International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 2 Issue 11, November-2013, pp: (22-34), Available online at: www.erpublications.com

Quantitative Geomorphology of analyzing tectonic activity in the Roczek and Shwork rivers valley in the Zagros Mountains (Iraqi Kurdistan)

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Abstract: Study area is located in the higher folded belt in the Zagros Mountain in the Iraqi Kurdistan. Analyzed geomorphic indices included sixteen sub basins: the stream gradient index (SL), drainage basin asymmetry (AF), hypsometric integral (Hi), Valley floor width-valley height ratio (VF) and mountain front sinuosity (J) is obtained relative of tectonic activity in the study area. These indices above based to calculated (lat), so classified theses values into very high, high, modern and low, Basins 3,4 and 16 are very high lat, basins 2, 7,8, 13 , 14, 15 are high relative of tectonic, modern relative are in 5, 9, 10 ,11,12 and low relative of tectonic is in sub basin 1. The uplift of Arabian plate was more impact in the Pleistocene. In the Pleistocene its importance was lesser in comparison with the influence of climate changes. Climate changes result in diversity fluvial processes mainly in the time, variety of neotectonic movements result in their diversity in the space more than in the time.

Key words: Geomorphic indices, SRTM image, Relative of tectonic activity, higher folded zone, Zagros Mountains, Iraqi Kurdistan.

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1. Introduction

Geomorphological studies of active tectonics in the late Pleistocene and Holocene are important to evaluate earthquake hazards in tectonically active areas (Keller , Pinter, 2002) such as the Higher folded Zone of Zagros Mountain in the Iraqi Kurdistan. General velocity of the Arabian and Turkish plates movements are known by (Walpersdorf et al., 2006). The review of the literature presented here shows that our knowledge of the effects of tectonic movements in the Middle East. This Knowledge is still insufficient in the Zagros Mountains of the Iraqi Kurdistan. The Zagros Mountains in Iraq are an area where these problems have not been subject to detailed investigation.

Previous studies in this kind of methodology has been found to be useful in various tectonically active areas such as the SW USA (Rockwell et al., 1985), the Pacific coast of Costa Rica (Wells et al., 1988), the Mediterranean coast of Spain (Silva, 1994), the southwestern Sierra Nevada of Spain (El Hamdouni et al., 2007) and the Sarvestan area, central Zagros, Iran (Dehbozorgi et al., 2010). The aim is to evaluate the relative of tectonic activity from the results of the geomorphic indices analyses based on field-based geomorphological observations.

2. Data

Longitudinal profile is drawn in the river tools software. Morphotectonic map was done in the Arc GIS. Several geomorphologic indexes including SL, AF, Hi, VF and T were done it in SRTM by river tools software for applied to assess the relative active tectonic. SL index is drawn on the overlap of the satellite image by Erdas and Arc GIS.

3. Study site

Study area located in the higher Zagros mountains belt in the Iraqi Kurdistan. Roczek and Shwork rivers valley are consisted case study (Fig.1). Five mountains are covered study site in elevations range from 2208.9 to 386.9 m.a.s.l. Both river valleys are divided in to sixteen sub basins to determent the relative of the tectonic activity (Fig.2).

Geological setting

The geological units exposed over the study area include fifteen formations that span the upper Triassic through Pliocene time interval (Fig.3). The major folds in the study area include anticlines and synclines. These folds generally strike NW-

SE (Numan , Al-Azzawi, 1993). According to the Burwary 1983, Omar 2005, Jassim , Goff 2006, Barzani 2008, I classified lithological composition of rocks into three types (Fig.4). The hard rock located within the Bultui,Kura, Qamchuqa and Aqra-Bekhme formations, the medium hardness located within the Shenkaiyan , Sarki and Pilaspi Formations and the soft rock located within in the Chia Gara , Barasain, Neokelkan, Sargalu, Khurmala Kolosh, Gercus, Upper and Lower Fars, Upper and Lower Bakhtiary Formations. Limestone and dolomite comprise medium hard and hard to very hard rocks. Medium hardness rocks are bonded with clay whereas soft rocks are clayey and chalky.

Regional Tectonic setting of the Zagros in the Kurdistan regional of Iraq

Zagros Mountains building started in Late Cretaceous time, due to the collision between the Arabian and Eurasian plates (Berberian, 1995; Talbot and Alavi, 1996). The shortening between the Arabian and Eurasian plates, whose horizontal velocity still reaches 2–2.5 cm/a, is partitioned into S–SW directed folding and thrusting and NW–SE to N–S trending dextral strike-slip faulting (e.g. Blanc et al., 2003; Dercourt et al., 1986; Dewey et al., 1973; McQuarrie, 2004; Talbot , Alavi, 1996; Talebian , Jackson, 2002).

In the Kurdistan Region of Iraq, the Zagros Orogeny is divided into four NW–SE striking tectonic units by (Numan,1997): Thrust zone, Imbricate Zones, High Folded Zone and finally Low folded zone (Fig.5).The boundary between the High Folded Zone and the Foothill Zone is marked by a regional morphotectonic feature, the Mountain Front Fault, delineated by a clustering of seismic events, which causes a sudden change in the level of exposed sedimentary layers. The Mountain Front Fault is trending parallel to the Zagros Belt and is interpreted as a result of the reactivation of Zagros basement structures (Berberian, 1995; Jassim and Goff, 2006; Mc Quarrie, 2004).The fold-and-thrust belt in the Kurdistan Region of Iraq is dominated by open to gentle folds, with a characteristic wavelength of 5–10 km (Ref et al, 2012), therefore considerably lower than the average values of 15–25 km in the SE parts of the Zagros fold-and-thrust belt (Mouthereau et al., 2007), and amplitudes of less than 2.5 km. The two main reasons for this difference in the fold-wavelength are the absence of major faults and thick salt horizons serving as detachments. For example, the Neo-Proterozoic Hormuz salt overlying the crystalline basement in the SE part of the Iranian Zagros, which acts as a ductile detachment during deformation (Mouthereau et al., 2007), is absent in the NW part of the Zagros (Bahroudi , Koyi, 2003).

Neotectonic and Morphotectonic setting

Zagros Mountains is located between three plates (Turkish, Eurasian and Arabian) Figure 6. General velocity of the Arabian and Turkish plates movements are 16 mm/yr, 4-6 mm/yr respectively (Walpersdorf et al., 2006).

Reilf et al., 2012 have been divided the earthquakes in three groups according to their focal point depths. The data extracted from the USGS/ NIEC, PDE database, 2011 (state to 6.7.2011) show results from years 1973 to 2011 (Fig.6). The shallowest and most common group recorded are earthquakes with hypocenter depth of 0 –30 km, the second, deeper and less common group with from 30 up to 150 km hypocenter depth. Only one earthquake with hypocenter deeper than 150 km was recorded. The most earthquake magnitudes are ranging between 4 and 5. The bulk thickness of the sediments is about 8 km in the High Folded Zone (study area) and about 12 km in the Foothill Zone (Fig.6), which means that the most of the hypocenters lie probably in the crystalline basement. Figure 7 shows the average rates of Holocene and Pleistocene uplift for a number of coastal regions around the world. Both Pleistocene and Holocene rates range from zero to a maximum of between 8 and 16 mm/1000 yr. So Arabian plat and Persian Gulf are shows in the Holocene and Arabian plate in the Pleistocene. The uplift of the Arabian Plate was 45 m in Holocene and 450 m in the Pleistocene.

