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New Tectonic Activity within Zagros – Taurus belt: A case study from north Iraq using Region Shuttle Radar Topography Mission (SRTM)

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Abstract

This work investigates fold growth and drainage evolution of the Duhok – Al-Qosh and Duhkan anticlines (Iraqi Kurdistan region) by means of structural and tectonic geomorphology using a geological map and SRTM remote sensing data (digital elevation model and satellite images). The implementation of geomorphic indicator will help understanding the mechanism between growth of fold and drainage pattern and also concluding the tectonic evolution in the study site. Fault has an impact on the width of the folds and also on the drainage basin in the study area. The Aspect ratio indicates that the folds in the study area are formed by thrust-cored or forced and buckling. The tributaries of the drainage basin are characterized by drainage parallel to the fold crest on the fold hinge, with less asymmetric and asymmetric forked networks. Perfect symmetry index (FSI) is represented by Al-Qosh fold. Higher value of front sinuosity can be in the first uplift fold and later exposed to erosion by stream basin on the limbs of folds for long time. The spacing ratio and basin shape show basin maturity.

Keywords: Geomorphic indices; SRTM; High Folded Zone; tectonic activity; fault system, Iraqi

1 Introduction

The Zagros Fold and Thrust Belt is orogenic belt and is a seismically active, which extends over 1800 km from Northern Iraq to the Strait of Hormuz in Iran.

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The Zagros Mountains started to form as a result of the collision between the Eurasian and Arabian Plates, whose convergence began in the Late Cretaceous and was the last of a series of extensional–convergent events within the extensive Alpine –Himalayan orogenic system [1,2].

A central question in tectonic geomorphology is what are the major implications for the regional geology? What is the limitation? The Drainage systems adapt to changes in the surface slope, recording fold growth and evolution [3,4,5,6] . Therefore, the drainage basin is a good indicator of the land form organization; it is adjustment to growth of fold. Structural patterns in the fold can be seen from statistical analyses patterns [7].

Recent studies on global scale described and classified the zones of the active tectonism using geomorphic parameters [8,9,10] in the Zagros Mountain at Iran Islamic Republic, and a few studies about the Zagros Mountain, in Iraq Republic; moreover, they recognized the relation between fold growth and drainage basin [11,12].

The study site covers Dohuk, Duhkan and Al-Qosh mountains located in Dohuk Governorate north Iraq, Dohuk River is crossing the west limb of Dohuk Mountain, while Duhkan River crosses the Duhkan Mountain (Fig.1).

The aim of this paper is to identify the relationship between fold growth and drainage basin and then evaluate the drainage basin in the Duhok- AL-Qosh and Duhkan folds. Using geomorphic indicator will help understanding the mechanism between growth of fold and drainage pattern and also concluding the tectonic evolution in the study site. Geomorphologic indicator was used to analyze and draw maps in the study site.

2 Data Used

Remote sensing data, which include Land sat satellite image (consisting of 4 spectral bands) and Digital Elevation Models (SRTM 90 meters), were used to calculate geomorphic indices of folds that may help categorizing them and detecting geomorphic criteria that indicate the fold growth. Satellite images were used to delimit fold shapes and to mark locations and diversions of the stream network. Two programs were used for completing the aims of this study, Arc GIS and River tools. Arc GIS program is used for calculating the geomorphic parameters of folds; using satellite image for the space ratio, and SRTM for calculating the front fold sinuosity. River tools program is used for calculating drainage basin on the limb of folds (from water divided to the break of slope of fold). Drawing drainage basin and calculating geomorphic parameters were obtained by Arc GIS software.

