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Tectonic geomorphology assessment of neotectonics in the north of Damghan region, Alborz mountain belt, Northern Iran

Mersana Keshavarz[1], Farzin Ghaemi*[1], Ali Faghih[2], Mostafa Ghanadian[3]

1. Department of Geology, Faculty of Science, Ferdowsi University of Mashhad, Iran
2. Department of Earth Sciences, School of Science, Shiraz University, Shiraz, Iran
3. Department of Geology, Iranian Offshore Oil Company, Tehran, Iran

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Abstract

In mountain ranges, neotectonics can be considered as the main factor contributing to tectonic-geomorphological features being the result of the competition between tectonics and erosion. Several tectonic-geomorphological indicators such as drainage basin based (asymmetry factor of drainage basin (A_f), hypsometric integral (Hi)) and mountain front based (mountain-front sinuosity (S_{mf}), valley floor width –valley height ratio (V_f)) were used to assess the tectonic activity in the north of Damghan Region, Alborz Mountain Belt, Iran. The results highlight that the tectonic activity of the Alborz region resulted from the growth of pop-up and flower structures during tectonic inversion and following strike-slip tectonic activities. The faults of Astaneh, Damghan and North Damghan, which collectively constitute the SW part of the sinistral Shahrud fault system control the tectonic activity of the study area during the Late Quaternary.

Keywords: *Alborz, Damghan, Morphotectonic, Morphometric parameters, Transpression*

1. Introduction

Tectonic geomorphology is the study of Earth's surface landforms resulting from competition between tectonics and erosion in the Quaternary and recent. Interaction of these processes led to the development of several characteristics landforms, which may influence human society impacting economic and political issues (Keller and Pinter 2002; Nourbakhsh 2014). As the present-day topography and rock uplift in the mountain ranges have resulted through competition between tectonics and erosion (England and Molnar 1990; Bishop 2007), drainage pattern, topography and geomorphic appearances are useful to rate recent tectonic activity in a given region (Keller et al. 2000; Azor et al. 2002; Molin et al. 2004; Bull 2007; Pérez-Peña et al. 2009; Gaidzik and Ramírez-Herrera 2017). Several morphometric parameters including hypsometric variables, gradient, georelief energy, valley networks and valley profiles, basins shape, slopes morphology are used in the tectonic geomorphological studies (Pánek 2004). Using the GIS (Geographic Information System) and remote sensing techniques via geo-processing operations, these parameters can be extracted from the Digital Elevation Model (DEM) for analysis and modeling approaches (e.g. Pérez-Peña 2009). Due to the fact that the study area is located in a tectonically active region, the study of young geological landforms in this region can help identify the active fault structures, which can be very useful in seismic studies in the city of Damghan.

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*Corresponding author.
E-mail address (es): fghaemi@ferdowsi.um.ac.ir

This research is aimed to investigate the tectonic activity recorded in the geomorphic features through quantitative analysis of geomorphological indices of sub-basins located north of the Damghan area, Southeastern Alborz Mountains, Iran (Fig 1).

2. Geological setting

The Alborz Mountain Belt with ~1200 km length is located in northern Iran. This sinuous shaped belt separates two major structural zones of Iran, South Caspian basin (-28 m elevation) from the central Iran (~1,000 m elevation). The tectonic activity in this belt is relatively well understood. In the central parts and west of the Alborz Mountains Belt, the tectonic activity is characterized by N–S regional shortening which led to partitioning of deformation into thrust and sinstral faults (Jackson et al. 2002; Allen et al. 2003; Vernant et al. 2004; Ritz et al. 2006; Guest et al. 2006; Tatar et al. 2007). Tectonic and geomorphological studies in the eastern parts of the belt, revealed that N–S shortening is partitioned onto the Khazar thrust and the sinistral Shahrud fault system (Wellman 1966; Tatar et al. 2007; Hollingsworth et al. 2010), which run along the north and south sides of the belt, respectively.

The Damghan city (Fig 1) which is now located on the southern edge of the Alborz Mountains 54.5° E, was greatly struck in 856 A.D by the destructive Qumis earthquake (Ambraseys and Melville 1982). There are several major faults including the Astaneh, North Damghan, and Damghan faults in the study area, which collectively constitute the SW section of the fault system of Shahroud with sinistral slipping (Fig 1).

