Evaluation of Watershed Stability using Geomorphologic and Tectonics Evidence (Case study: Alvand Mountain)

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ABSTRACT Study area is located in West of Iran with relatively rough topography. Lithologic units in the region belong from Jurassic and Cretaccous till recent era. The study area of the Alvand mountain region is related to the tectonic zone of the Sanandaj–Sirjan region and the area dominant neo-tectonic regime appears to be compressional-extensional type. One of the identification tools to find out the existence of recent neotectonic activities is tectonic geomorphology evaluation. In this study, we tried to measure the required parameters using topographic maps with scales of 1:50000 utilizing AutoCAD software. In order to identifying the morphologic landform anomalies we use asymmetry factor, transverse topographic symmetry factor and mountain-front sinuosity index. The neotectonic activity of the study area investigated by considering geologic, seismic and remote sensing evidences and with establishing relationship between these evidences and morphologic landforms. Results indicated that tilting occurred around NW-SE axis. There is a remarkable correlation between active mountain front, fault and cleavage identified (from satellite images) and position of earthquake epicenters of study area. Hence all of these evidence indicating the activity of the study area from neotectonic and instability of sub watersheds point of view.

Key words: *Alvand, Geomorphologic index, Iran, Stability, Tectonic*

1 INTRODUCTION

In the past decade, there has been a huge progress in development of quantitative geomorphology especially in terms of statistical tools and mathematical models. Vast research carried out in this field resulted in the useful quantity Geomorphological methods describing the morpho-evolotive processes and, also, in studying the active tectonic regions (Avena *et al.,* 1967, Buonasorte *et al.,* 1991, Pike, 1993, merta Dela, 2004). The neotectonic effects on morphogenetic processes have been determined through the application of statistical analysis. Juilo and Garothe (2006) studied the geometry of drainage basin in a part of Mississippi Embayment near New Madrid earthquake region to recognize the change zone of the river as an active tectonic index. An asymmetrical vector of the drainage basin provided on the basis of a digital model was compared to geological structure, rock faces, earth quakes Remote sensing study and inter stream divide

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drainage basins in the region. The measurement (change of Lateral River) was carried out using 4500 regional drainage basins. Based on the Transverse topographic symmetric index, the geomorphic region revealed in the North of Mississippi was linked to the deep shelf blocks limited to the probable curves or faults. Almost 12 regions were identified, some of them with edges on the identified faults related to Paleozoic era, valley grabens systems of Mississippi (incline to Northeast), thrust belts and Couachita Mountains faults front (incline to Northwest). Juilo and Garothe (2006) mentioned that the process of analysis is compatible with the regional satellite images having cleavages in the surrounding region. Also, studies concerning the triangular surface, fault shape Escarpments, rivers digression and the Terraces Rivers (Pauola and Molin, 1999) or morphometric analysis (Marta and Harkins, 2005) are used in the geological studies. As an example, studies are done on Red Rock Fault in which the Fans and Terraces, soil characteristics desert surrounding the fault were identified to coordinate with morphometric analysis to determine the Systematic and fault divisions. The number of divisions increased to three from two (Marta and Harkins, 2005). Focusing on topography metrics, drainage patterns, river profiles and the result analysis, in tectonic geomorphology study it is possible to depict the tectonic deformities of the surrounding region on the drainage pattern and also the adjustment of the rivers to local tectonic regime. The quantity geomorphlogical measurements and morphotectonic process have many useful results such as study methods of slope profile and filed measurements (Blong, 2007). Compton (2008) presented slope processes and their analysis by using of manual field geoligeal methods. Sarigear (2009) showed the changes of watersheds, drainage patterns and tectonic regime by using of geomorphology and tectonic maps.

The aim of this study is to use the procedure and the information of geology, seismology and the cleavage extracted from the satellite pictures to understand the tectonic activities of the recent era in Alvand region of Hamadan.

2 MATERIALS AND METHODS
2.1 Study area
The study area was located in the North Slope of Alvand, the central part of Hamadan Province (Figure 1) in the central Zagros Iran (48° 6' 45" to 48° 44' 29" N; 34° 35 '20" to 39° 50'34"), with ca. 2745 km2.The rocks of the region are influx granite, shiel, eslite and schist of the Jurasic era (Figure 2). Based on data of Asad Abad climatology station (1997-2007), the annual temperature average of this region is +10.75˚c varying from -15˚c to +34˚c from winter to sun. The coldest month is February and the hottest is August. The annual average precipitation of this region is 443.11mm. According to Ambrothermic curve, the driest months are May to September. The regional climate according to Ambreget method is semi-arid cold and semi-humid (Ildoromi, 2007).