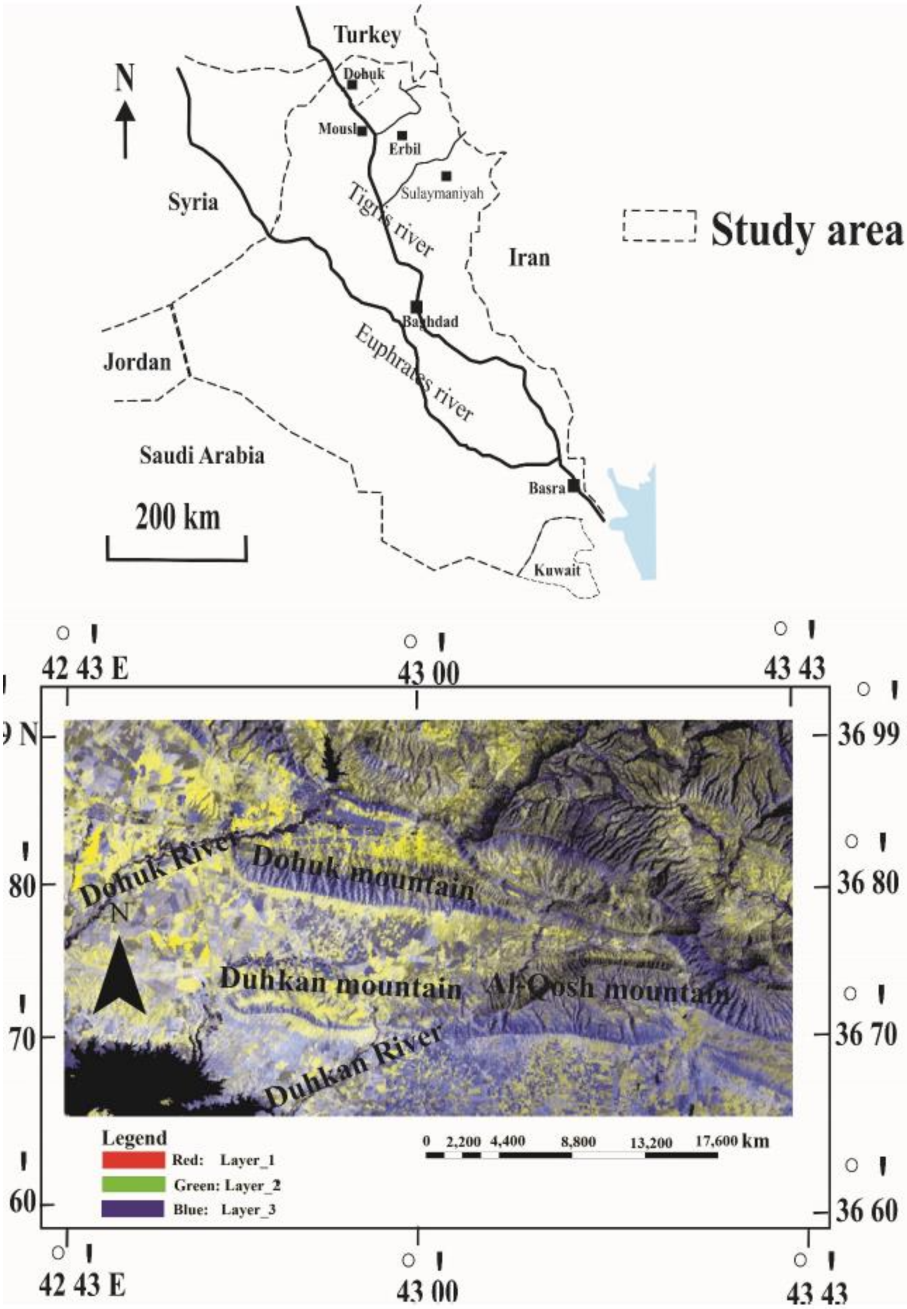

Fig. 1: (A) Location of the study site in the Iraq, (B) Satellite image (2D) shown the mountains in the study site by NASA 2015

3 Geological and Tectonic Roller of the Study Site

Zagros Mountain has resulted from the convergence between the Arabian and Eurasian Plates (Fig.2). The study area is located in the southeastern part of the Zagros High Folded Zone in the Iraqi Kurdistan Region (Fig.2 A). The structural map of the northern part of the Zagros orogeny can be divided into two principal zones, 1) the High Folded Zone, between the Main Zagros Thrust and the Mountain Front Flexure, and 2) the Lower Folded Zone, between the Mountain Front Flexure and the Zagros Deformation Front (Fig.2 B).

