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Morphotectonic analysis of Darband area (Southwest of Azna) through Digital Evaluation Model (DEM)

Siamak Baharvand[1*], Jafar Rahnamarad[2]

*1)Department of Geology, Khorramabad Branch, Islamic Azad University, Khorramabad, Iran

Email:Baharvand_si@yahoo.com

2) Department of Geology, Zahedan Branch, Islamic Azad University, Zahedan, Iran

Email:jrahnama2003@ yahoo.com

***Corresponding Author**

Abstract

Morphotectonic indices are useful tools for the evaluation of neotectonics of areas. The advantage of these indices is their quickness in analysis and their capability in determining neotectonic activities. In order to analyze the neotectonic activities of Kohesefid area in western Iran, some morphotectonic indices including sinuosity of the mountain front (Smf), valley floor width to valley height ratio (Vf), sinuosity of river's channel (S), Asymmetry factor (Af), Steram length - gradient index (SL) and condition of alluvial fans were measured and investigated using Digital elevation model (DEM) and some remote sensing techniques in GIS environment. The measured Results showed that the studied area in terms of morphotectonic has high activity to moderate Democrats.

Keywords: Morphotectonic, Neotectonic, Lorestan, Kohesefid of Azna

1. Introduction

On the Earth's surface, there is almost no region unaffected by neo-tectonic activity over several thousand years. In fact, it can be argued that active neotectonics is deforming the Earth.

The dynamics of the earth form rugged landscape neotectonics and provide the main geomorphologies. Their impact, however, deals with the structural change and active geomorphology of effective dynamic processes in shaping the landscapes.

An example of quantitative studies on the relationship between neotectonics and geomorphologies is morphological indices, specifically applied for neotectonics studies. These indices can be employed to explore the neotectonic activity in the short term through the next in-depth investigation. The geomorphological indices are useful in the evaluation of neotectonic activities, because they can easily identify the regions experiencing rapid or slow tectonic activities in the past (Ramirez-Herrara, 1998). Such indices are usually calculated through topographic maps and digital elevation model (DEM) (Karami, 2009).

2. Geographical area under study

The study area is geographically located in the southwestern of Azna and west of Aligodarz. Geographically, it is situated at of 17" 33" to 33" 33" N and 10" 49" to 02" 49" W (Fig. 1). The study area was identified on the 1:250,000 Khorramabad map published by the Iranian GSI (B.HALBron, P.MAURiZof, M.R.Sahandi, F.Berthier, j. P. BilliAult). This region stretches from the north to Bowki village and Emamzadeh Shahgheib, from the south to Ghalghale Spring Qolqoleh, from the east to the city of Azna and Aligoudarz and from the west to the city of Doroud (Fig. 2).

3. Access points to the study area

The region can be accessed through two major paths:

1. Aligoudarz-Azna road approximately 25 km.
2. Doroud-Azna road approximately 25 km (Fig. 3, 4 and 5).

Along this asphalt road, there are a number of minor roads allowing access to the study area. The examples are Gorji and Kamandan roads branching from Azna, while the minor roads cross several villages including Dehsefid, Kanesorkh and Malekabad.

4. Geomorphic indices

The study on forms created through tectonic and geomorphic processes will provide better insight into the influential forces involved. Accordingly, geomorphics is a science covering all relational aspects of geological structures and forms found on Earth (Adams et al. 1999).

In recent years, researchers have been exploring the qualitative evidence in an effort to quantify the behavior and tectonic movements of various regions. In this procedure, researchers have proposed a variety of markers under morphotectonic quantitative evidence. A major advantage of using these markers is to quickly assess the level of tectonic activity across wide areas within a short time. Obviously, these markers can be applied as one of the basic guidelines on earthquake risk analysis. Therefore, a geomorphic study was carried out on Sefidkuh region. To achieve this objective, several indices including sinuosity of mountain front (S_{mf}), river channel sinuosity (S), river gradient (SL), valley width to height ratio (Vf) and drainage basin asymmetry (Af) were calculated precisely.

5. Sinuosity mountain front (S_{mf})

This index is used to calculate the following equation:

$$Smf= \frac{Lmf}{LS}$$

Where S_{mf} represents the mountain front sinuosity, L_{mf} represents mountain front length along the mountain-alluvial link, and LS represents the mountain front straight line (Fig. 6).

This index represents the balance of forces between the front side of the mountain (S_{mf}) and the erosive

