Geomorphometric Analysis of Maroon River by Digital Elevation Model

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Abstract

Digital Elevation Models (DEMs) are used to estimate different morphologies, analysis of river profile, delineating drainage basin and drainage pattern associated with lithological and structural changes. The study area is Maroon River located in Khuzestan Province, Iran. In this study geomorphometric analysis based on DEM carried out to understand Maroon river uplift rate and tectonic- erosion relationships in its catchment. Geomorphic processes, such as stream length gradient, Hypsometric Integral, Isobase map, Incision map and concavity of the river were extracted from digital elevation model. Slope- Area plot was used for analysis of uplift rate and stream power of the river. Results show that the changes in stream length (SL) are because of lithological change in the study area. More erodible lithologies cause low SL values. Isobase map of the study area was obtained by relating drainage network and topographic surface. Isobase map delineate structural and lithological erosional processes. Hypsometric integral and hypsometric curve of the Maroon River catchment indicates a old catchment, so erosion is more effective in landscape evolution than tectonics. Uplift rate map of Maroon River shows different rates in upstream and downstream of the river. Concavity and Steepness indices were obtained using stream profile analysis and by using power function, uplift rate is calculated. Logarithmic regression of the area and slope values of the Maroon River lead to calculating concavity and steepness values. It is concluded form this investigation that erosional condition is more powerful in the study area.

Keywords: *Geomorphometric Analysis, Maroon River, DEM, Uplift Rate*

1. Introduction

In regions with active tectonic, the geometry and evolution of river systems are sensitive to surface uplift rate (Clark et al, 2004). Zagros simply folded belt developed during late Cenozoic (Mobasher, 2007) and is still active as is affected by tectonic activity of Arabian- Iranian plate boundary shortening processes, as wide spread seismic activity in this region is an evidence (Berberian and King, 1981). In a tectonically active region, geomorphic markers, such as alluvial fans, multiple river terraces and some other geomorphic features are essential as a reference frame for gauge deformations (Tsai and Sung, 2003). Stream profile analysis is more stable parameter in tectonic studies rather than river terraces. By using digital elevation models (DEMs) such analyses become more easy, fast and precise.

Geomorphic responses to tectonic uplift provide

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key insights on mountain belt evolution and landscape morphology (Whipple, 2004). In this study, tectonic-erosion setting of Maroon River catchment is investigated based on geomorphometric analysis of DEM. Some parameters, such as stream length gradient (SL), Hypsometric Integral (HI), Isobase map, Concavity, Steepness and uplift rate of the main stream are calculated and tectonic setting of the study area is discussed. The aims of this study are to find out Maroon River uplift rate and discuss the tectonic-erosion setting of the study area.

2. Material and Methods

The study area is located between 30° 30´ N and 30° 55´ N latitudes, and 50° 00´ E and 50° 30´ E longitudes, in the southwestern Zagros simply folded Belt (ZSFB) in southwestern Iran (Fig. 1). The Zagros Mountain range hosts more than half of the world's known hydrocarbon reserves (Sepehr and Cosgrove 2005). Compressional tectonic forces have 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 and King 1981, Berberian 1995).

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).

In this study, morphometric indices are used as indicators of landscape response to tectonic activity or erosion processes. Shape and structure of the drainage constitute a response to the uplift process, more or less modulated by lithologic condition of the area (Jackson and Leeder, 1994). In this research, morphometric data are not statistically analyzed, but