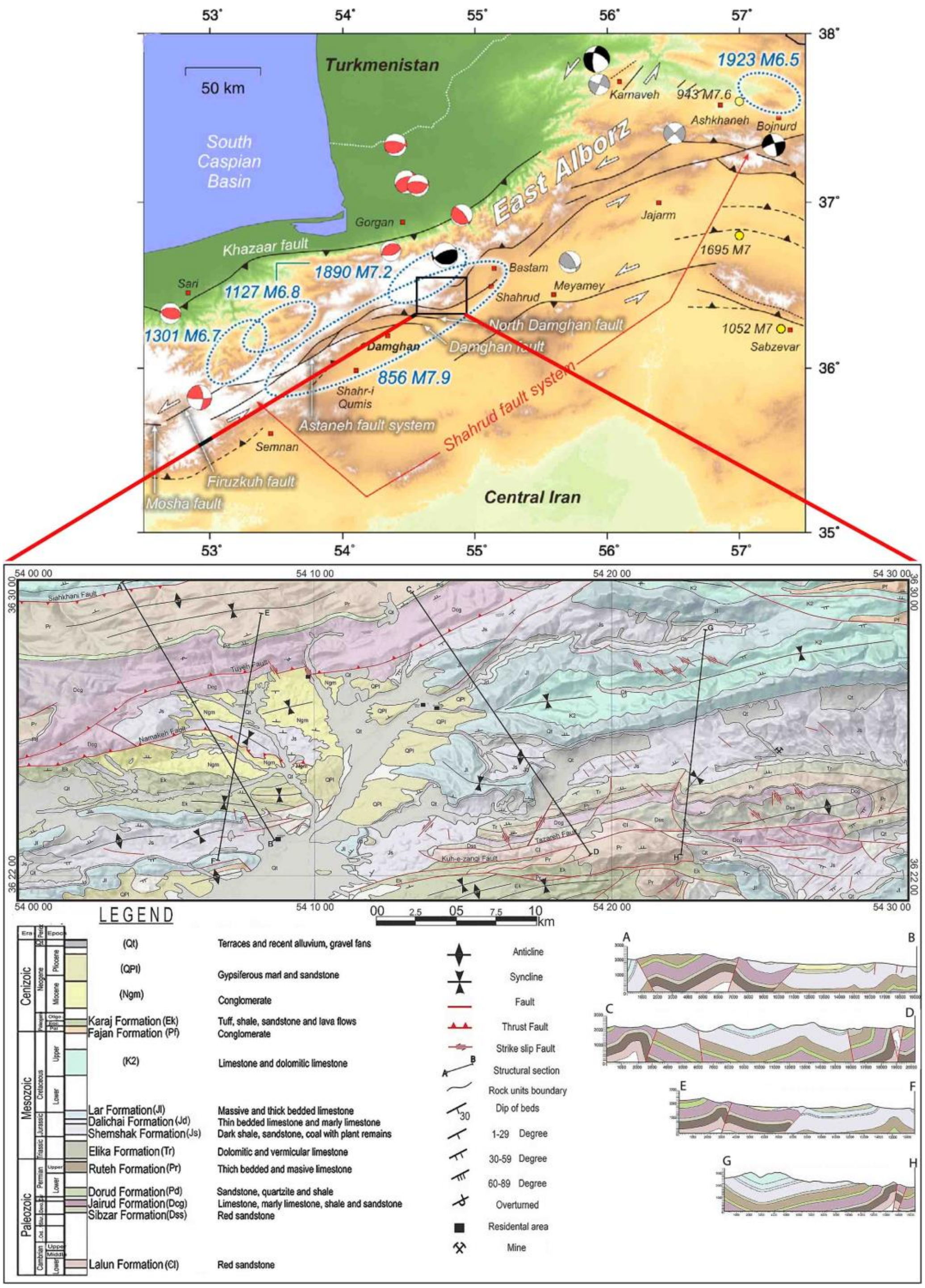

Fig1. Regional geological map of the study area. The map shows the location of the study area in the east Alborz (modified after Hollingworth et al. 2010).

The NE–SW striking Astaneh with more than 150 km length is the longest fault in the southern part of the Alborz range. Evidence of tectonic activity during the late Quaternary can be observed along these faults (Hollingsworth et al. 2010; Klinger 2010). The Shahrud Fault is the southern border of the Alborz Mountains and continues toward the Shahrud city. The Damghan fault is located south of the Astaneh fault and separated from which, and passes directly from north of Damghan city. At the edge of the heights of Kuh-e-Katcast, the North Damghan thrustis parallel to the Astana fault in the north of Damghan fault. (Fig 1) (Hollingsworth et al. 2010). Damghan, Astaneh and North Damghan faults show sinistral shearing, concertedly make the SW part of the

Shahroud fault system. These faults are the southern margin of Mountains in east Alborz from Bojnurd to Semnan. The study area includes pop-up structures that are formed during inversion tectonic activities of Alborz mountain belt. Strike-slip faults and flower structures suggest transpressional tectonic regime at eastern part of Alborz (Mc Clay and Buchanan 1996; Turienzo et al. 2005; Zanchi et al. 2006; Ehteshami and Yassaghi 2007; Hollingsworth et al. 2010) (Fig 2).