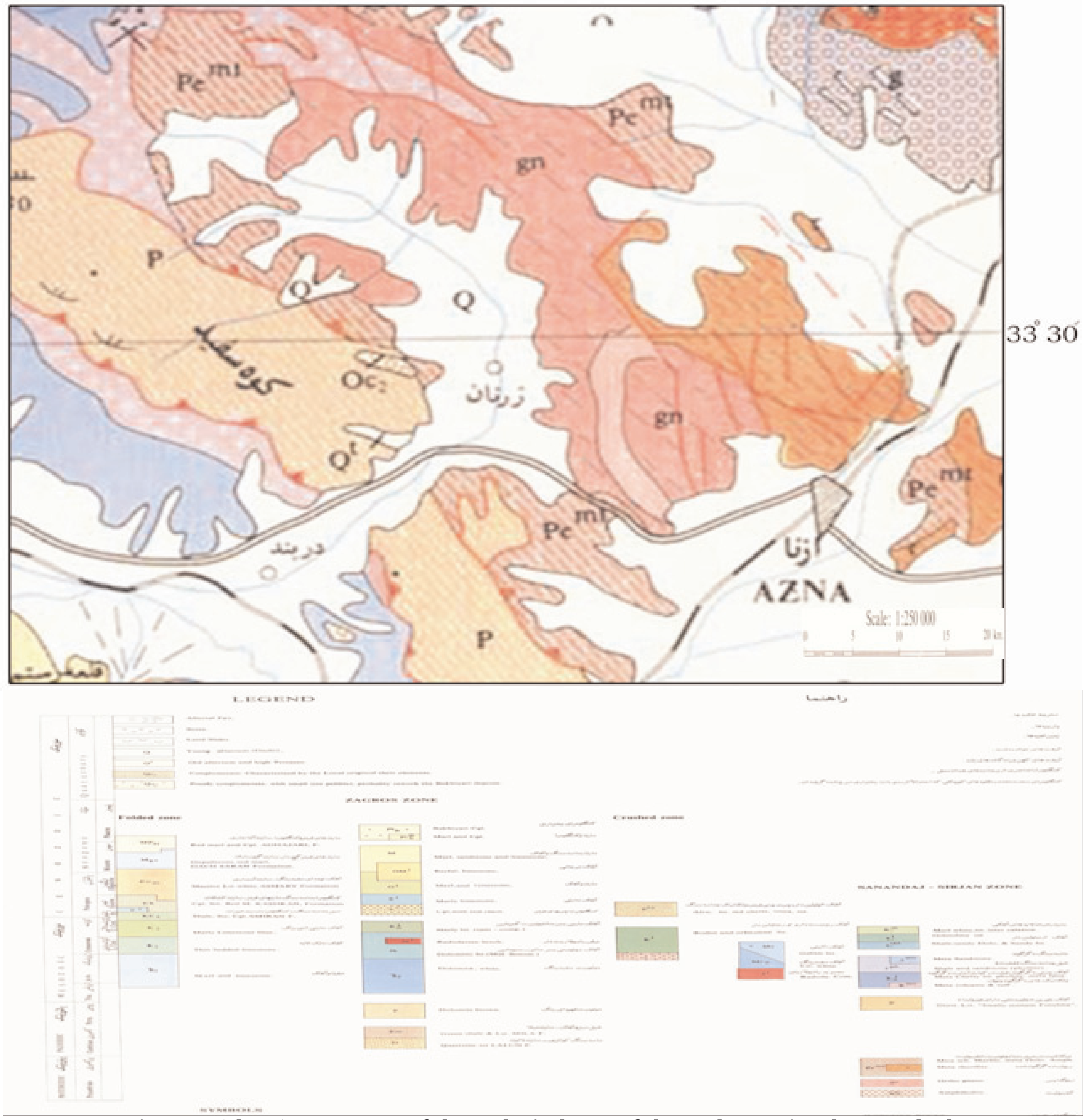

Figure 1. (above) covers part of the geological map of the study area in Khorramabad. Basic map published by the Iranian GSI at a scale of 1:250,000. (bottom), part of the geological map guide of Khorramabad. (See attachment A).

forces tending to cut and create the gulf shapes into the mountain front. On the other hand,the neo-tectonic tends to create a straight mountain front simultaneously with successive faulting.

This index is divided into three categories (EI Hamdouni et al. 2007):

1-Category 1:1.1≥S_{mf}

2-Category 2: 1.5≥1.1≤ S_{mf}

3-Category 3: 1.5≤S_{mf}

In general, if sinuosity approaches 1, it reflects that the recent mountain uplift and active neotectonics. Conversely, as it approaches over 1, it reflects lower neotectonic activity and dominance of erosion. And the larger number represents a decrease Neotectonic activities and overcome the erosion.

Table 1 illustrates the values of mountain sinuosity using satellite images, geological maps and GIS. According to the results, the value of S_{mf} in this area

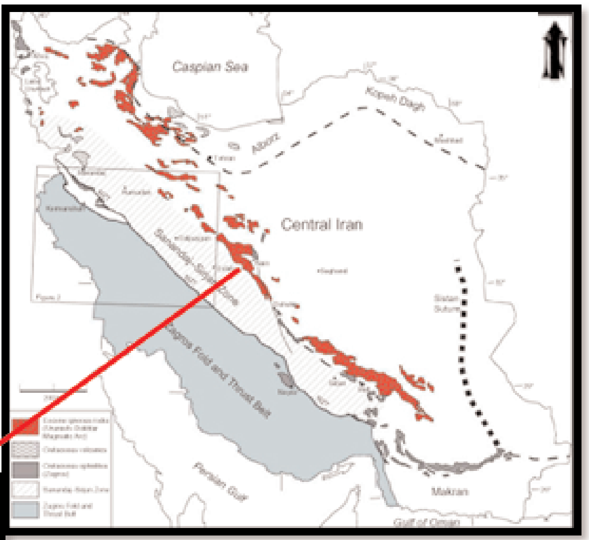

Figure 2. Map of Iran (Moosavi and Mohajjel, 2014)

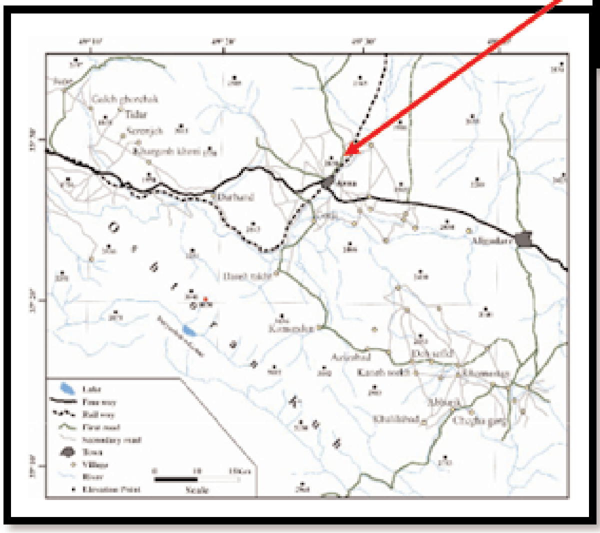

Figure 3. Access road map of the study area (Sadr, 2009).

Table 1. Calculation of mountain front sinuosity in the selected study areas

Line Colour	L_{mf}(Meter)	L_s(Meter)	S_{mf}
Pink	10127	9637	1.05
Blue	12453	9471	1.31
Green	3970	2812	1.41
Dotted Green	14627	11729	1.25

was between 1.05 to 1.41, where the lowest S_{mf} is related to Zone 1 (pink line) located in the north-western of Sefidkouh (small), where the majority of spots entail high S_{mf}.

According to the results in the table, Sefidkouh front in Zone 1 in the northwest had lower S_{mf} and the mountain front in these regions are nearly straight line, which could be due to major fault activity in the study area. In Zone 3, similarly, the averages of the index are closer together indicating moderate activity (EI Hamdouni et al. 2007). In Zone 1, however, this index is less than other areas and has relatively high tectonic activity. Due to the predominance of erosion on tectonic forces, these areas were not allowed to erode the mountain front and form a sinuosity (Fig. 7).

6. River channel sinuosity (S)

The pattern of rivers is very sensitive to gradient variations (Adams et al. 1999). He examined the relationship between the tilt in the river bed and sinuosity variations, concluding that by increasing the amount of tilt to achieve a constant gradient, the river sinuosity decreases followed by lower tilt.

In steep areas, however, the river has straight channel and path, and as gradient decreases, the river meanders. Many of the new rivers show different patterns including straight, meanders and branches. By identifying these patterns and the sinuosity levels, the active tectonic situation of an area along the river can be explained.

Generally, sinuosity of a river increases at lower gra-

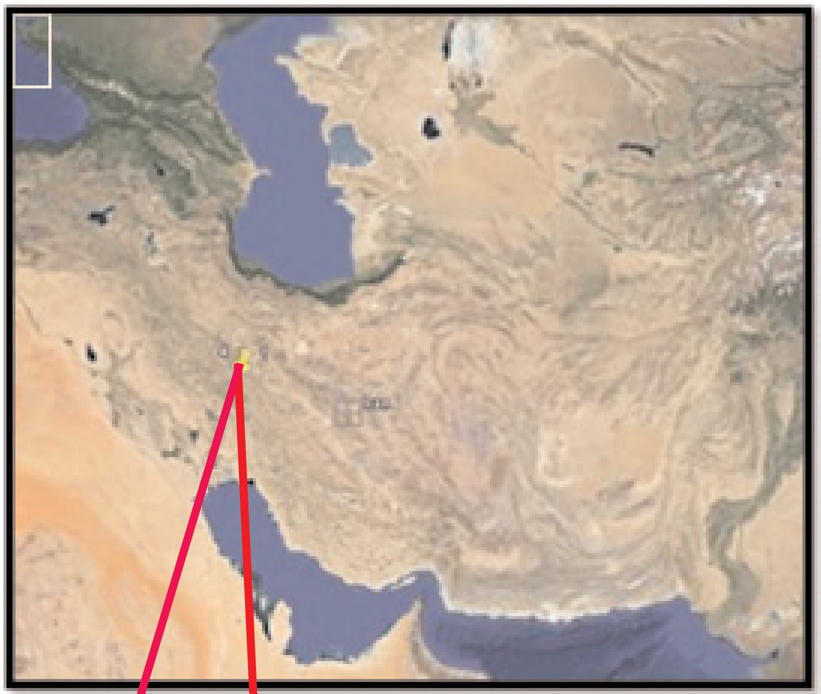

Figure 4. Satellite image of the study area.