2.2 Research Methodology
First, the studied region was located on the topographic map as 1:50,000. Then the working units were determined using satellite images, aerial photos and available maps. The lithological map was drawn using the geological map (1:250,000) and the Digital map using Auto CAD software. For the asymmetric factors, initially 12 different drainage basins were identified to the North front of Alvand among which only the 3rd and the 4th drainage levels were taken into consideration. For the asymmetrical index, the right side surface of the basin was measured comparing the main river and the total surface area of the basin. The index was then determined by using Eq. 1 for each watershed. In order to calculate the transverse topographic symmetry, the median

line of the drainage basin and meander belt were identified and the D_a and D_d parameters were determined and calculated for each of the basins (Eq. 2). To determine the mountain front sinuosity, first the frontals mountain were recognized and consequently L_{mf} and L_s parameter were calculated using formulae (3) and (4) (KomakPanaah and Montazerghaem, 1990; Soleimani, 1997). The details of the methodology have been given in the following.
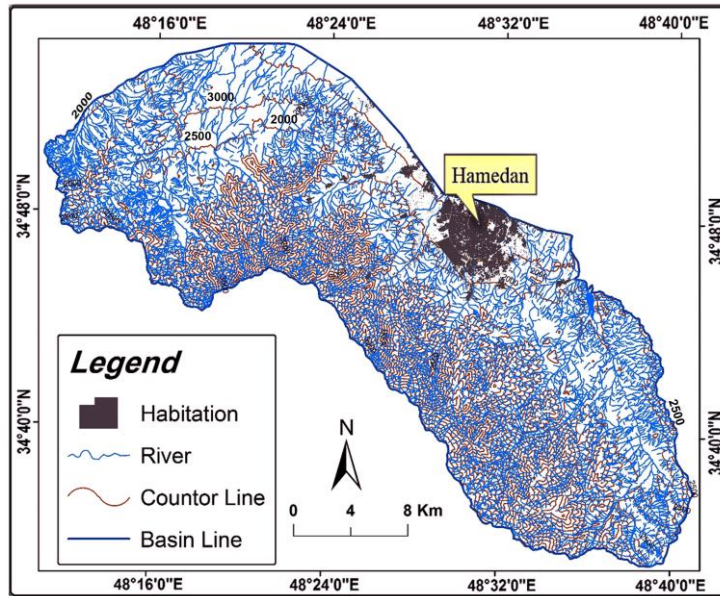

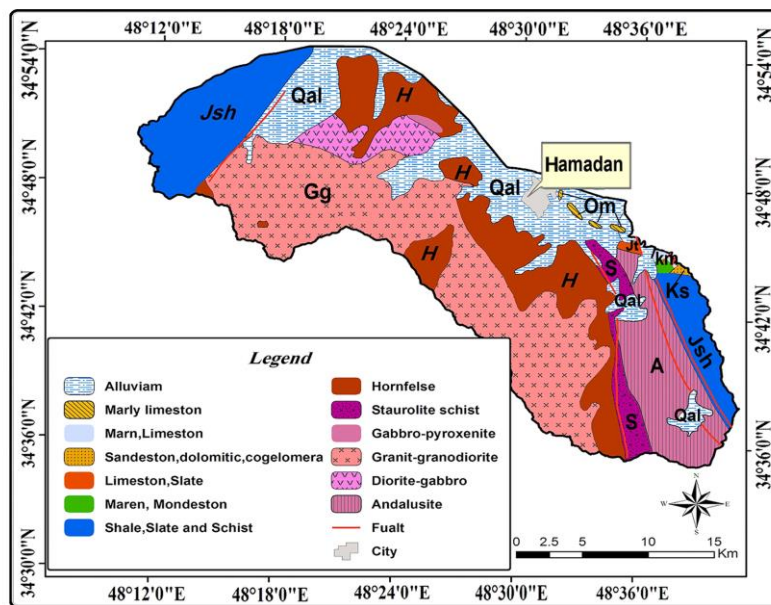**Figure 1** The position of study area in Hamadan.

Figure 2 The geology map of study area.

