

## Quantitative assessment of relative tectonic activity in the Alamarvdasht river basin, south of Iran

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Received: Aug. 15, 2016 Accepted: Dec. 27, 2016

### Abstract

Tectonic processes are major factors controlling landform development in tectonically active areas. In order to evaluate quantitative measurement of tectonic activities in the Alamarvdasht basin in the south of Iran, six different morphological indices including stream-gradient index (SL), drainage basin asymmetry (Af), hypsometric integral (Hi), valley floor width-valley height ratio (Vf), drainage basin shape (Bs) and mountain-front sinuosity (Smf) were calculated. These indices were combined to generate the relative active tectonics index (IAT) and the study area was divided into three classes: high, moderate and low relative tectonic activity based on IAT values. The results of IAT index showed that high and moderate tectonic activity areas are located near the main faults and anticlines. The results are also consistent with geology and field observations on landforms and GPS data of Lamerd geodynamics station. GPS data shows subsidence and north-eastern movement in the basin because of convergence between the Arabian and Eurasian plates in the Zagros Mountains zone.

### Keywords

Alamarvdasht basin, geodynamics, geomorphic indices, relative active tectonics, tectonic geomorphology.

## 1. Introduction

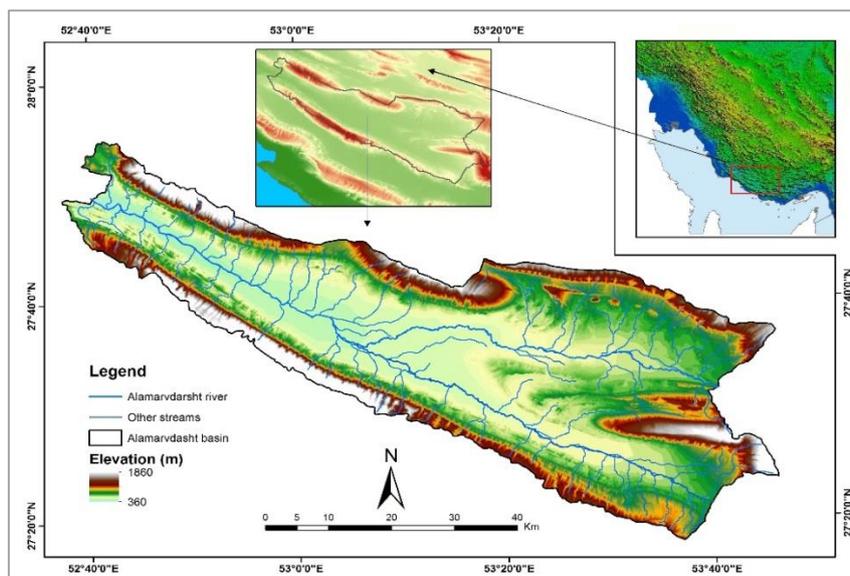
Tectonic geomorphology is defined as the study of landforms produced by tectonic processes, or the application of geomorphic principles to the solution of tectonic problems (Keller & Pinter 1996). The development of landscapes in tectonically active areas results from a complex integration of the effects of vertical and horizontal motions of crustal rocks and erosional processes (Bahrami, 2013). The quantitative measurement of landscape is based on the calculation of geomorphic indices using topographic maps, aerial photos, satellite images and field work. Geomorphic indices are extremely useful for the study of drainage basins. The quantitative measurement of landscape shapes allows geomorphologists to calculate parameters, or geomorphic indices, which are useful in establishing the characteristics of an area (Baioni, 2007). The results of several indices can be combined in order to highlight tectonic activity and to provide an assessment of a relative degree of tectonic activity in an area (Keller & Pinter 1996). The analysis of geomorphic indices gathered in the study of drainage basins, and their integrated comparisons, can contribute to the understanding of the Morphotectonic structure, or they can be particularly useful in detecting the factors that may have influences on morphogenetic processes (Baioni, 2007). Active tectonics in the uplifting anticlines of Zagros structural zone, especially in Simply Folded Belt, has produced various landforms. Quantitative measurement of such landforms helps to identify and to analyze tectonic deformation in an area (Bahrami, 2012).

Active tectonic geomorphic indices are known to be useful in active tectonic studies (Keller

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& Pinter, 2002). This methodology has been previously tested as a valuable tool in different tectonically active areas such as Conca river basin in central Italy (Baioni, 2007), the south-western Sierra Nevada of Spain (El. Hamdouni et al., 2007), the Karaj drainage basin, north of Iran (Khavari et al., 2010), the Sarvestan area in central Zagros of Iran (Dehbozorgi et al., 2010), Kermanshah area, west of Iran (Arian & Aram, 2014), Eastern Alborz (Rezaei Moghadam & Kheirizadeh, 2015), Borujerd area in SW Iran (Omidali et al., 2015), Jarahi-Hendijan basin, south of Iran (Ehsani & Arian, 2015), Atrak river, NE Iran (Mosavi & Arian, 2015), Tabas area, central Iran (Mosavi et al., 2015) and Shahriary basin in central Iran (Habibi & Gharibreza, 2015). Also the results have combined field observations of the region and geodynamics data of the area.