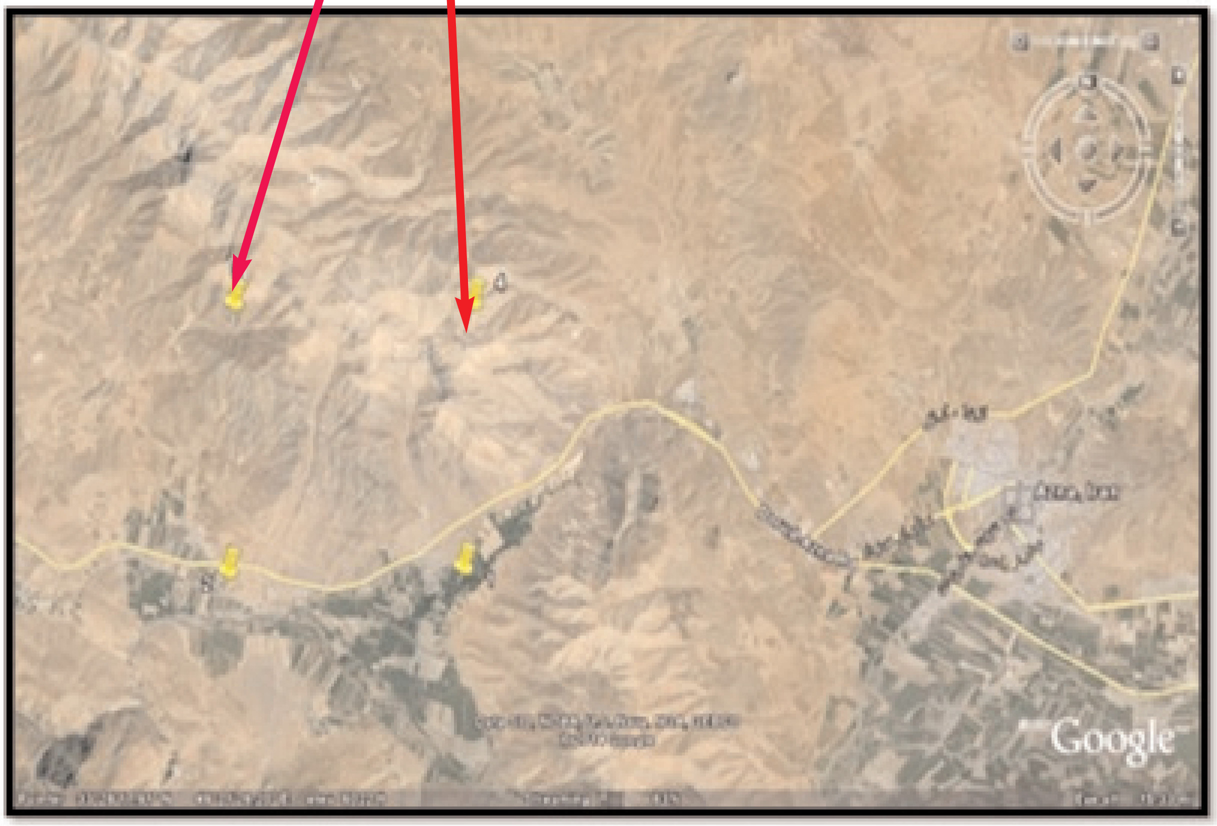

Figure 5. Google Earth image of the study area.

dient. Such sinuosity changes reflect the reduction in tectonic activity in the region. Similarly, as the gradient increases, the river channel morphology tends toward branches which can well explain the tectonic upheaval.

By definition, river channel sinuosity refers to the length of the straight line across the valley (Adams et al. 1999). This is calculated using the following equation. Where, V is the channel length, and C in the length of the straight line across the valley (Fig. 8).