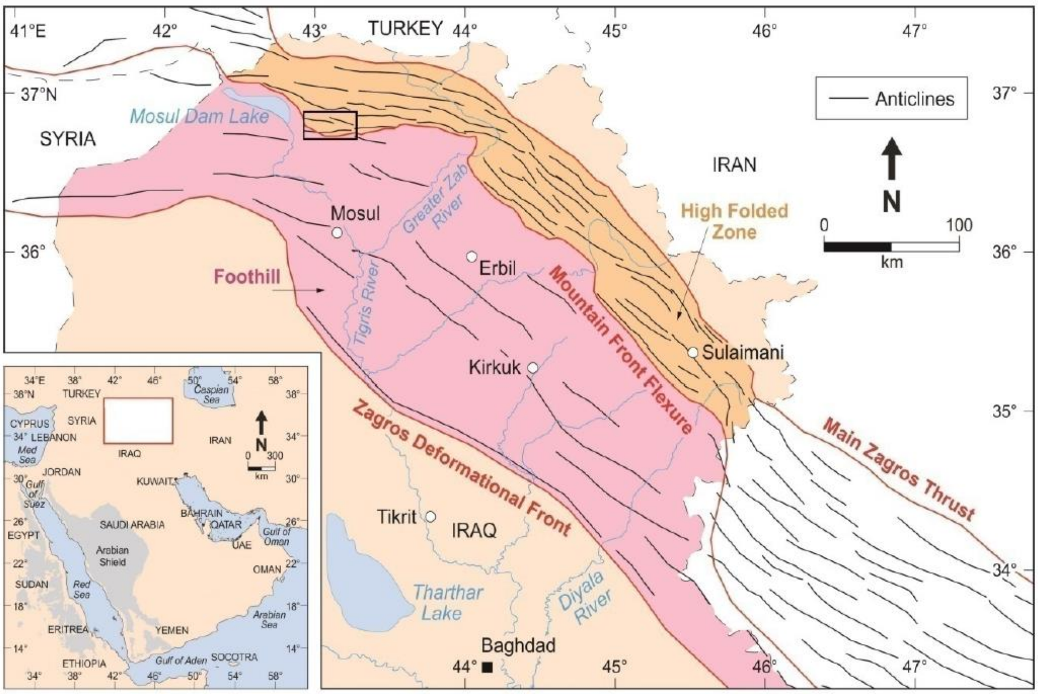

Fig.2: location of the Iraqi Kurdistan in the Middle East A; Study site in the higher folded zone, B; Structural map of the main folded zones (Modified after [12]).

Recently, the Zagros Thrust – Fold Belt in Kurdistan Region has become a region of interest and scholars started to address the structural development of Kurdistan [13,14,15,16] . According to Figure (3), there are three systems of faults in the Iraqi Kurdistan Region. The first of these faults is the set of N-trending basement faults that formed from EW directed shortening during the Nabitah Orogeny (680 – 640 Ma), these faults are conspicuous in the basement of southern and western Iraq and are less obvious in northern Iraq [17, 18] . One well-known fault within this trend is the Kazerun Fault in Iran, which separates the Fars Zone from the Dezful Embayment [8, 19] . In addition, the presence of N-trending lines of salt diapers within the Gulf Region further implies that this system has been reactivated in both pre-Cretaceous and Miocene deformation events [20].

A second trend is oriented NW and belongs to the Najd Fault System, which formed from NW-SE directed extension during the Najd rifting event (610–520 Ma) [17]. This trend is parallel to the present day Zagros trend and thus may have influenced the locations of major deformation zones. Major zone-bounding thrust faults; such as the Main Zagros Thrust (Fig. 2) are interpreted to be the surface expressions of reactivated basement faults from this system [13,17, 22]. Lastly, there is the NE- SW trending Transversal Fault System, seen prominently in northern Iraq. This fault system may be related to the Najd Fault System, and is therefore interpreted as Late Proterozoic [17].

