	0.50	78	108.64	0.73
1500	600	1.00	1.1		0.01

hypsometry curve (basin 11)

$$y = -1.1787x^2 + 0.1738x + 0.9984$$
$$Hi = 0.69$$

Figure 8. Classification map for Asymmetry factor index.

3.7. Transverse Topographic Symmetry Factor (T)

The transverse topographic symmetry factor (T) was calculated as follows:

$$T = Da/Dd$$

where Da is the space from the midline of the drainage basin to the midline of the active belt and Dd is the space from the midline to the basin limit [104]. In a completely symmetric basin T = 0 and as asymmetry increases T approaches to value of 1.0. We can consider class 1 for T > 0.4, class 2 for T between 0.2 and 0.4 and class 3 for T < 0.2 and so, sub-basin No. 3 shows higher activity (**Table 7**, **Figure 12** and **Figure 13**).
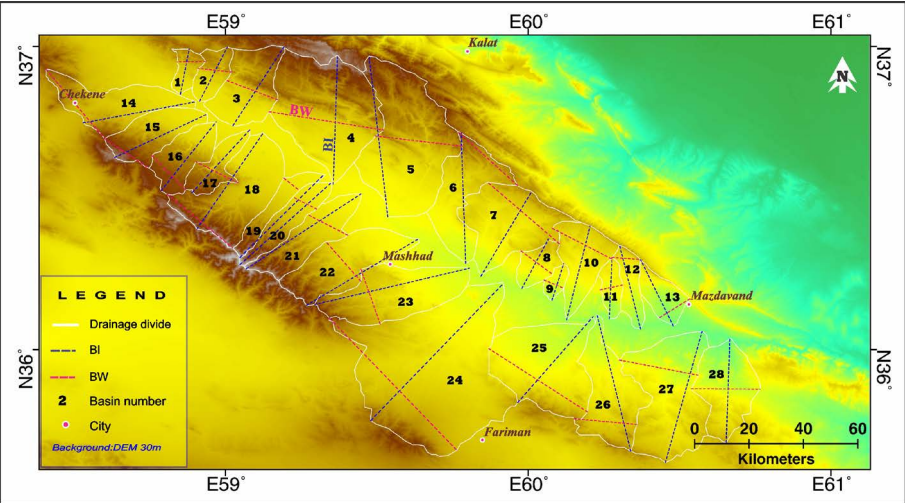
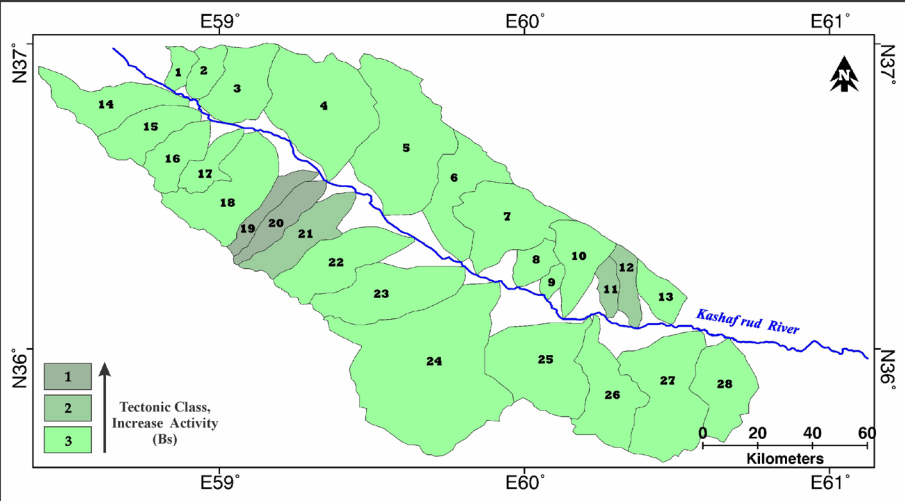**Figure 9.** Basic map for Basin shapeindex calculation.