Morphotectonic map of the study area is illustrated in (Fig.8). Six faults are occurred in the study area. Fault along the South range of Qara anticline is over 19.26 km. Western limb of the Khoshka mountain there is fault over 6.75 km. Fault over 6.25 km is located between Rabatki and Khairy mountain. South range of Khoskha there is two faults over 15.5 and 8.25 km. North range of the Aqra mountain there is thrust fault over 15.26 km. Field trip is observed Faults in the part of the study area(Fig.9).

Integral to testing the hypothesis of concurrent basement faulting and surface folding is information on the depth to basement within the Zagros higher fold, the accurate location, in Figure 8. According to the USGS / NIEC, PDE database there are four numbers of hypocenter in the study area, two are strike slip faults related and two are thrust fault –related in depth.

3.1.1. Stream-gradient index (SL)

The Stream Length- Gradient Index (SL): is defined as:

$SL = (\Delta H / \Delta L) * L$

Where:

SL denotes the Stream Length Gradient Index, $\Delta H / \Delta L$ denotes the channel slope or gradient of the reach (ΔH is the change in elevation of the reach and ΔL is the length of the reach), and L denotes the total channel length from the point of interest.

The Values were classified in to six categories : 1(< 250), 2(250-200), 3 (200-150), 4 (150-100), 5 (100-50) and 6 (>50). The result of classification is shown in table 1. Divided values of SL into three classes, 1 ≤ 150, class 2 ≥100- ≤150 and classes 3 ≥ 100 (Fig.10).

Longitudinal profiles of the both river channels are illustrated in Figure 11. Total length of Rocezk from the spring to the mouth of the river channel is 45 km and total length of the Showrk is 33 km.

3.1.2. Asymmetric factor (Af)

The Asymmetry Factor is defined as $Af = 100*(Ar/At)$,

Where:

Ar denotes the basin area to the right (facing downstream) of the trunk stream and A t denotes a total area of the drainage basin. In case of tectonic tilting, the values of AF are either greater or lower than 50 and the tributaries present on a tilted side of the main stream grow. The latter is not the case for those located on the other side (Pinter 1996, Keller Pinter, 1996, 2002). Classified Af into three classes is shown in Figure 12 and table 1. Class 1: 45<, Class 2: 45< -50 ≥ and class 3 are: ≤ 50.

3.1.3. Hypsometric integral (Hi)

The hypsometric integral (Hi) describes the relative distribution of elevation in a given area of a landscape particularly a drainage basin (Strahler, 1952). The index is defined as the relative area below the hypsometric curve and thus expresses the volume of a basin that has not been eroded. A simple equation to approximately calculate the index (Pike , Wilson, 1971; Mayer, 1990; Keller , Pinter, 2002) is:

Using Eq. (3), we computed Hi for each sub basin. It ranges from 0.24 to 0.61 in the sixteen sub basins (Fig.13). Then Hi values were grouped into three classes with respect to the convexity or concavity of the hypsometric curve. The result of classification is shown in table 1.Class 1 with convex hypsometric curves (Hi≥0.4); Class 3 with concave hypsometric curves (≥0.3- ≤0.4); and Class 2 with concave–convex hypsometric curves (> 0.3).

3.1.4. Ratio of valley floor width to valley height (Vf)

They can be differentiated by index of ratio of valley floor width to valley depth (Vf). This parameter is calculated as:

Where: Vf denotes the valley floor width to valley height ratio, Vfw denotes the width of the valley floor, E ld and E rd stand for elevations of the left and right valley divides, respectively, and E sc denotes the elevation of the valley floor. Classification of the Vf in to three classes is shown in (Fig.14) and table1. Class 1 :> 0.1 Class 2: 1.0 > - > 3.0 and classes 3: are <3.0.

The calculated Vf parameter is measured at a set distance from the mountain front for every valley studies. This index differentiates broad-floored valleys with relatively high values of Vf from V-shaped canyons with relatively low values of Vf. High values of Vf are associated with low uplift rates and characterize places where the stream cut broad valley floor. Low values of Vf reflect deep valleys of actively incising streams, commonly associated with uplift (Keller , Pinter, 1996, 2002; Cuong , Zuchiewicz, 2001). Hi = (average elevation-min.elev.) / (max.elev-min.elev.) Vf = 2Vfw / [(E ld − E sc) + (E rd − E sc)].

The valleys are often narrow upstream from the mountain front (Ramírez-Herrera, 1998). As a result, values of VF vary depending on basin size, stream discharge, and rock type encountered (El Hamdouni et al., 2007).

3.1.6. Mountain-front sinuosity index (J)

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Mountain front sinuosity is defined as follows:-

Where S mf denotes the mountain front sinuosity; L mf denotes the length of the mountain front along the foot of the mountain at the pronounced break in slope: and L s denotes the straight-line length of the mountain front. Mountain front sinuosity is an index that reflects the balance between erosion forces that tend to cut embayment into a mountain front and tectonic forces that tend to produce a straight maintain front coincident with an active range- bounding fault (Zygouri ,Kokkalas, 2004). The sinuosity of highly active mountain fronts generally ranges from 1.0 to 1.5, that of moderately active fronts ranges from 1.5 to 3, and that of inactive fronts ranges from 3 to more than 10. A sinuosity greater than 3 describes a highly embayed front (Bull, Mcfadden 1977). The mountain front sinuosity is shown in Table 1 and in (Fig.15), the obtained data show that south range of 1.1 to 1.2 in the study area so it is higher active. Profiles of the mountains front are from 9 km in the south range of Kafiy Mountain to 63 km in the north range of Khairy Mountain (Fig.16). The contour is more sinuous in this profile.

3.2. Evaluation of relative tectonic activity (lat)

The high class values for Iat mainly occur in the sub basins 7, 8, and16 (Fig.17) while the rest of the study area has classes of Iat suggesting moderate to high S mf = L mf / L s tectonic activity in the sub basins (2, 3,4, 5, 6, 9,10,11,12,13,14 and 15) and the low value for lat is in the sub basin 1.

The distribution of the indices of the relative tectonic activity (lat) defines areas associated with different mountain fronts and estimates of relative rates of tectonic activity. Within the study area, about (87.7 km2) is class 1 (very high relative tectonic activity) as measured by Iat; (298.657 km2) shows high relative tectonic activity as measured by Iat (class 2); (396.859 km2) has moderate values of tectonic activity in terms of Iat (class 3); and (49.17 km2) has the lowest values of relative tectonic activity (class 4) based upon Iat. Thus, two thirds of the study area is classified into classes 2 or 1 of high to very high tectonic activity in terms of the apparent geomorphic response. In different tectonic environments with greater rates of active tectonics, the values of indices would differ as well as their range in value. Values of Iat would also be different, as would the boundaries between classes of relative tectonic activity.

