Islamic Azad University
Mashhad Branch

Morphotectonics investigations of the Garehbagh basin area based on morphometric indices, NW Iran

Hassan Haji Hosseinlou

Department of Geology, Khoy branch, Islamic Azad University, Khoy, Iran

Received 18 August 2016; accepted 8 Mar 2017

Abstract

Morphotectonic investigations were carried out by the use of morphometric indices which serve as a tool of identification in regions with active tectonic warp. Landforms in active deformation area are produced from relations of tectonic and surficial processes. One of the most significant landforms underground is rivers that are extremely responsive to tectonic movements mainly uplift and tilting. Accordingly, based on investigation of the rivers and interrelated drainage networks by the use of morphometric indices, we will be able to achieve valuable information about tectonic record of the study area. In this study, in order to find out the tectonic activities of the study area, geomorphic indices were surveyed in Garehbagh basin. In order to determine tectonic movement of Garehbagh basin area, six different morphometric indices including Mountain Front Sinuosity (Smf), Valley Floor Width to Height Ratio (Vf), Index of drainage basin shape (Bs), Stream Length Gradient Index (Sl), Hypsometric integral (Hi), Drainage basin asymmetry (Af) were applied to the study area. According to generated results, SL values change between Smf value according to generated outcome; the most active mountain fronts faults of the study area. Deep and narrow valleys show low Vf values <1.0, these valleys can be classified as V-shaped valleys and Vf values between 1 and 1.5 indicate moderately active regions and Vf values greater than 1.0 can be classified as ―U‖ shaped valleys. According to generated outcome, in the study area, the Hi value is 0.86. High values of the hypsometric integral specify deep incision and rugged relief. Intermediate low values of the integral are related with more evenly dissected drainage basins. Asymmetry factor extensively greater than 50 suggest tectonic tilt. Results from the analysis are accumulated and expressed as an index of relative active tectonics (Iat), which is divided into one class from relatively high tectonic activity. The study area relatively high rates of active tectonics are associated with indicative values of Iat.

Keywords: *Morphotectonics, Morphometric Indices, Garehbagh Basin*

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. The quantitative measurement of landscape is based on the calculation of geomorphic indices using topographic maps, aerial photographs and field work. 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 and Pinter 2002). In recent years DEM data and GIS technologies have been extensively used to determine the morphometric properties of tectonically active regions. The main objective of this study is to define morphological properties of tectonic basin located on the GBFZ, by using GIS technique. Morphometry is defined as quantitative measurement of landscape shape. At the simplest level, land forms can be characterized in terms of their size, elevation (maximum, minimum or average), and slope.

Quantitative measurements allow geomorphologists to objectively compare different landforms and to calculate less straightforward parameters that may be useful for identifying a particular characteristic of an area such as level of tectonic activity area (Keller and Pinter 2002).

We use geomorphic indices of active tectonics, known to be useful in active tectonic studies (Keller and Pinter 2002; Silva et al. 2003). This methodology has been previously tested as a valuable tool in different tectonically active areas, such as SW USA (Keller and Pinter 2002), the Pacific coast of Costa Rica (Silva et al. 2003). and the Mediterranean coast of Spain (Samadkhah 2016). In detail, the combination of the Smf and VF indexes allows Individual Mountain fronts to be assigned different tectonic activity classes (Class 1 to Class 3) developed under decreasing uplift rates (El-Hamdouni et al. 2008). Most studies of geomorphic indices have concentrated on specific indices at specific sites, such as a drainage basin or mountain front. With the exception of the stream length-gradient index (SL), most of the indices are not spatially analyzed over a region.

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*Corresponding author.
E-mail address (es): hajihosseinlou@iaukhoy.ac.ir

Morphometric indices have been developed as basic reconnaissance tools to identify areas experiencing rapid tectonic deformation (Keller and Pinter 2002).
The objective of this paper is to quantify several geomorphic indices of relative active tectonic and topographic development to produce a single index that can be used to characterize relative active tectonics. For this purpose, we will present the tectonic geomorphic analysis of indices followed by a discussion of the active tectonics based upon recent field-based structural and geomorphic observation and analysis. These indices based on topography that are useful in studies of active tectonics. Some of the morphometric indices used for active tectonic studies are:
stream length-gradient index (SL), drainage basin asymmetry (Af), hypsometric integral (Hi), ratio of valley-floor width to valley height (Vf), index of drainage basin shape (Bs), and index of mountain front sinuosity (Smf).