are spatially analyzed in order to reveal spatial relationship between geomorphometric parameters and tectonic- erosion and uplift rate of the study area. The main material for this study is digital elevation model (DEM). Wide ranges of DEMs are available, from global to local scales. ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model) was used here, with horizontal spatial resolution of about 30 meters a vertical resolution of about 7 meters. Delimitation of the morphological units was performed by threshold application on slope and azimuthal maps derived from DEM and confirmed by conformation with hydrographic network and associated drainage basin automatically derived from DEM (Delcaillan et al, 2006). These data are used to calculate various morphometric indices. Table 1 summarizes the indices that used in this study. Figure 2 shows Maroon basin boundary that HI parameters are calculated according to this area.
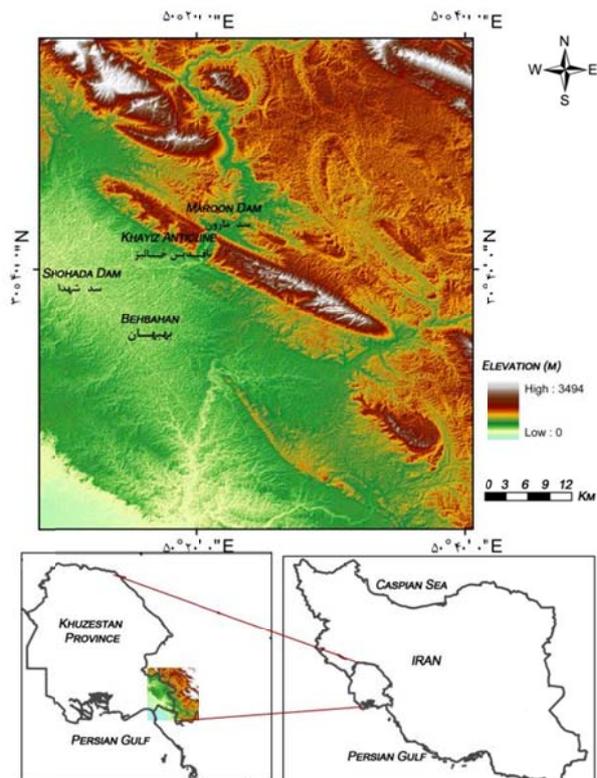

Fig. 1: The study area location on Iran

Table 1: Geomorphometric indices that used in this study

| Indices	symbol	formula	Reference
Stream Length Gradient	SL	$SL = (\Delta H / \Delta L)L_{tc}$	Hack (1973)
Hypsometry Integral	HI	$HI = \dfrac{h_{mean} - h_{min}}{h_{max} - h_{min}}$	Strahler (1952)
Isobase map	-	Discussed in the text	Cox & Rosenthal (1993)
Concavity	-	Discussed in the text	Shahzad and Gloaguen (2011)
Steepness	-	Discussed in the text	Shahzad and Gloaguen (2011)
Uplift Rate	-	Discussed in the text	Shahzad and Gloaguen (2011)
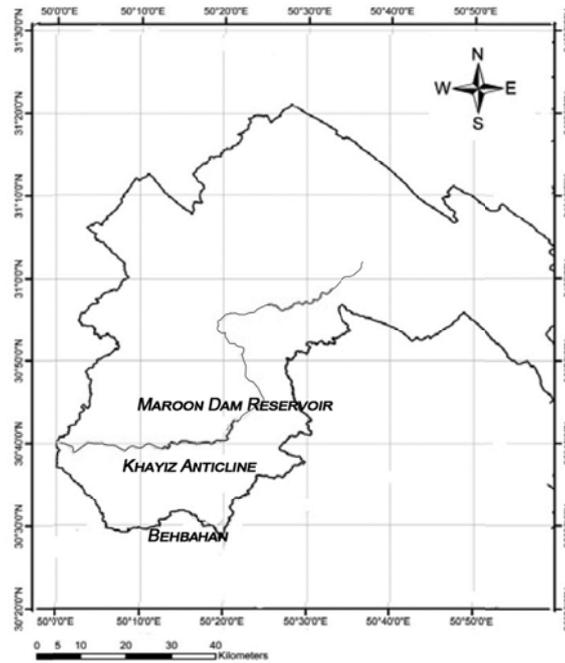
Fig. 2: Maroon basin boundary

Drainage network was ordered according to strahler (1952). Longitudinal profile of the main river is used for identifying breaks in slope. Such knickpoints then are used as indicator of uplift and to divide two parts with different uplift rates.

TecDEM (Tectonics from Digital Elevation Model) is a MATLAB toolbox that uses Global DEMs. DEMs are replacing traditional topographic maps in geosciences and provide us the automatically extracted drainage networks. Because of rapid response of drainage to tectonic changes, thus it is a potential parameter for tectonic analysis. DEMs provide an opportunity to quantify the influence of neotectonic processes on landscape development (Shahzad and Gloaguen 2011a, 2011b). It first extracts the drainage network using Deterministic-8(D8) algorithm. D8 algorithm is the most convenient and widely used method to extract drainage network (Hogg et al., 1997; Maidment, 1993).

2.1. Processing of SL Map using GIS

Anomalies of stream profiles, especially knickpoints, are important for studying tectonic impacts on fluvial landforms. Studies on knickpoints and other slope break indices mostly use discrete data representation.

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Some authors have tried to make contours of SL values to detect anomalies of stream profiles, whereas others have tried to connect SL values to geological objects. This study is innovative because its result is a map showing SL anomalies along the main rivers of a watershed. It can highlight zones with high values of SL which will be interpreted in terms of differential erosion, or tectonic activity.