Result

The scope of tectonic activity in the area under investigation exerts a great influence upon long lasting movements, increases their rate and differentiates their types as this area is an uncommonly mobile as for this part of the world and peculiar in terms of geological structure of the mountains.

Three plates (Arabian, Turkish and Eurasian) are impact on the Zagros Mountains in the Iraqi Kurdistan. The uplift of Arabian plate was more impact in the Pleistocene. In the Pleistocene its importance was lesser in comparison with the influence of climate changes. Climate changes result in diversity fluvial processes mainly in the time, variety of neotectonic movements result in their diversity in the space more than in the time.

The alternate hypothesis that earthquakes nucleate in the sedimentary cover instead of the basement is tested by comparing the depth locations of relocated earthquakes with the projected depth of the basement within the higher folded zone and by comparing the location of earthquakes with structures within the higher folded zone. Values of the uplift in the Holocene and in the Pleistocene shown the Arabian plate is impact on the Zagos mountain.

According to the acquired data and geological maps, almost all moderately anomalous values of SL are located either along active Faults such as the southern flank of Qara anticline and north west and south flank of the Khoshka anticline.

Al though structural controls play a significant role in the development of the basin asymmetry (El Hamdouni et al ,2007) the high values of the Af that demonstrate the most prominent asymmetry occur in the faults.

The Vf value has been calculated for the main valleys and tributaries that cross mountain fronts of the study area. Valley-floor width increase with watershed size erodibility of rock type, and along with a decrease of uplift rate. The V-shaped valleys in the sub stream high values of index can inform about hard rock in or intensive uplift movements. Low vales of the shape board-floored are more connected with soft rocks and less with the great tectonic activity.

Hypsometric index is the similar to the SL index in that rock resistance as well as structural geological and geomorphic processes. High Values of Hi could be produced by active tectonic and also result from the recent incision in to young geomorphology. Low values of Hi are related to order land scape that have been more eroded and less impact by recent active tectonic.

Smf (Fig.16) shows well-development triangular facets of the mountains. These facets suggest active folding triangular facet at different elevation that indicates several stages of uplift and reactivation of tectonic processes (Riley, Moore, 1993).

Results from the analysis are accumulated and expressed as an index of relative active tectonics (Iat), which I divide into four classes from relatively low to highest tectonic activity. I test the hypothesis that areas of known, relatively high rates of active tectonics are associated with indicatives values of Iat. The approach of this paper is to provide a quantitative method to focus on areas for more detailed work to establish rates of active tectonics.

Conclusion

I used drainage pattern (sub basin), geological map, image and geomorphological indexes to determent the relative of tectonic activity in the Zagros Mountain in the Iraqi Kurdistan. These analyses are illustrated four classes of the lat over the study area.

Acknowledgements

I thank A Lundin Group Company for their support geological map of the study area. Thanks Prof. Grasemann and Dr. Ref (Vienna University) for support earth quake data of the Zagros mountain Iraq- Kurdistan.