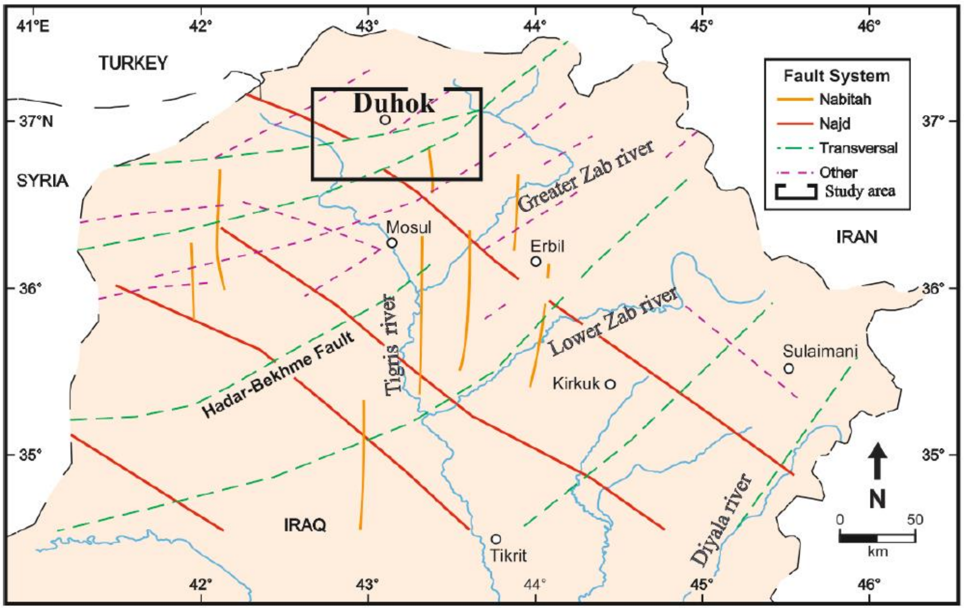

Fig. 3: Basement fault map of northern Iraq, showing the three main fault systems (Transversal, Najd and Nabitah) as well as other faults, which have been mapped but not formally named or assigned to the main systems and location of the study site. (Modified after [21]).

Nabitah, Transversal and other faults cross the folds in the study area from the southwest to the northeast changing the width of these folds (Fig.4). Transversal fault changes the width of Dohuk fold in the west and middle parts. Nabitah fault crosses the middle parts of Duhkan folds and other fault divide the Duhkan and Al-Qoh folds. These faults may have been reactivated as a transpersonal structure, creating a topographic step or a pronounced change in thickness, which affected the foreland-ward propagation of the High Folded Zone. Changes in the width of folds may be geomorphic indictors of the fold and drainage basin. Because the drainage basin is a good geomorphic indicator of the land form organization; it is adjustment to growth of fold.

The geological formations of the study area are called Aqra-Bekhme, Shiranish, Kholosh, Khurmala, Gercus, Pila Spi, Fatha, Injana, Mukdadiya and Bai Hassan formations and Quaternary sediments (Fig.5).

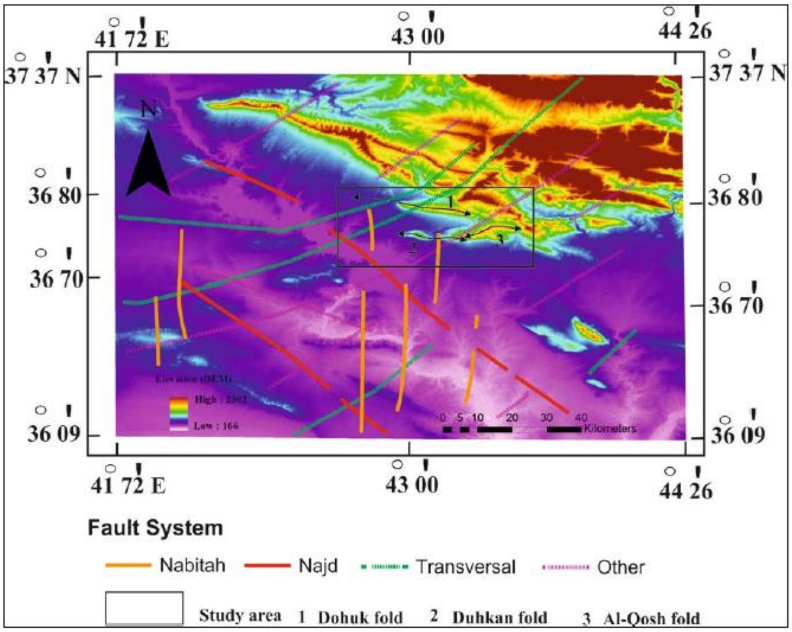

Fig. 4: System of faults in the study area, base map form [21].