Generally, the values needed to compute SL are measured from topographic profiles. Instead of a commonly used method for calculating a slope map from a DEM using a moving window, we computed slope using contour lines derived from a DEM. The contouring method averages out much of the vertical noises included in many available DEMs, particularly in steep and narrow watersheds.

2.2. The stream Power Law

Deviations from the typical concave-up shape of stream longitudinal profiles, such as knickpoints or convex segments, indicate a disequilibrium state resulting from tectonic, base level or lithological perturbations (Kirby and Whipple, 2004; Chen et al., 2003; Pedrera et al., 2009; Font et al., 2010). The normalized steepness index (k_{sn}) is widely used to investigate tectonically induced perturbations in river longitudinal profiles and has been used to propose patterns of uplift (Kirby and Whipple, 2004; Wobus et al., 2006; Whittaker et al., 2008). The lithological or structural contrasts force the streams to reach a new equilibrium condition. Mathematically, this is written in below equation:

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

which 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 steady state equilibrium, equation 2 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 K is steepness of the profile. So, it can be written as:

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

which θ and ks are concavity and steepness indices, respectively. They can be calculated directly using regression analysis of data as shown in equation 2, i.e., area and slope (Howard 1994, Snyder et al. 2000, Whipple 2004, Wobus et al. 2006). By combining equations 1 and 2, a useful relationship for calculating uplift rates is presented below:

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

which ksn 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 3, uplift rate is calculated. Constant values of n and K is obtained from previous studies (Seidl and Dietrich 1992, Wobus et al. 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.

2.3. Basin Hypsometry

The hypsometric curves have been used to infer the stage of development of the drainage network and also it is a powerful tool to differentiate between tectonically active and inactive areas (Keller and Pinter, 2002). The curve is created by plotting the proportion of total basin height against the proportion of total basin area (Figure 3).Convex hypsometric curves characterize young slightly eroded regions; S

shaped curves characterize moderately eroded regions; concave curves point to old, highly eroded regions. In the present study, all basins are automatically processed to calculate Basin hypsometry using TecDEM. The simplest way to characterize the shape of hypsometric curve for a given drainage basin is to calculate its hypsometric integral (HI).

The HI shows the distribution of landmass volume remaining beneath or above a basal reference plane (Strahler, 1952; Schumm, 1956). This index proved as an efficient factor in evaluating the response of landscapes to active tectonics (e.g., Pérez-Peña et al., 2009; Mahmood and Gloaguen, 2012; Andreani et al., 2014; Domínguez-González et al., 2015). In theory, hypsometric integral value ranges between 0 and 1. Low hypsometric integral values indicate old and more eroded areas and evenly dissected drainage basins. High values of the hypsometric integral value indicate that most of the topography is high relative to the mean, such as a smooth upland surface cut by deeply incised streams indicating young and less eroded areas.
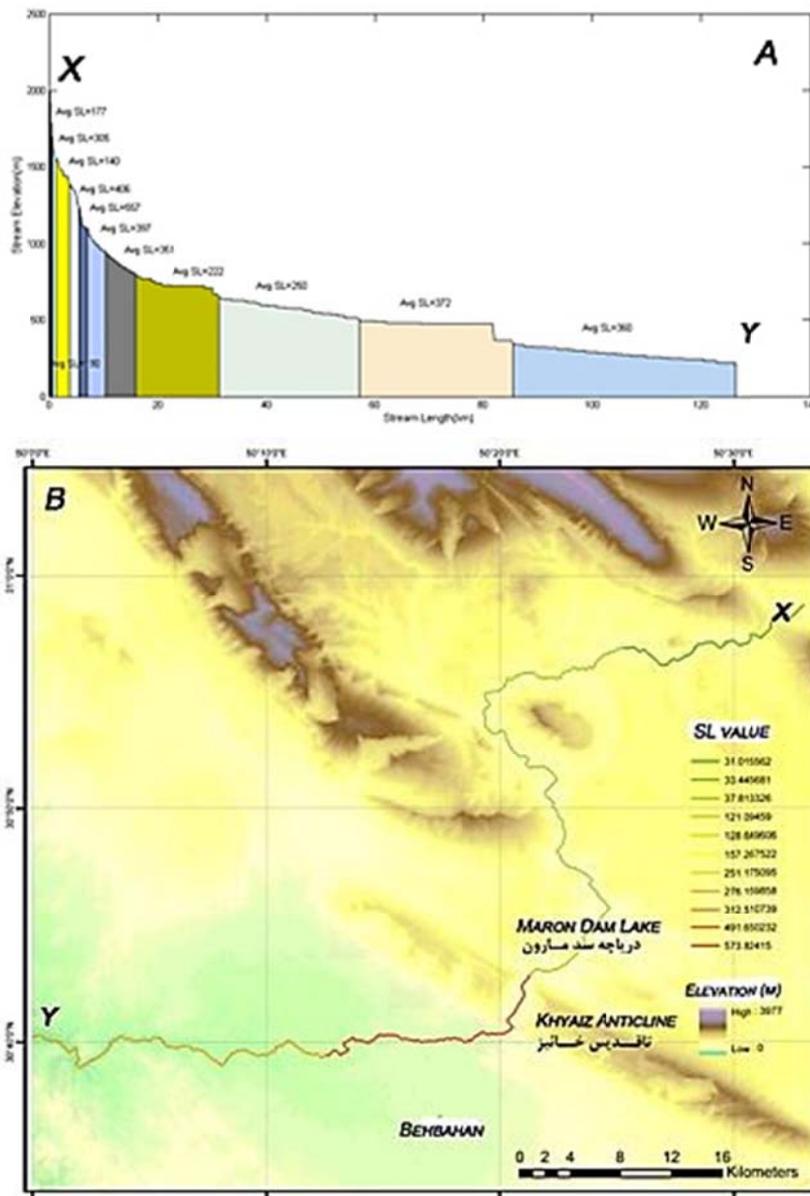