**Fig. 1. Location of the study area in Iran and the Folded Belt of the Zagros Mountains**

## 2. Study area

The study area of Alamarvdasht river basin is situated in the south of Fars province, south of Iran. Alamarvdasht river basin is located in the Simple Folded Belt of the Zagros Mountains in Fars region (Fig. 1). The Alamarvdasht basin area is 2925 Km<sup>2</sup> and located between latitudes 27°17'N - 27°55'N and longitudes 52°37'E-53°46'E. The maximum elevation of study area is 1860 meters in the south of basin and the minimum elevation is 360 m in northwest of the basin. The study objective is to calculate different geomorphic indices to assess tectonic activities of the area. Zagros in south of Iran is the most active tectonic zone (Mosavi et al., 2015). Active deformation in the Zagros is caused by the northward motion of the Arabia with respect to Eurasia, which occurs at a rate of 25 mm year<sup>-1</sup> at longitude 56 E (Ramsey et al., 2008). Almost half of the Arabia-Eurasia shortening is accommodated in the Zagros Mountains of southern Iran (Talebian & Jackson, 2002; Tatar et al., 2002; Blanc et al., 2003), and the remainder in the Alborz mountains and Kopeh-Dagh mountains of northern Iran. The seismically active areas are concentrated around the margins of the Central Iranian Plateau, which is virtually a seismic and appears not to be deforming rapidly. The style of deformation appears to vary along the strike of Zagros. In the south east of Zagros (Fars) the shortening as accommodated by a series of east-west trending thrusts (Ramsey et al., 2008). The study area is located along a simply folded belt of southeastern Zagros and shaped by the anticlines and synclines with SW–NE trending. These geological structures are partly buried by the younger Quaternary alluviums. Age of rock layers in the area varies from Upper Cretaceous (Bangestan Group) to Pliocene-Lower Pleistocene (Bakhtiari Formation). The level of rock resistance categorized to very low (alluvial deposits), low (older alluvial fan deposits, weakly consolidated conglomerate and marl), moderate (gypsum marl, chalky fine dolomite limestone and gypsum) and high (limestone, sandstone, dolomite, shale and hard conglomerate) (El. Hamdouni et al., 2007). Figure 2 shows the geology map of the study area.

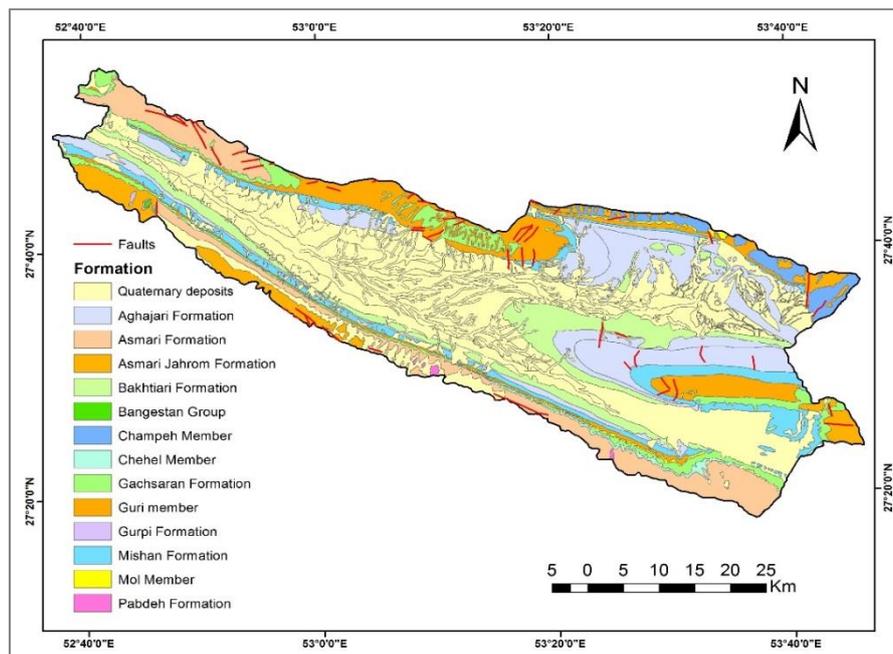


Fig. 2. Geology of the study area

### 3. Materials and Methods

It is necessary to have some primary maps to calculate the geomorphic indices (Mosavi et al., 2015). Spatial tools including geographic information systems (GIS) and morphometric analyses which may provide useful information on this subject. Afterwards, geomorphic indices were analyzed by 10m Digital Elevation Model (DEM) generated from topographic maps (1:25000). Geological data such as faults distribution and their types, geological formations in the basin and structural information were obtained from geological maps (1:100000). To calculate geomorphic indices in the basin, first of all the Alamarvdasht basin was divided into 64 sub-basins by using ArcHydro extension in ArcGIS and Global Mapper softwares. Then the following geomorphic indices including stream-gradient index (SL), drainage basin asymmetry (Af), hypsometric integral (Hi), valley floor width-valley height ratio (Vf), drainage basin shape (Bs) and mountain-front sinuosity (Smf) were calculated. The classification of each index by El. Hamdooni et al. (2007) is shown in Table 1.

#### 3.1. The stream-gradient index (SL)

Rivers flowing over rocks and soils of various strengths tend to reach equilibrium with specific longitudinal profiles and hydraulic geometrics (Hack, 1973; Bull, 2007). Hack (1957, 1973, 1982) 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 SL index can be used to evaluate relative tectonic activity (Keller & Pinter, 2002). An area on soft rocks with high SL values indicates active tectonics. Although an area on soft rocks with high SL values indicates recent tectonic activity, anomalously low values of SL may also represent such activity when rivers and streams flow through strike-slip faults.

The calculation formula is in this manner (Cooley, 2015):

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

where  $(\Delta H / \Delta L)$  is local slope of the channel segment located between two contours and L is the channel length from the divide to the midpoint of the channel reaches for which the index is calculated. Amount of  $\Delta H$ ,  $\Delta L$  and L are gained from DEM.

#### 3.2. Asymmetry factor (Af)

Asymmetry factor index was developed to detect tectonic tilting at drainage basin scale or larger scale area (Hare & Gardner, 1985). This index is related to two tectonic and non-tectonic factors. Non-tectonic factors may be related to lithology and rock fabrics. The asymmetric factor can be used to evaluate tectonic tilting at the scale of a drainage basin (Hare & Gardner,

1985; Keller & Pinter, 2002). The asymmetry factor is sensitive to the direction of the asymmetry and in drainage basins that display change of direction throughout the river; the opposite directions will compensate each other giving a lower value of Af. For this reason, the asymmetry factor is useful mostly in drainage basins where the asymmetry has the same direction (Baioni, 2007). The method may be applied over a relatively large area (Hare & Gardner, 1985; Keller & Pinter, 2002). The index is defined as follows:

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

where Ar is the right side area of the basin of the master stream (looking downstream) and At is total area of the basin that can be measured by ArcGIS software (Omidali et al., 2015).