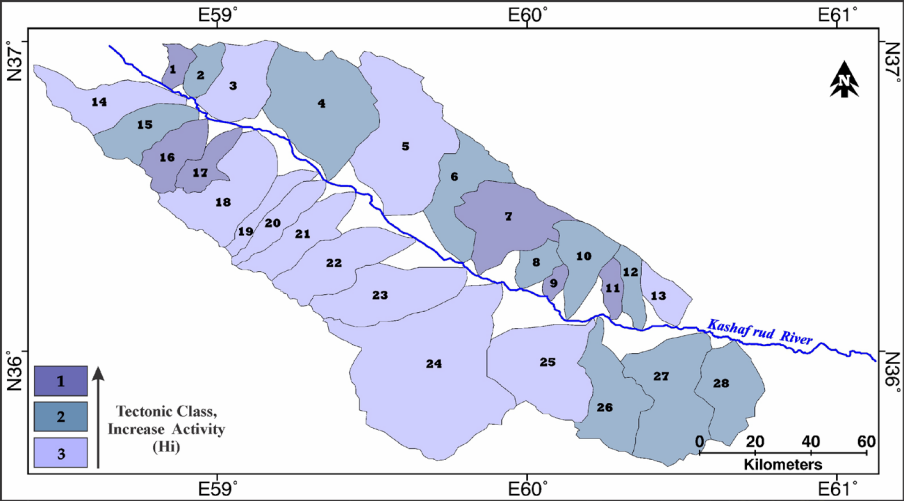**Figure 10.** Classification map for Basin shapeindex.

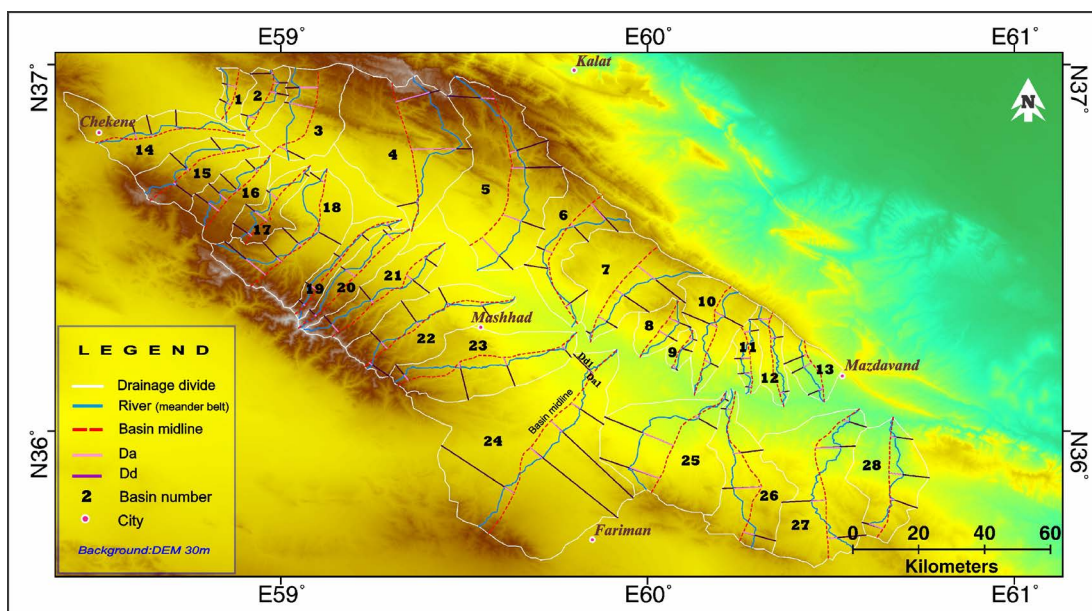**Figure 11.** The hypsometric integral classification map for study area.

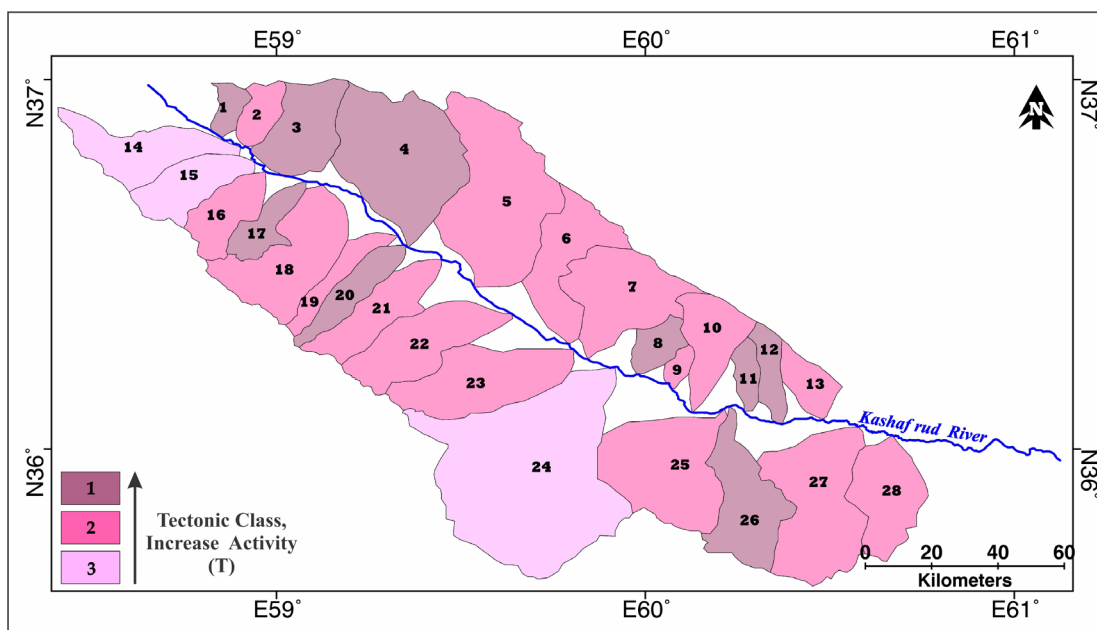**Figure 12.** Basic map for Tindex calculation.