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Figures and Tables

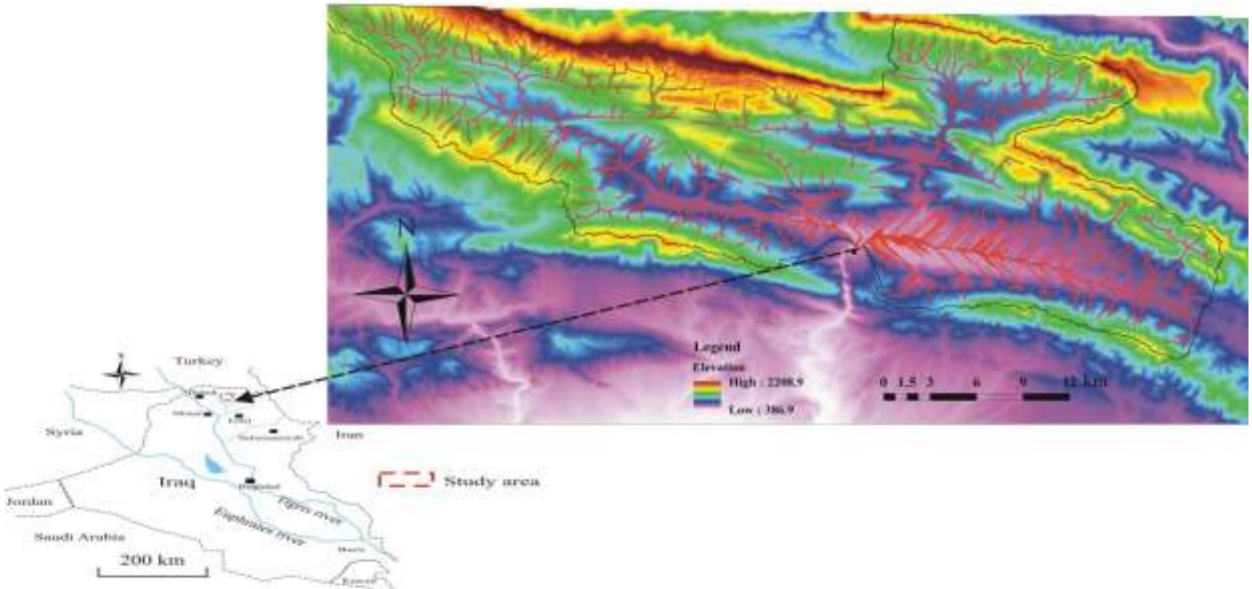

Fig.1 Site of the study area

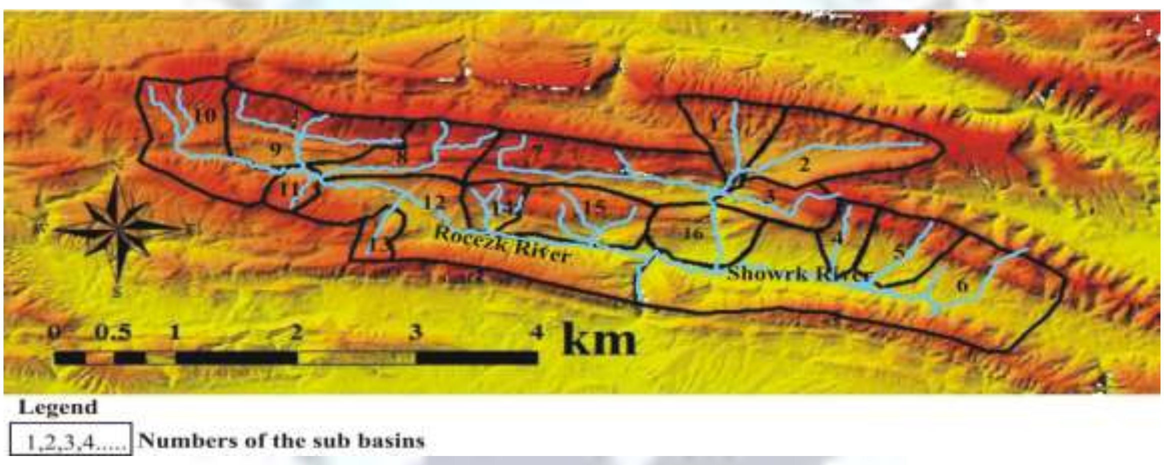

Fig. 2: sub basins of the study area

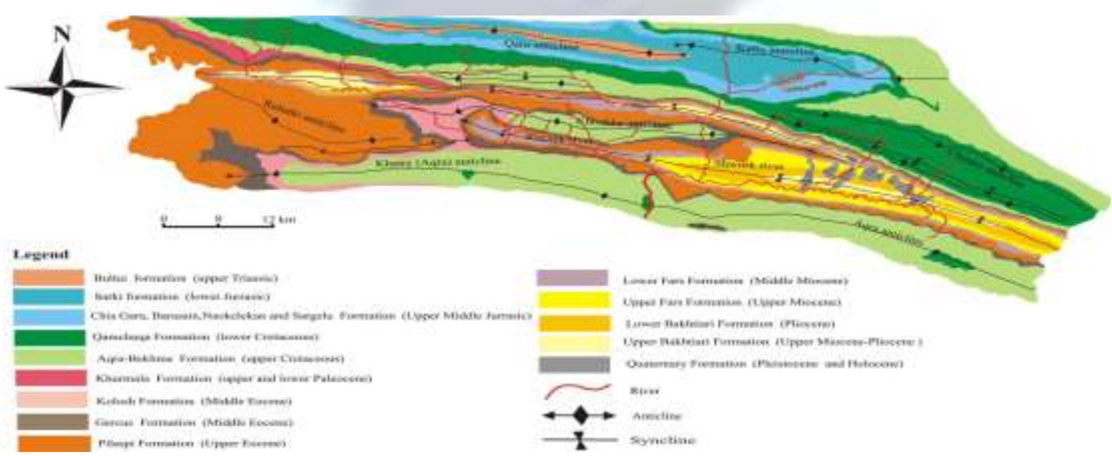

Fig. 3: Geological map of the study area by (A Lundin Group company)

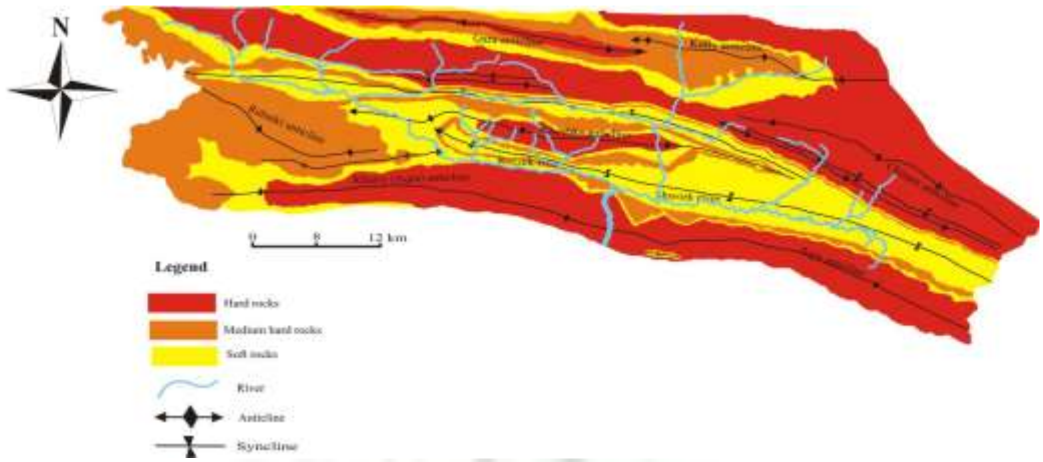

Fig.4 Classified rocks in study area

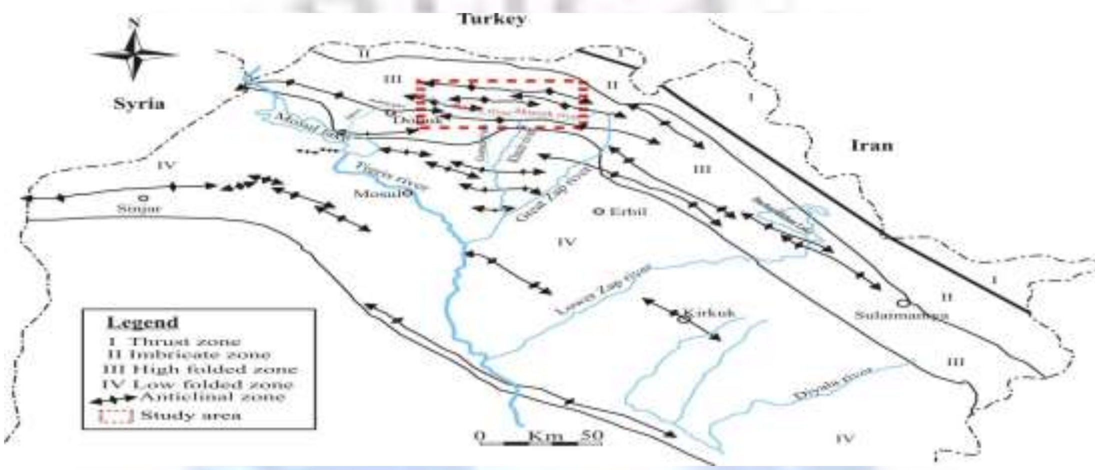

Fig. 5 Tectonic subdivisions Iraq Kurdistan by Numan (1997) modified

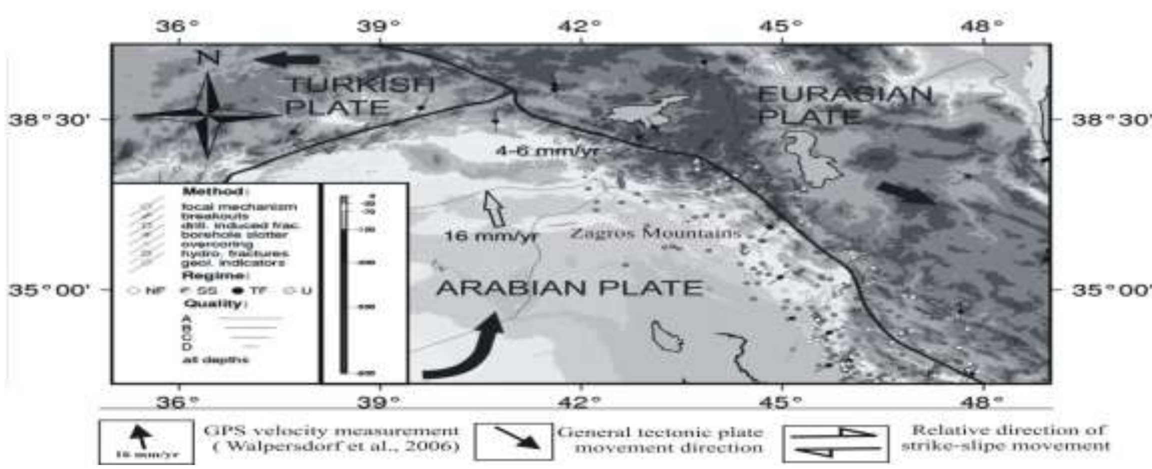

Fig.6. Neotectonic setting of the Zagros mountain in the Iraqi Kurdistan, Depth of the earthquake hypocentres (values in km, dark gray to white circles, USGS/ NIEC, PDE database, 2011 (state to 6.7.2011) combined with the σ Hmax data from World Stress Map (Heidbach et al., 2008) with plotted focal mechanism regimes (NF-normal faulting, SS-strike-slip, TF-thrust faulting) and GPS velocities of plate movement (Walpersdorf et al., 2006). The plate boundaries (in dark-grey) originally from the World Stress Map are modified after Ziegler, 2001 and Reilf et al., 2012.