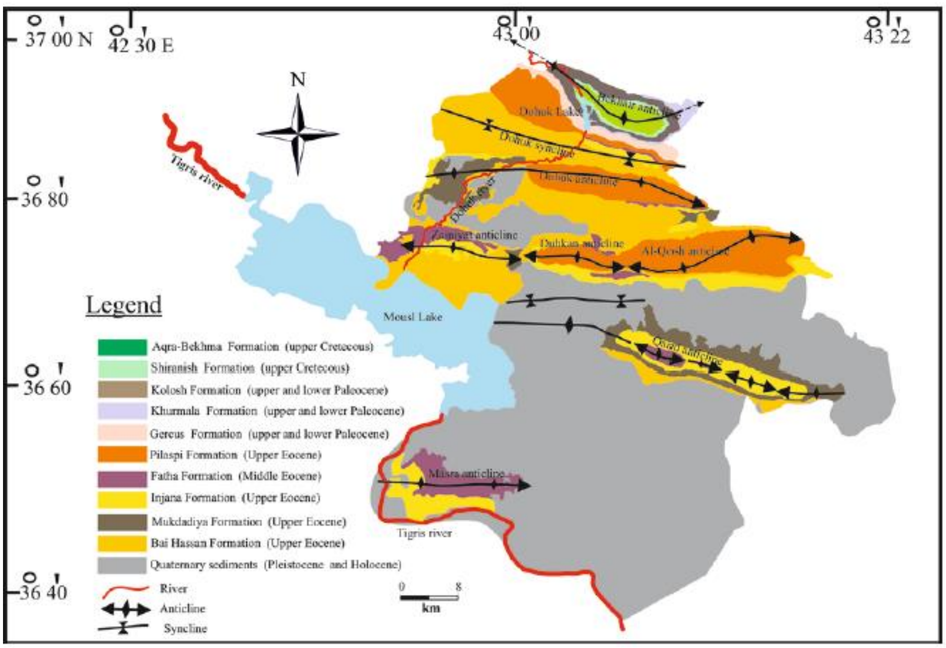

Fig.5 Geological map of the regional area including study site (after [23])

4 Geomorphologic Parameters

Geomorphic parameters used in this study to characterize the tectonic activity and basin maturity of certain regions are aspect ratio (AR), fold symmetry index (FSI), fold front sinuosity, the spacing ratio (R), and the basin elongation ratio (Bs).

Aspect ratio (AR), fold symmetry index (FSI), fold front sinuosity is calculated as shown in Figure (6). The aspect ratio is the ratio of the fold hinge length to the width of fold or half wavelength [24].

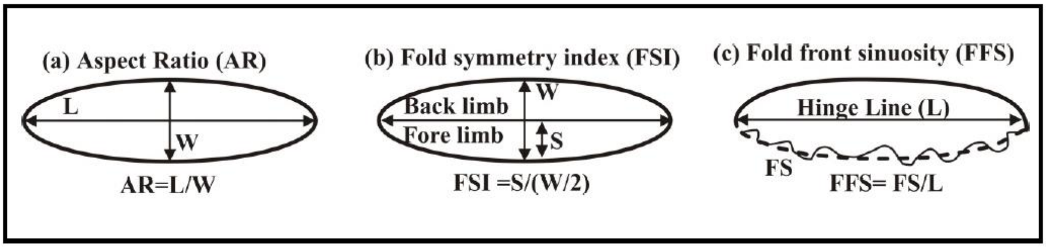

Fig. 6 Measurements for calculating the fold indices described in the text: (a) Aspect Ratio (AR) = length of hinge line (L) divided by width of the fold (W); (b) Fold Symmetry Index (FSI) = width of forelimb (S) divided by half of fold width (W), with forelimb and backlimb labeled; and (c) Fold Front Sinuosity (FFS) = length of the fold front (FS) divided by fold length (L). Figures are adapted after [10].

The fold symmetry index (FSI) equals the width of the forelimb of the fold, divided by half-width of the fold [10]. If the fore limb is the shortest, then the FSI will be less than 1.0. For a hinterland-verging structure, the FSI will be greater than 1.0. A value of 1.0 indicates a perfectly symmetrical fold. These indices are typically used together, to estimate whether a fold is likely to be thrust-cored or not[25]. A low aspect ratio (< 10) and near-perfect symmetry (FSI close to 1.0) indicate that a fold formed by buckling, rather than by some forcing member, whereas a high aspect ratio (> 10) and pronounced asymmetry typically indicate a thrust-cored or forced fold [8,9,10].