2.2.1 Transverse topographic symmetry index

The concept of transverse topographic symmetry index (T) vectors with special directions and with measurement of 0 to 1 and calculated by using Eq. (1) has been shown in Figure 1. The figures near to 1 show the morphodynamic activities and erosion and reversibly.

$$T = \frac{D_a}{D_d} \qquad (1)$$

Where T is transverse topographic asymmetry, D_a is distance of active meanderic tape from medial line of drainage basin and D_d is distance of center line of drainage basin from divide.

2.2.2 Drainage Asymmetry Factor

This index which is calculated by using Eq. (2) is used for comparison of area equality in both sides of the main river of the watershed (Figure 4). The value equal 50 expresses symmetric condition and verifies the equilibrium condition in the watershed. The values far from 50 verify the role of erosion in right or left banks of the river (Figure 4).

$$A_F = 100(A_v/A_t) \qquad (2)$$

Where A_v is the basin area includes the secondary drainages in the right side of main river (km^2), A_t is the basin area includes the secondary drainages in the left side of main river (km^2) and A_F is drainage asymmetry index.

2.2.3 Distance and sinuosity index

This index which is calculated by using Eq. (3) shows the distance between sub watersheds adjacent. When this distance increases, the sinuosity value increases. Also when the width of the mountain is more, the sinuosity value will be more (Figure 5).

$$S_{ref} = \frac{2A + B + C}{B + C} = \frac{2A}{B + C} + 10 \qquad (3)$$

Where S_{ref} is **sinuosity** index, A is the limit width of mountain blocks, B is the width drainage basin and C is the width gap spreader banks (spur).
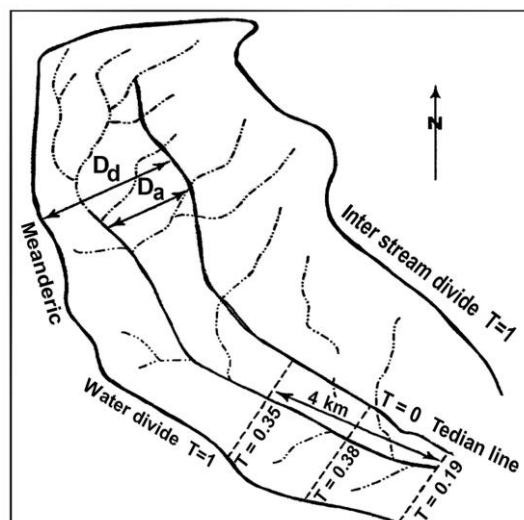

Figure 3 Schematic map of drainage basin and T index.

2.2.4 Mountain front sinuous index

This index that has shown in Eq. 4 indicates the equilibrium between erosion forces (they have appetence to create gulfs in mountain front) and tectonic forces (they have appetence to create mountain bank with active fault).

$$S_{mf} = \frac{L_{mf}}{L_s}. \tag{4}$$

Where S_{mf} is sinuosity front of mountain, L_{mf} is the in between length of region limit in mountains till pediment and L_s is the direct length of front mountain (Figure 6).
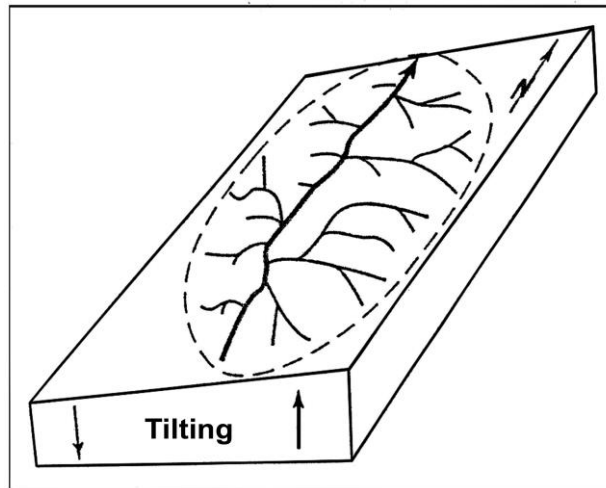

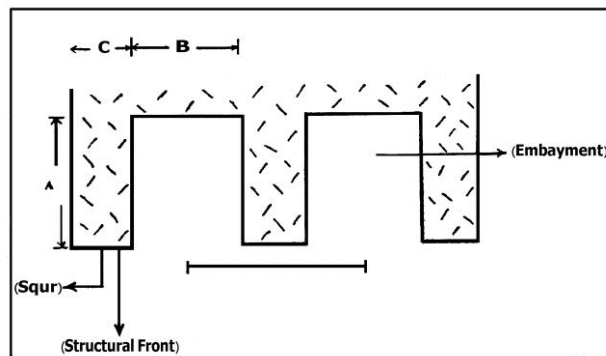**Figure 4** Diagram block schematic for drainage asymmetry index.

