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MEHDI MUMIPOUR (*), MOHAMMAD H. REZAEI-MOGHADDAM (**)
& ALI M. KHORSHIDDOUST (**)

ACTIVE TECTONICS INFLUENCE ON DRAINAGE NETWORKS IN DINARKOOH REGION, ZAGROS MOUNTAIN RANGE, IRAN

ABSTRACT: MUMIPOUR M., REZAEI-MOGHADDAM M.H. & KHORSHIDDOUST A.M., *Active Tectonics Influence on Drainage Networks in Dinarkooh Region, Zagros Mountain Range, Iran*. (IT ISSN 0391-9838, 2012).

Drainage networks are usually influenced by the type, orientation and recent activity of regional and local faults and folds in tectonically active regions. In the Zagros Mountain Range, Western Iran, most drainage systems are controlled by neotectonics processes. The development of the drainage system of Dinarkooh region in the late Quaternary depends mostly on the activity of Main Zagros Thrust Fault (MZTF) and similar NW-SE oriented faults in Zagros fault system. We have done a geomorphometric study by observing river profile and characteristics of mountain fronts in order to find spatial variations and style of rock uplift. Mountain front sinuosity (S_{mf}), area- altitude relations (Hypsometric curves), V_f and AF indices differ significantly between different parts of the study area. River profiles indicate maximal river entrenchment in the southern part of Dinarkooh Region, probably related to the uplift of footwall of MZTF fault system. Therefore our geomorphic analysis suggests that Southern and Western parts of Dinarkooh are tectonically more active and also Samand active fold plays a significant role in this activity because of an active blind thrust fault beneath it.

KEY WORDS: Active Tectonics, Drainage Network, Geomorphometry, Digital Elevation Model, Dinarkooh Region, Zagros Mountain Range.

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شبکه‌های آبراهه‌ای عموماً تحت تأثیر نوع، جهت و فعالیت جدید چین‌ها و گسل‌های محلی و ناحیه‌ای در مناطق فعال تکتونیکی قرار می‌گیرند. در رشته کوه زاگرس، واقع در غرب ایران، اکثر سیستم‌های آبراهه‌ای تحت تأثیر و کنترل فرآیندهای نئوتکتونیکی هستند. توسعه‌ی سیستم آبراهه‌ای منطقه دینارکوه در کواترنر پایانی تحت تأثیر فعالیت گسل تراستی اصلی زاگرس (MZTF) و سیستم گسلی هم جهت NW-SE بوده است. در این مقاله، مطالعه‌ای ژئومورفومتریک با مشاهده‌ی نیمرخ‌های رودخانه‌ای و جبهه‌های کوهستانی صورت گرفته تا تغییرات مکانی و نحوه‌ی بالاآمدگی سنگ بستر مشخص شود. پیچ و خم جبهه کوهستانی (Smf)، روابط مساحت- ارتفاع (منحنی‌های هیپسومتری)، شاخص‌های VF و AF بطور قابل ملاحظه‌ای در نقاط مختلف منطقه متفاوت از هم هستند. نیمرخ‌های رودخانه‌ای حداکثر بازشدگی رودخانه‌ای را در بخش جنوبی دینارکوه نشان می‌دهند که احتمالاً به دلیل بالاآمدگی کمرپایین سیستم گسل MZTF است. بنابراین تحلیل‌های ژئومورفیکی نشان می‌دهند که بخش‌های غربی دینارکوه فعالیت تکتونیکی بیشتری نشان می‌دهند که احتمالاً چین فعال سمند نقش قابل ملاحظه‌ای در آن بازی می‌کند و عامل آن هم گسل تراستی پنهان در زیر آن می‌باشد.

واژگان کلیدی: تکتونیک فعال، شبکه آبراهه‌ای، ژئومورفومتری، مدل رقومی ارتفاع، منطقه دینارکوه، رشته کوه زاگرس

INTRODUCTION

One of the fastest growing disciplines in earth sciences is active tectonics because of its developments in techniques and forwarding to more accurate analysis (Keller & Pinter, 2002; Bull, 2007, 2009a, b; Pérez-Peña & *alii*, 2010). Another reason is importance of its results for regional studies on active tectonics and evaluates hazards of natural disasters such as earthquakes (e.g., Cloetingh & Cornu, 2005; Pérez-Peña & *alii*, 2010). In Dinarkooh region, the study of active tectonics of Zagros on drainage network is important for landuse planning programs.