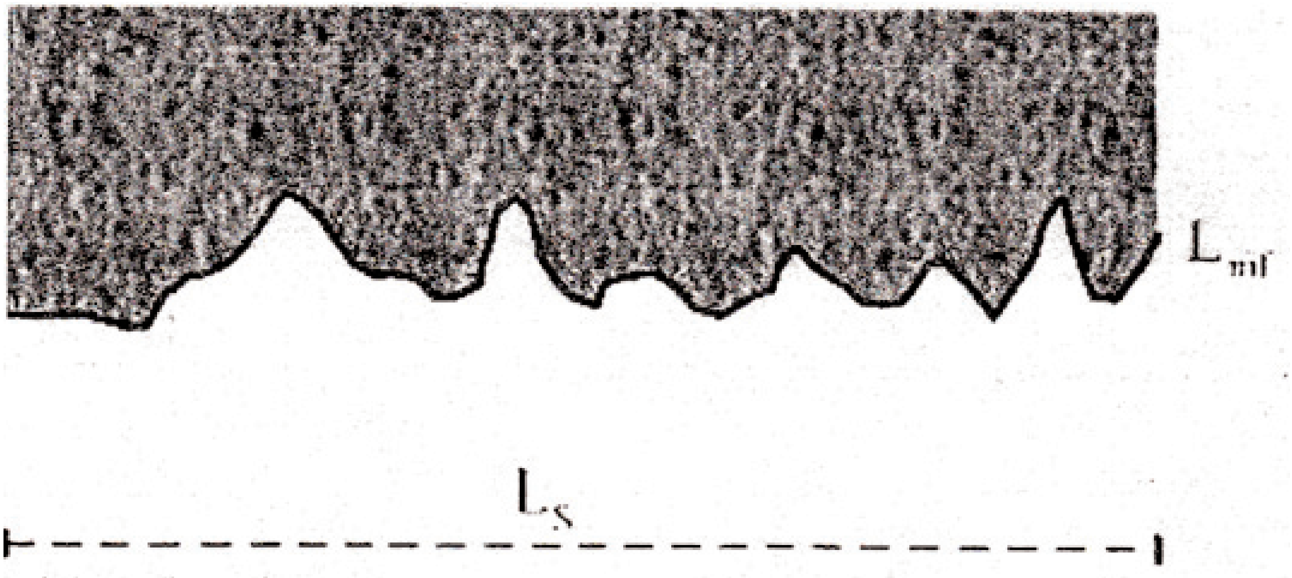

Figure 6. Factors determining sinuosity of mountain front

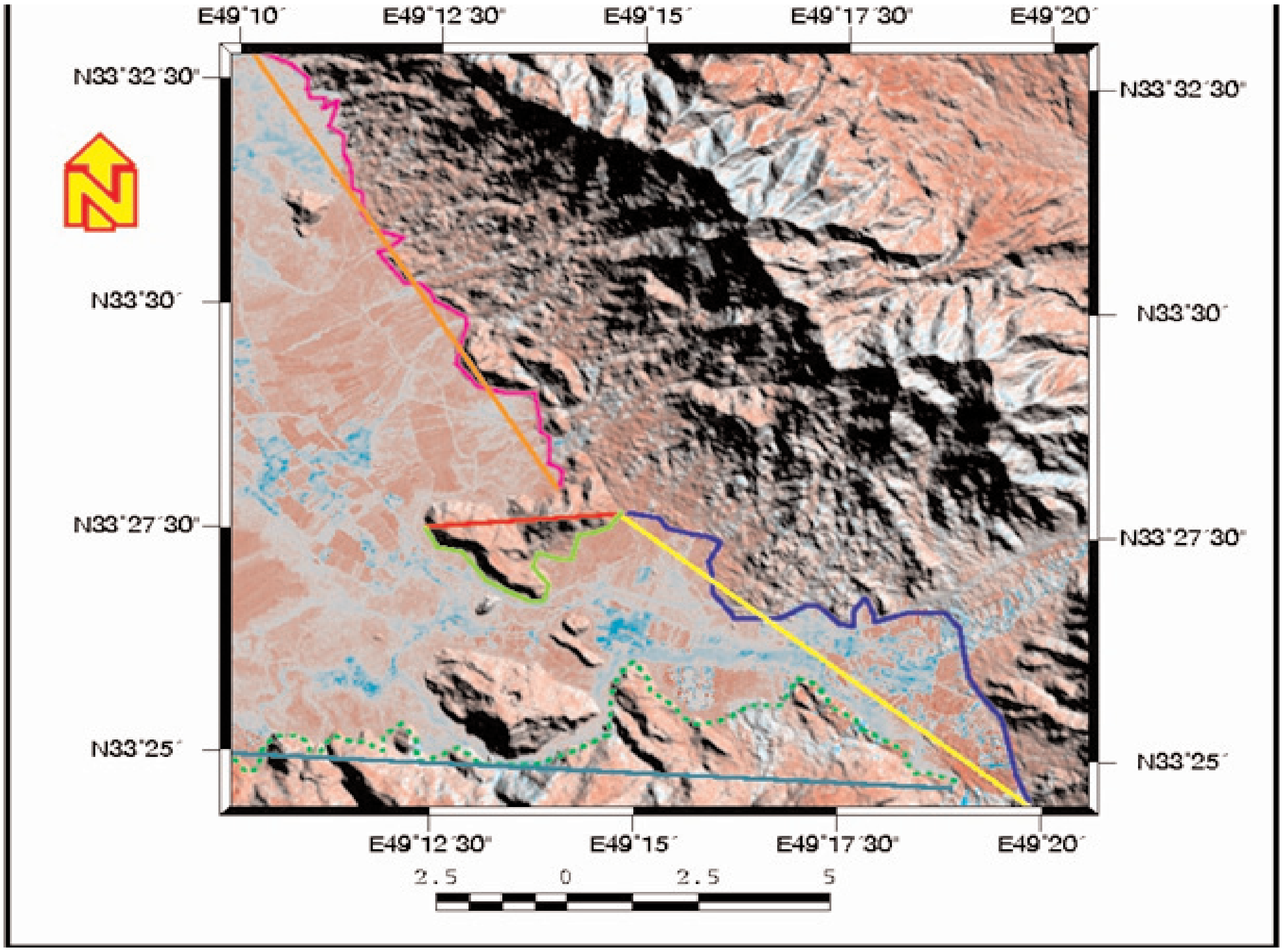

Figure 7. Satellite image of the mountain fronts in the study areas (colored lines correspond to the table).

S=V/C

This morphometric index was assessed by selecting the three most important rivers of the region (Fig. 8) as the length of river channels and river straight lines across the valleys were measured using Arc GIS as shown in Table 2. As can be seen in the table, all the values calculated for sinuosity on river channels of Sefidkouh area represent average tectonic activity.

7. River length-gradient index (S_L)

The third index within the assessment of the area was SL. The river length-gradient is an active tectonics index associated with river channel shapes formulated through the following equation:

$S_L = \Delta H / \Delta L \times L$

Where $\Delta H / \Delta L$ represents the river local gradient (ΔH is the height difference while ΔL is the area length). Moreover, L represents the channel length from the point where the index is calculated to the highest channel point.

The river gradient index is used to show the gradient changes in the river longitudinal profile. It is believed to be factor reflecting the strength of the river (Hach, 1973). The river gradient index is usually very sensitive to changes in gradient, which is why thetectonic activity relationships are evaluated through rock strength and topography (Keller and Pinter, 1996). Since the river gradient index is particularly sensitive to changes in gradient, it can be beneficial in evaluating active tectonics. The river gradient index is also sensitive to rock strength, making it difficult to distinguish the effects of active tectonics and rock strength. The value of this index is high in regions where the rocks show high strength or active tectonic leads to vertical deformation. Hence, high values