### 3.3. Hypsometric integral index (Hi)

Hypsometry is a measure of the relationship between elevation and area in a basin, watershed, or catchment. Basin hypsometry is strongly tied to flood response and the erosional maturity of a basin. The hypsometric integral (Hi) is a product of hypsometric analysis and describes the relative distribution of elevation in a given area of a landscape particularly a drainage basin (Cooley, 2015). The Hypsometric index is defined as the relative area below the hypsometric curve and it is an important indicator for topographic maturity and can shed light on the local effects of denudation and tectonic uplift. A simple equation to approximately calculate the index (Keller & Pinter, 2002) is:

$$Hi = (H_{ave} - H_{min}) / (H_{max} - H_{min})$$

where H ave, H min and H max represent average, minimum and maximum elevations. The required values were calculated from 10m Digital Elevation Model.

### 3.4. Valley floor width-valley height ratio (Vf)

The valley floor width to valley height ratio (Vf) is another index sensitive to tectonic uplift (Dehbozorgi et al., 2010). The index is a measure of incision and not uplift, but in an equilibrium state, incision and uplift are nearly matched. The calculation formula is in this manner (Cooley, 2015):

$$Vf = 2V_{fw} / [(E_{ld} - E_{sc}) + (E_{rd} - E_{sc})]$$

where Vfw is the width of the valley floor, and Eld, Erd and Esc are the elevations of the river-left and valley divides (looking downstream) and the stream channel, respectively (Bull, 2007).

### 3.5. Basin shape index (Bs)

Relatively young drainage basins in active tectonics areas tend to be elongated in shape normal to the topographic slope of a mountain. The elongated shape tends to evolve to a more circular shape (Bull & McFadden, 1977). Horizontal projection of basin shape may be described by the basin shape index or the elongation ratio, Bs. 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 widest point of the basin. Relatively young drainage basins in tectonically active areas tend to be elongated in shape, normal to the topographic slope of a mountain (Bull & McFadden, 1977). Therefore, Bs may reflect the rate of active tectonics (Dehbozorgi et al., 2010).

### 3.6. Mountain-front sinuosity index (Smf)

Mountain Front Sinuosity is a classic index of tectonic activity. Straight mountain fronts tend to lie along active faults. 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 (Bull & McFadden, 1977). Index of mountain front sinuosity (Bull, 2007) is defined as:

$$Smf = L_{mf} / L_s$$

where Lmf is the sinuous length of the mountain measured along an undulating, weaving path at the mountain hill slope -alluvial fan slope break-, and Ls is the straight-line length of the main front segment.

Table 1. Range of geomorphic indices (El. Hamdouni et al., 2007)

Geomorphic index	Class 1 (high tectonic activity)	Class 2 (moderate tectonic activity)	Class 3 (low tectonic activity)
SL	SL > 500	500 > SL > 300	SL < 300
Af	Af < 35 or Af > 65	57 < Af < 65 or 35 < Af < 43	43 < Af < 57
Hi	Hi > 0.5	0.4 < Hi < 0.5	Hi < 0.4
Vf	Vf < 0.3	0.3 < Vf < 1	Vf > 1
Bs	Bs > 4	3 < Bs < 4	Bs < 3
Smf	Smf < 1.1	1.1 < Smf < 1.5	Smf > 1.5

### 3.7. Index of active tectonics (IAT)

The average of the six measured geomorphic indices was calculated to evaluate the index of active tectonics (IAT) in the study area which is the most important and widely used geomorphic index. This index represents a summary and average of the given geomorphic indices where used in the study as follows:

$$IAT = S/N$$

where S represents the sum of previous indices and N represents the number of selected indices (Habibi & Gharibreza, 2015). The values of the index were divided into four classes to define the degree of active tectonics: 1—very high ( $1.0 \leq IAT < 1.5$ ); 2—high ( $1.5 \leq IAT < 2.0$ ); 3—moderate ( $2.0 \leq IAT < 2.5$ ); and 4—low ( $2.5 \leq IAT$ ) (Mosavi & Arian, 2015).

After geomorphic indices calculation the 8-year geodynamics data of Lamerd GPS station was used to discernment the general tectonic activity of the area and to compare with geomorphic indices results. Field observation also was used to find some morphotectonic evidences of active tectonics such as alluvial fans sequences and triangular facets in the study area.

## 4. Results and Discussion

### 4.1. The stream-gradient index (SL)

This index is calculated along the master stream for each sub-basin. The minimum value of SL is 18 in sub-basin 30 and the maximum value is 757 in sub-basin 3. The average of this index in all 64 basins is 310.9 that shows moderate tectonic activity based on Table 1. The results of SL value and classification are shown in Table 2. Highest values of this index are seen in the northwest and southern regions of study area. This index is correlated with geological and lithological condition of the study area. Comparison between geology map (Fig. 2) and SL index distribution map (Fig. 6) reveals that the highest values of SL are seen where the rocks strength is in higher level (Asmari and Jahrom formations) and sub-basins with low rock resistance such as Aghajari, Mishan and Gachsaran formations and the Quaternary deposits in the eastern parts of study area have lower values of SL index. Calculation of SL index for the whole of study area along the main river shows that there are the highest values of this index in the northwestern part of Alamarvdasht basin, where the Alamarvdasht river passes some strike-slip faults. Since the whole area of Alamarvdasht plain is covered by the Quaternary deposits along the main river and there is no change in rock resistance, the Alamarvdasht basin SL index values and anomalies represent the effect of tectonic activity of strike-slip faults but in the sub-basins with different rock resistance, this index is effected by rock strength changes of different geological formations too.