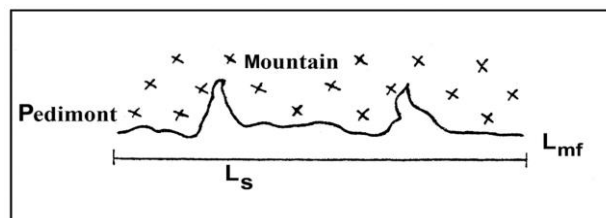**Figure 5** Section of mountain front for sinuosity index.

Figure 6 Section Schematic for sinuous index.

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The value of S_{mf} is classified in 3 groups: 1) when $1 < S_{mf} < 1.4$ it shows the high activity of erosion forces, 2) when $1.4 < S_{mf} < 3$ it shows less activity and 3) when $1.8 < S_{mf} < 5$ it is inactive (McFadden and MacAuliff, 1997 and Bull, 1990).

The results of these indices combined with geology data, fault and cleavage identified (from satellite images), information of earthquake and vectors horizontal speed of Zagros region for assessment of tectonic activity in the study area.

3 RESULTS

3.1 Tectonic geomorphology
By the quantity analysis of the geomorphic evidences known as morphometry and employing geometrical parameters, it would be possible to introduce different indices to find out the faults and compare them. In this study, in order to determine the symmetry of drainage basins and also to determine the axis tension of general strike of the studied region, the

symmetry of the drainage basins were assessed with the help of two factors of asymmetry and transverse topographic symmetry. These two factors were calculated considering only levels 3 and 4 of drainage basins. It is worthy to mention that these two factors cannot be the direct causes (without exception) of drainage instability but might act as a tool to recognize the quick predicted tilting. The indices measurements were based on topography maps of 1:50.000 (Figure 7).

3.2 Drainage Asymmetry Factor (A_F)
The sub watersheds, whose drainages developed based on changes in active tectonic shapes, have almost a known pattern drainage network. The asymmetry factor to recognize the skew tilt was used to compare the flow of drainage basin. In this study, the pattern given by Gardner (2002) was used to calculate this factor (Eq. 2). The result for calculation of drainage asymmetry factor in this region has given in the table 1.
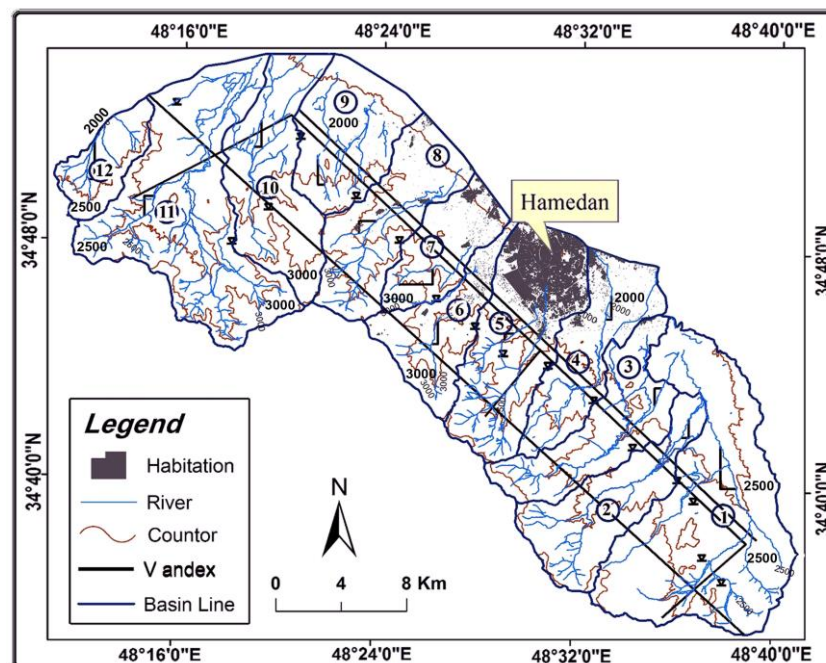

Figure7 Morphometric indices calculation method.