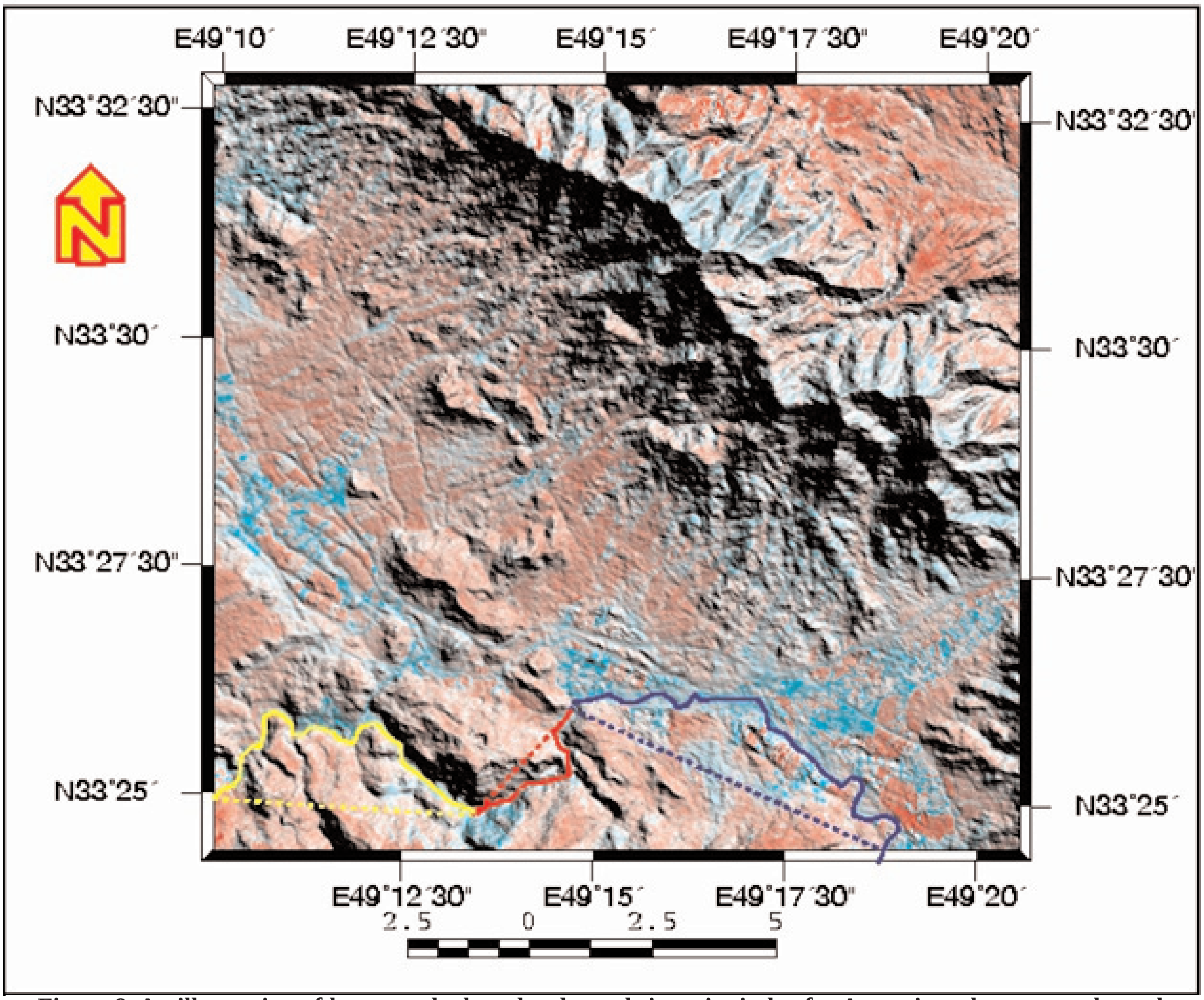

Figure 8. An illustration of how to calculate the channel sinuosity index for Azna river that passes through Takht valley.

Table 2. Channel sinuosity calculated in the study area

Line Colour	V(Meter)	C(Meter)	S
Yellow	6103	4853	1.26
Red	2979	2517	1.18
Blue	8721	6325	1.38

of this index in low-strength rocks could represent active tectonics (Pourkermani, 1997).

In normal circumstance, the value of river gradient index declines from upstream to downstream areas. Therefore, the increases from upstream to downstream could indicate river activity. The river gradient index can be interpreted as follows:

A basin with a small uplift rate entails high gradient in the upper river tapering off toward the lower gradients.

A basin with an average uplift rate entails greater slope at the downstream with extreme changes in the upper areas.

A basin with high uplift rate has slope all along the river and the maximum values can be found in the middle and the bottom parts.

As mentioned previously, high levels of SL in low-strength rocks or those with identical strength values could reflect young active tectonic movements. This index is divided into three categories (EI Hamdouni et al. 2007):

1-Category 1: $S_L \geq 500$

2-Category 2: $300 \leq S_L \leq 500$

3-Category 3: $S_L \leq 300$

The S_L values were calculated for the main river lengths using 1/250000 digital topographic maps and GIS from the straight line to the mainstream catchment area. The results have been displayed in Table 3.

In most cases, the river slope index in the study area reflected a semi-active tectonics. The minimum tectonic activity can be seen in the northern part of the region (red). The maximum tectonic activity is visible in the south and southeast areas (the yellow). The table above shows the results of this model.

Table 3. The values of SL in selected water channels of Sefidkouh

Line Colour	ΔH	ΔL	L	Sl
Yellow	1691-1564	6103	4853	100.1
Red	1712-1691	2979	2517	25.3
Blue	1798-1712	8721	6325	62.4

7.1. The valley width to depth or height ratio Index (V_f)

This index is the ratio of valley width multiplied by two to height of the both sides of the valley (Fig.9) which is calculated using the following formula.

$$V_f = \frac{(2 \times Vfw)}{\{(Eld-Esc)+(Erd-Esc)\}}$$

Where V_f is the valley bottom width to valley height ratio, V_{fw} is the valley bed width, E_{sc} is the average height above sea level, E_{ld} is the height of the left wall of the valley, and E_{rd} is the height of the right

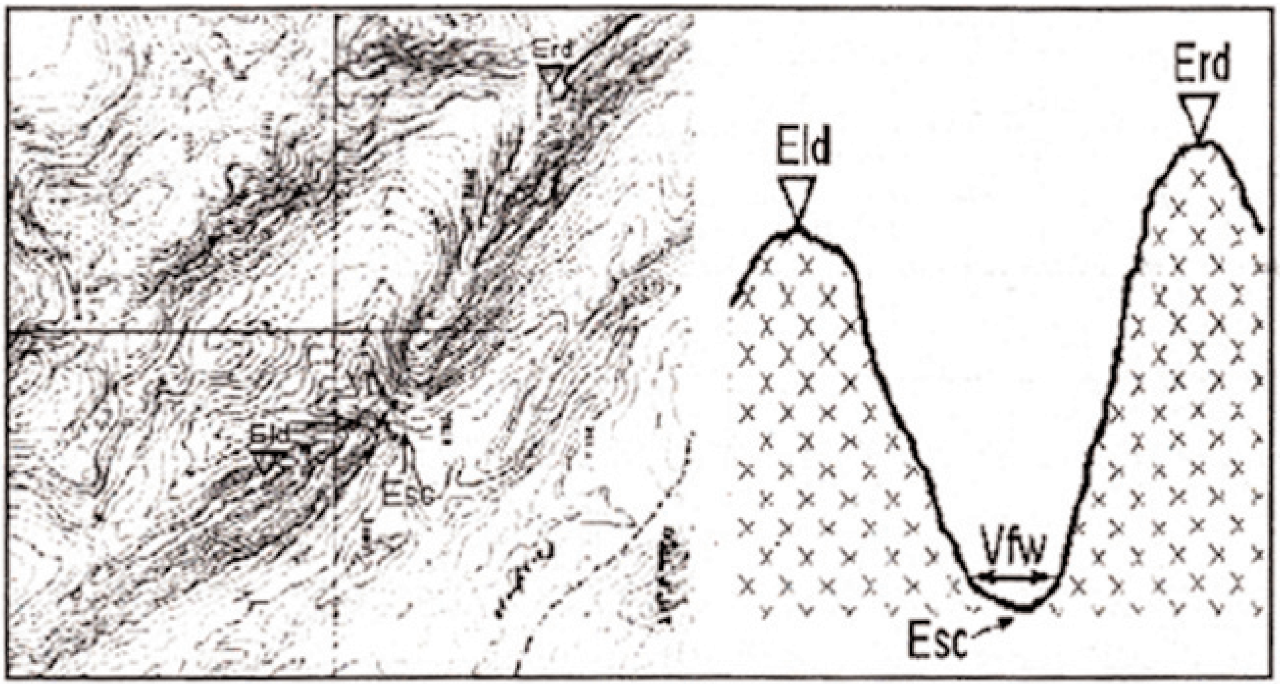

Figure 9. Valley floor width to height (side view) and how its illustration on the topographic map (vertical view)

Table 4. V_f values in different regions of the study area

Valley No.	Vfw(M)	Esc(M)	Erd(M)	Eld(M)	Vf
1	11026	1537	1906	1778	3.615
2	6421	1754	2603	2208	0.981
3	5147	1738	2630	2595	0.588
4	1609	1793	2355	2215	0.327

wall of the valley.