Fig. 3: SL values of Maroon River in the study area, a) SL values in longitudinal profile, b) SL values as shown on DEM map.

2.4. Isobase Map

The spatial distribution of stream height (isobase map) is a useful proxy for investigating geologic or tectonic processes (e.g., Dury, 1952; Filosofov, 1960; Golts and Rosenthal, 1993; Grohmann et al., 2007, 2011). Drainage networks are commonly organized according to Strahler (1957) stream order. According to Golts and Rosenthal (1993) streams of similar orders are of similar geological age and are related to similar geological events. Hence the interpolation of isobase lines, which connect streams with a similar order, produce a surface resulting from the same erosional events. Isobase lines represent erosional surfaces which have formed due to recent tectonic and erosional events (Filosofov, 1960). Studies suggest that Isobase maps are prepared by interpolating the elevation at the location of 2nd and 3rd order streams (Golts and Rosenthal, 1993; Grohmann, 2004). Sharp changes in the isobase map indicate the possible location of faults and/or lithological contrasts.

As suggested by Grohmann et al. (2011), isobase maps can be seen as a smoothed version of the original topographic surface, from which was removed the "noise" of the first Strahler order stream erosion. Sharp topographic changes affecting an isobase surface were used to infer potential structures or uplifted blocks associated with tectonic movements (e.g., Golts and Rosenthal, 1993; Grohmann et al., 2007; Garrote et al., 2008; Domínguez-González et al., 2015).

2.5. Incision Map

The Incision map shows relative or local relief and is a tool for quantifying relative elevation. It is calculated by measuring the difference between the maximum and minimum elevation in a moving window. The calculation of relative relief is influenced by the shape and size of the moving window and is a well documented problem (Ascione

et al., 2008). The moving window should be large enough to include at least two major ridges and/or valleys otherwise the results will not represent local relief but simply the slope gradient (Evans, 1972). Moving window is 10*10 km in this study and results are shown in figure 6.

3. Results and Discussion

The generation of maps that reveal some surface dynamics parameters by using TecDEM is a tool for analysis of tectonic influence on geomorphological pattern of the study area. These types of analyses are especially suitable in regions with drainage network anomalies and relief pattern discontinuities (Gloaguen et al., 2007, 2008; Kurz et al., 2007).

Values of the SL index over the study area, determined from digital elevation models and geographic information system (GIS), are shown on Fig. 3. In order to discriminate values at the index related to rock resistance, different levels of average rock strength were defined (by rock type and field observation) from very low strength (silt, sand and marl), low strength (older alluvial fan deposits and fairly well-consolidated conglomerate), moderate strength (fillite and schist), high strength (calcareous sandstone, travertine, and conglomerate), and very high strength (marble). Based upon the quantitative SL indices linked to relative rock resistance described above with field observations suggest that:

1- Along the southern part of the Maroon River, values of the SL index show a variable distribution. The highest and perhaps most anomalous values of the index are along the Maroon River on its pass from Khayiz anticline. These high indices are not associated with particularly resistant rocks, so is interpreted to be a tectonic signal. Several locations along the western flank of the Khayiz anticline also have anomalously high SL index values on relatively soft rocks.