Table 1 Result of estimated in Drainage asymmetry factor in sub watershed of the study of region (AF).

Sub watershed	1	2	3	4	5	6	7	8	9	10	11	12
Watershed area includes the secondary drainages in the right side of main river in km^2 (A_v)	62.5	25.1	17.8	31.3	42.5	25.4	11.2	19.8	30.6	24.7	30.3	24.4
Watershed area includes the secondary drainages in the left side of main river (km^2) (A_t)	122.6	51.6	48.3	47.3	72.4	52.7	26.6	45.1	43.3	51.2	102.6	35.1
Drainage Asymmetry index (A_f)	50.97	48.6	36.8	66.1	58.7	48.2	42.1	43.9	70.7	48.2	29.5	69.5
Total area (km^2)	60.1	26.5	30.5	16	30.9	27.3	15.4	25.3	12.7	26.5	72.3	10.7

Table 2 The results of transverse topographic asymmetry (T) in sub watershed of the studied region.

Sub watershed	1	2	3	4	5	6	7	8	9	10	11	12
Distance of active meanderic tape from central line of drainage basin (D_a).	6.4	3.8	2.4	2.6	3.5	2.2	2.4	3.1	3.1	2.3	4.3	1.6
Distance of medial line of drainage basin from divide basin (D_d)	2.5	2.3	1.4	1.2	1.3	1.7	0.9	2.2	1.1	0.8	2.7	1.1
Transverse topographic asymmetry (T)	2.56	1.65	1.7	2.16	2.7	1.3	2.7	1.4	2.8	2.9	1.6	1.45

3.3 Transverse Topographic Symmetry (T)

The results for calculation of Transvers topographic symmetry (T) by using Eq.1 in the study area are given in the Table 2.

For the drainage basins which are completely symmetric, T is 0 with asymmetry increase to 1. Considering that the bed rock slope has low effect on the river change and migration direction of the land tilting in the same direction.

3.4 Mountain front sinuosity (S_{mf})

This index indicates the balance between the erosion forces tending to create embayment in the frontal side of the mountain and the tectonic forces tending to create the mountain front of cape of the mountain. This index is defined on the basis of Eq. (4) with a minimum value of 1 showing the maximum activity in the mountain front of the mountain. Any increase of the afore-mentioned activity decreases the activity in the mountain front.

These factors were measured in the study area by using Eq. (4). The results are given in Table 3. To locate the active faults in the mountain front of the region, the mountain front sinuosity was calculated using the topographic maps (1:50.000) and equation 3 for 12 sub

watersheds in mountain. Front based on the measured factor, the results of the geological maps and also the satellite images of the region, it was revealed that the mountain front adjacent to the identified faults have a sinuosity ranging from 2 to 3.7 (Table 3) which are in agreement with the result of the study. Other mountain front with indices less than 2 are the regions with an acceptable conformity with the identified cleavage located in satellite images as seen in sub watersheds 3, 6, 7, 8, 9 and 12 (Figure 8).

Table 3 Mountain front sinuosity (S_{mf}) for regional sub watersheds.