This index reflects the difference between V-shaped and U-shaped valleys. The more a valley's morphologyresembles V-shaped, the more V_{fw} approaches to zero which represents the destruction and erosion of river waters in response to active tectonic processes. Conversely, the more a valley's morphologyresembles U-shaped, the greater the value of V_{fw}, which reflects the widening and leveling the valley by the water current and low intensity of tectonic processes and higher stability.

This index is divided into three categories (EI Hamdouni et al. 2007):

1-Category 1: $V_f \leq 0/5$

2-Category 2: $0/5 \leq V_f \leq 1$

3-Category 3: $V_f \geq 1$

The values of this index for 4 valleys were calculated using DEM data, as shown in Table 4.

According to the obtained values for valleys 2,3 and 4, the tectonic processes are more active and V-shaped. In the region where Valley 4 is located, values are closer to 1, the valley is stable and U-shaped, indicative or lower tectonic processes.

7.2. Asymmetry of waterways in the catchment area (Af)

This index is calculated as follows:

$$AF=\frac{AR}{AT}\times100$$

Where AF (asymmetry of waterways), A_R is the area of sub-drainage basin on the right bank of the main waterway (in square kilometers), A_T is the area of secondary sub-drainage basin on the left bank of main waterway (in square kilometers).

Drainage basin asymmetry index refers to the Earth's tilt due to tectonic activity. It should be noted that the right and left side of the basin should be assumed in the direction of river flow. If the numerical value of this index is about 50, it will indicate symmetry on both sides of the main waterway and thus no neotectonic activity. If the catchment area is affected by these forces, the numerical value obtained for AF might be higher or lower than 50. If the index is greater than 50, it will indicate uplift in the right side of the main channel. If the index is less than 50, it will indicate uplift on the left side of the main channel. This index is divided into three categories (EI Hamdouni et al; 2007):

1-Category 1: Af $\geq$ 35 or Af $\geq$ 65 (50-AF is greater than 15).

2-Category 2: 35 $\leq$ Af ? 43 or 57 $\leq$ Af $\leq$ 65 (50-AF is between 7 and 15).

3-Category 3: 43 $\leq$ Af $\leq$ 57 (50-AF is less than 7).

According to the calculated value, it can be argued that both basinsare active in neotectonic terms, i.e. the left side is more active than the right side. Under the influence of these activities, the left side of the basin is longer than the right side, and the tilting inclines toward the right bank of the river.

8. Alluvial fans

Alluvial fans are triangular shaped deposits created usually at lower altitude due to a sudden drop in slope. Alluvialfans are one of the newest deposits in any area in terms of relative age. Hence, any developments and tectonic deformation can be influential on these deposits. Alluvial fans are the final points in a system of erosion-sedimentation, composed of sediment eroded from mountains through muddy rivers and streams transmitted to the mountain front (Pourkermani, 1997). Alluvial fans are important for identifying active areas. After all, they form as a results of a difference in the tectonic processes such as mountain uplift of the mountains where sediments originate along the fault. When the uplift of the mountain front lowers compared to downlift and the sedimentation of the fan is high, there will be sedimentation at the top of the fan as the youngest

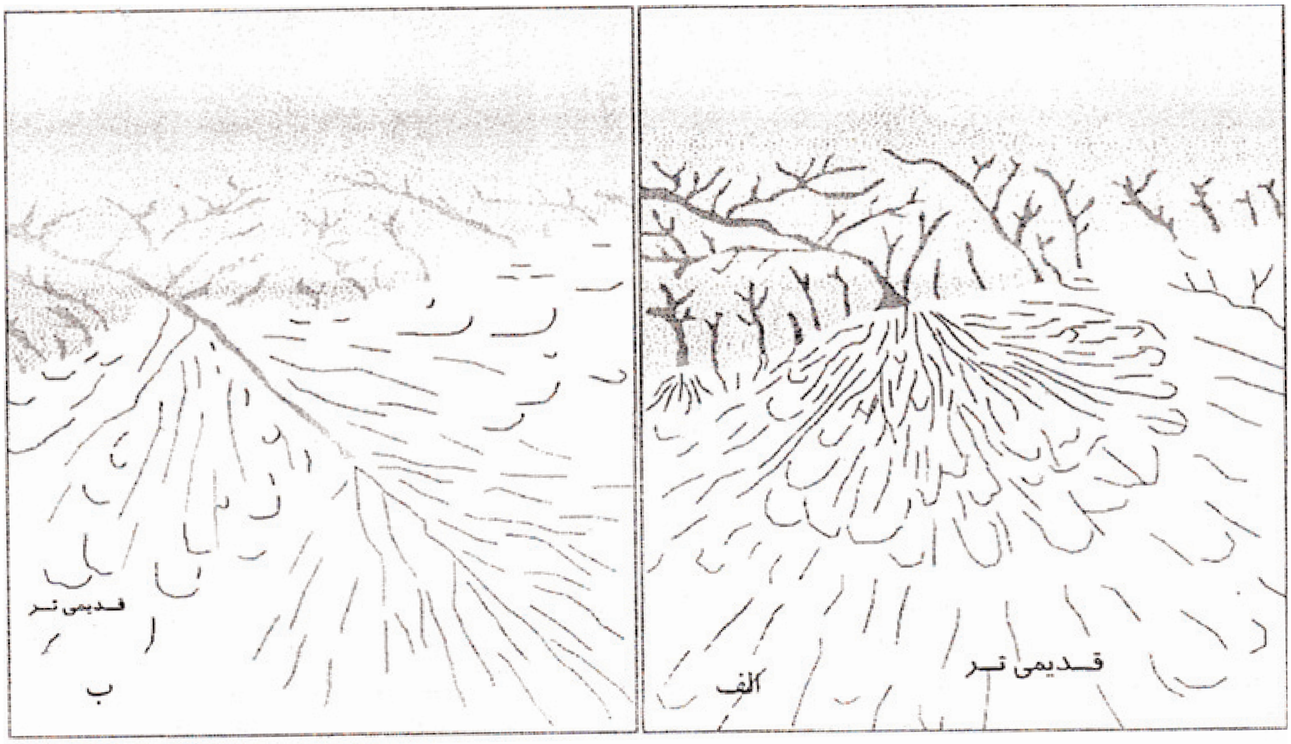

Figure 10. Status of alluvial fans in A: Active fronts, b: The low-activity fronts (Pourkermani, 1997, redrawn)

Figure 11. Google Earth satellite image of the alluvial fan area.

conic sections are created near the top (Fig.10a).

If the uplift of the mountains front is less than or equal to the down lift, however, the top of the fan is dug down by the river and the sediments are carried to lower sections as the younger parts are observed at greater distances from the mountain front (Fig.10b).

The change in the amount of sediment and river flow could be digging the top of the fan, even though its impact will be temporary so long as the rising mountain front is constant. As shown in (Fig. 11), the geometry and situation of the alluvial fan reflects the active areas.