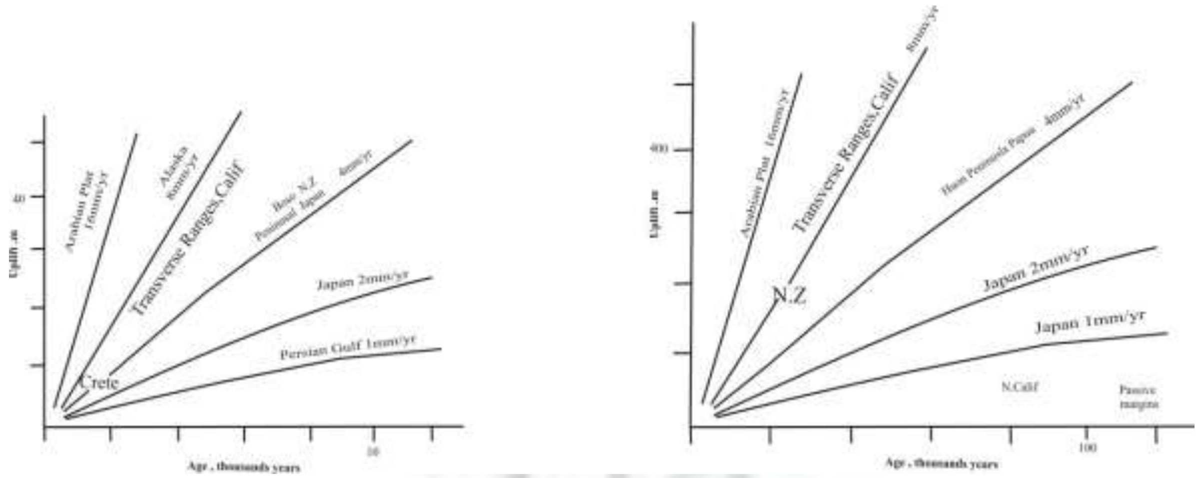

Fig. 7 Rates of uplift for selected (A) Holocene and (B) Pleistocene coast by (Lajoie 1986 and Moores , Twiss 1995) modified

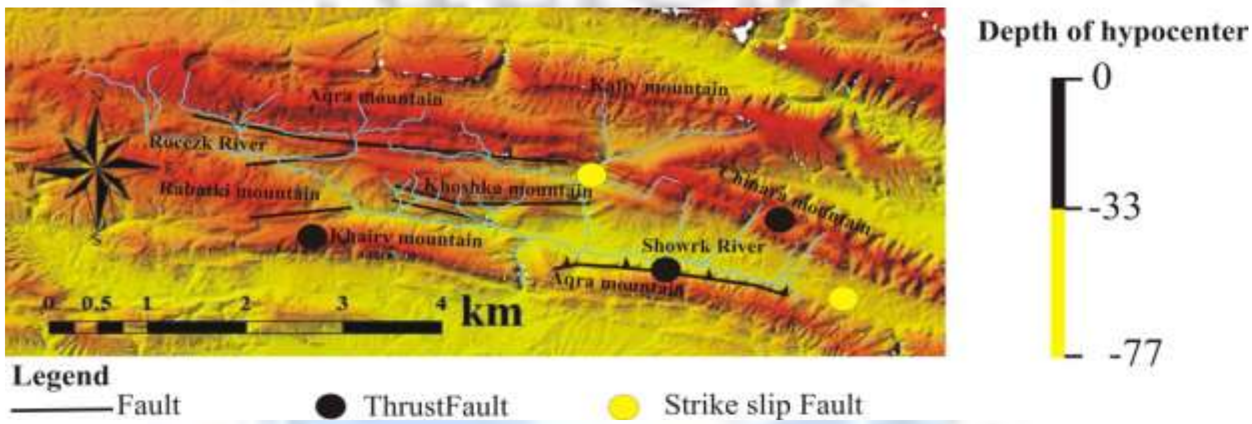

Fig.8 Morphotectonic map of the study area shown the fault and depth of hypocenter by Geological map and USGS / NIEC, PDE database.