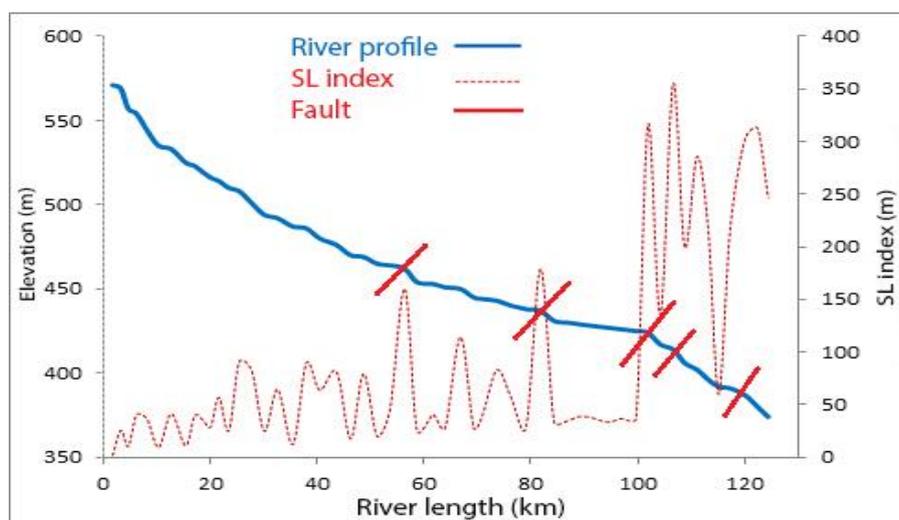


Fig. 3. SL index changes along Alamarvdasht river long profile and faults

#### 4.2. Asymmetry factor (Af)

The asymmetry factor (Af) is an important geomorphic index that is useful in the geomorphological analysis of drainage basins and it has been used to measure the drainage basin asymmetry and usually it is represented by a single number (Baioni, 2007).

To calculate this index in the area  $A_t$  and  $A_r$  were obtained by using of the sub-basins and the master river maps. For most networks that formed and continued to flow in a stable setting and there is no or little tilting perpendicular to the direction of the master stream, the value of Af should be equal to about 50 (Keller & Pinter, 2002). Af is significantly greater or smaller than 50 under the effects of active tectonics or strong lithological control. In the study area, Af varies from 22 (Sub-basin 24) to 85 (Sub-basin 61). Average value of Af index in 64 sub-basins is 0.56 and shows little basin tilting in the study area.

#### 4.3. Hypsometric integral index (Hi)

Computing the Hi index for each sub-basin shows that this value ranges from 0.11 (Sub-basin 13) to 0.41 (Sub-basin 63). The average of this index in 64 basins is 0.26 that shows low tectonic activity based on El. Hamdouni classification (Table 1). The results of Hi values and classes are shown in Table 2. This index has the most similarity between sub-basins than other indices and except only one sub-basin in the west of the basin all of other sub-basins are classified in low tectonic activity class. Because Hi values are less than 0.5 (Table 2), this basin is considered to be dominated by fluvial erosion and channel processes play a larger role than active uplifting.

#### 4.4. Valley floor width-valley height ratio (Vf)

This index allows comparison of erosional patterns between watersheds and can separate V-shaped valleys with small amounts while it can separate U-shaped valleys with greater amounts (Bull & McFadden, 1977). V-shaped valleys are common in areas of active uplift and deep, linear stream incision (low Vf values, often close to 0). U-shaped valleys are representative of formerly glaciated or tectonically stable areas where stream valley bottoms tend to be wider (higher Vf values). Bull and McFadden (1977) found significant differences in Vf between tectonically active and inactive mountain fronts, because a valley floor is narrowed due to rapid stream down cutting. When calculated for several streams that draining a mountain range (or larger region), the index can reveal spatial variations in incision and differential uplift. The Vf ranges from 0.09 (sub-basin 3) to 7.87 (sub-basin 7) and was classified into three classes (Table 2) The average of this index in 64 basins is 0.68 that shows moderate tectonic activity. Most of V-shaped valleys are located in the southern anticline which mostly created from resistant limestone of Asamari and Jahrom formations (Fig. 6).

#### 4.5. Basin shape index (Bs)

In the study area Bs ranges from 1.17 (sub-basin 17) to 3.5 (sub-basin 31) and is classified into three classes (Table 2). The average of this index in 64 sub-basins is 1.88 which represents few reactive tectonic effects or more mature basins. This index shows similarity between sub-basins and except for two sub-basins in the center of Alamarvdasht plain, the others are classified in low tectonic activity class.

#### 4.6. Mountain-front sinuosity index (Smf)

The values of Smf ranges from 1.01 (Sub-basin 31) to 1.65 (Sub-basin 14) and are classified into three classes (Table 2). The average of this index in 64 basins is 1.09 that shows high tectonic activity according to Table 1.