9. Relative categorization of tectonic activity

The results of geomorphic indices can be combined to develop a relative categorization of tectonic activity in the region (EI Hamdouni et al; 2007 and Jose Vicente et al. 2010). Areas with high tectonic activity fall under Category 1 (active) generally indicating lower S_{mf} and VF, and lower A_f and S_L. In Category 3 (inactive) there is still visible tectonic activity, even though the morphometric indices are less active than in Category 2 (Table 6). The boundaries between the categories mentioned above are optional only referring to the relative difference. Hence, the geomorphological indices cannot be delimited, because they reflect to a large extent the local conditions, type of rocks, structure and weather. In this procedure, the mountain fronts can be divided into three categories of very active, averagely active and inactive. The data obtained through geological and topographic maps can be useful for regions where accurate field studies are impractical (Pourkermani, 1997).

The results demonstrated that the rate of tectonic activity was high under Category 1 in most indices, taking into account the various subjects. Some indices however, fall in Category 2 and a small portion of the region remains within the semi-active and inactive categories.Overall, the relative assessment of tectonic activity reveals the fact that different watersheds in study area were affected by tectonic movements at varying degrees, so that tectonic activities were higher in the vicinity of the main fault zone and lower in others. Based on this analysis, Darband area is tectonically active (Fig. 12).

10. Seismotectonics evaluation of the study area

Lorestan is a seismic zone in Iran due to its location on the ZagrosSeismotectonics. Destructive earthquakes in Seimareh, Sayervan, Silakhor Valley, Boroujerd etc. in different historical periods were evidence of seismicity of the area. Many researchers divided the Iranian tectonic plate into different sections, most of which locate Lorestan on the Zagros range.

Lorestan is a part of the folded-driven Zagros mountain range. According to Berberian (1995), Zagros can, based on morphotectonic data, sedimentary facies and seismic structural,divided into five components separated through deep basement faults.

Zagros earthquakes occur due to shortening of the basement and reverse faults of the basement (with a slope towards the northeast) as reverse steep faults. In most earthquakes of the region, there is a folded-driven faulting with strike-slip fault and reverse slope-slip. Concerning the cause of numerous earthquakes across Zagros range, it can be noted that Iran is located between the Arabic plate and Eurasia plate which are moving towards each other (about 5.3 centimeters per year), not to mention that Iran is on an ongoing unique deformation process. The main Zagros thrust fault can be found on the border of Iranian plateau and the Arabic plate. Another part of the deformation is caused by the Arabic plate motion and compression forces across Zagros appearing as seismic events, every now and then leaving destructive earthquakes in this zone.

11. Gutenberg-Richter (G-R) preliminary method

The preliminary distribution function or Gutenberg-Richter was introduced in 1956. One of the best ways to evaluate the regional seismic potentials is to use the data from earthquakes occurringin that region over the past years and centuries. A study conducted by Gutenberg-Richter found thatthere is a linear relationship between the frequency and intensity of earthquakes that occurred in each region. The two variables can be plotted. In this equation, Nc is the linear and cumulative frequency of earthquakes associated with magnitude (M) by taking the following simple equation.

$\log N_c = a - bM$

Even by using this simple formula, the seismicity and corresponding coefficients (a and b) could be obtained through appropriate categorization for mag-

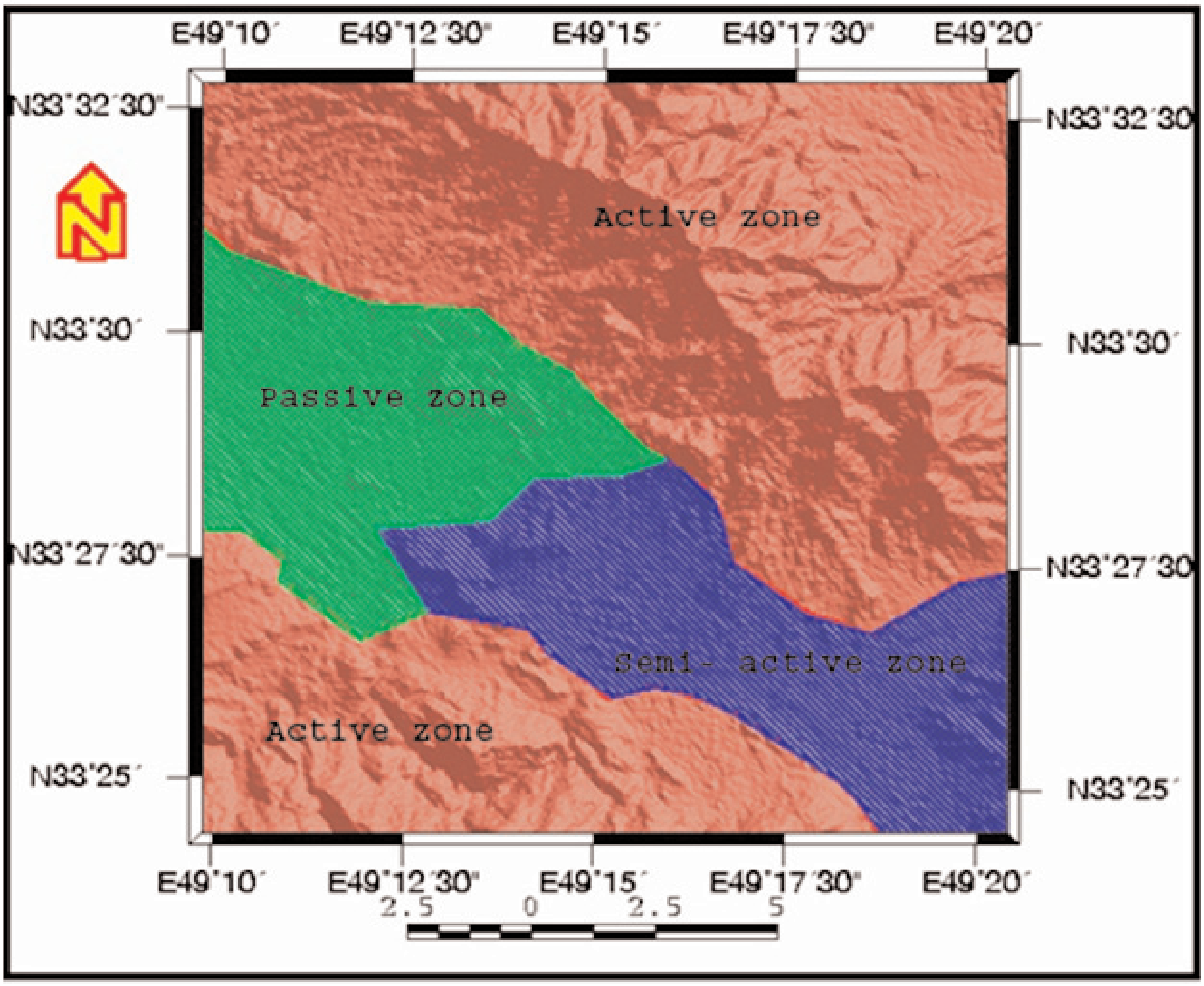

Figure 12. The map prepared for the relative categories of tectonic activity in the study area based on the calculated indices

nitude of earthquakes. Given the limitations of this equation, however, it is impossible to use the historical earthquakes. Moreover, due to the lack of lower and upper bounds for magnitude, the results are subject only to the nature of the mathematical equation and are not consistent with the realities of regional seismicity (earthquakes registered by devices in the twentieth century) and are fairly acceptable within the magnitude range of (5.3-5.7 M). This study examined an area of 100 km, where a total of 62 earthquakes occurred from 1909 to 2013 registered by International Institute of Earthquake Engineering and Seismology (IIEES) and USGS and ISC.Most notably was an earthquake on January 23, 1909 not too far from the study (Darband).