2. Regional setting of the study area

The study area is located North-western of Iran. Tectonically active strike slip GBFZ passing along this area. Basin area mainly drained by Mama, Varid, Bare, Megetalo, Garebagh and Govarchigle rivers. The main flow direction of those rivers is not consistent along the drainage basins due to the irregular topography of the area. The main flow directions of Garebagh and Mama rivers are controlled by the GBFZ. The total area covers 2120 km^2 the main location of Garebagh basin area and its drainage networks are given in Fig 1.

3. Morphometric analysis and geomorphic indices of active tectonics

Several geomorphic indices may be used to analyze topography as well as relative tectonic activity. Individual indices are based on analysis of the drainage network or mountain fronts. The indices represent a quantitative approach to differential geomorphic analysis related to erosion and depositional processes that include the river channel, long profile, and valley morphology as well as tectonically derived features, such as fault scarps. Indices of active tectonics may detect anomalies in the fluvial system or along mountain fronts. These anomalies may be produced by local changes from tectonic activity resulting from uplift or subsidence. The research design is to analyze several different indices in subbasins of the Garebagh river basin (Fig 2) and break them into tectonic classes based upon the range of values of individual indices. These are then summed and averaged and arbitrarily divided into classes of relative tectonic activity over the study area.

3.1. Stream length-gradient index (SL)

Rivers that are not tectonically perturbed typically develop a smoothly changing, concave longitudinal profile. Departures of the river gradient from this ideal smooth shape may reflect variations in the lithology of the river bed, or tectonic activity. Rivers that are tectonically disturbed are predicted to approach a gradient profile rapidly (El-Hamdouni et al. 2008). once such disturbance cases. Thus, perturbations in river profiles may be interpreted as response to ongoing tectonism.
The stream length-gradient index (SL) was defined by Hack (1973) in a study of the role of rock resistance in streams of the Appalachian Mountains of the southeastern United States. The SL index is defined as:

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

Where $\Delta h/\Delta l$ is the local slope of the channel segment being evaluated and l is the channel length from the divide to the midpoint of the channel reach for which the index is calculated. The SL index can be used to evaluate relative tectonic activity. The SL index will increase in value as rivers and streams flow over active uplifts and may have lesser values when flowing parallel to features such as valleys produced by strike–slip faulting (Keller and Pinter 2002). Values of the SL index over the study area, determined from digital elevation models and geographic information system (GIS), are shown on Fig 3. In order to discriminate values at the index related to rock resistance, different levels of average rock strength were defined (by rock type and field observation) from very low strength (silt, salt flat and silty marl), low strength (old terraces and dissected alluvial plain), moderate strength (schist), high strength (sandstone, travertine, meta gabbro, limestone and conglomerate), and very high strength (low grade metamorphisms producing rocks). The values shown in Table 1 for SL index. In the selected Garebagh area SL index is calculated for 20 location selected on 7 river channel. According to generated results SL indices changes between 257 and 1380. The SL index values are relatively low where rock types are alluvion and SL index increases dramatically where the river channel crosses the hard rocks.
Along the Bare Chay River, indices increase where they cross the mountain front with the Garebagh fault. Other relatively high values are related to faults in the harder granitoid (Fig 4). Along Garebagh, the highest values of the indices, which are anomalously high for the area, exist where the river crosses the Garebagh fault.

3.2. Asymmetric factor (AF)

Asymmetry factor analyzed for the basin to determine there any tectonic tilt in the area due to strike slip motion of tectonically active fault zones and its related branches.