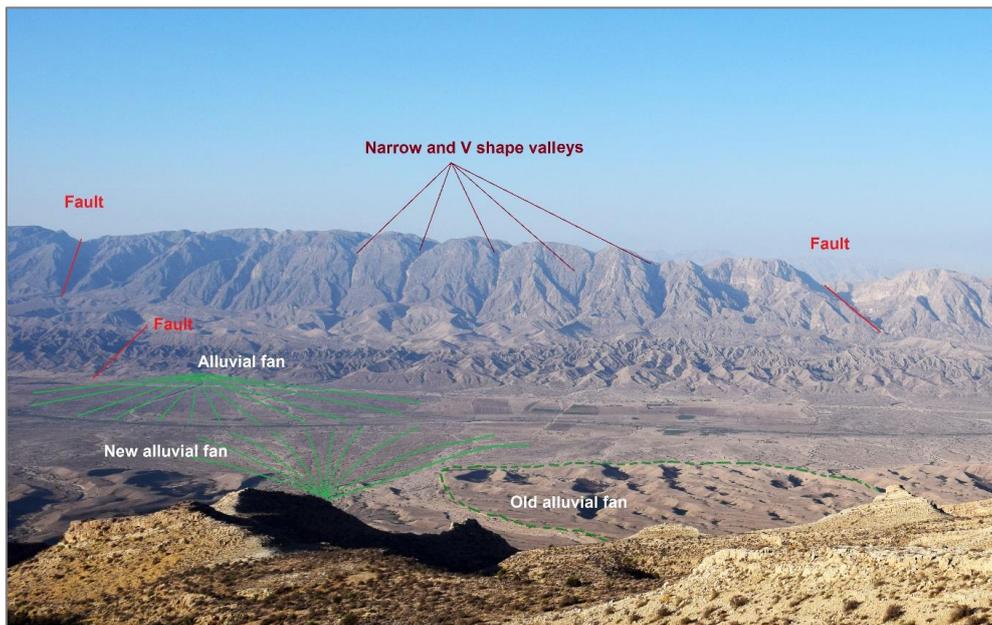


Fig. 4. V-shaped valleys and other tectonic-induced landforms in the northwest of Alamarvdasht basin (view to the south)

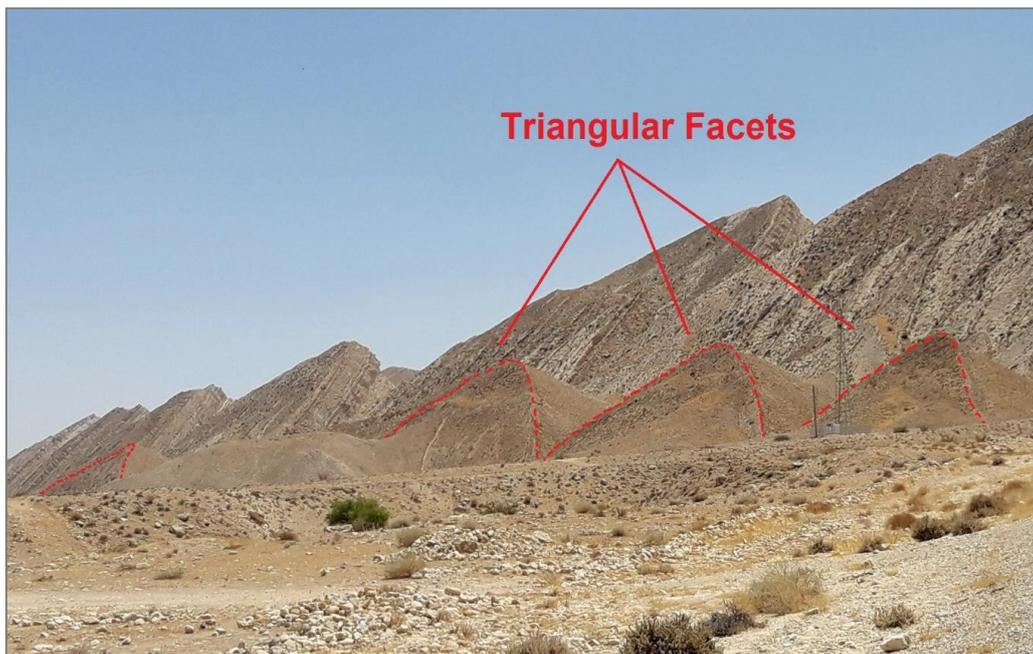


Fig. 5. Triangular facets of Varavi anticline in the south of Alamarvdasht basin (view to the south)