Figure 13. Classification map for Tindex.

4. Results and Discussion

The average of the seven measured geomorphic indices (Vf, Smf, SL, Af, Bs, Hi and T) was used to evaluate the distribution of relative tectonic activity. Through averaging these seven indices (**Table 8**), we obtain one index that is known as modified index of active tectonics (Miat). The values of the index were divided into four classes to define the degree of active tectonics: 1-high ($1 < \text{Iat} < 1.5$), 2-moderate ($1.5 < \text{Iat} < 2.5$) and 3-low ($2.5 < \text{Iat}$).

Thus, there are low relative tectonic activities in sub-basin No. 6, 10, 13, 14, 21, 22, 23, 24 & 28 and moderate relative tectonic activities in the other sub-basins (**Figure 14**). These sub-basins have got the more active uplifting by Cimmerian-Eurasian convergent movements. These uplifting are related to active faults and folds [105] [106].
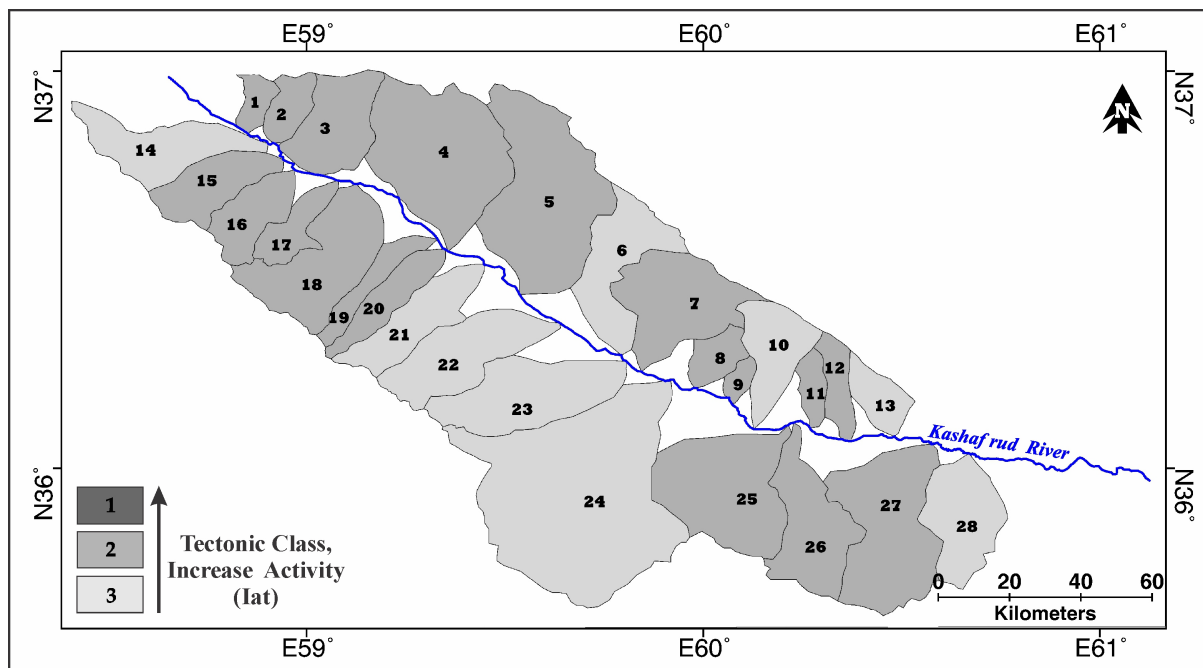
Figure 14. Relative tectonic activity classification and fault map of study area.

Table 7. Values of T index for 5 sub-basins.