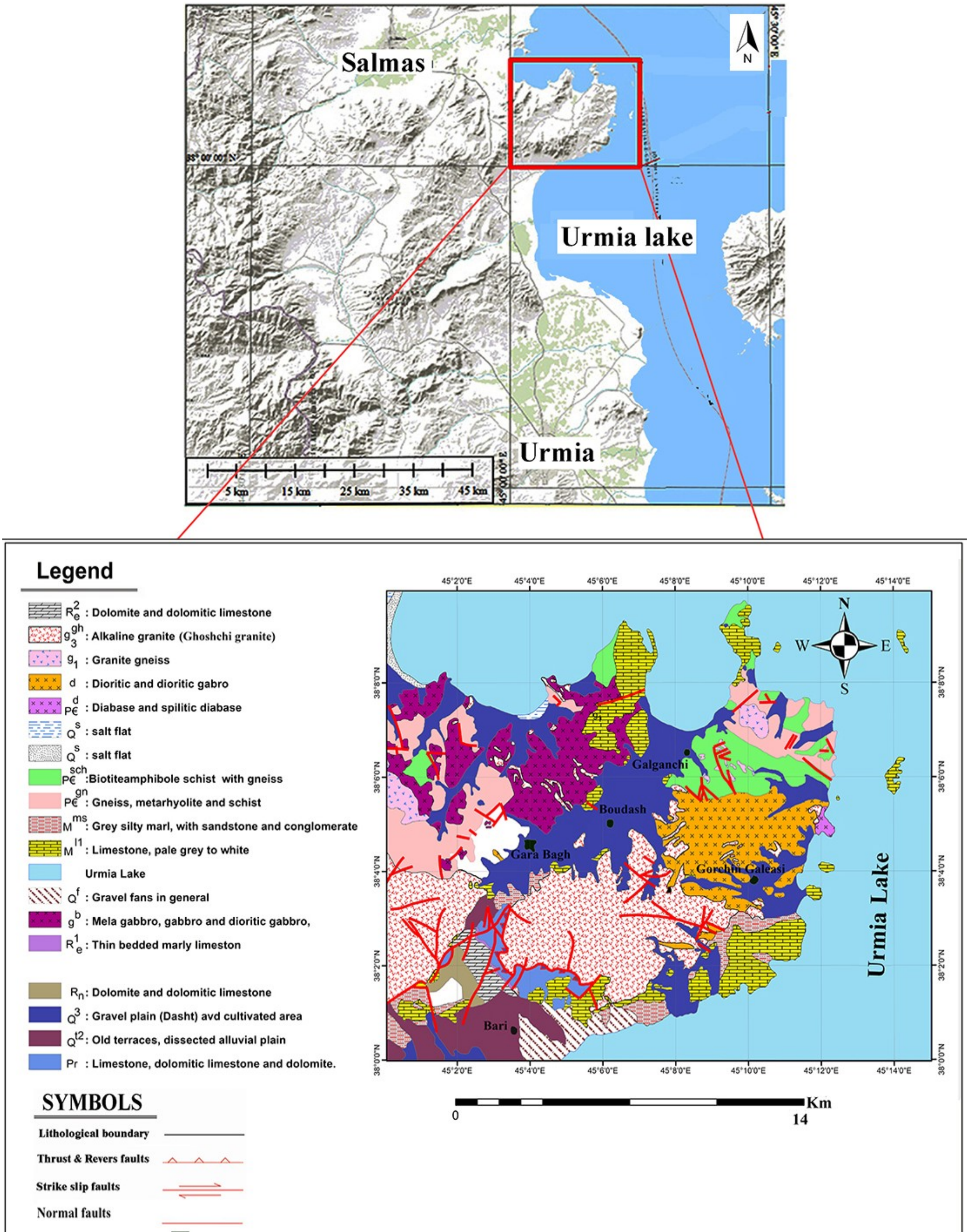

Fig 1. Simplified geological map of the Garehbagh area modified after the geological map of Survey of Iran in 1:100,000 scale, and modified after (Khodabandeh and Amini-Fazl 1993).