Recent and active tectonics is considered as the main factor affecting rock uplift on mountains ranges and their present-day topography is the result of the competition between tectonics and erosion processes. So drainage pattern analysis and geomorphic features can be used for evaluating active tectonics (e.g., Keller & *alii*, 2000; Beneduce & *alii*, 2004; Capolongo & *alii*, 2005; Bull, 2007; Bishop, 2007; Ribolini & Spagnolo, 2008; Pérez-Peña & *alii*, 2010; Mumipour & Nejad, 2011).

This paper aims to evaluate the active tectonics control and influence on drainage network evolution in Dinarkooh region located in the Zagros mountain range (Western Iran) by using geomorphic indices and stream profile analysis. Dinarkooh Region is a part of Western Zagros Fold

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(*) *Physical Geography Department, University of Tabriz, Tabriz - 51666-16471, Iran. Corresponding author*, e-mail: mumipur@tabrizu.ac.ir

(**) *Physical Geography Department, Faculty of Humanities and Social Sciences, University of Tabriz, Tabriz - 51666-16471, Iran.*

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and thrust belt, and it posed on the Northern flank of Iranian-Arabian collision zone. For examining the influence of tectonics activity on drainage networks and get conclusions about the evolution of the area detailed geomorphometric analysis was done focusing on knickpoints and slope changes. For extracting geomorphological characteristics with quantitative measurements, the longitudinal profiles of main streams and hypsometric curves of the basins were analysed (Maroukian & *alii*, 2008). The tectonic setting of the Dinarkooh Region is influenced by the NW-SE trend of subduction of the Arabian plate beneath Iranian plate as shown in fig. 1. The drainage networks in active regions are strongly and rapidly influenced by tectonics and erosion changes, and hence they are potential instruments for tectonic geomorphology analysis. The drainage network of Dinarkooh has showed good geological record of the movement, displacement, regional uplifts and erosion of tectonic units. The Meymeh River crosses Dinarkooh. It divides the Dinarkooh into Western, Central and Eastern parts (fig. 2).

We prepared the Digital Elevation Model (DEM) of study area from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite stereo images. MATLAB script files (Shahzad & *alii*, 2009; Shahzad & Gloaguen, 2011) were used to extract drainage network and lineaments from DEM. By the stream profile analysis, uplift rates of each stream were calculated under certain assumptions. The streams in central and southern Dinarkooh showed high steepness and concavity indices as compared to the streams in northern and western Dinarkooh. Spatial distribution of geomorphic indices and uplift rates differentiated among eastern, central and western parts. The central and southern parts showed more deformation and high uplift rates.

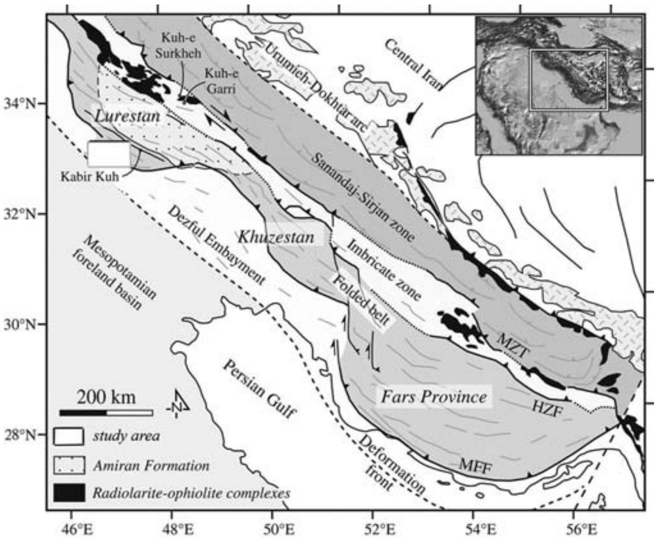

FIG. 1 - Generalized tectonic map of Iranian-Arabian collision zone (modified form Homke & *alii*, 2004). The study area is represented by white rectangle and shown in detail in figure 2. MZT: Main Zagros Thrust; HZF: High Zagros Fault; MMF: Mountain Front Flexure.