After eliminating the earthquakes below 3 and above 3.5 Richter, the Gutenberg-Richter graph was drawn. Data shows that by increasing the intensity of an earthquake it is less likely that an earthquake over 5.5 on the Richter scale will occur in the study area. Given the frequency of earthquakes in the study area, however, there is relatively high seismicity level (Fig. 13).

Although Lorestan is a seismic province forbeing located on Zagros Seismotectonic state, the faults in the area of Zagros are elevated. Hence, Dorud fault is probability the main cause of earthquakes in Lorestan province. According to the close distance of the two faults to the study area and the results of this study, it could be concluded that the study area has a relatively high level of seismicity.

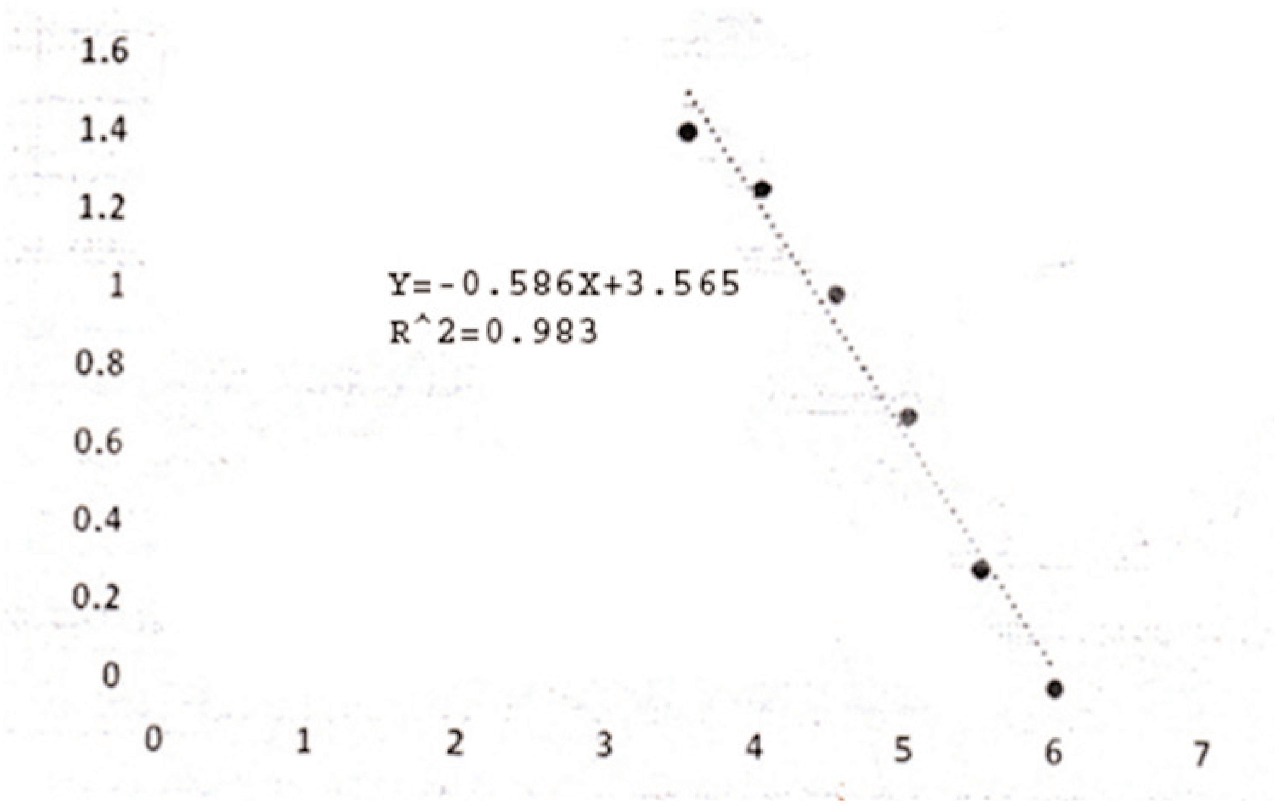

Figure 13. Gutenberg-Richter Chart within the range of 100 kilometer

12. Conclusions

The morphotectonic study involved five indices, the results of which have been as follows:

1-The mountain sinuosity index (S_{mf}), which represents the balance between tectonic and erosional forces along the mountain front, suggested that the mountain fronts in the study area often have moderate to high tectonic activity. Most of the areas surveyed were almost identical in terms of this index, and the highest activity was found in the north and south of the region possibly due to the main faults.

2-The next index, river channel sinuosity (S) decreased at greater tilting to achieve a constant slope and vice versa.

This index was examined based on two rivers crossing the region. The results indicated that the two rivers have moderate tectonic activity.

3-The river length-gradient index (S_L) or gradient index is used to show the longitudinal profile gradient changes as a reflection of the river strength. Moreover, it is employed to assess the relationship between tectonic activity, rock strength and regional topography. The high value of this index represents the most active and severe uplift, whereas the lower values represent the lack of tectonic activity.

The values obtained for the region are average, suggestive of no rapid uplift and average movement in terms of that index. The study area has moderate tectonic activity in terms of SL.

4-The fourth index was the ratio of width to depth or height of the valley (V_f). As the numerical value of the index (V) approaches to 1, cross-section will more U-shaped striking a balance between uplift and erosion in the area. However, as the value of the index surpasses 1, there will be greater erosion in the valleys. Finally, the values of the index lower than 1 reflect V-shaped valleys with more activities.This index was evaluated by selecting four zones, where the ridges, valley floor and cross-section were employed in the calculation.The results indicated that it is located within semi-active tectonic activity.

5-The next index is waterway asymmetry in the catchment area (A_f) studied in the region. Drainage basin asymmetry index refers to the Earth's tilt due to tectonic activity. If the numerical value of this index is higher or lower than 50, it will indicate symmetry on both sides of the main waterway and thus no neotectonic activity. If the catchment area is affected by these forces, the numerical value obtained for AF might be higher or lower than 50. If the index is greater than 50, it will indicate uplift in the right side of the main channel. If the index is less than 50, it will indicate uplift on the left side of the main channel.

According to calculations carried out in the river basin Azna and Zarnani, the Afvalue in both is over 50. The right side is more active than the left side due to lower erosion on the rightside of the valleys.

According to the results and considering the categorizations proposed by different scholars, Darband Kuh fell under Category 1 for a few indices and Categories 2 and 3 for a few other indices. Hence, the study area has a high to moderate morphotectonic activity.

The seismotectonic of the study area was examined through a list of 62 earthquakes from 1909 to 2013 registered by several seismic data centers. The data revealed that by increasing the intensity of an earthquake it is less likely that an earthquake over 5 on the Richter scale will occur in the study area. However, the region is highly seismic mostly explaining the earthquakes occurring in Lorestan.

On the basis of all the indices calculated, the geotectonic of the region entails high to moderate activity, reflecting the regeneration of morphological developments.The predominance of such dynamic phenomena provides the necessary infrastructure for the establishment of human teams, even though it can become a threat to the facility and equipment due to morphological hazards.

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