3. Material and Method

Two categories of tectonic geomorphological indicators have been used in this study, which can be categorized into two groups as drainage basin based: asymmetry factor of drainage basin (Af), Hypsometric integral (Hi) and parameters of mountain front based: valley floor width - valley height ratio (Vf), mountain-front sinuosity (Smf), which are effective gadget for active tectonic studies (Bull and McFadden 1977; Rockwell et al. 1985; Keller 1986; Ramirez-Herrera 1998; Silva et al. 2003).

Satellite images and geological maps (1:100000 and 1:250000) were used for essential data for geomorphometric analysis. Arc Hydro Tools and Arc GIS 10.3 were used to obtain 5th order sub-basins in this area (El-Hamdouni et al. 2008; Dehbozorgi et al. 2010; Alipoor et al. 2011; Mahmood and Gloaguen 2012; Faghih and Nourbakhsh 2015; Partabian et al. 2016). In this study, ASTER GDEM version 2, ArcHydro hydrology module and ArcGIS 10.3 were used to draw out network of rivers from DEM.

3.1. Mountain front sinuosity index (*Smf*)

The balance between erosion and tectonic processes represents the *Smf* index. The first erodes the mountain front and active tectonics product straight mountain fronts (Bull and Mc Fadden 1977; Keller 1986). This index can be used to rate mountain fronts tectonic activities (Azor et al. 2002; Keller and Pinter 2002; Silva et al 2003; Bull 2007). Frontal sinuosity of mountain (*Smf*) is introduced by Bull and McFadden (1977) as follows:

$Smf = Lmf/Ls$

Lmf is the length of the mountain front beside the mountain domain and Ls is the length of the mountain front along a direct line. Where the tectonic uplift is stronger than the erosive processes, the value of *Smf* will be high, while the low *Smf* is an indication of the erosion superiority over the tectonic uplift (Keller 1986; Silva et al. 2003; Pérez-Peña et al. 2010; Giaconia et al. 2012).

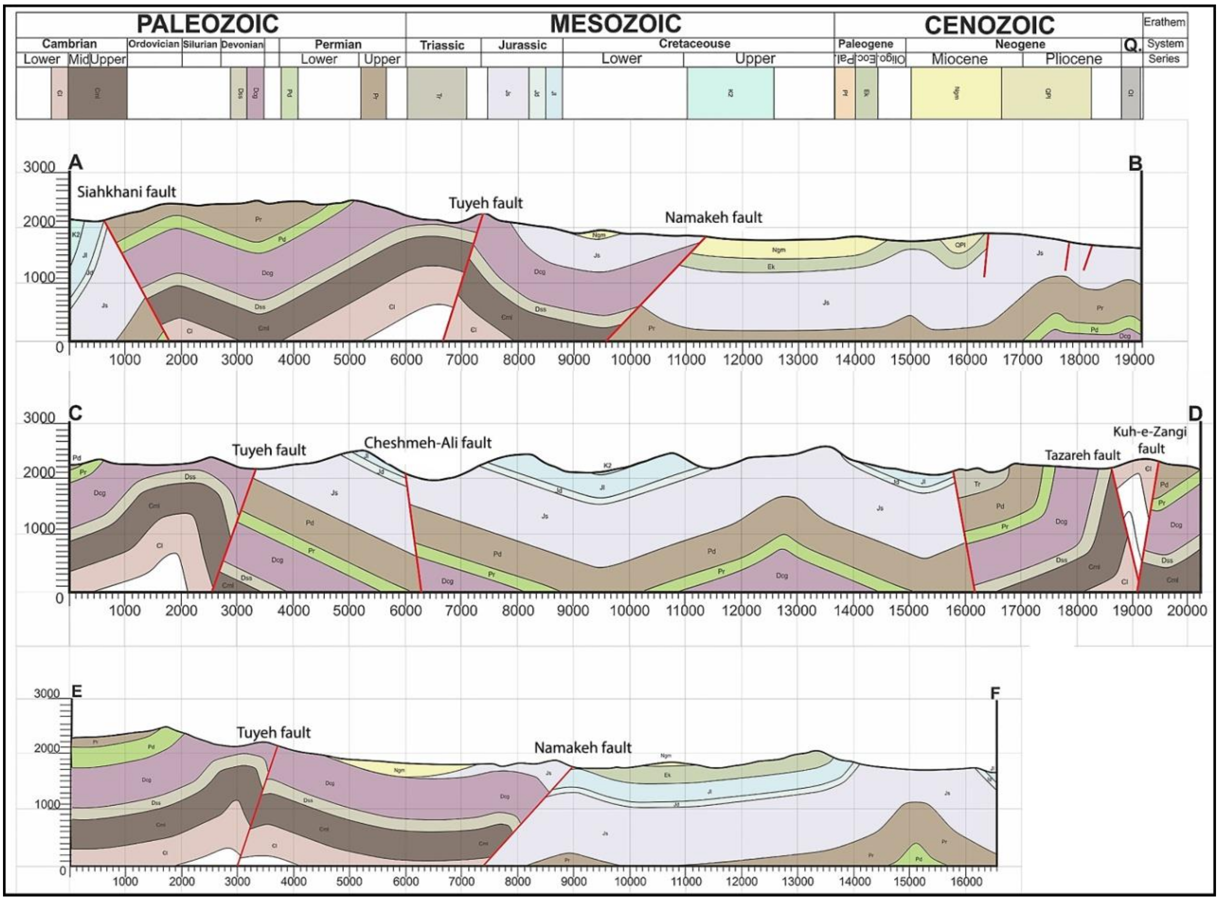

Fig2. Simplified geological cross section of the study area. Major faults and folds (main structures) are shown (modified after Hollingsworth et al. 2010).