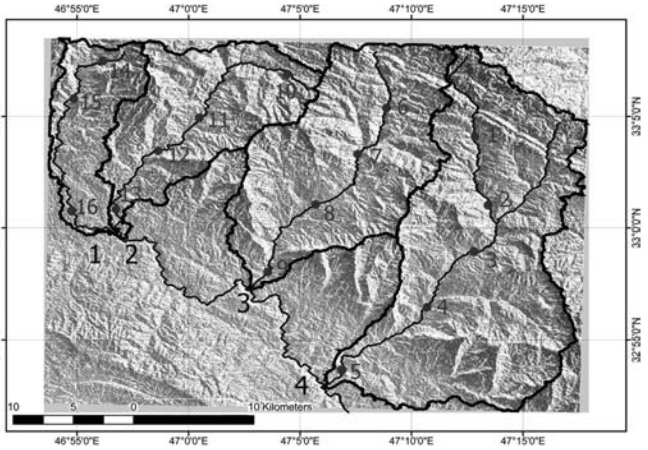

FIG. 2 - Hillshade of study area showing 4 main basin and 4 main streams. Inner numbered points show the location of Valley cross sections that used to calculate Vf. Outer numbers are Basin number.

STUDY AREA

The study area is located between 32° 52´ N and 33° 08´ N latitudes, and 46° 54´ E and 47° 17´ E longitudes, in the western Zagros Fold and Thrust Belt (ZFTB) in southwestern Iran (figs. 1 and 2). The Zagros Mountain range hosts more than half of the world's known hydrocarbon reserves (Sepehr & Cosgrove, 2005). Compressional tectonics led to folding, thrusting, and large-scale strike-slip faulting and significant crustal shortening in the Zagros Mountains. The basement has gone through an extensional tectonic event during the Precambrian before the deposition of the Cambrian sediments (e.g., Stocklin 1968; Berberian & King, 1981; Berberian, 1995; Mobasher, 2007).

The compressional Zagros orogeny formed a variety of asymmetric, NW-SE trending, en-echelon folds, and NE-dipping thrusts on the southwestern limbs of the folds. Fold axial planes generally dip to N-NE, so that the southern limbs of the folds are steeper, and in some cases they are overturned or vertical (Mobasher, 2007). Our study area is located in Zagros folded belt, northern Balaroud Fault. Samand anticline, located in this region, is one of the major gas reservoirs in Iran.

METHODOLOGY

Satellite images are available in variety of resolutions, so this can affects the quality of analysis. We used the ASTER DEM of 15 m spatial resolution to extract drainage network and lineaments. The drainage network is extracted from digital elevation model (DEM) of the area by calculating flow directions at all points using D8 algorithm (O'Callaghan & Mark 1984). Flow direction is related to specific basin area and upslope area, that both of them can be calculated using DEM and capabilities of GIS. Choosing stream delineation algorithms may affect the results, for example slope, area and stream strahler order may vary in different algorithms. Stream longitudinal profiles are identified and selected based on least cost path analysis that computes the paths of least resistance down slope (i.e. the downstream flow path). This algorithm was implemented in MATLAB (Shahzad & Gloaguen, 2011) and all of the required parameters were calculated. Applying stream profile analysis on each stream, valuable information was obtained.

Stream Power Law

The lithological or structural contrasts force the streams to reach a new equilibrium condition. Mathematically, this is written in the following equation:

$$\frac{dz}{dt} = U - E = U - KA^m S^n \qquad (1)$$

that U and E are uplift and erosion rates, respectively. K is erosion efficiency factor which is related to sediments and rock strength directly, A is upstream drainage area and S is channel slope. The constants m and n are dependent on basin hydrology, hydraulic geometry and erosion process. dz/dt is the rate of changing elevation within specific time. So, if landscape is in steady-state condition, then it is equal to 0. Thus for a steady state equilibrium, equation 1 can be written as:

$$S = \left(\frac{U}{K}\right)^{\frac{1}{n}} A^{m/n} \qquad (2)$$

Where m/n is the concavity of the profile and coefficient is steepness of the profile. So, it can be written as:

$$S = K_s A^{-\theta} \qquad (3)$$

that θ and k_s are concavity and steepness indices, respectively. They can be calculated directly using regression analysis of data as shown in equation 3, i.e., area and slope (Howard, 1994; Montgomery & *alii*, 1996; Snyder & *alii*, 2000; Whipple, 2004; Wobus & *alii*, 2006; Shahzad & *alii*, 2009). By combining equations 2 and 3, a useful relationship for calculating uplift rates is presented below:

$$U = k_{sn}^{n} K \qquad (4)$$

that k_{sn} is normalized steepness index. This equation gives uplift rate for the area with steady state landscape by choosing appropriate values of *m*, *n* and *K*. after logarithmic regression, analysis of area and slope values, concavity and steepness values were calculated and by using their values in equation 4, uplift rate is calculated. Constant values of *n* and *K* is obtained from previous studies (Tucker & Slingerland, 1996; Wobus & *alii*, 2006). Because of importance of knickpoint selection in understanding landscape responses to tectonics, these points were selected in stream longitudinal profile based on change in slope and concavity. Selected points (illustrated as lozenge) can be viewed in longitudinal profiles shown in figures 4, 5, 6 and 7 respectively for stream numbers 1, 2, 3 and 4.

Geomorphic indices

We used three geomorphic indices including mountain front sinuosity (S_{mf}), valley floor width-to-height ratio (V_f), and asymmetry factor (AF), together with longitudinal stream profiles and hypsometric curves for the main catchments of the Dinarkooh region calculated and extracted from Digital Elevation Model (DEM).

Mountain front sinuosity (S_{mf})

Mountain front sinuosity (S_{mf}) was defined by Bull (1977) as:

$$S_{mf} = \frac{L_{mf}}{L_s} \qquad (5)$$

that L_{mf} is the length of the mountain front along the foot of the mountain, i.e., the topographic break in the slope, and L_s is the length of the mountain front measured along a straight line. This index has been used to evaluate the relative tectonic activity along mountain fronts (Bull & McFadden, 1977; Keller & Pinter, 2002; Silva & *alii*, 2003; Pérez-Peña & *alii*, 2010). When a mountain front is active, uplift is more than erosion, led to straight front with low S_{mf} value. In less active mountain fronts, erosion rate is more than uplift rate, leading to sinusoid and irregular fronts, so S_{mf} increased. Some studies proposed that the values of the S_{mf} index lower than 1.4 are indicative of tectonically active fronts (Keller, 1986; Silva & *alii*, 2003).

Valley floor width-to-height ratio (V_f)

Valley floor width-to-height ratio (V_f) (Bull & Mc Fadden 1977) is a geomorphic index for distinguishing V-shaped and U-shaped valleys. This index is defined as:

$$V_f = \frac{2V_{fw}}{E_{ld} + E_{rd} - 2E_{sc}} \qquad (6)$$

that V_{fw} is the width of the valley floor, E_{ld} and E_{rd} are elevations of the left and right valley divides, respectively, and E_{sc} is the elevation of the valley floor. Deep V-shaped valleys ($V_f<1$) are a sign of linear, active downcutting streams, that shows areas subjected to active uplift, while flat-floored valleys ($V_f>1$) indicate an inactive streams and steady state areas (e.g. Keller & Pinter, 2002; Bull, 2007). This index has been applied to mountain fronts of Dinarkooh region.

Asymmetry factor (AF)

The asymmetry factor (AF) of basins was used to detect possible tectonic tilting at the basin scale. The AF is defined as below (Keller & Pinter, 2002):

$$AF = \frac{A_R}{A_T} \times 100 \qquad (7)$$

that A_R is the area of the basin to the right (facing downstream) of the main stream, and A_T is the total area of the drainage basin. Values of AF above or below 50 indicate that the basin is asymmetric.

In order to avoid possible confusions between the catchments located in the northern and southern slopes, we expressed AF as the absolute value minus 50 in table 1.

$$AF = 50 - \frac{A_R \times 100}{A_T} \tag{8}$$

We have divided AF absolute values in four classes based on Pérez-Peña & *alii* (2010): AF<5 (symmetric basins), AF=5–10 (gently asymmetric basins), AF=10–15 (moderately asymmetric basins), and AF>15 (strongly asymmetric basins). AF values in the eastern and western parts of the Dinarkooh region shows moderate to strong asymmetries. In the central part of the Dinarkooh region, basins are gently asymmetric.