The spacing ratio (R) and the basin elongation ratio (Bs) index are calculated as shown in Figure (7). The Spacing ratio is expressed as:

$$R=W/S, \quad Bs=B1/Bw$$

where W is the half-width, measured from the mouth of the basin to the main drainage divide perpendicular to the mountain front, and S is the spacing between the two mouths (Fig. 7a). For this study drainage networks include only 29 sub basins along the fold of the anticlines. The basin elongation ratio (Bs) is expressed as:

where (B1) is the length of the basin from its mouth to the most distal point and (Bw) is the width of the basin (Fig. 7 b and c).

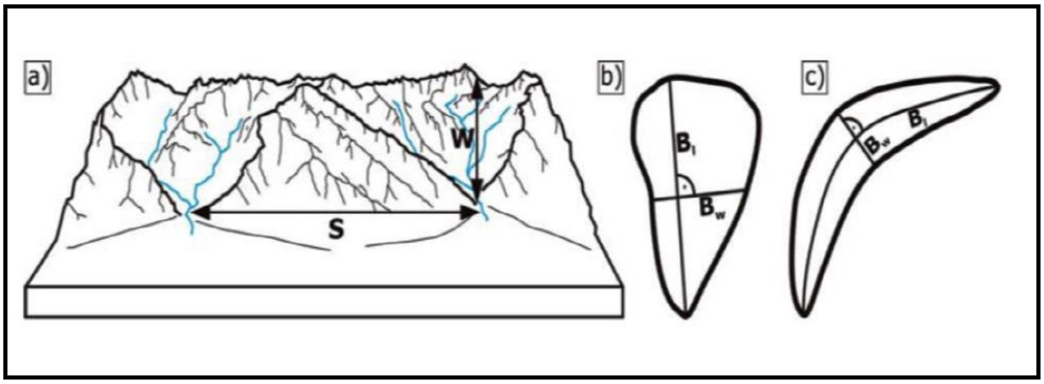

Fig.7: a; Two mountainous catchments. W is the half width a drainage basin, defined as the distance from the mountain front to the main drainage divide and S is the distance between the outlets of two catchments (modified by [11]). B; Drainage basin where Bl is a straight line between the mouth ofthe basin and the most distal point on the drainage divide and Bw is a straight line perpendicular.

5 Results

Geomorphologic indicator of aspect ratio and fold asymmetry are shown in Figure (8 a and b). Aspect ratio has been registered as 16, 6 and 2.3 for Duhok, Al-Qosh and Duhkan folds, respectively. Thus the formed folds in the study area are of thrust-cored or forced fold in Dohuk fold and buckling in Al-Qosh and Duhkan folds. Fold symmetry index proved that the presence of perfectly symmetrical fold in Al-quash and near-perfect symmetry in Dohuk and Duhkan.

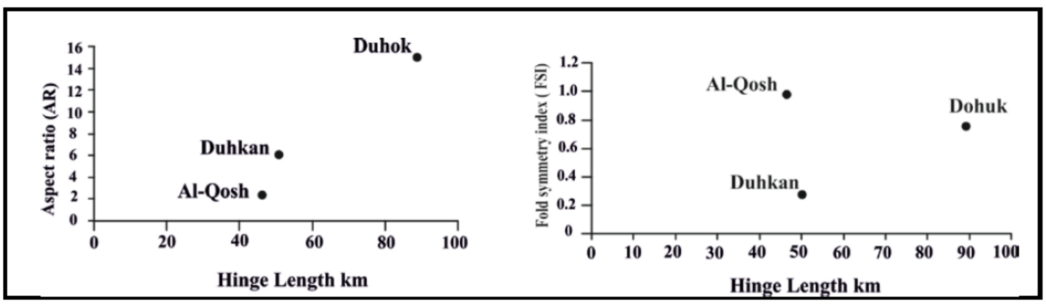

Fig.8.Geomorphic parameters for measurement (AR) and (FSI) Fold index

Geomorphic index of the fold front sinuosity in the study site is shown in Figure (9). Higher values of front sinuosity can be found in firstly uplifted fold and exposed for erosion for long time. According to Table (1), the values of fold sinuosity vary from 1.6 in Al-Qosh fold, 1.2 in Duhkan fold and 0.9 in Dohuk fold. The Fold front sinuosity may change from one fold to another. The south eastern end of Al-Qosh fold and north western end of Dohuk exhibit higher fold front sinuosity than the north western halves. The south eastern part of the Al-Qosh is also more sinuous than its other parts. The north western part of Duhkan is more sinuous and the half part of Dohuk is more sinuous than the other parts (Fig.8).