2- Along the NE portion of the study area, SL indices tend to be relatively low compared with the other

parts. Anomalous values of the indices are related to outcrops of the resistant massive limestone found along the river profile.

Hypsometry analysis is based on investigating the shape of basin hypsometric curves which vary from concave to convex. Hypsometric plot of the Maroon river basin is shown in Figure. 4. Hypsometric integral of the Maroon river basin is about 0.22 that means this basin is an old basin. Analysis suggest that as th basin is in old stage, so erosion processes are more influent that tectonic ones.
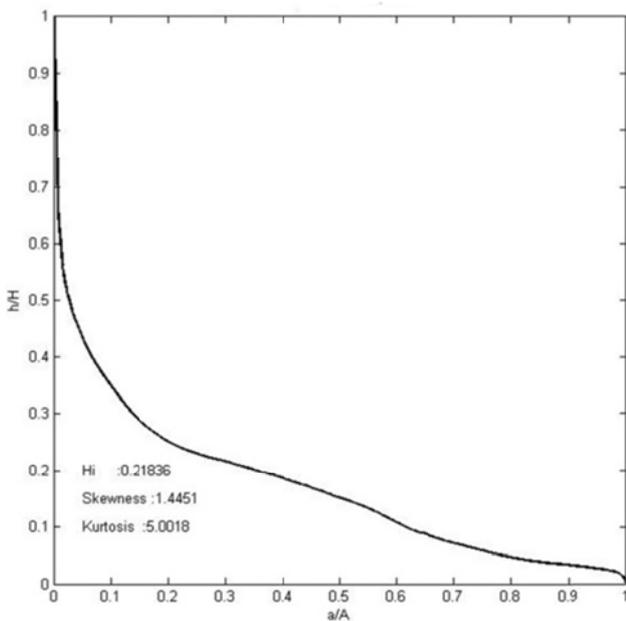

Fig. 4: Hypsometric curve and Hypsometric Integral Values for Maroon River basin

The analysis of surface dynamics parameters such as Isobase, Incision and vertical dissection maps provides insight into the tectonic geomorphology of the study area. These parameters might reveal major tectonic features. The Isobase map of the study area (Fig. 5) which shows the location of 2nd and 3rd order streams is changable. Changes in the relative position of 2nd and 3rd order streams at high or low relief correlates with some of the tectonic features, e.g. Main Boundary Thrust and linear features. Other minor changes in the Isobase map might be related to residual morphotecronic features in the study area.

The isobase map, constructed based on second and higher order drainages, allowed depiction of the features controlled by recent structures as an inflexion in the fault line area or a lineament (Fig. 5). As a first analysis, it shows three large domains in the study area: High (A), Medium (B) and Low (C. High isobase values occur in the central-southern portions of the area and include mainly carbonate rocks. Medium values occur in the central-west part of the area, over sedimentary rocks. Low isobase values occur over alluvium deposits of the Quaternary formation. The main morphological difference between the isobase and the original topographic surface is the removed of the noise of the low- order streams, which allows the identification of possible tectonic influence.
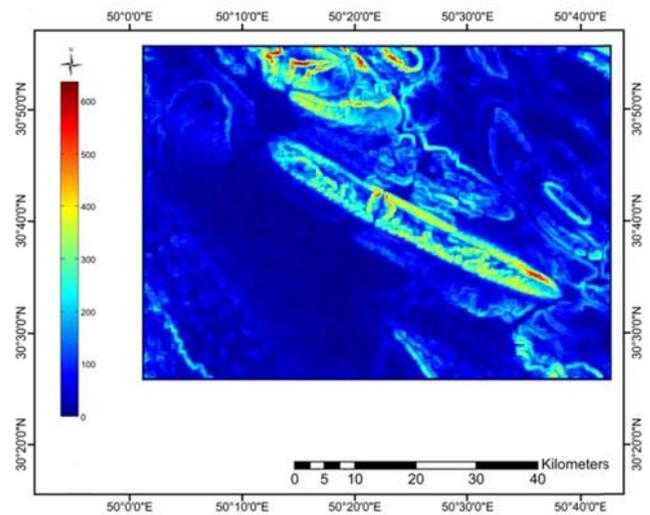

Fig. 5: Isobase map of the study area.