HYPSOMETRIC CURVES

A curve that shows the distribution of area and altitude within it in a basin is called hypsometric curve (Strahler, 1952). In this study, the hypsometric curves were drawn by plotting the relative area (0–1) above each relative height (0–1). A useful characteristic of these curves is that basins of different sizes can be compared, since area and elevation are plotted as functions of total area and total elevation (Keller & Pinter, 2002; Pérez-Peña & *alii*, 2009a, c; Pérez-Peña & *alii*, 2010). The shape of this curve is related to the degree of dissection of the basin, i.e., its erosional stage. Convex hypsometric curves specify relatively «young» lowly eroded regions, regions with moderate erosion are specified by S-shaped curves, and concave curves specify relatively «old» highly eroded regions. The area below the hypsometric curve is known as the hypsometric integral (HI), varying from 0 to 1, with values close to 0 in highly eroded regions and values close to 1 in weakly eroded regions. The shape of the hypsometric curves (and the HI values) also provides valuable information about the tectonic, climatic, and lithological factors controlling catchment landscape (Moglen & Bras, 1995; Willgoose & Hancock, 1998; Huang & Niemann, 2006). We calculated hypsometric curves for four main basins with the aid of an ArcGIS extension (Pérez-Peña & *alii*, 2009b). The hypsometric curves show differences between the curves of the eastern, central and western parts of the region (fig. 3).

TABLE 1 - Values of V_f (valley floor width-to-height ratio) for 16 points in main streams (presented in fig. 2) and AF (asymmetry factor) for four main basins of the Dinarkooh Region

Basin Number	Point of measurment	Vfw	Eld	Erd	Esc	Vf	AF
1	1	110	1240	1220	1160	1.57	18
	2	150	1150	1140	1000	1.03	
1	3	75	920	920	870	1.5	
	4	65	710	720	645	0.46	
	5	70	525	525	430	0.36	
2	6	75	1150	1150	1050	0.75	7
	7	100	980	980	900	1.25	
	8	50	850	850	800	0.5	
	9	95	690	680	600	0.4	
3	10	75	1170	1160	1100	1.15	6
	11	105	1050	1000	950	0.52	
	12	50	890	890	850	0.62	
	13	40	695	700	675	0.26	
4	14	55	1040	1020	990	1.37	12
	15	100	1000	1000	900	1	
	16	50	775	760	740	0.9	

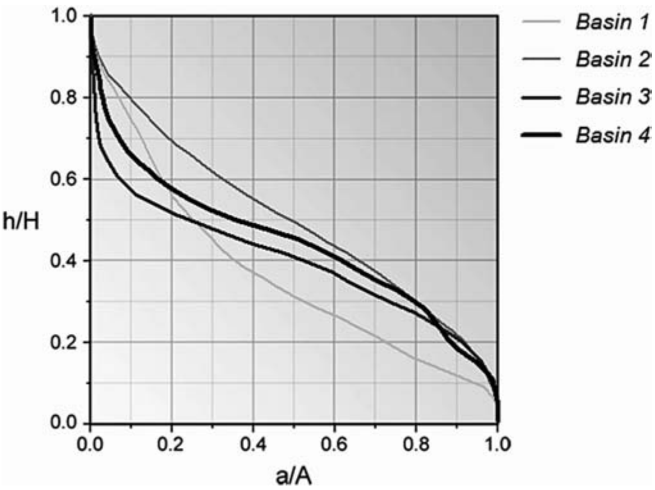

FIG. 3 - Hypsometric curves of four main streams of study area. Curves have been calculated using a 15-m DEM and CalHypso ArcGIS module (Pérez-Peña & *alii*, 2009b). For basin number refer to figure 2.

RESULTS AND DISCUSSION

The geomorphic indices presented in this paper suggest that the Dinarkooh region is tectonically active, that more uplift occurs along its central and southern mountain fronts, where S_{mf} and V_f present the lowest values (fig. 2 and tables 1 and 2).