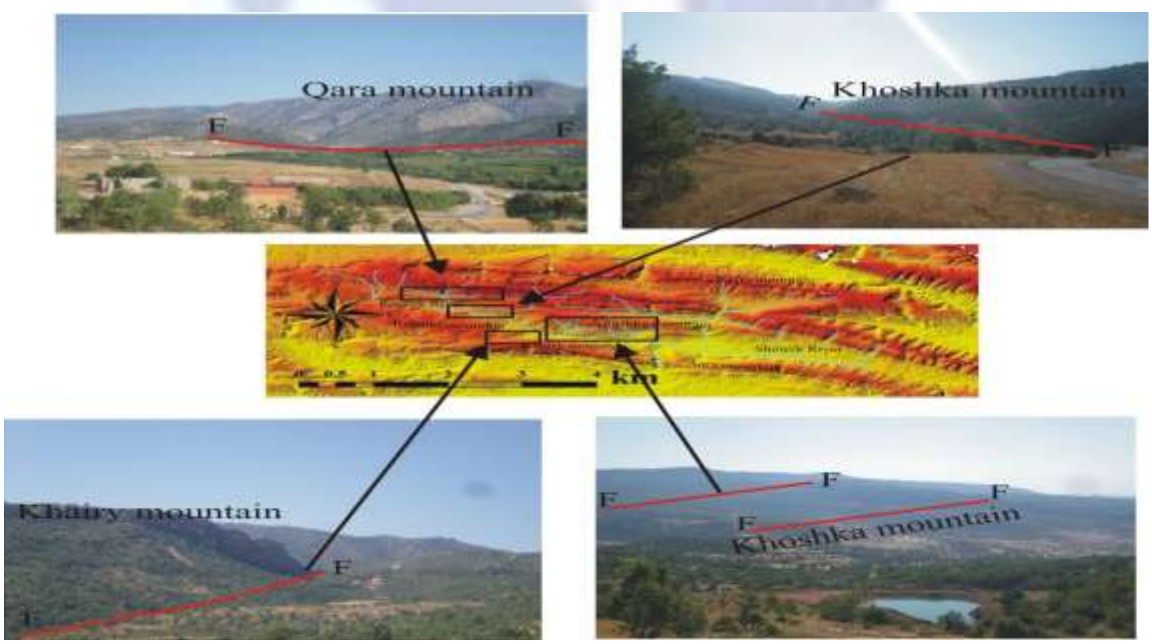

Fig.9 Field trip observed Faults

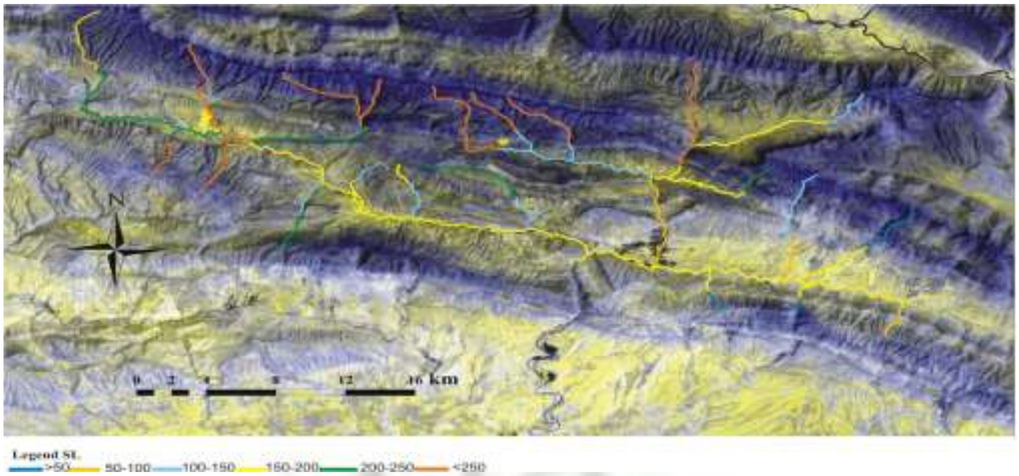

Fig.10 Overlaying of the SL index on interpreted satellite images

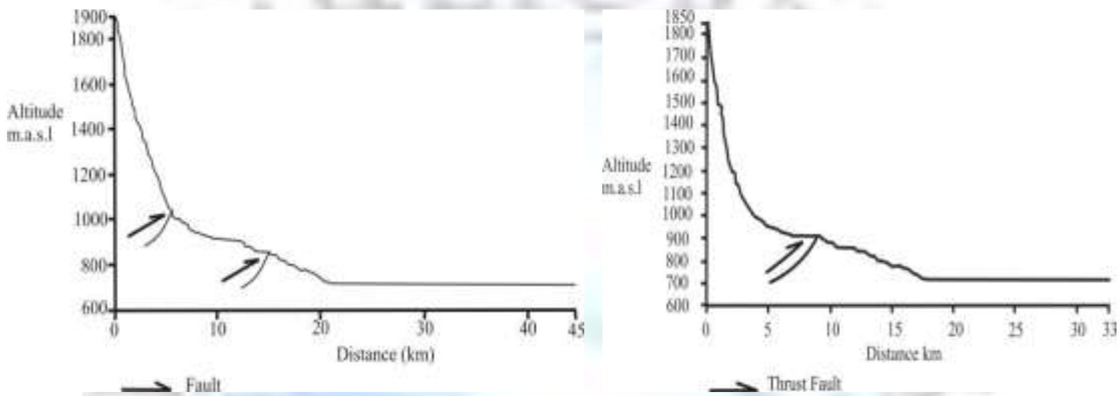

Fig.11 Longitudinal profile of the Roczek and Shwork channel

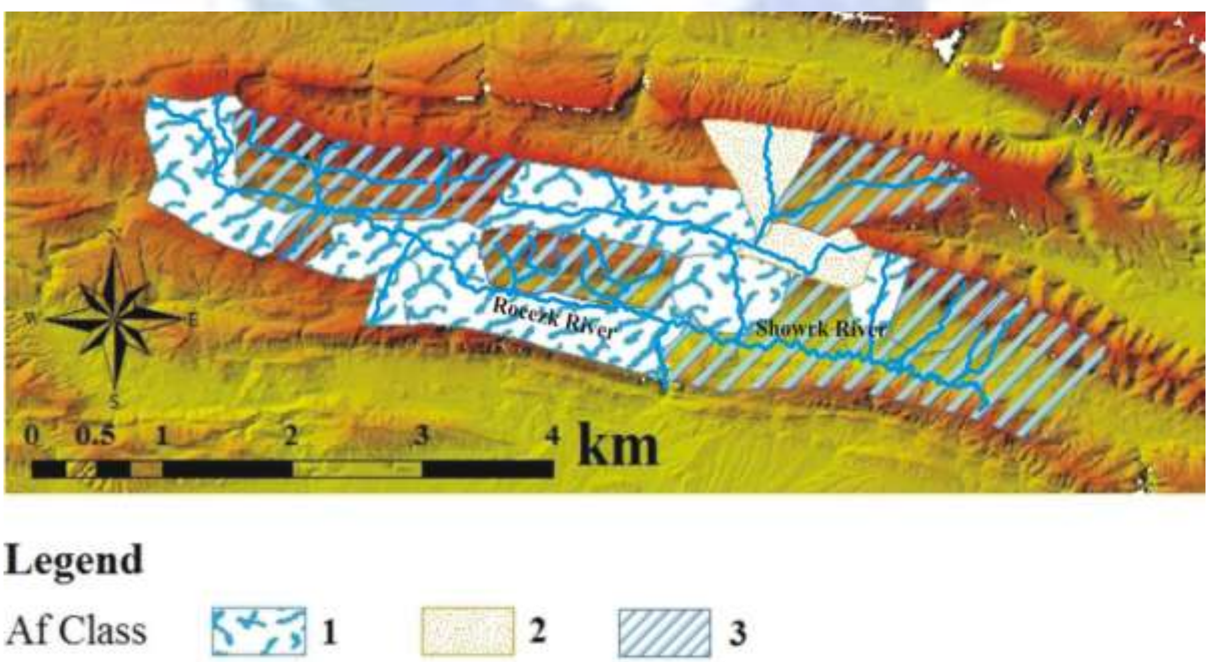

Fig.12: Distribution of AF

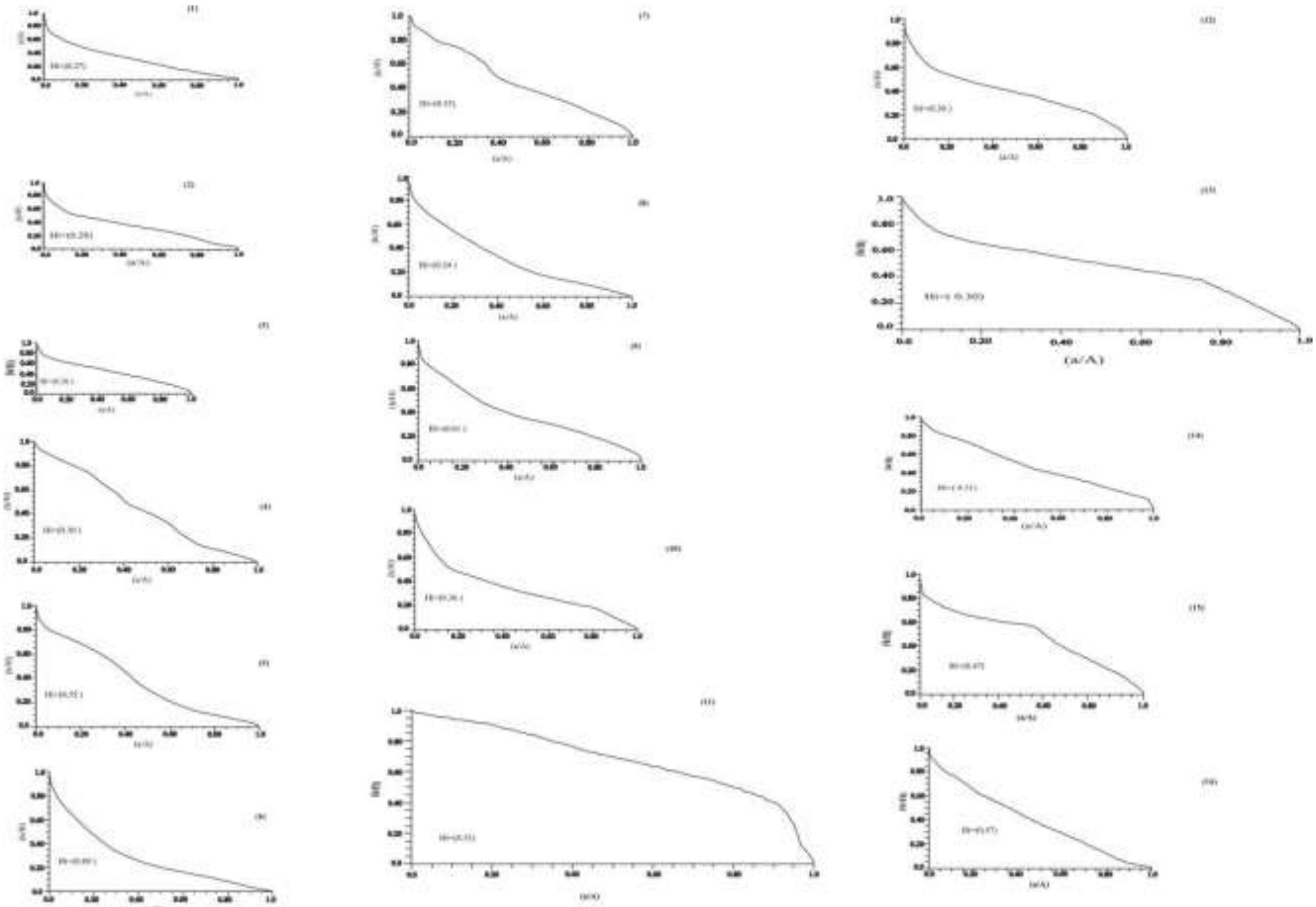

Fig.13 Hypsometry curves of sub basins

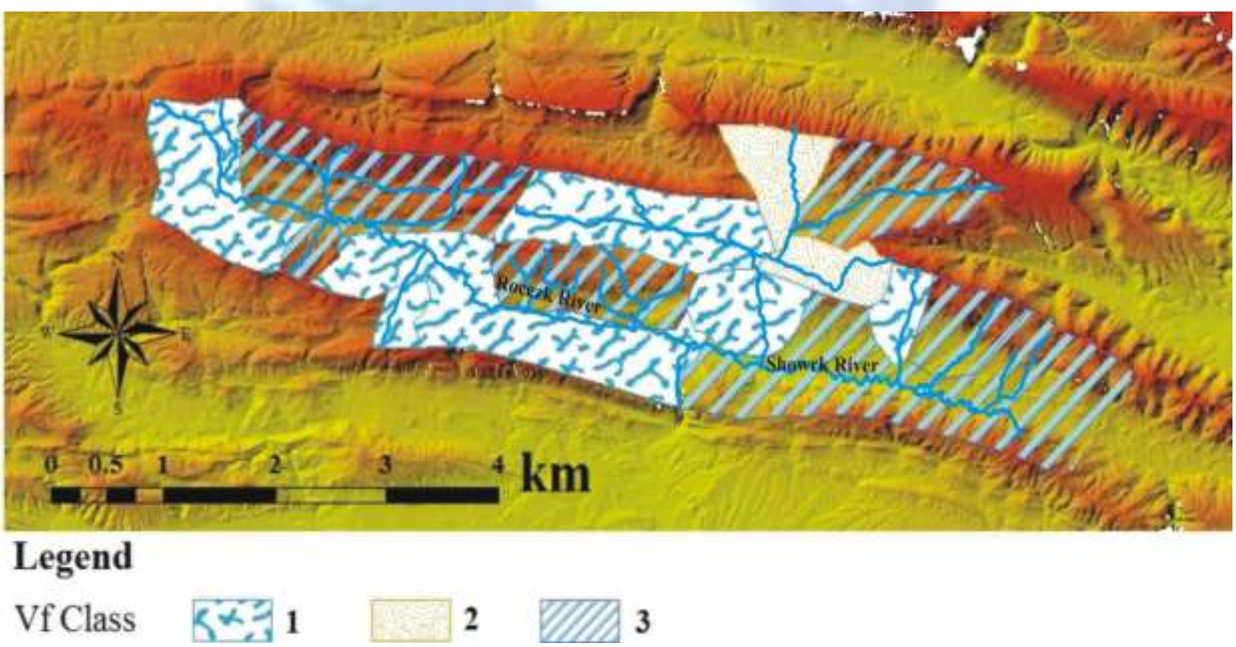

Fig.14 Distribution of Vf

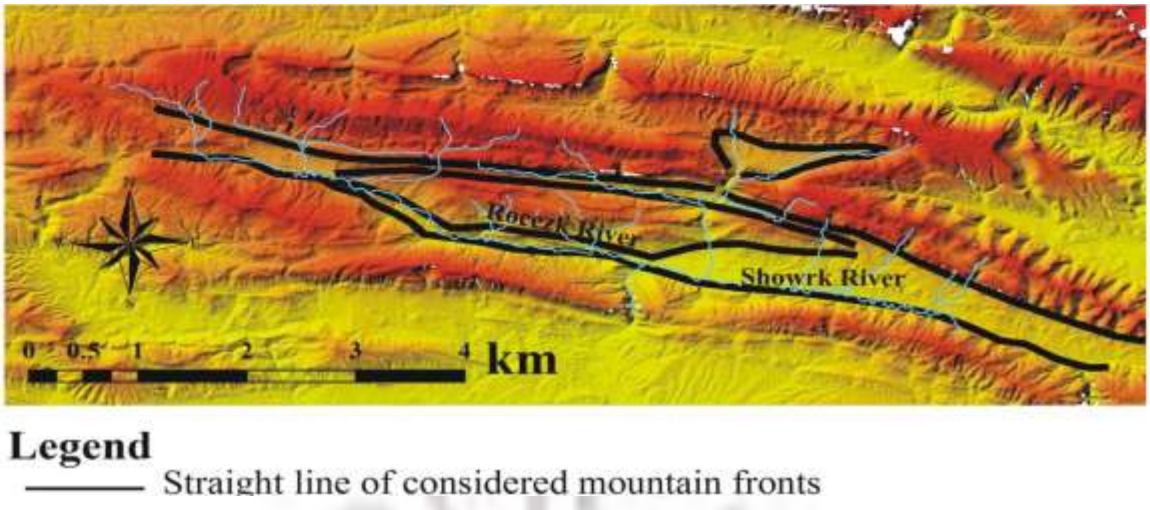

Fig. 15 Mountain front sinuosity

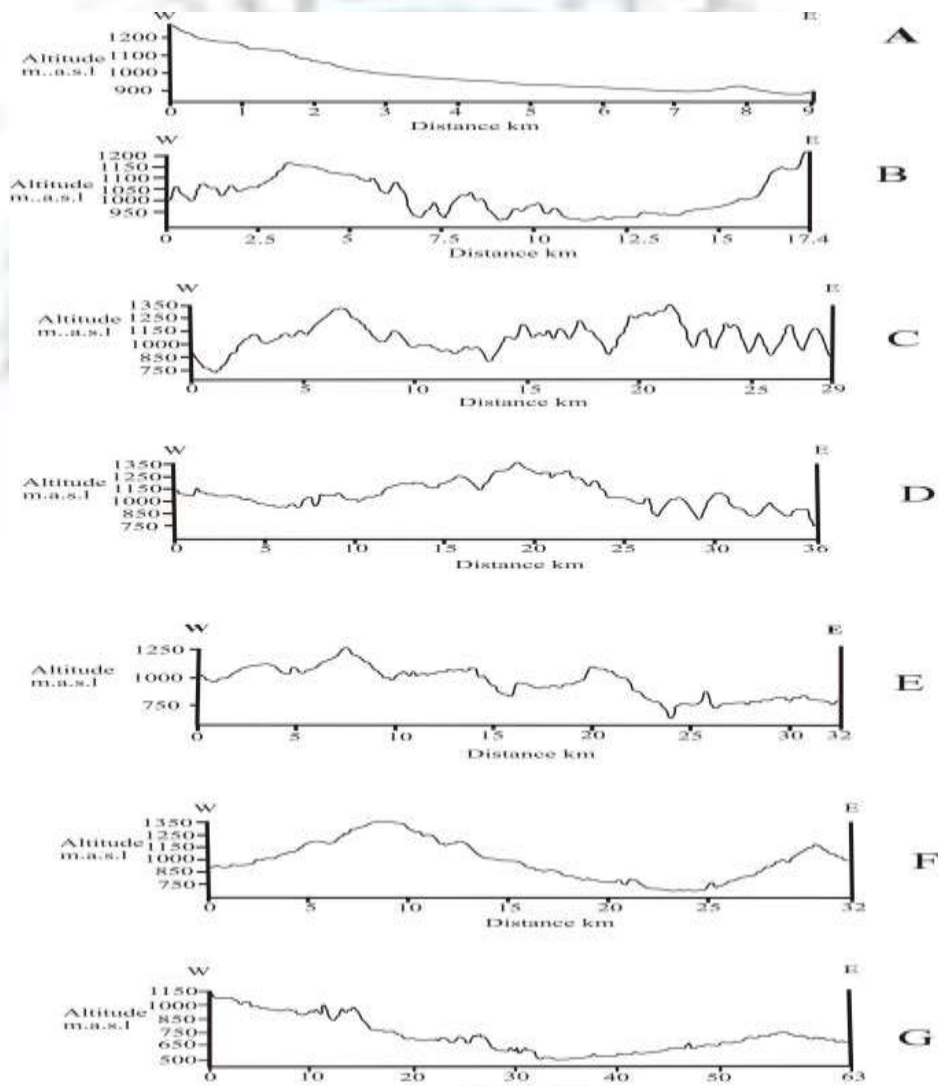