The incision map or local relief is used to identify regions of high gradients (Guzzetti and Reichenbach, 1994). The incision map of the study area was also prepared using a moving window of 1 km^2 and again shows steep changes to the west of the Khayiz. This map also shows a series of sharp changes in the NW side of the study area, which is related to the EW-trending series of lineaments. Using the incision map these lineaments can be further traced to prepare a more detailed neotectonics map of the study area (Fig. 6). As can be seen on the map, incision is high on NE part of the study area, which is mainly composed of sedimentary rocks with medium erodibility. Low altitude parts of the area have less incision value.
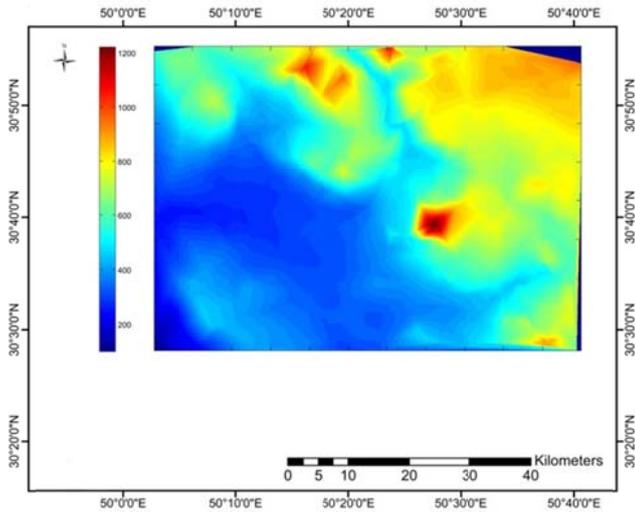
Fig. 6: Incision map of the study area.

The Maroon River is studied using stream power law (Fig. 7 and Fig 9). The analysis is discussed here in detail. The stream profile analysis of the Maroon river is shown in figure 8. This is a three segment stream. Two knickpoints shows tectonic activity. All 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 107.64 and uniform concavity index 0.69, which means that it suffer less erosion. The middle segment shows

intermediate concavity 60.33 and steepness 0.6, which means that erosion process are active. The lower segment suggests lower concavity and steepness indices, i.e., 0.27 and 61.49 respectively. As the stream go down, the sharp change in the geomorphic indices shows gradual changes in lithology and tectonic activity. The northern part of the region has low steepness values and because steepness is directly related to uplift rate it means that region undergone less deformation processes on northern section, compared to other parts. Figure 8 shows correlation between geologic formations and faults locations to SL values.

The evolution of landscapes results from complex interactions between climatic and tectonic processes (e.g., Willett and Brandon, 2002; Ferrater et al., 2015). Recent tectonic or climatically induced base-level fall are associated with the propagation of an erosion wave, which represents the limit between an upper-relict landscape and a lower adjusting zone (e.g., Pérez-Peña et al., 2015). As a result, relict portions of landscapes (i.e., where uplift is not yet counterbalanced by fluvial erosion) may persist though time (e.g., Burbank and Anderson, 2012; Clark et al., 2005; Legrain et al., 2014; Giletycz et al., 2015).
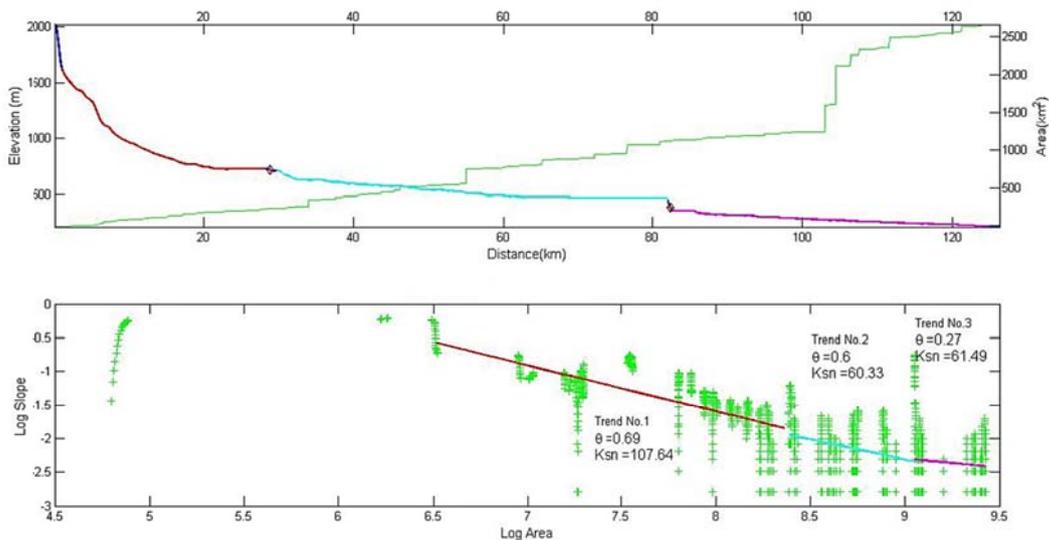