3.2. The valley width/height ratio (*Vf*)

To distinguish among V and U-shaped valleys representing active and inactive regions, *Vf* is defined as the ratio of width to average height of the valley (Bull and McFadden 1977). V_f can be calculated as follows:

$V_f = 2\ V_{fw} / ((E_{ld}\text{-}E_{sc}) + (E_{rd}\text{-}E_{sc}))$

where the ratio of the width of the valley floor to the height of the valley is *Vf*, the width of the valley floor is *Vfw*; height to the left side of the valley is *Eld*; the elevation on the right side is *Erd* and medium height of the valley floor is Esc. Comparing the width with average height of the valley put out an index that the flow is more downcutting or more eroded laterally on adjacent dips. V-shaped valleys (V_f<1) indicate rivers with downcutting and strong tectonic uplift, while U-shaped valleys (V_f>1) represent rivers that are more subject to lateral erosion (Keller and Pinter, 2002). *Vf* commonly is high in U-shaped valleys, but is low in V-shaped valleys (Keller and Pinter 2002; E1-Hamdouni et al. 2008). This index (Vf) has been used on different mountain fronts (e.g. Silva et al. 2003; El-Hamdouni et al. 2008; Pedrera et al. 2009; Pérez-Peña et al. 2010; Giaconia et al. 2012).

3.3. Drainage basin asymmetry factor (*Af*)

The asymmetric factor (*Af*) is a way to detect conceivable tectonic effect on the tilting of basins (Keller and Pinter, 2002). This is how *Af* is calculated:

$Af = (A_r / A_t)*100$

where the total area of the drainage basin is A_t and the area of the right side of basin (downstream) of the trunk stream is A_r. The borderline of *Af* is equal to 50. Values greater than or less than 50 are controlled by tectonic factors, differences in erosion processes or rock type (El-Hamdouni et al. 2008). Following Pérez-Peña et al. (2010) and Mahmood and Gloaguen (2012), we also present *Af* as an absolute value where the number of variations between the value of Af and the value of 50 which is the base could be seen. Low Af-50 values (Af-50 <5) are commonly indicate symmetric basins, while high values of Af-50 indicate asymmetric basins (Giaconia et al. 2012).

3.4. Hypsometric integral (*Hi*)

The hypsometric integral index represen the area and altitude distribution of a given drainage basin (Strahler 1952; Giaconia et al. 2012). The *Hi* can be calculated as follows (Pike and Wilson 1971; Keller and Pinter 2002):

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

where H_{mean} is the mean elevation, H_{max} is the maximum and H_{min} is minimum heights of an area. *Hi* varies between 0 and 1, when tectonic activity is young, the *Hi* index will be high, but in older landscapes it will decrease, indicating greater erosion strength and less tectonic activity (Keller and Pinter 2002; Pedrera et al. 2009; Mahmood and Gloaguen 2012).

4. Results

To calculate the *Smf* index, eight mountain fronts in the region were surveyed (Fig 3). The index varies from 1.03 (the front no 1) to 1.22 (the front no 3). The *Smf* values of the sub-basins are assigned in Table 1. This index is divided into three classes by El-Hamdouni et al. (2008): Class 1, *Smf* = 1.0 to1.5 (High), Class 2, *Smf* = 1.5 to 2.5 (Moderate) and Class 3, *Smf* >2.5 (Low). Fronts 1 and 4 belong to class 1 and others belong to class 2 of tectonic activity.