The principal aim of tectonic geomorphology is to extract tectonic information from the longitudinal profiles and geomorphic indices. Tectonic information of such stream profiles lies in the knickpoints and Strahler order of streams. As the stream responds to tectonic forces or lithologic changes, knickpoints location moves downward or upward in the stream. By using stream power law the data of steepness and concavity indices mostly give similar information, because of changing between two different steepness values is normally interleaved by a zone of very high or low concavity. Generally low concavity value of a stream shows increasing incision rate or lithological changes. The knickpoints sharpness gives relative information about

TABLE 2 - S_{mf} values for the different mountain front segments. Mean values for each main front are also indicated

Mountain Front	Segment No.	Smf	Mean Smf
North	1	1.41	1.76
	2	1.50	
	3	1.60	
	4	1.40	
	5	1.38	
South	6	1.31	1.20
	7	1.29	
	8	1.06	
	9	1.10	
	10	1.23	

recent tectonics activity. In general, the sharper knickpoints indicate more recent activity (Wobus & *alii*, 2006).

We have studied four main streams using stream power law. The analysis of four main streams, i.e., the Meymeh river (stream No. 1) in western part, streams 2 and 3 in central part and stream 4 in eastern part is discussed here in detail. The stream profile analysis of the Meymeh river is shown in figure 4. This is a four segment stream. Three knickpoints shows tectonic activity. All the knickpoints show the presence of local faults. Three trends observed in this stream based on morphologic conditions, i.e., an upper segment, middle segment and lower segment. The upper segment passed on relict landscape with steepness index 67.98 and uniform concavity index 0.42, which means that it suffer moderate erosion. The middle segment shows intermediate concavity 0.17 and steepness 73.73, which means that erosion process are active. The lower segment suggests higher concavity and steepness indices, i.e., 0.64 and 372.51. As the stream goes down, the sharp change in the geomorphic indices shows gradual changes in lithology and tectonic activity. The eastern part of the region has low steepness values, and because steepness is directly related to uplift rate, it means that the region underwent less deformation processes on the eastern section. We studied streams 2, 3 and 4 from central part to understand the tectonic control on drainage behavior, shown in figures 5, 6 and 7. The morphology of all the streams consists of three segments which separated by knickpoints. The first seg-

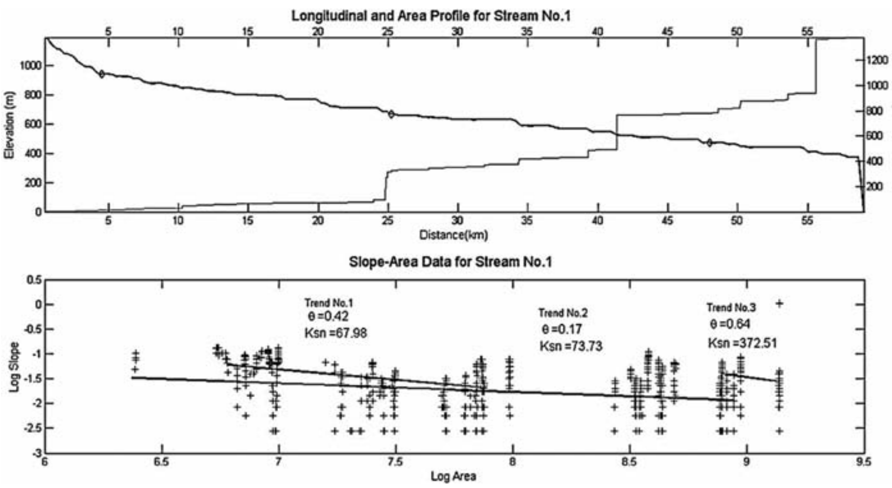

FIG. 4 - Stream profile analysis of the Meymeh River (stream No. 1). It clearly shows that the three main knickpoints and three clear segments are identified. This helps us separate the Northern, Southern and Central Dinarkooh.