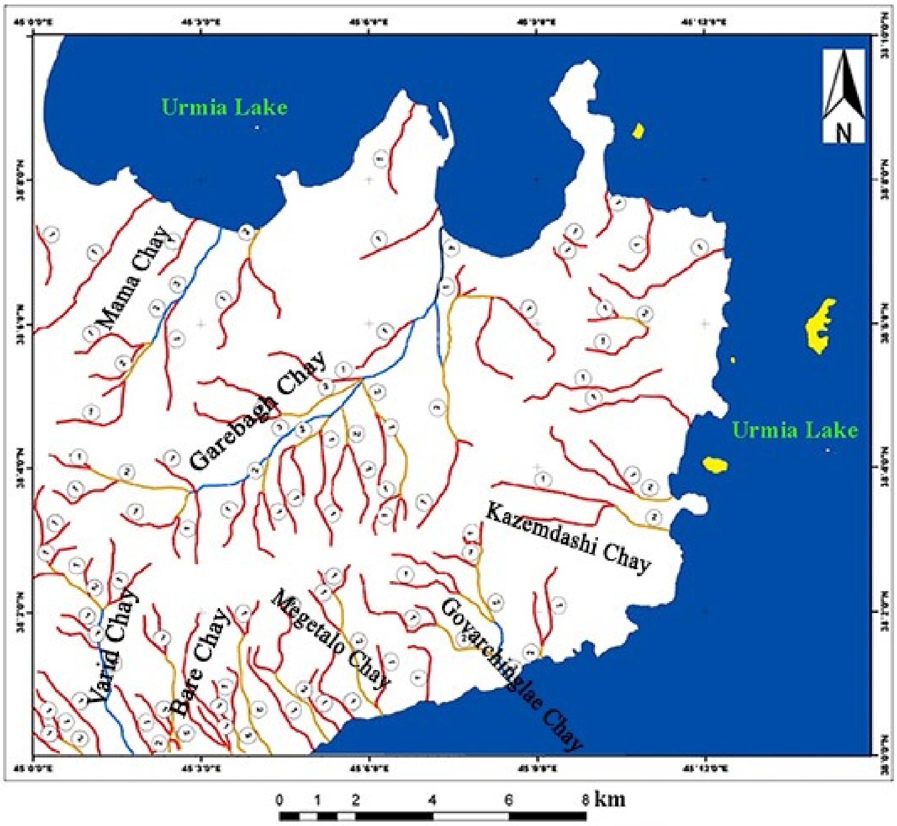

Fig 2. Subbasins of the Garebagh river basin and its reference number

Table.1 SL index values of the different basins of the study area.

No	Basin	L (m)	ΔL (m)	ΔH (m)	SL (m)	Class
1	Mama Chay	6000	2333	100	257	3
2	Varid Chay	9222	2000	120	553	1
3	Bare Chay	4777	1967	202	573	1
4	Garebagh Chay	15333	2222	200	1380	1
5	Megetalo Chay	7333	2500	180	518	1
6	Govarchingale Chay	5000	1111	120	540	1
7	Kazemdashi Chay	5556	1666	122	400	2

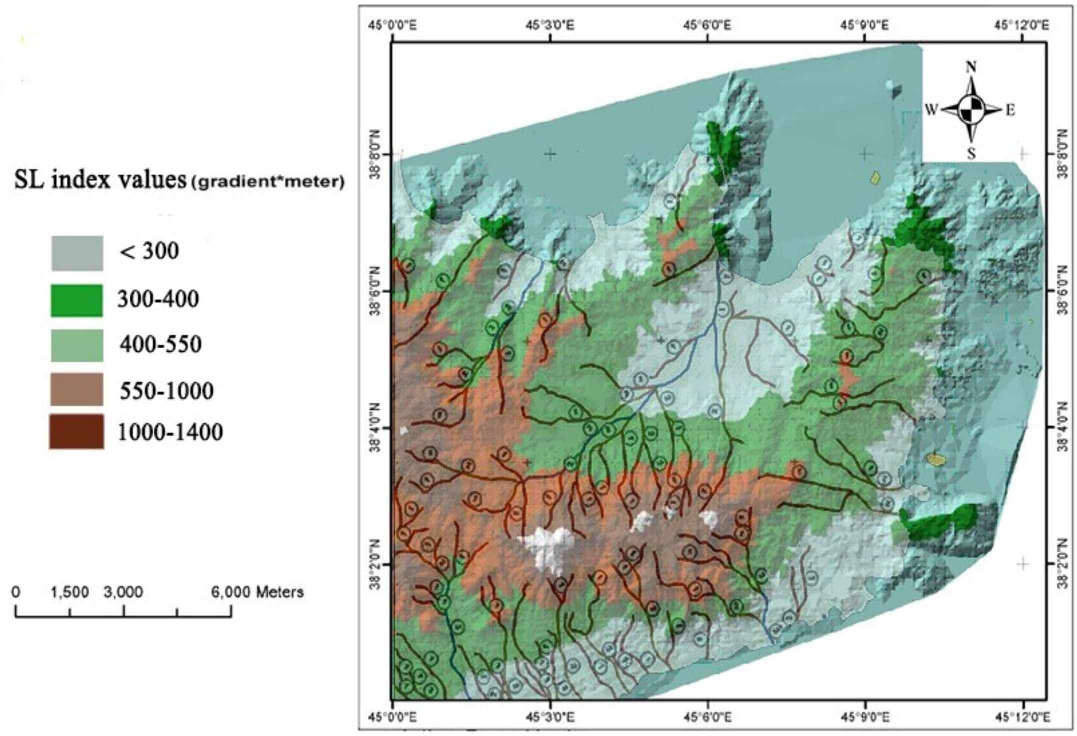

Fig 3. SL index along the Garebagh River drainage network

Fig 4. Faults in the harder granitoid rocks, Kazemdashi area.