Sub watersheds	1	2	3	4	5	6	7	8	9	10	11	12
Sinuosity front of mountain (S_{mf})	3.69	2.39	1.7	2.4	3	1.3	1.5	1.6	1.6	2.4	2.29	1.59
Length of region Limit in mountains to Pediment (L_{mf})	1400	1100	900	700	700	1100	6500	900	450	1100	1400	500
Direct length of front mountain (Ls)	378.4	458.4	529.4	287.5	333.3	846.1	433.3	562.5	281.2	458.3	608.7	314.3
Type of activities	Inactive	less	above	less	less	above	above	above	above	less	less	above
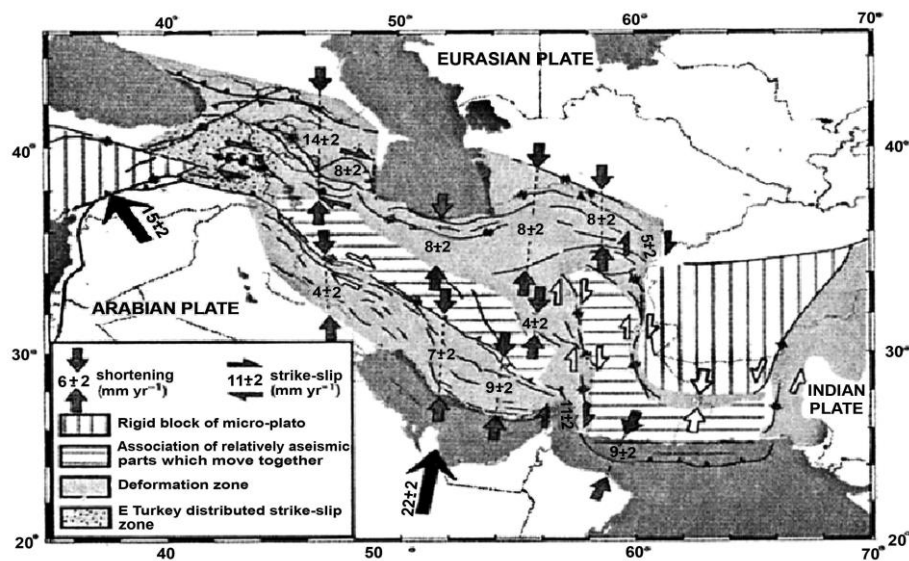
Figure 8 Schematic description of the shelf change and the current plates kinematic in Iran (Grey arrows show the measured deformity).
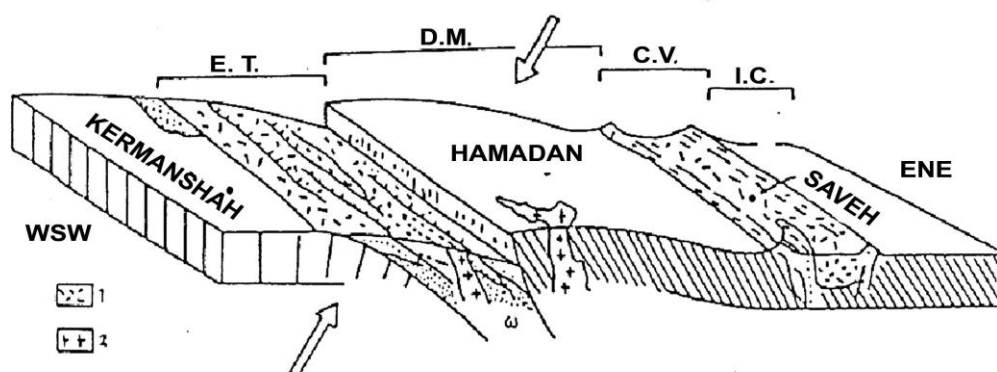
Figure 9 The position of forces to constituting of topography and basins in the study area
ET: Tercypore sheet (tinsel), Dm: extended metamorphic, Cv: volcanic field, Tc: central Iran, w: Refueled cost way cretaceous.

4 DISSCUTION AND CONCLUSION

Under the tectonic effect and the strengths of the activity of the morphodynamic factors and the erosion rate, the morphology of the drainage sub watersheds in the North frontal Alvand has been changed and turned into the state of instability. Based on the active morphodynamic evidences of the region, which are signs of instability in the drainage basins, the sinuosity of northern front of Alvand situation could be specified. The sinuosity condition of the frontal Alvand which are linear in some parts and curved-linear in some other parts, showed the change in the region and it is under the effect of the spacing of the adjacent drainage basins, time and the width of the area. The morphometric indices indicate the strong morphodynamic activity, remarkable Erodibility and the change regions. The results of the numerical value of the river gradient index (S_L) with the bed rock shows that the high degree of the index (S_L) pertaining to the low or the same strength stones in the sub watersheds 3, 7, 8 and 10 are due to the mechanical destruction (weathering) of the granite stones. This destruction is caused by a number of cracks and less mechanical strength as well as a higher degree of sensitivity of the shiest to the pre-glacier erosion process. This process led to the morpho-dynamic segmentation of sub watersheds and the drainage density (Soleimani, 1997 has also drown similar conclusions). The values of the asymmetrical index show that the sub watersheds 1, 2, 5 and 10 are symmetrical with regard to drainage. However, the values of the indices related to drainage asymmetry factor (A_F) were less than 50 which are less erosion in the left side of the main channel. Sub watersheds of 3, 7, 8 and 11 are among those sub watersheds in which the erosion and the morpho-dynamic activities are more evident in their left sides. Sub watersheds 4, 5, 9 and 12 with respect to more A_F are tilted due to the strong morpho-dynamic activities in the right side and have longer sub watersheds Secondary net banks (Pauola and Molin, 2004 have reported this as well). The transverse topographic symmetry index (T) showed diversion in all sub watersheds from the Transverse topographic point of view and asymmetry between the left and right sides of the main river, as well. A diversion rate of more than 1 proved the strength of the morphodynamic activity. In conclusion, the calculated results proved that;

1) drainage Asymmetry factor was preferred since it is less dependent on field measurement (Gardner, 2002).