Table 2. Values and classes of six geomorphic indices and IAT index

Sub.	SL		Af		Hi		Vf		Bs		Smf		IAT	
	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class
1	209.36	3	0.61	2	0.29	3	0.50	2	1.31	3	1.38	2	2.50	4
2	607.92	1	0.60	2	0.32	3	0.24	1	1.85	3	1.49	2	2.00	3
3	756.64	1	0.54	3	0.22	3	0.09	1	1.67	3	1.14	2	2.17	3
4	596.59	1	0.74	1	0.33	3	0.54	2	1.62	3	1.06	1	1.83	2
5	463.16	2	0.61	2	0.31	3	0.17	1	2.39	3	1.29	2	2.17	3
6	531.61	1	0.70	1	0.37	3	0.19	1	2.28	3	1.59	3	2.00	3
7	387.61	2	0.54	3	0.26	3	7.88	3	1.82	3	1.41	2	2.67	4
8	157.41	3	0.45	3	0.23	3	1.57	3	2.08	3	1.27	2	2.83	4
9	218.78	3	0.74	1	0.18	3	0.90	2	2.39	3	1.35	2	2.33	3
10	121.67	3	0.72	1	0.16	3	0.54	2	1.86	3	1.14	2	2.33	3
11	410.48	2	0.42	2	0.21	3	0.53	2	2.60	3	1.32	2	2.33	3
12	313.48	2	0.42	2	0.22	3	0.78	2	2.53	3	1.18	2	2.33	3
13	228.34	3	0.43	2	0.12	3	0.61	2	2.28	3	1.39	2	2.50	4
14	372.06	2	0.42	2	0.21	3	0.46	2	1.95	3	1.65	3	2.50	4
15	417.22	2	0.51	3	0.23	3	0.91	2	1.52	3	1.25	2	2.50	4
16	375.31	2	0.44	3	0.23	3	0.39	2	1.36	3	1.21	2	2.50	4
17	336.09	2	0.50	3	0.26	3	2.95	3	1.18	3	1.02	1	2.50	4
18	246.44	3	0.80	1	0.23	3	0.45	2	2.37	3	1.14	2	2.33	3
19	76.97	3	0.65	1	0.13	3	-	-	1.59	3	-	-	2.50	4
20	209.33	3	0.71	1	0.26	3	0.23	1	1.62	3	1.19	2	2.17	3
21	261.60	3	0.38	1	0.19	3	1.71	3	1.88	3	1.08	1	2.33	3
22	212.81	3	0.28	1	0.13	3	0.64	2	1.60	3	1.27	2	2.33	3
23	316.92	2	0.56	3	0.32	3	0.65	2	1.40	3	1.20	2	2.50	4
24	464.25	2	0.22	1	0.34	3	0.70	2	2.19	3	1.06	1	2.00	3
25	114.39	3	0.59	2	0.25	3	1.11	3	1.94	3	1.09	1	2.50	4
26	98.51	3	0.46	3	0.22	3	-	-	1.82	3	-	-	3.00	4
27	44.02	3	0.50	3	0.24	3	-	-	1.94	3	-	-	3.00	4
28	28.85	3	0.55	3	0.19	3	-	-	3.07	2	-	-	2.75	4
29	37.51	3	0.71	1	0.16	3	-	-	1.75	3	-	-	2.50	4
30	18.33	3	0.58	2	0.21	3	-	-	1.67	3	-	-	2.75	4
31	21.76	3	0.64	2	0.20	3	-	-	3.50	2	-	-	2.50	4
32	211.51	3	0.37	2	0.19	3	0.67	2	2.56	3	1.16	2	2.50	4
33	148.03	3	0.55	3	0.14	3	1.69	3	1.30	3	1.14	2	2.83	4
34	212.20	3	0.57	3	0.16	3	0.35	2	1.24	3	1.15	2	2.67	4
35	154.62	3	0.35	2	0.18	3	0.41	2	1.89	3	1.16	2	2.50	4
36	406.94	2	0.59	2	0.25	3	1.41	3	1.83	3	1.28	2	2.50	4
37	190.90	3	0.65	2	0.35	3	1.46	3	1.40	3	1.09	1	2.50	4
38	147.91	3	0.44	3	0.32	3	1.66	3	1.60	3	1.12	2	2.83	4
39	128.31	3	0.77	1	0.24	3	2.03	3	2.76	3	1.18	2	2.50	4
40	140.88	3	0.57	3	0.26	3	0.32	2	2.01	3	1.21	2	2.67	4
41	270.88	3	0.49	3	0.31	3	1.98	3	1.99	3	1.24	2	2.83	4
42	302.42	2	0.46	3	0.33	3	0.71	2	1.56	3	1.22	2	2.50	4
43	369.98	2	0.64	2	0.36	3	0.20	1	1.63	3	1.30	2	2.17	3
44	318.46	2	0.63	2	0.24	3	0.24	1	1.52	3	1.10	1	2.00	3
45	198.12	3	0.52	3	0.30	3	0.13	1	2.02	3	1.19	2	2.50	4
46	191.12	3	0.55	3	0.27	3	0.18	1	1.57	3	1.34	2	2.50	4
47	363.66	2	0.75	1	0.23	3	0.38	2	1.82	3	1.13	2	2.17	3
48	319.81	2	0.78	1	0.25	3	0.10	1	1.74	3	1.22	2	2.00	3
49	364.63	2	0.57	3	0.30	3	0.12	1	1.83	3	1.26	2	2.33	3
50	405.24	2	0.57	3	0.30	3	0.18	1	1.61	3	1.19	2	2.33	3
51	480.17	2	0.52	3	0.27	3	0.35	2	1.71	3	1.26	2	2.50	4
52	539.65	1	0.67	1	0.29	3	0.19	1	1.70	3	1.15	2	1.83	2
53	664.16	1	0.70	1	0.26	3	0.68	2	2.05	3	1.18	2	2.00	3
54	590.19	1	0.77	1	0.21	3	0.18	1	2.02	3	1.10	1	1.67	2
55	627.71	1	0.43	3	0.31	3	0.23	1	1.68	3	1.24	2	2.17	3
56	588.70	1	0.57	2	0.27	3	0.30	1	1.74	3	1.07	1	1.83	2
57	402.81	2	0.45	3	0.34	3	0.50	2	2.39	3	1.06	1	2.33	3
58	240.68	3	0.63	2	0.32	3	0.24	1	2.04	3	1.08	1	2.17	3
59	577.32	1	0.76	1	0.29	3	0.17	1	2.07	3	1.62	3	2.00	3
60	551.39	1	0.73	1	0.21	3	0.34	2	1.76	3	1.26	2	2.00	3
61	303.67	2	0.85	1	0.33	3	0.17	1	2.04	3	1.08	1	1.83	2
62	265.24	3	0.32	1	0.29	3	0.23	1	1.71	3	1.19	2	2.17	3
63	316.94	1	0.42	2	0.41	2	0.63	2	1.37	3	1.55	3	2.17	3
64	250.00	3	0.34	1	0.38	3	0.59	2	1.25	3	1.20	2	2.33	3