Transverse Topographic Symmetry Factor (T)						
Basin	Number	Da (m)	Dd (m)	T (m)	T_{ave} (m)	Tectonic Class
1	1	2270	3589	0.63	0.52	1 (High Activity)
	2	1289	3179	0.41		
2	1	299	5520	0.05	0.31	2 (Moderate Activity)
	2	1172	3405	0.34		
	3	1543	4602	0.34		
	4	1956	3860	0.51		
3	1	4386	7830	0.56	0.57	1
	2	6280	7480	0.84		
	3	2178	7200	0.30		
4	1	8530	11,010	0.77	0.53	1
	2	10,920	14,770	0.74		
	3	427	5280	0.08		
5	1	3091	11,440	0.27	0.34	2
	2	1602	10,110	0.16		
	3	3082	12,290	0.25		
	4	5010	11,210	0.45		
	5	6810	12,200	0.56		

Also, based on [96], this area is a moderate seismic risk zone with following seismicity parameter: b = 0.83, M max = 7.5. Focal mechanisms of several earthquakes are dextral strike slip faulting such as Garmkhan-e Boj-nourd (Ms = 6.4, 1996) and thrusting. This region experiences low to moderate earthquakes with high frequency,

Table 8. Relative tectonic activity classification.

Sub-Basins	Class of V_f	Class of S_{mf}	Class of H_i	Class of B_s	Class of AF	Class of SL	Class of T	S/n	Iat Index
1	3	3	1	3	1	3	1	2.14	**2**
2	3	1	2	3	3	3	2	2.43	**2**
3	3	2	3	3	1	3	1	2.29	**2**
4	2	2	2	3	1	2	1	1.86	**2**
5	2	2	3	3	2	2	2	2.29	**2**
6	3	3	2	3	2	3	2	2.57	**3**
7	3	2	1	3	1	3	2	2.14	**2**
8	2	3	2	3	1	3	1	2.14	**2**
9	3	2	1	3	2	3	2	2.29	**2**
10	3	3	2	3	3	2	2	2.57	**3**
11	3	2	1	2	2	3	1	2.00	**2**
12	2	3	2	2	2	3	1	2.14	**2**
13	3	1	3	3	3	3	2	2.57	**3**
14	3	2	3	3	3	3	3	2.86	**3**
15	1	–	2	3	2	2	3	2.17	**2**
16	1	–	1	3	2	2	2	1.83	**2**
17	1	–	1	3	2	2	1	1.67	**2**
18	–	–	3	3	1	3	2	2.40	**2**
19	–	–	3	1	3	2	2	2.20	**2**
20	–	–	3	1	1	2	1	1.60	**2**
21	3	3	3	2	3	2	2	2.57	**3**
22	3	3	3	3	3	3	2	2.86	**3**
23	2	3	3	3	3	3	2	2.71	**3**
24	2	3	3	3	3	3	3	2.86	**3**
25	3	2	3	3	1	3	2	2.43	**2**
26	3	1	2	3	1	3	1	2.00	**2**
27	2	3	2	3	2	3	2	2.43	**2**
28	2	3	2	3	3	3	2	2.57	**3**

short repeat time and down to 20 Km focal depth. Sometimes in northern margin of south Caspian basin, focal depths exceed to 70 Km which is a depiction of its subduction. Intensity of earthquakes is in low levels.

The most serious seismic hazards in this province, which contains large city such as Mashhad are landslide in high regions, settlement in some plains, and surface faulting.

5. Conclusions

The calculated geomorphic indices are suitable for assessment of tectonic activity of the study area. The seven geomorphic indices: stream-gradient index (Sl), valley floor width-valley height ratio (Vf) and mountain-front sinuosity (Smf), drainage basin asymmetry (Af), hypsometric integral (Hi), drainage basin shape (Bs) and transverse topographic symmetry factor (T) have calculated in Kashaf rud river.

Therefore, firstly the area was divided to 28 sub-basins and for each one, indices were calculated, then all of the indices were divided into relative tectonic activity classes. Afterwards, the seven measured indices for each

sub-basin were compounded and a unit index obtained as the modified index of active tectonics (Miat) for the first time. According to this index, there are low and moderate relative tectonic activities levels.

Low relative tectonic activities level has been fund in sub-basin No. 6, 10, 13, 14, 21, 22, 23, 24 & 28 and moderate relative tectonic activities level has been fund in the other sub-basins. It means that these sub-basins have got the more active uplifting by Cimmerian-Eurasian convergent movements, because they are on the longitudinal faults that have been formed above an old suture zone.

Acknowledgements

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