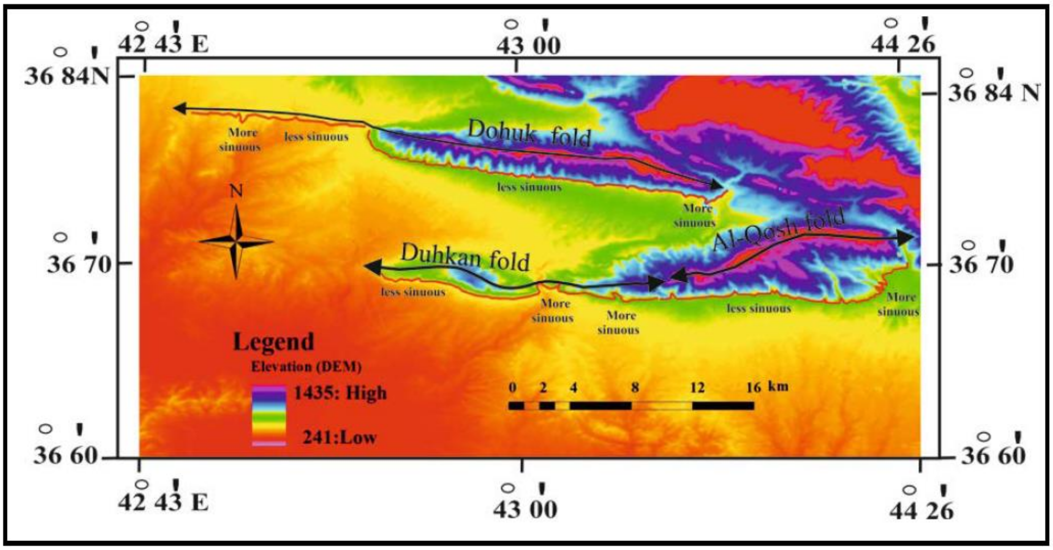

Fig.9 SRTM image shown fold front sinuosity

Classified tributaries of the drainage basin into three types (Fig.10) are pronounced in wider and lengthier folds. Sub parallel tributary is responded to the fold hinge in the western and eastern limbs of the folds. Less symmetric and asymmetric tributaries are located in different parts of the folds. The Spacing ratios (R), elongation ratio (Bs), sinuosity and slope of the studied folds are shown in Tables (2-4). Difference in the shape and area of the sub basins (Fig.11) gave higher sinuosity and wider channel along the studied folds with different slopes. The spacing ratios (R) indicate that drainage basin in the Dohuk fold range between 2.52 in sub basin (4) to 5.69 in the sub basin (5), and indicate high rates of tectonic activity, while lower spacing ratios indicate lower rates of active tectonics. Valley basin shape (BS) ranges in value from low in sub basin (1) to high in sub basin (2).