The asymmetry factor of the basin is calculated using formula as;

$$AF = 100*(Ar/At)$$

Where Ar is the area of the basin to the right (facing downstream) of the trunk stream and at is the total area of the drainage basin. If a basin has developed under stable conditions with little or no tilting, the Af factor is close to 50. The index is sensitive to change in inclination perpendicular to the channel direction. An Af factor above or below 50 may result from basin tilting, resulting either from active tectonics or lithologic structural control differential erosion, as for example the stream slipping down bedding plains over time. The values shown in Table 2 for AF and values of Af range from about 17 to 52.

3.3. Hypsometric integral (Hi)

The hypsometric integral is an index that describes the distribution of elevation of a given area of a landscape (El-Hamdouni et al. 2008). The integral is generally derived for a particular drainage basin and is an index that is independent of basin area. The index is defined as the area below the hypsometric curve and thus expresses the volume of a basin that has not been eroded. The simple equation that may be used to calculate the index (El-Hamdouni et al. 2008; Keller and Pinter, 2002) is:

$$H_i = H_{int} - H_{min} / H_{max} - H_{min}$$

The values of elevation necessary for the calculation are obtained from a digital elevation model. The average elevation is from 20 points of elevation taken at random from the drainage basin. The hypsometric integral does not relate directly to relative active tectonics. This index is similar to the SL index in that rock resistance as well as other factors affects the value. High values of the index generally mean that not as much of the uplands have been eroded, and may suggest a younger landscape, perhaps produced by active tectonics. High values of Hi could also result from recent incision into a young geomorphic surface produced by deposition. In our analysis of Hi, we consider whether the curve is convex in its upper portion, convex to concave, or convex in the lower portion, as well as the value of the index itself. We assume that if part of the hypsometric integral is convex in the lower portion, it may relate to uplift along a fault or perhaps uplift associated with recent folding. High values of the index are possibly related to young active tectonic and low values are related to older landscapes that have been more eroded and less impacted by recent active tectonics. In general, high values of the hypsometric integral are convex, and these values are generally >0.5. According to generated results, in the study area the Hi values change between 0.56 and 0.86. High values of the hypsometric integral indicate deep incision and rugged relief. Analysis of the hypsometric integral in the study area was based upon digital elevation models and utilization of all basins of greater than the third order. Some of the results are shown on Fig 5. The values shown in Table 3 for Hi and values of Hi range from about 0.56 to 0.86.

3.4. Ratio of valley floor width to valley height (VF)

This index is based on the observation that areas undergoing rapid uplift are marked by incised streams, with narrow valley floors and v-shaped valley profiles. The index is defined as:

$$VF = 2Vw/ [(Eld - Esc) + (Erd - Esc)]$$

Where VF is the ratio of valley floor width to valley height; Vfw is the width of the valley floor; Eld is the elevation of the divide on the left side of the valley; Erd is the elevation on the right side; and Esc is the average elevation of the valley floor. This index differentiates between valleys with a wide floor relative to the height of valley walls with a “U” shape compared to narrow, steep valleys with a “V” shape. Valleys with a U shape generally have high values of VF, whereas V-shaped valleys with relatively low values. Values of VF for the study area are shown in Table 4. Values of VF vary from a low of 0.21 for the Govarchingale, where it is deeply incised into hard gabbro bedrock. In general, the values of VF are relatively low for most of the study area. A similar analysis, carried out by Silva et al. 2003 in the Eastern Betic Cordillera (SE Spain), suggests that V-shaped valleys with low Vf values <1 develop in response to active uplift, and that broad U-shaped valleys with high Vf values >1 indicate major lateral erosion, due to the stability of base level or to tectonic quiescence.