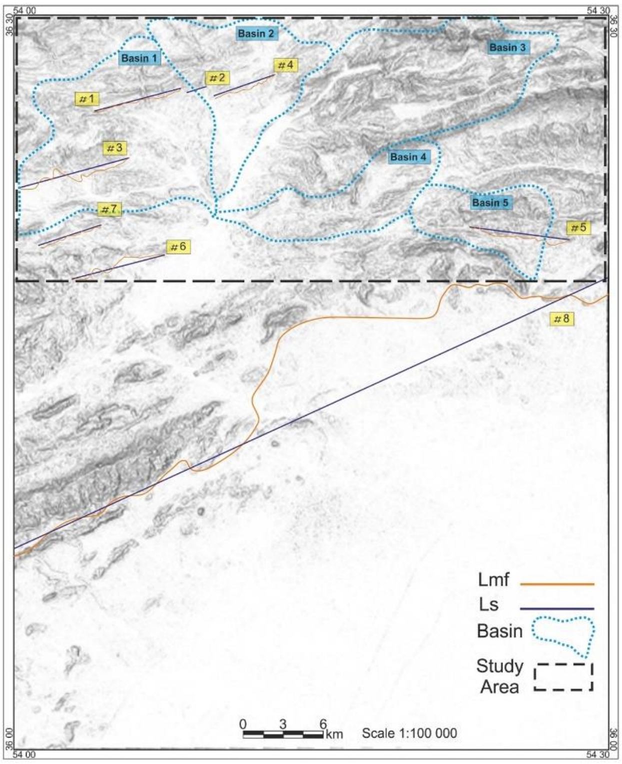

Fig 3. Geographical locations selecting for calculation of Smf index in the area of study

Tectonically active mountain fronts with relatively low *Smf* values are relatively straight, while more tortuous mountain fronts are specified by high values of *Smf* (Keller and Pinter 2002). Facets or flat irons that are separated by wineglass valleys characterize some mountain fronts in this area.

The valley cross-sections are placed 0.5 to 1 km upstream of the mountain fronts, related to the drainage basin size as recommended (Silva et al. 2003). *Vf* values in the major valleys that are cut on the mountain fronts are calculated using the cross-sections drawn from the digital elevation model. The valleys that cut the mountain fronts in this area show *Vf* values from 0.32 (northeast of basin 3) to 4.29 (southeast of basin 1) (Fig 4). The Vf index is separated to three classes: (Vf <0.5) = Class 1, (0.5 <Vf <1.0) =Class 2 and (Vf> 1) =Class 3 (El-Hamdouni et al. 2008).

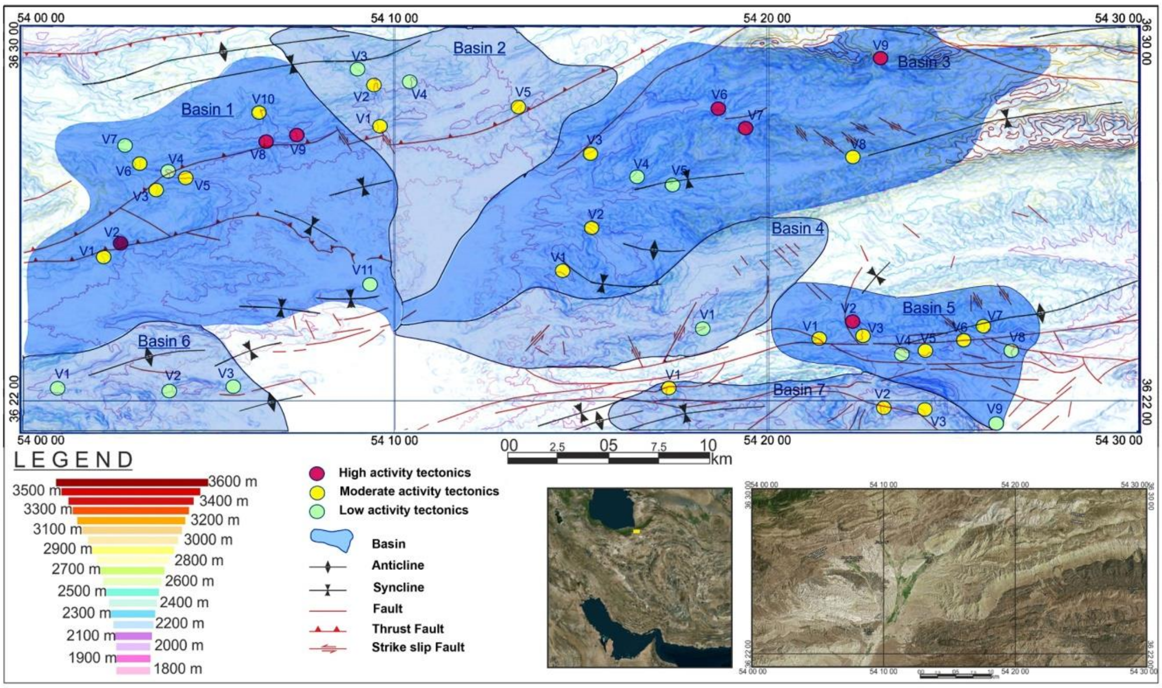

Fig4. Geographical locations for calculation of V_f index in the study area

The valleys are mostly narrow above the mountain front (Ramirez-Herrera 1998). The measured values of V_f are assigned in Table 1 In general, *Vf* values are rather low in most study areas, indicating that V shape-valleys with values of $Vf \leq 1$, indicating the development of Class 1 in response to active uplift.