Based on the results of the two factors, related to asymmetry and transverse topographic symmetry factors of the studied basins, the following could be drawn: A) In sub watersheds 4, 5, 9 and 12, the uplifting was seen in the eastern side and tilting in the western. B) In sub watersheds 3, 7, 8 and 11, the southern part showed more uplifting and the overall tilting tends towards the North showing the strong erosion and morphodynamic activity in the left side (also these results have confirmed by Keller and Pinter, 2002 and Spyros *et al.,* 1999). C) In sub watersheds 4, 5, 9 and 12, the maximum A_F value was seen due to strong activity in the right side showing more length of the sub watersheds Secondary. D) It seems that, tilting occurs towards axis NW-SE general strike and is in agreement with the direction of NNW-SSE strike of the vectors speed horizontal measured through NUVEL 1-A for the west of Iran (Kocyigit, 2001 and Talebian, 2002). 2) The results of the mountain front index showed that the active mountain frontals in the studied region are in complete agreement with known active faults, cleavages drawn from the satellite images and the center oriented position of the earthquake stressing the active state of the studied region from the tectonic point of view in the recent era (Nathan, 2005 and Vernant, 2004). In this study we investigated and measured asymmetry factor, transverse topographic symmetry factor and mountain front sinuosity index in order to identifying the morphologic landform. Also we established relationship tectonic evidence and morphologic landforms to indicating neotectonic activity and identifying current activity of the region. It seems that these results can be used in some human activity such as improving construction sites for watershed management.

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بررسی و تحلیل پایداری حوزه‌های آبخیز بر اساس شواهد ژئومورفولوژی تکتونیکی
(مطالعه موردی: کوهستان الوند)

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چکیده منطقه مورد مطالعه در غرب ایران واقع شده و دارای توپوگرافی نسبتاً خشنی است. واحدهای سنگ‌شناسی موجود در منطقه متعلق به ژوراسیک و کرتاسه تا عهد حاضر می‌باشند. جایگاه مورفوتکتونیکی کنونی توده کوهستانی الوند که منطقه مورد مطالعه نیز در آن واقع شده، مرتبط با موقعیت تکتونیکی زون سنندج- سیرجان بوده و به نظر می‌رسد که رژیم نئوتکتونیکی حاکم بر منطقه از نوع فشارشی- کشیدگی باشد. از راه‌های شناسایی فعالیت‌های تکتونیکی جوان در یک منطقه، مطالعات ژئومورفولوژی تکتونیکی می‌باشد. در این مطالعه با استفاده از نقشه‌های توپوگرافی منطقه با مقیاس ۱:۵۰۰۰۰ و به کمک نرم افزار AutoCAD، پارامترهای مورد نیاز را اندازه‌گیری شد و سپس شاخص‌های عدم تقارن، تقارن توپوگرافیک عرضی و سینوزیته جبهه پیشانی کوهستان محاسبه شد تا ناهنجاری‌های عوارض مورفولوژیک شناسایی گردد. سپس با توجه به شواهد زمین شناسی، سایزمیک، سنجش از دور و همچنین برقراری ارتباط بین عوارض مورفولوژیکی و شواهد مذکور، سعی گردید تا شدت فعالیت تکتونیکی منطقه بررسی شود. نتایج نشان داد که کج‌شدگی در منطقه حول یک محور با امتداد NW-SE اتفاق می‌افتد. همچنین جبهه‌های کوهستانی فعال در منطقه با گسل‌های فعال و مشخص، خط و راه‌های شناسایی شده (از روی تصاویر ماهواره‌ای) و موقعیت رو به مرکز زلزله‌های منطقه انطباق قابل توجهی دارد. این شواهد نشان دهنده فعال بودن منطقه از لحاظ نئوتکتونیکی و ناپایداری حوزه‌های آبخیز آن می‌باشند.

کلمات کلیدی: الوند، ایران، پایداری، تکتونیک، شاخص‌های ژئومورفولوژیکی