Fig.16 Profile of the front sinuosity in the A, b, south and east range of Kafiy mountain, C south range of range of Chinara mountain, D south range of Qara mountain, E and F north and south range of Khoshka mountain and G north range of Khairy mountain.

International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 2 Issue 11, November-2013, pp: (22-34), Available online at: www.erpublications.com

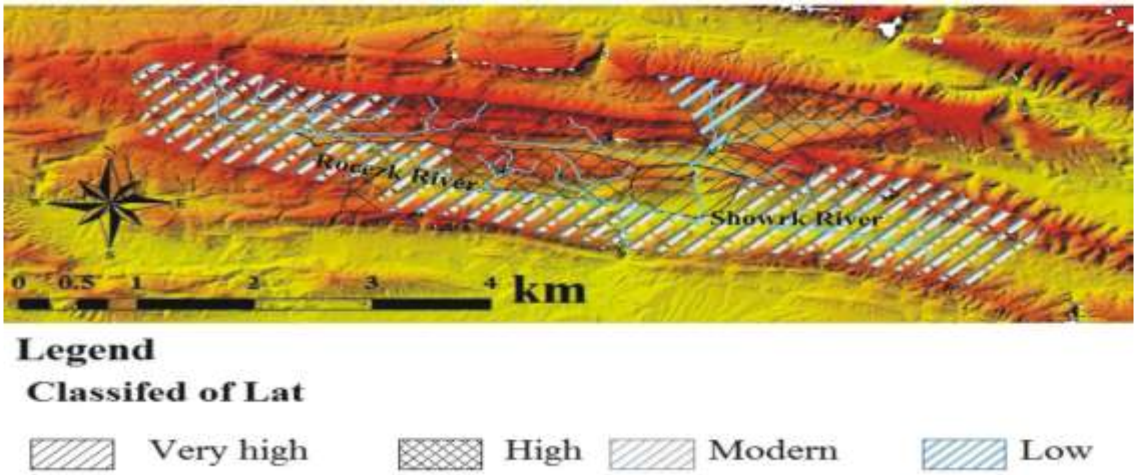

Fig.17 Classified of Lat

Table 1

Value of At (total sub basin area) ; the class of SL (stream gradient index), Af (drainage basin asymmetry) , Hi (hypsometric integral) , Vf (valley floor width- valley height ratio), J (mountain front sinuosity) and values and class of lat (relative tectonic activity)

Basin no	At km	Class of SL	Class of AF	Class of Hi	Class of Vf	Class of J	Value of Lat	Class of at
1	49.17	1	2	2	3	3	2.7	4
2	36.79	2	3	2	2	2	1.9	2
3	56.89	2	2	2	2	1	1.2	1
4	13.70	2	1	3	2	1	1.5	1
5	14.62	2	3	3	2	2	2.1	3
6	29.712	3	3	1	1	3	1.6	2
7	153.55	3	1	1	3	1	1.2	2
8	32.11	1	3	2	1	2	1.8	2
9	42.203	1	3	1	2	2	2.1	3
10	71.709	1	1	3	1	2	2.2	3
11	4.107	2	3	3	2	2	2.1	3
12	264.22	3	1	2	3	2	2.2	3
13	12.101	2	1	2	1	2	1.6	2
14	14.042	3	3	3	2	2	1.7	2
15	20.351	2	3	1	2	2	1.7	2
16	17.11	3	1	1	3	1	1.2	1