The obtained *Af*-50 values vary between 41.5 and 0.59 in this area (Fig 5). According to the measured index, the south of this area and the junction of thrust and strike slip faults shows higher *Af*-50 values and are more affected by movements of active tectonic (Fig 4). These values indicate Class 1 of tectonic activity. The asymmetry factor (*Af*) is sort into three categories: Class 1 ($Af > 65$ or $Af < 35$), Class 2 ($35 < Af < 43$ or $57 < Af < 65$), and Class 3 ($43 < Af < 57$) (El-Hamdouni et al. 2008).

Hypsometric integral index (*Hi*) that varies from 0 to 1, defined as the area below the hypsometric curve. *Hi* values close to 0 indicate very eroded and large values close to 1 indicate weak eroded basins. The resulting values of *Hi* varies from 0.28 (in sub-basin 2) to 0.33 (in sub-basins 1 and 3) (Fig 6 and 7). The Hypsometric Integral index (*Hi*) is sort into three categories: Class 1 ($Hi > 0.5$), Class 2 ($0.4 < Hi < 0.5$) and Class 3 ($Hi < 0.4$) (El-Hamdouni et al. 2008). Based on the estimated values of *Hi*, the whole of sub-basins are highly eroded and belong to class 3 of tectonic activity.

5. Discussion

The active tectonics of the Alborz is relatively well understood based on tectonic geomorphological observations and seismic approach (Hollingsworth et al. 2010). The N–S trending shortening is partitioned into the thrust and strike-slip faults including Khazar thrust is located on the north side and sinistral Shahrud fault system is located on the south side of the mountains, respectively (Wellmann, 1996; Tatar et al. 2007; Hollingsworth et al. 2008). Eastern Alborz has experienced several destructive earthquakes during historical periods (Masson et al. 2005). Seismic records show a large number of earthquakes with small magnitude and and rare large earthquakes in Alborz (Berberian and Yeats, 2001; Masson et al. 2007). In this study, we have analyzed morphotectonic and neotectonic indices to appraise the tectonic activity of this area. These are *Smf* (sinuosity factor of mountain), *Vf* (the ratio of width to height of valley), *Af* (Basin asymmetry coefficient) and *Hi* (hypsometric integral). For *Smf* we calculated this index for 5 fronts and based upon obtained results we concluded that front 1 show moderate to high tectonic activity, which is located in sub-basin 1 and situated along Tuyeh fault. *Vf* index (41 locations in total) shows that in 27 locations there are moderate to high tectonic activity, in good agreement with fronts with moderate to high *Smf* index. In general, the results of this index show high tectonic activity for main faults of the study area including Tuyeh fault, Namakeh fault and Kuhzangi fault. Evaluation of Af index in this area shows sub-basins 1, 4 and 5 have a medium tectonic activity and sub-basins 2 and 3 have a high tectonic activity. In addition, sub-basins 1 and 5 are tilted to the right and sub-basins 2, 3 and 4 are tilted to the left. Based on the results of this study, detailed description of tectonic activity in the Damghan region of the east Alborz, NE Iran was presented based on the geomorphic indicators via quantitative analysis.

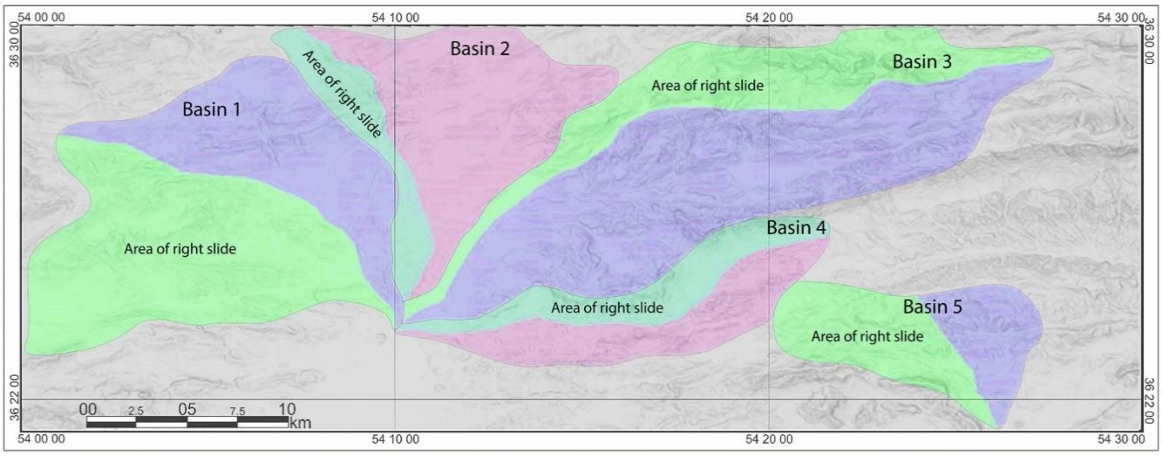

Fig5. Tilting of sub-basins that are shown after calculation of *Af* index in this area