3.5. Index of drainage basin shape (Bs)

Relatively young drainage basins in active tectonic areas tend to be elongated in shape normal to the topographic slope of a mountain. With continued evolution or less active tectonic processes, the elongated shape tends to evolve to a more circular shape (El-Hamdouni et al. 2008). Horizontal projection of basin shape may be described by the elongation ratio, Bs (El-Hamdouni et al. 2008; Ramirez-Herrera 1998) expressed by the equation:

$$Bs = Bl/Bw$$

Where Bl is the length of the basin measured from the headwaters to the mouth, and Bw is the width of the basin measured at its widest point. High values of Bs are associated with elongated basins, generally associated with relatively higher tectonic activity. Low values of Bs indicate a more circular-shaped basin, generally associated with low tectonic activity. Rapidly uplifted mountain fronts generally produce elongated, steep basins; and when tectonic activity is diminished or ceases, widening of the basins occur from the mountain front up (Ramirez-Herrera 1998). Bs was calculated for 7 subbasins in the study areas. The results are shown in Table 5 and values range from 1.67 to 2.80. The classification used in this paper for each morphometric index is based upon EL Hamdouni et al. 2008 (Table 6).

Table 2. Asymmetry factor (AF) values of the different basins of the study area.

No	Basin	A_t (m^2)	A_r (m^2)	%AF	lass
1	Mama Chay	12473	5103	41	2
2	Varid Chay	18530	9638	52	3
3	Bare Chay	5232	2418	46	2
4	Garebagh Chay	25949	50240	52	3
5	Megetalo Chay	7588	3035	40	2
6	Govarchingale Chay	11792	3611	31	1
7	Kazemdashi Chay	20803	3467	17	1

Table 3. Hypsometric integral (Hi) values of the different basins of the study area.

No	Hi	Class	Basin	Values			
1	0.83	2	Mama Chay (h⁄H Values)	0.94	0.99	0.92	0.89
1	-	-	Mama Chay (a ⁄A Values)	0.41	0.59	0.77	0.95
2	0.76	2	Varid Chay (h⁄H Values)	0.94	0.95	0.75	0.88
2	-	-	Varid Chay (h⁄H Values)	0.23	0.48	0.62	0.44
3	0.56	3	Bare Chay (h⁄H Values)	0.97	0.55	0.54	0.73
3	-	-	Bare Chay (a⁄A Values)	0.15	0.81	0.61	0.53
4	0.63	1	Megetalo Chay (h⁄H Values)	0.90	0.83	0.74	0.66
4	-	-	Megetalo Chay (a ⁄A Values)	0.40	0.60	0.81	0.91
5	0.86	1	Garebagh Chay (h⁄H Values)	0.84	0.88	0.91	0.91
5	-	-	Garebagh Chay (a ⁄A Values)	0.31	0.61	0.68	0.76

Table 4.Vf (ratio of valley floor width to valley height) values calculated in the Garebagh area

No	River or creek	E_{ld} (m)	E_{rd} (m)	E_{sc} (m)	V_{fw} (m)	V_f	Class
1	Bare (Baydagh)	1700	1500	1400	150	0.75	2
2	Garebagh (Gavorgan)	1710	1650	1420	110	0.42	1
3	Govarchingale (Garegani)	2250	1950	1300	175	0.21	1
4	Mama (Gezlgayeh)	1635	1535	1400	125	0.68	2

3.6. Index of mountain front sinuosity (Smf)

This index is based on the observation that tectonically active mountain fronts are often more straight than mountain fronts in regions where erosion dominates over tectonics. The index is defined as;

$$Smf = Lmf / Ls$$

Where Lmf is the length of the mountain front along the foot of the mountain where a change in slope from the mountain to the piedmont occurs; and Ls is the straight line length of the mountain front. Smf represents a balance between erosive processes tending to erode a mountain front, making it more sinuous through streams that cut laterally and into the front and active vertical tectonics that tend to produce straight mountain fronts, often coincidental with active faults or folds (El-Hamdouni et al. 2008).

The morphology of a mountain front depends upon the degree of tectonic activity along the front. Active fronts will show straight profiles with lower values of Smf, and inactive or less active fronts are marked by irregular or more eroded profiles, with higher Smf values (El-Hamdouni et al. 2008). Values of Smf are readily calculated from topographic maps or aerial photography.

In the present study Smf values computed for nineteen fronts and generated Smf values are categorized according to EL Hamdouni et al (2008) (Fig 2). According to generated results values less than 1.4 indicates tectonically active areas . Smf values between 1.4 and 3 indicate slightly active areas, Smf values greater than 3 indicate inactive areas (Table 7). This study concluded that the most active mountain fronts associated with active faults of the area.

Table 5. Value of Bs in the analyzed basins or subbasins.