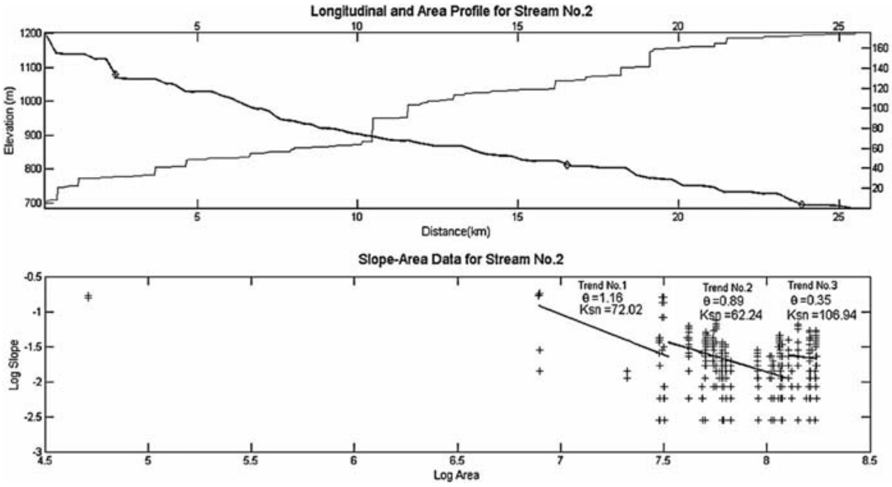

FIG. 5 - Stream profile analysis of Stream 2 from central Dinarkooh. It clearly shows that the location of some local faults is identified by the three main knickpoints.

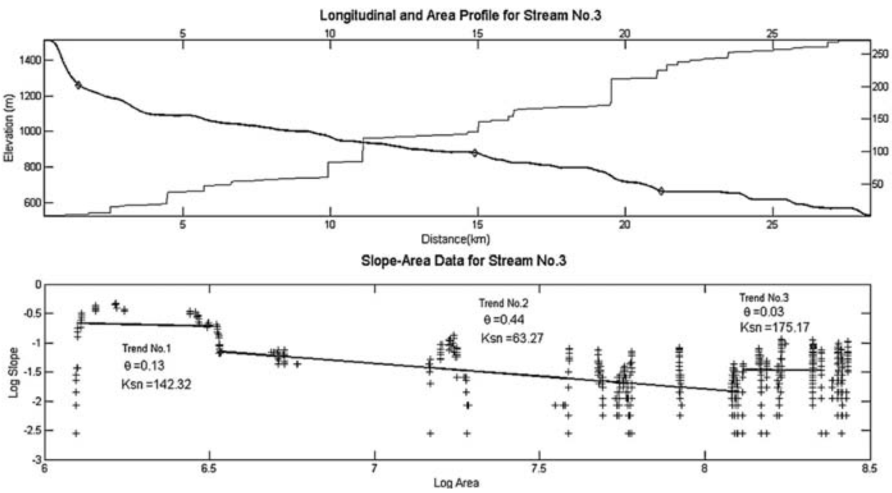

FIG. 6 - Stream profile analysis of Stream 3 from central Dinarkooh. It is a three segment profile showing less variation in steepness.

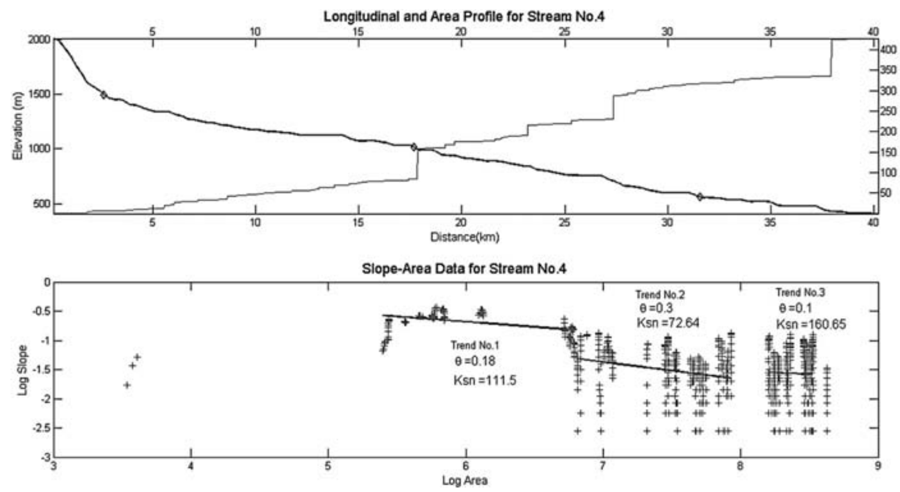

FIG. 7 - Stream profile analysis of Stream 4 from eastern Dinarkooh. It clearly shows that the location of some local faults is identified by the three main knickpoints.