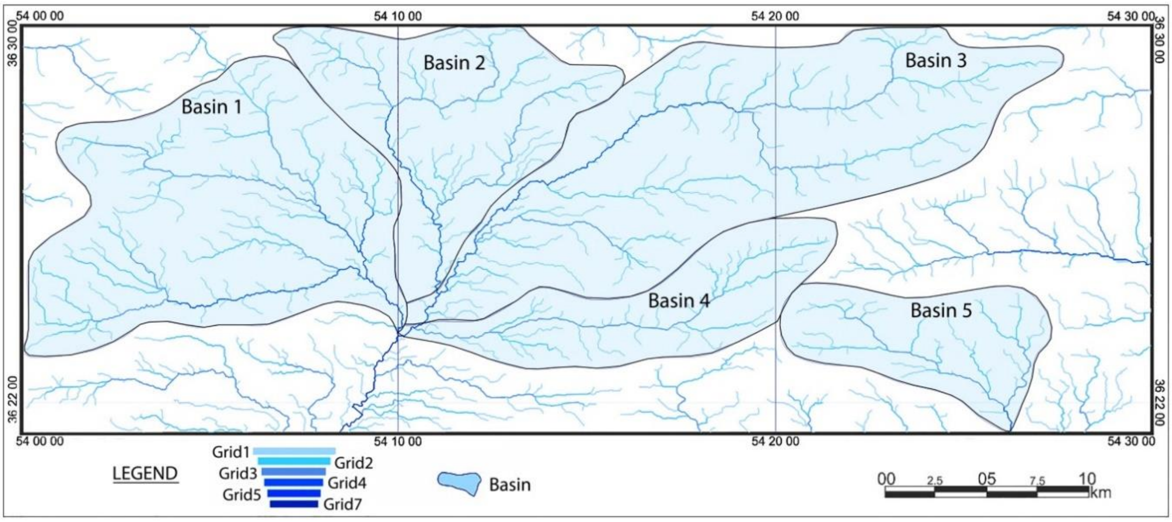

Fig6. Sub-basins that are considered for calculation of *Hi* index in the study area.

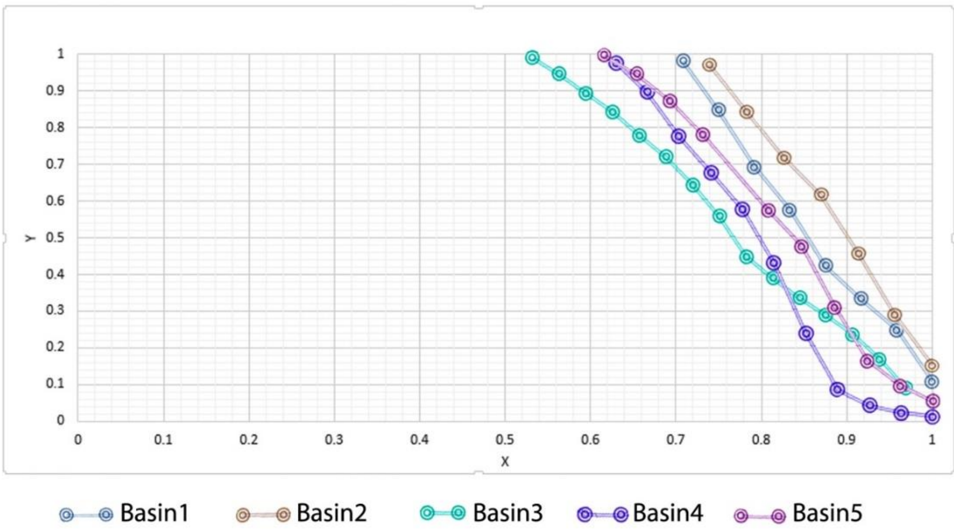

Fig7. Hypsometric curves of the basins

Table 1: Geomorphic indices and related class of tectonic activity meseared in the study area

Basin	*Af*	class	*Vf*	class	*Smf*	class	*Hi*	class
1	62	2	1.36	3	1.03	1	0.33	3
2	22	1	1.22	3	1.13	2	0.27	3
3	30	1	0.78	2	1.22	2	0.33	3
4	42	2	1.5	3	1.09	1	0.30	3
5	63	2	1.08	3	1.11	2	0.29	3

The late Quaternary tectonic geomorphology in the study area was expressed in form of frequent stream offsets due to regional deformation on the other side of Astana fault, Damghan and North Damghan faults, together form the SW part of Shahroud fault. The tectonic activity along these faults led to occurrence of several great earthquakes during the Holocene (Fig 8). Distribution of earthquake epicenters in this area indicates the presence of several active seismic sources. The highest density of earthquakes is concentrated in the vicinity of Damghan and Astaneh faults. One of the prominent features of these faults is the occurence of earthquakes with smaller magnitude but in greater numbers. According to Barbarian et al. (1993), the earthquake of December 22, 856 A.D. with a magnitude of Ms = 7.9 is probably related to the movements along the Damghan and Astaneh faults. The results of this study are consistent with other works (e.g. Hollingsworth et al. 2010) were carried out in this region based on the seismological approach.