No	Basin	BL (m)	BW (m)	B_S	Class
1	Mama Chay	7100	3440	2.06	3
2	Varid Chay	7440	2660	2.80	3
3	Bare Chay	3890	1440	2.70	3
4	Garebagh Chay	11670	7000	1.67	3
5	Megetalo Chay	4220	2330	1.81	3
6	Govarchingale Chay	4000	1670	2.40	3
7	Kazemdashi Chay	3440	1660	2.07	3

Table 6. Morphometric indices classifications used in this study (El-Hamdouni et al. 2008).

Class	Vf	SL	Bs
1	<0.5	SL≥500	4≤Bs
2	0.5-1	500 >SL≥300	4>Bs>3
3	>1	SL<300	3≥Bs

4. Relative tectonic activity index (Iat)

Relative tectonic activity index (Iat) is obtained by the average of the different classes of geomorphic indices (S/n) and divided into four classes, where class 1 is very high tectonic activity with values of S/n between 1 and 1.5; class 2 is high tectonic activity with values of S/n > 1.5 but < 2; class 3 is moderately active tectonics with S/n > 2 but <2.5; and class 4 is low active tectonics with values of S/n >2.5 (El-Hamdouni et al. 2008).

We have chosen to have three classes of tectonic activity for the various indices. The averaging of the indices of the active tectonics S/n and values of Iat are summarized in Table 8 drainage basins in the study area (Samadkhah 2016).

The high class values (low tectonic activity) for Iat mainly occur in the northwest and southeast of Garebagh, while the rest of the study area has classes of Iat suggesting moderate to high tectonic activity (south and southwest of Garebagh); and very high along parts of the northeast Garebagh (Samadkhah 2016).

5. Discussion and Conclusions

Mountain front sinuosity and valley width to height ratio were used to evaluate the tectonic activity of northeast Garebagh. The outcropping rocks in these fronts are mainly gravel plain and gabbro. Precambrian hard gabbro and dioritic gabbro are exposed in Garebagh front and Govarchingale front, respectively. The resistance of these rock types to erosion is generally similar, which is different from the mountain fronts southwest of Garebagh, where the lithological differences play a role in the morphotectonics indices variation. Smf values for Govarchingale front and Garebagh front are extremely low (1.80 and 1.90, respectively), while the Smf value for Galgachi front is larger (3.50). The average VF values for the valleys in Govarchingale front and Garebagh front are low (0.21 and 0.42, respectively) and relatively high in Bare front (0.75). The higher Smf and VF for Bare front relative to Govarchingale front and Garebagh front are attributed to two factors: the curved shape of the front, which causes a higher Smf, and the uplift of the base level.

According to generated results, the Garebagh basin is mainly influenced by GBFZ. The results of the applied indices: SL indices change between 257 and 1380 indicative of tectonical influence of the area by GBFZ. Smf values computed for six fronts show that the most active mountain fronts are associated with active faults of the area. Valley floor width to height ratio (Vf) ranges between 0.21 and 0.75 in the deep area and narrow valleys show low Vf values <1.0. These valleys can be classified as “V” shaped valleys and Vf values between 1 and 1.5 indicative of moderately active regions and Vf values greater than 1.0 can be classified as “U” shaped valleys. These areas are subjected to major lateral erosion due to right lateral motion of GBFZ. Hi values change between 0.56 and 0.86 and high values of the hypsometric integral indicate deep incision and rugged relief. Asymmetry factor significantly greater than 50 suggests tectonic tilt. Calculating morphometric indices for Garebagh basins show that, direction of tilting is towards the southwest. Morphotectonic indices indicate that differential uplifting has occurred in the past. The northeast of the study area shows very high relative tectonic activity.