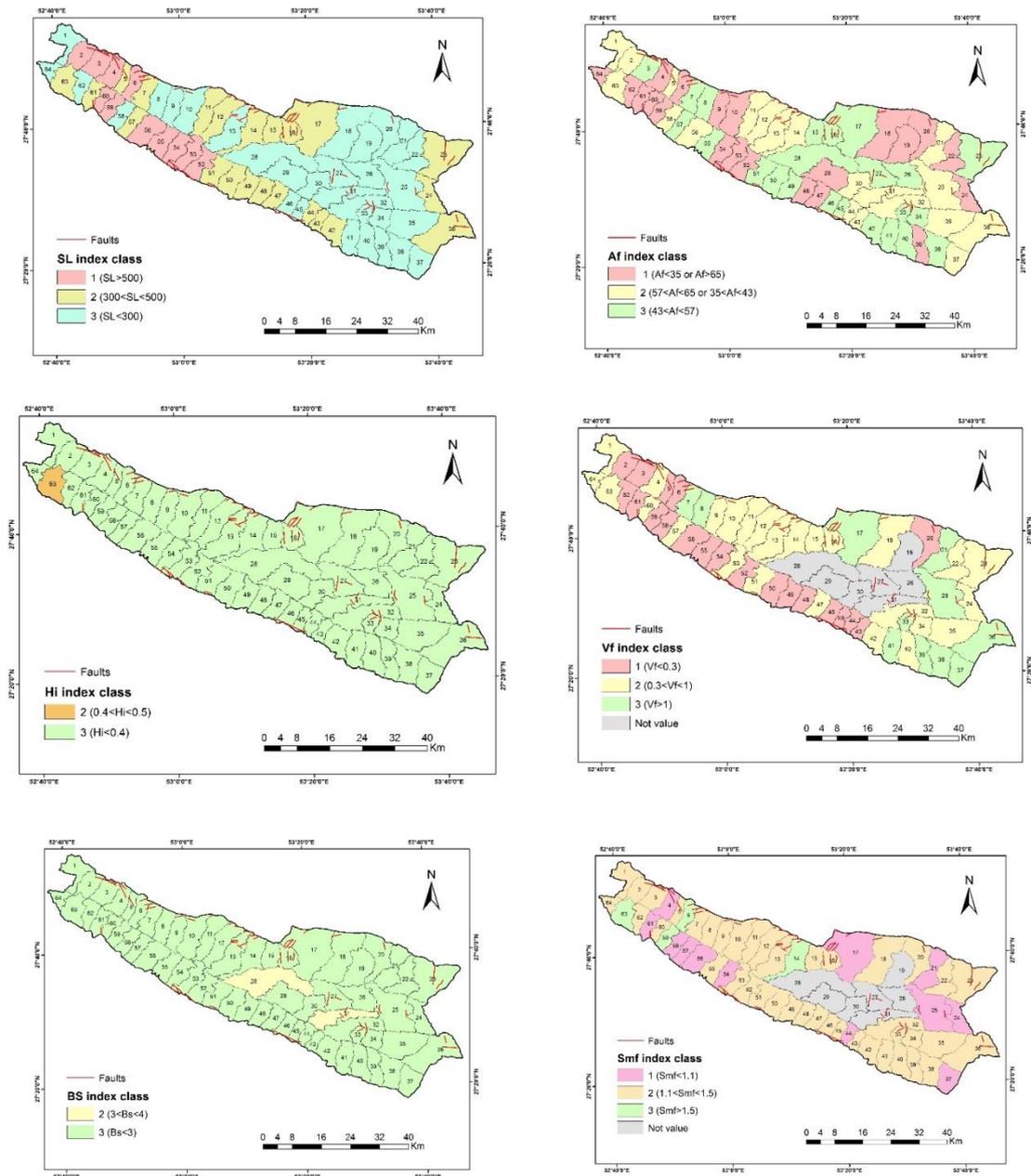


Fig. 6. Distribution of 6 geomorphic indices (SL, Af, Hi, Vf, Bs, Smf) and classification of them.

#### 4.7. Index of Active Tectonic (IAT)

The average of the six measured geomorphic indices (IAT) was used to evaluate the distribution of relative tectonic activity in the study area (El. Hamdouni et al., 2007). There is no IAT value in very high activity class ( $1.0 \leq IAT < 1.5$ ), therefore the values of the index were divided into three classes to define the degree of active tectonics (Table 2).

The distribution of these three classes is shown in Figure 7, and Table 2 shows the result of the classification for each sub-basin. About 57.28% of the study area (1670 km<sup>2</sup>) belongs to Class 4 (low activity); 36.56% (1066 km<sup>2</sup>) to Class 3 (moderate activity) and 6.15% (179.4 km<sup>2</sup>) to Class 2 (high activity). The average of this index in 64 basins is 2.36 which shows the tectonic activity is in moderate level.