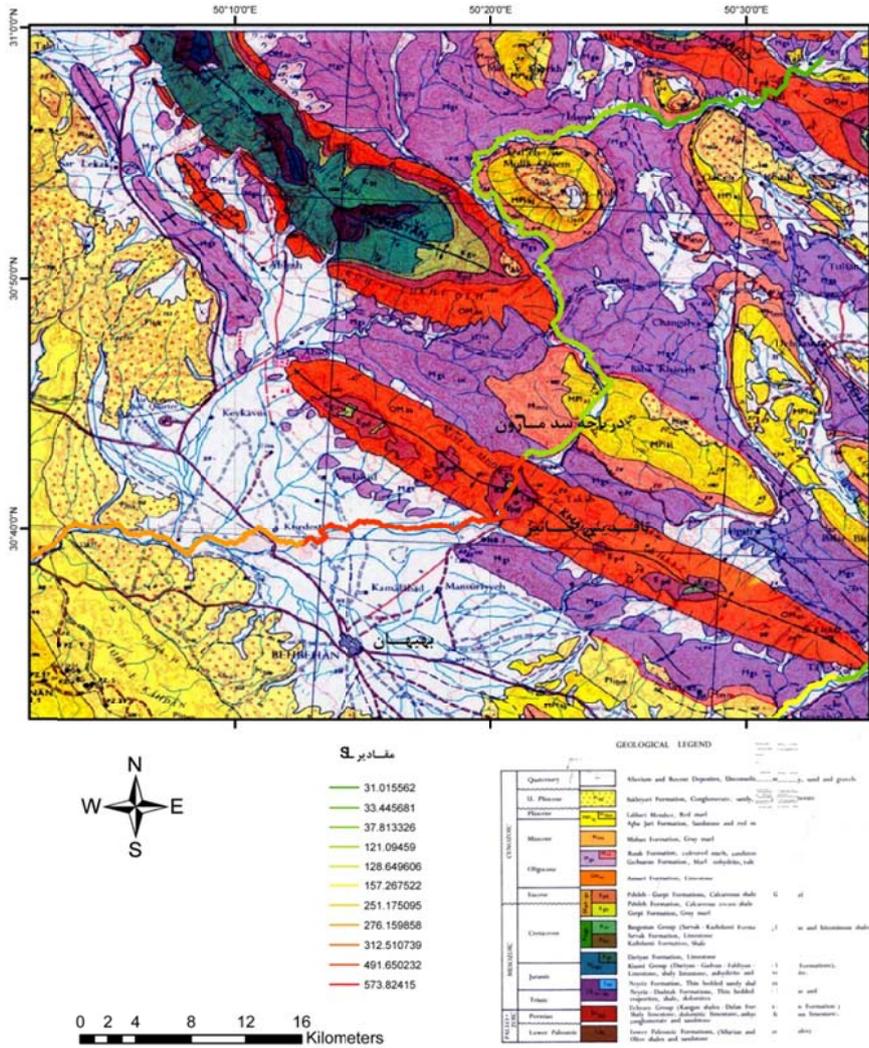Fig. 7: Slope- Area plot of the study area.