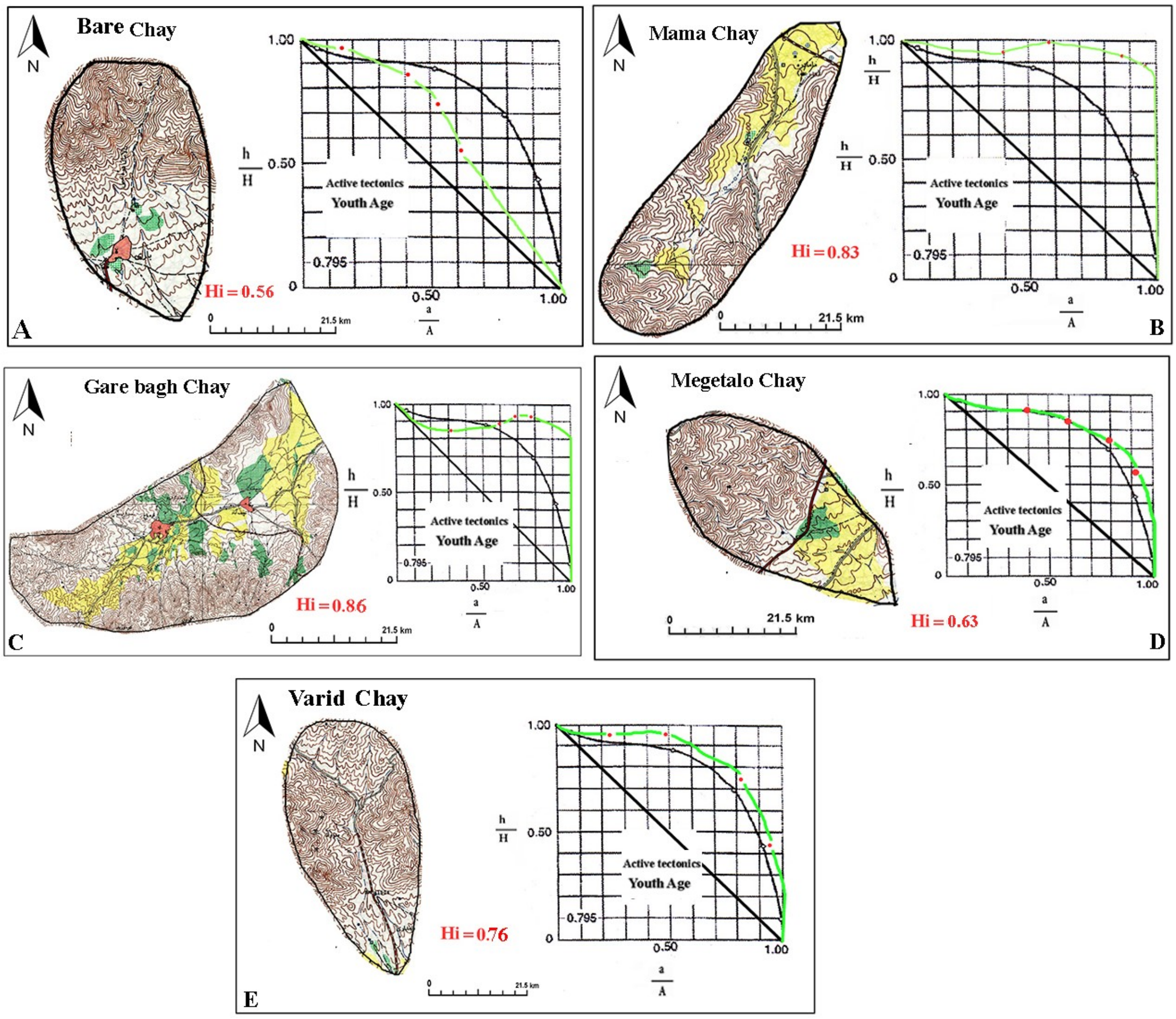

Fig 5. Hypsometry curves of subbasins in the study area.

Table 7. Values of the Smf in the defined mountain fronts

No	Mountain front	L_{mf} (m)	L_s (m)	S_{mf}	Class
1	Gezlgayeh	38800	19350	2	2
2	Gavorgan (Garebagh)	34400	18300	1.90	2
3	Varid	47300	16130	2.90	2
4	Sal	38700	20600	1.90	2
5	Govarchingale	25800	13980	1.80	2
6	Galgachi	49450	13980	3.50	3

Table 8. Classification of the Iat (relative tectonic activity index) in the subbasins of the Garebagh basin (SL: stream length-gradient index; Af: drainage basin asymmetry; Hi: hypsometric integral; Vf: ratio of valley floor width to valley height; Bs: index of drainage basin shape; Smf: index of mountain-front sinuosity).

No	Basin	SL	Af	Hi	Bs	Vf	Smf	Iat =S/n	Class
1	Mama Chay	3	2	2	3	2	2	2.33	3
2	Varid Chay	1	3	2	3	2	2	2.17	3
3	Bare Chay	1	2	3	3	2	2	2.17	3
4	Garebagh Chay	1	3	1	3	1	2	1.83	2
5	Megetalo Chay	1	2	1	3	2	3	2	2
6	Govarchingale Chay	1	1	2	3	1	2	1.67	2
7	Kazemdashi Chay	2	1	2	3	2	3	2.17	3

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