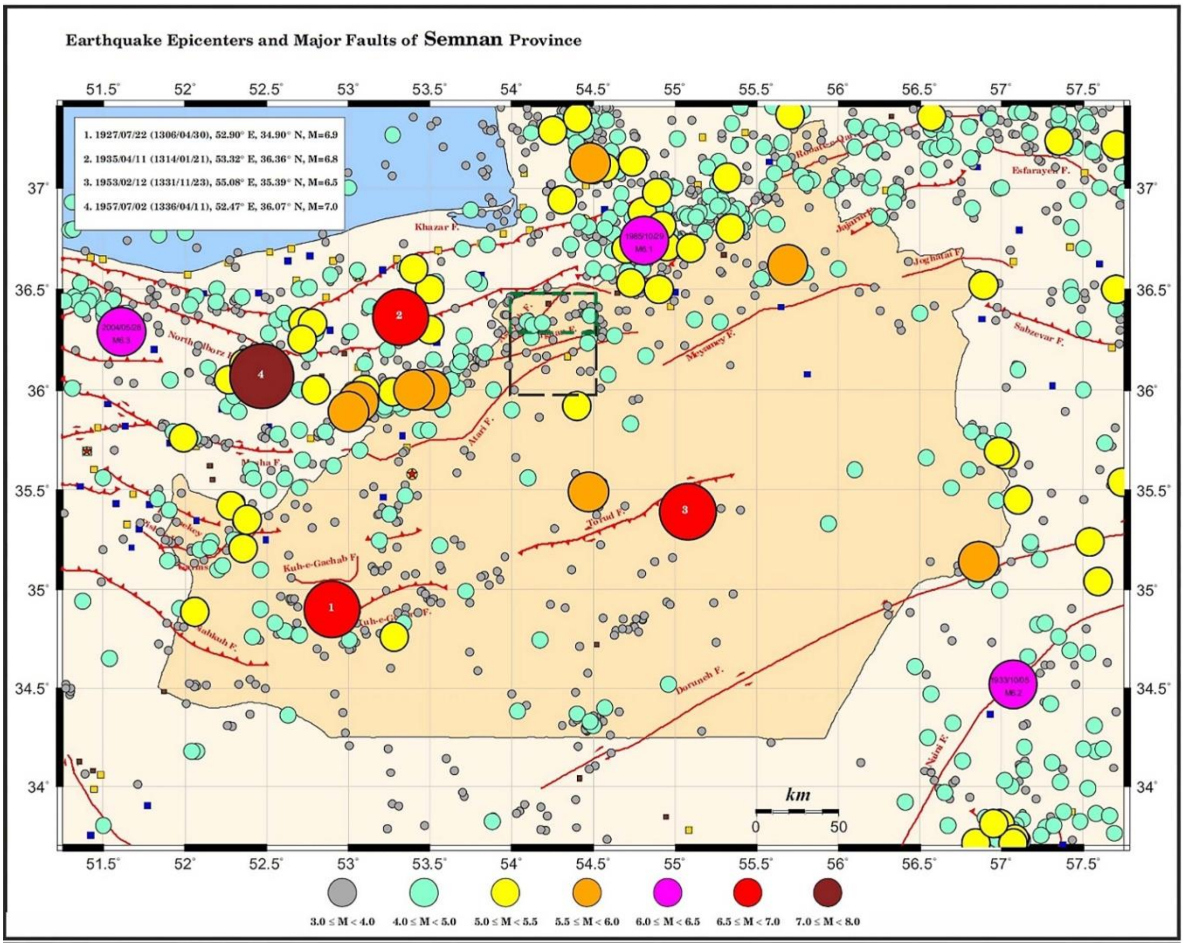

Fig8. Earthquake hypocenter maps of Semnan province taken from the Iranian Seismological Center (Institute of Geophysics). The location of the study area is marked with a green box and the position of the 1: 100000 map of Damghan is marked with a black box. Earthquakes magnitude in the study area and the 1:100,000 map of Damghan ranges between 3 to 5 (modified after Hollingsworth et al. 2010).

6. Conclusion

Tectonic geomorphological indicators that are used in this study are drainage basin based (e.g. Hypsometric integral (*Hi*), drainage basin asymmetry factor (*Af*)) and mountain front based (e.g. valley floor width – valley height ratio (*Vf*), mountain-front sinuosity (*Smf*)) which can provide helpful tools for active tectonic study. Quantitative analysis and measurements of geomorphic indicators were used to apprise the tectonic activity in this area. In general, obtained results of these indices shows high tectonic activity for main faults of the study area include Tuyeh fault, Namakeh fualt and Kuhzangi fault while in around their vicinity this index shows moderate tectonic activity.

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