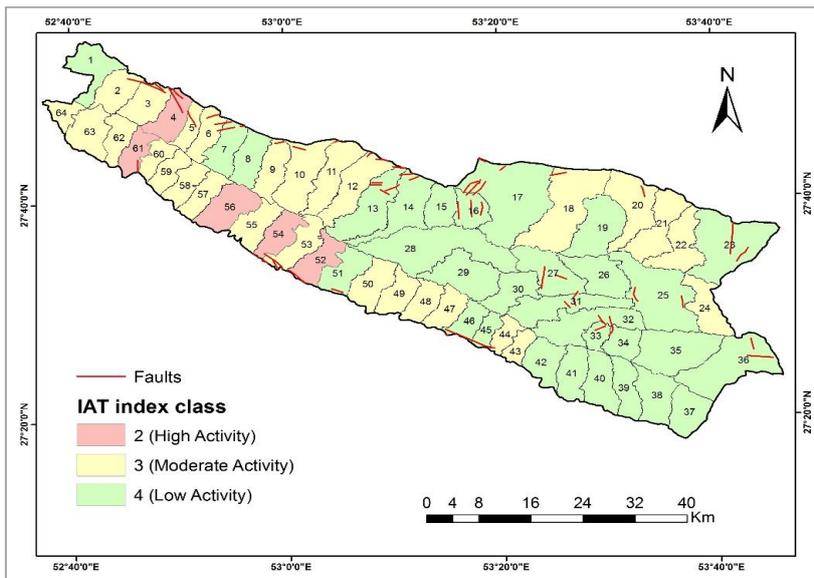


Fig. 7. Distribution of IAT classes in the study area

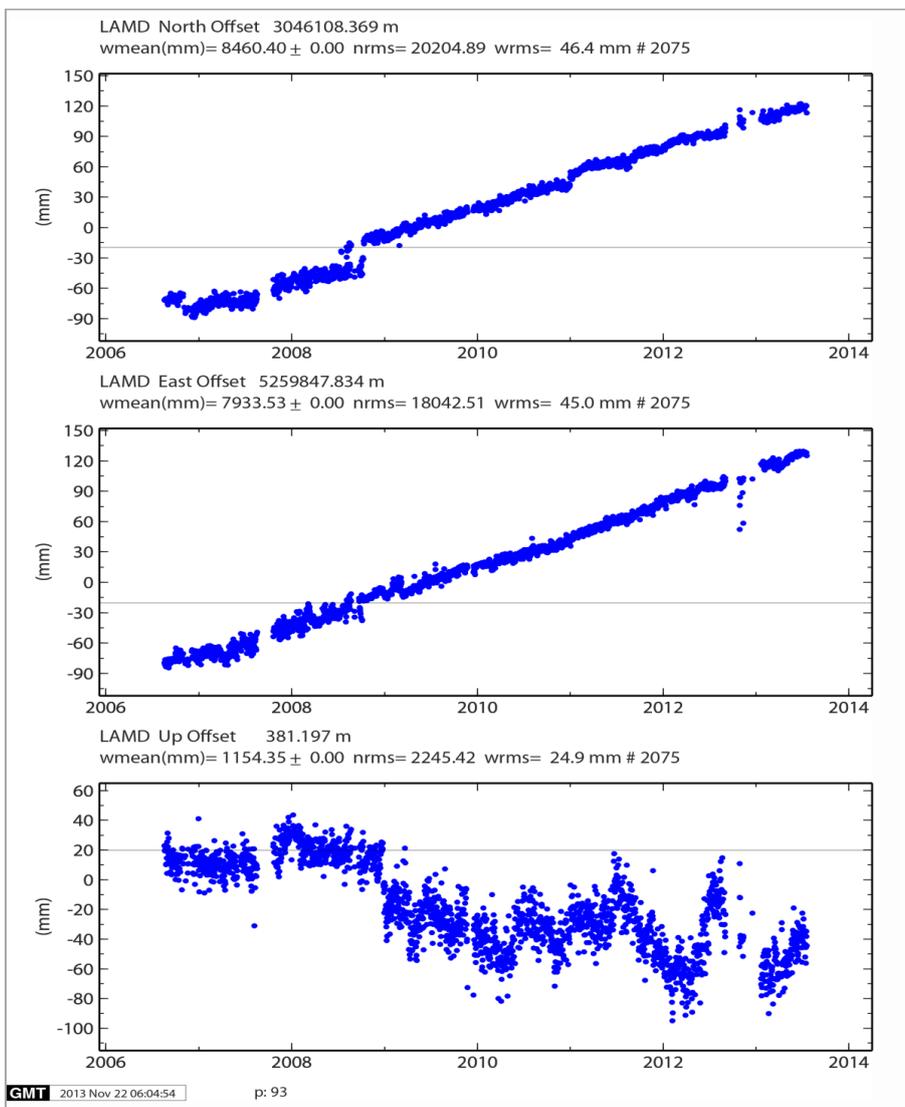


Fig. 8. GPS data of Lamerd geodynamics station (2006-2014) in North, East and Up offsets

After calculating the geomorphic indices, to compare the results with numerical rate of tectonic deformation, the Iranian Geodynamic Network data was used which estimates the general tectonic movements of Iran. GPS data of Lamerd station (2006-2014) in the south of Alamarvdasht basin shows the linear movement in northern offset (north-south) to the north (min. -9 cm and max. 12.2 cm) and to the east (min. -8.8 cm and max. 13.6 cm) in eastern offset (east-west). The variation range of northern offset is 21 cm and 22.1 cm in eastern offset in 8 years (Fig. 8). So the average range of movement to the northeast is about 26 mm year<sup>-1</sup>. The linear movement of this area to the northeast is a result of collision between the Arabian and Eurasian plates and correlate with their convergence. The Zagros belt accommodates roughly half of 25 mm year<sup>-1</sup> convergence between the Arabian and Eurasian plates (Ramsey et al., 2008), so this value is almost equal to these plates total convergence. On the other hand, although GPS data shows negative values in the vertical offset, but it should be considered that the geodynamic station located in the Lamerd plain which may have subsidence because of non-tectonic factors; so because there is only one station with a short term data period near the study area, we must consider the probable inaccuracy in tectonic assessment based on these data.

## 5. Conclusions

The geomorphic indices considered to be useful for evaluating the effects of active tectonics in Alamarvdasht basin. The method was applied for this area and according to the results, the higher value of SL, Hi and Bs indices were found along main folds (northern and southern anticlines). The values of Af show different drainage basin asymmetry related to the tectonics in the anticlines and the values of Smf show that the mountain fronts especially in the south and southwest of the basin are tectonically active and the values of Vf showed that many valleys are narrow and deep especially in southern anticline and show a high rate of incision associated with active tectonics.

About 6.15% of the study area is classified in class 2 of high tectonic class of IAT, indicative of the most active tectonics occurs mainly in the southwestern areas of basin and its northwestern end. Class 3 of IAT correspond to moderate active tectonics mainly in the north and south parts of area and covers about 36.56% of basin area. Many sub-basins which are classified in class 3 are located near sub-basins with high tectonic activity and there aren't specific changes and difference in geological and lithological between them. So it seems that in high tectonic activity regions, because of the faults, tectonic activity is higher and classified those sub-basins to high activity class. Class 4 of IAT indicates low active tectonics and covers most of the area in Alamarvdasht basin (57.28%). These classes of tectonic activity spread mainly in the plain of Alamarvdasht and eastern parts of the basin with more gentle and lower strength structural condition including syncline and anticline plunges.

These tectonic activity classes have also well conformity to some morphotectonic landforms in the basin. For example, there are many landforms such as triangular facets, deep narrow gorges and sequences of alluvial fans in regions with high tectonic activity and consider as active tectonic evidences in the study area (Figs. 4 & 5). Finally, according to the absence of tectonic uplift in geodynamic data and results of geomorphic indices that showed there is no sub-basin in very high tectonic activity and also low percent of area with high tectonic activity in the basin and rather wide span of low activity regions, it can be concluded that although there are many morphotectonic evidences in some regions of Alamarvdasht basin, but generally this basin has moderate or low tectonic activity. The sub-basins with moderate or low activity are located in the center, east, southeast and north of basin while southwest and northwest of basin has more tectonic activity.

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