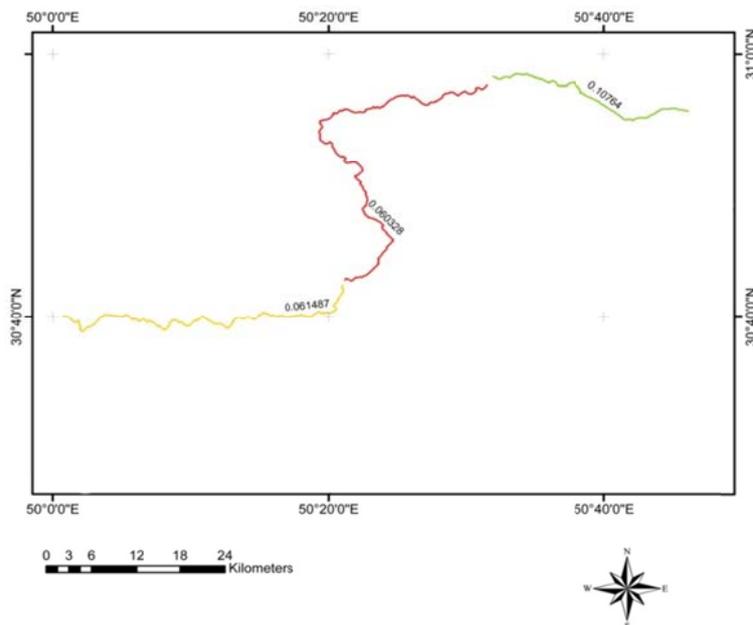Fig. 8: Lithologic and Faults map of the study area showing SL values.

Fig. 9: Uplift rate map of Maroon River

3.1. Upstream Impacts of Dam Implementation

Geomorphological adjustments upstream of a dam are primarily concerned with sedimentation due to trapping of sediment within the reservoir. A reservoir leads to hydraulic conditions that reduces the flow velocity to near zero, so any sediment transported to the reservoir will settle out (Petts, 1984; Brierley and Fryiers, 2005). The settling out and deposition of sediments results in trapping a large amount of sediment. In addition, the formation of delta deposits may occur in the upstream channel as a result of deposition of coarse materials at the upstream end of the reservoir. This ultimately will reduce the river channel capacity (Wang and Hu, 2004; Brierley and Fryiers, 2005).

As a result of degradation and aggradations, geomorphological adjustments can take place in channel cross section and capacity, slope, plan form and bed form. Changes in channel cross section and capacity occur through adjustments in width and depth. Erosion of the bed and bank will increase depth and width of the channel, respectively. This leads to enlarging cross section area and capacity of the river (Petts, 1979; Schumm, 2005). In contrast, deposition of material will reduce cross section area and capacity of the river. Julien (2002) describes the slope adjustments in rivers in order to reach equilibrium between water discharge and sediment yield. Degradation lowers and flattens the slope, so the river erosion is reduced. In contrast, aggradation generally increases the slope as the river aims to increase its competence (Julien, 2002; Gordon and Meentemeyer, 2006). Plan form changes may also occur below dams as a result of erosion and deposition processes. It has been stated that erosion and degradation below dams will transform braided rivers to straight or sinuous river. However, meandering river may experience little changes in width, but migration rate will be reduced (Shields et al., 2000; Wang and Hu, 2004). The aggradation of river due to sediment availability that flow power is

unable to transport it; lead to disruption and filling of pools along with the formation of bars, berms and lag deposits. These structures may be destroyed during degradation and erosion (Bierley and Fryiers, 2005).

Despite the range of adjustments that may occur, the implementation of a dam may do not lead to geomorphological changes. For example, if the discharge released is incompetent to erode and redistribute the existing river boundary, then neither erosion nor deposition takes place. So, the flow will accommodated within the pre existing channel and no adjustments observed (Petts, 1979; Knighton, 1998; Gilvear, 2004).

Conclusions

The SL index describes the morphology of a stream network based on the distribution of the slope gradients along rivers. This work has discussed whether it is sensitive enough to detect the impact of different uplift rates on the drainage network. The SL map has provided the following implications: 1- SL values are significantly influenced by bedrock lithology, such as differences in erodibility, 2- Significant variations in SL values are associated with fault zones. This study shows that mapping SL from a DEM, instead of using topographic profiles, helps to understand the geomorphological impacts of differential uplift. This approach may be effective for other areas with potential influence of differential uplift. Base-level analysis has been successfully applied to semi-detail scale morphotectonic studies in the past. In this paper, we presented an example of the applicability of the method to regional-scale investigations. The base-level map constructed with 2nd and 3rd-order valleys was considered to present the best results and used for the interpretation of regional-scale morphostructures. The method provided results consistent with the scale of the data used as topographic base and with the drainage network. Geomorphological changes don not occur immediately, but a lag time exists between changes

to the first order and those of the second order and also between phases of adjustment before reaching quasi-equilibrium. In this case, no geomorphological changes is observed in Maroon River before and after dam construction. But, these changes may occur later in an extended time scale. The prediction of potential geomorphological changes is not a simple process, because multiple adjustments can take place.

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