ment of stream 2 shows relict landscape with low erosion, but after crossing a local fault it shows high concavity and steepness indices. Stream 2 is flowing in central part and has higher concavity values from 0.35 to 1.16 and steepness values from 62.24 to 106.94. Since the values of steepness are directly related to uplift, comparing these values to those of stream 1 we can conclude that the central part is more deformed and is uplifting, whereas eastern part is more stable. The concavity and steepness values are shown in table 3. This table shows normalized steepness and concavity in the upper, middle to lower segments, and variability of concavity indices in the middle segments and normalized steepness indices in the upper segment. The normalized steepness index is calculated with a fixed mean concavity value of 0.45. The streams No. 3 and No. 4 also show higher uplift rates in their middle segments.

TABLE 3 - Steepness and concavity values

Stream No.	Segment No.	Concavity	Steepness
1	1	0.42	67.98
1	2	0.17	73.73
1	3	0.64	372.51
2	1	1.16	72.02
2	2	0.89	62.24
2	3	0.35	106.94
3	1	0.13	142.32
3	2	0.44	63.27
3	3	0.03	175.17
4	1	0.18	111.50
4	2	0.30	72.64
4	3	0.10	160.65

By applying stream profile analysis on four main streams of the basins and calculating the concavity and steepness values, we calculated uplift rates in different parts of the region (fig. 8). For using stream profile analysis to determine uplift rates, we assume that region is in steady state (Shahzad & *alii*, 2009). The uplift rate map shows the amount of uplift per year in different parts of the region. In the eastern section the uplift rate ranges from 0.622 mm/yr to 1.11 mm/yr, in the central section from 0.633 to 1.75 mm/yr and in the western section from 1.10 to 3.72

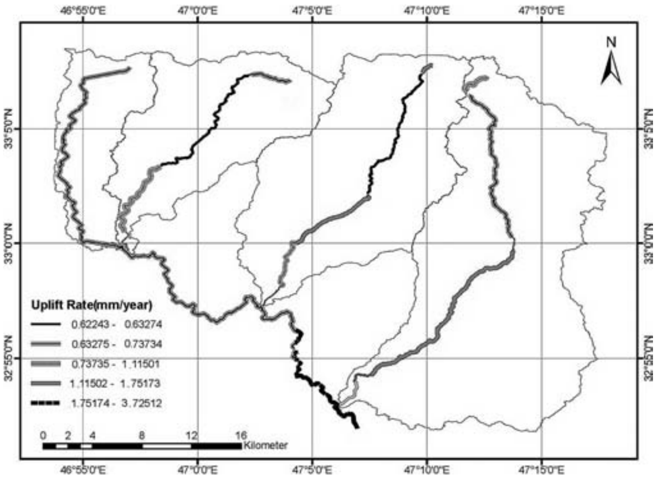

FIG. 8 - Uplift rate map of the area showing uplift values (cm/yr).

mm/yr. This suggests that the central and to some extent western parts have been experiencing more uplift compared to the rest of the region. As shown in this map, the southern part of the region has greater uplift rate value that indicates more tectonic activity. Blind thrust faults beneath this region may have a role in this activity (Berberian, 1995).

CONCLUSION

The geomorphic indices presented in this paper show that Dinarkooh region in Zagros mountain range is tectonically active. Mountain front sinuosity (S_{mf}) and river incision (V_f) indicates activity in central and southern mountain fronts, and the moderate activity in northern fronts. These central and southern mountain fronts are associated with active NW-SE thrust. The northern front is associated with an inactive limb of Samand anticline. The asymmetry indices calculated for the main basins suggest the presence of active NW-SE oriented folds in Dinarkooh region and the main activity is concentrated in central parts.

The hypsometric curves and the longitudinal stream profiles suggest a higher tectonic activity in the central and southern parts of the Dinarkooh region, however any of basins don't show "High" activity, but moderate and low values are observed. Also, hypsometric curves show, along with S_{mf} and V_f, an intermediate activity of northern mountain fronts.

Digital elevation model (DEM) is an essential material for computer-based analysis of river profiles and drainage basins as it provides elevation information for the land surface. In this study we applied tectonic geomorphology analysis on the four main streams in the Dinarkooh region to study their behavior. Tectonics and subsurface lithology cause changes in the course of streams. Any change in tectonics of the region influence on drainage network development. This study can be improved by using other geological information.

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