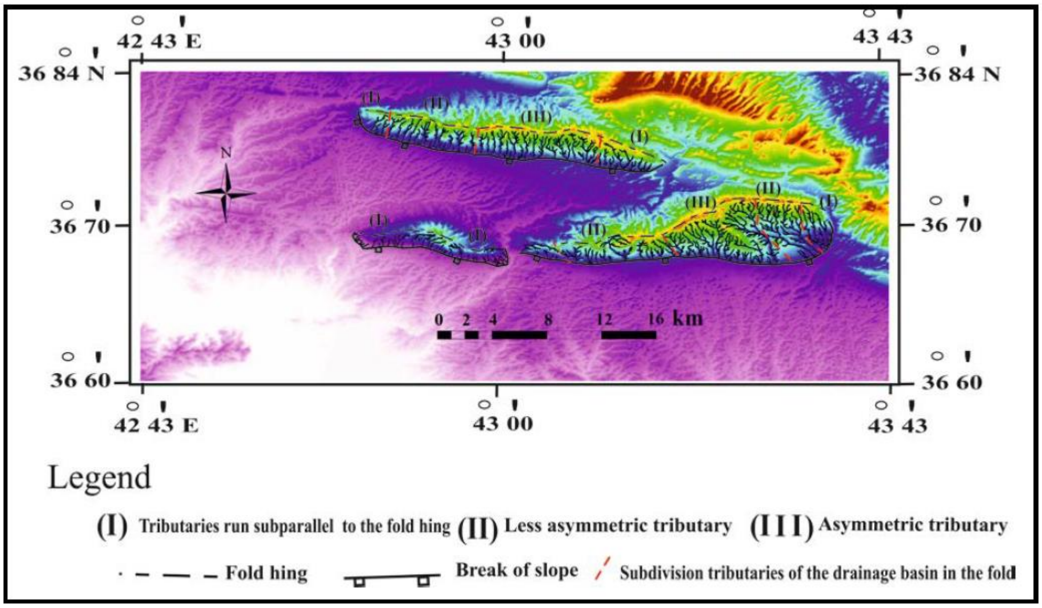

Fig.10 Response tributary to Fold growth and fold front sinuosity (Break of slope)

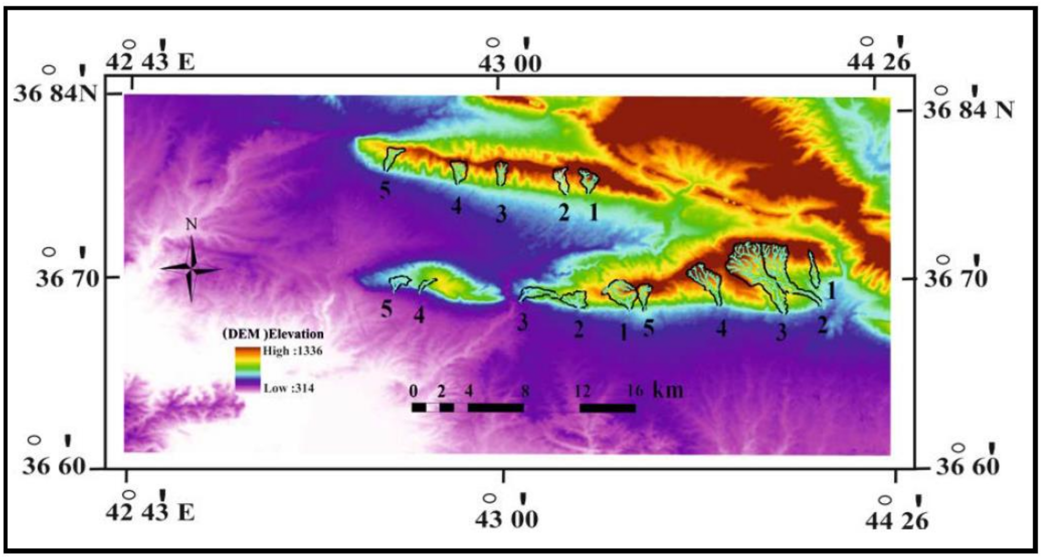

Fig.11 sub basins in the study site

The spacing (R) ratios in drainage basin of Al-Qosh and Duhkan folds range between 3.42 in sub basin (5) to 10.78 in sun basin (2) and 3.02 in sub basin (1) to 5.81 in sub basin (3) respectively in Al-Qosh and Duhkan folds (Tables 3 and 4) indicating high rates of tectonic activity, while lower spacing ratios indicate lower rates of tectonic activity. Valley basin shape (BS) ranges from low in sub basin (4) to high in sub basin (1) in Al-Qosh fold and in sub basin (5) to high in sub basin (4).

The major implications of the fault in study area are:

1- Changes the width of the west and middle parts of the Dohuk fold.

2- Crossed the middle part of the Duhkan fold and divides the Duhkan and Al-Qosh folds.

3- Creating a topographic step or a pronounced change in width of the folds.

4- It has an impact on the drainage basin; this impact is shown in the high tectonic activity of the region and a low maturity of the drainage sub basins.

5- Adjustment of the drainage basin to the fold and fault in the case study is by sub parallel tributary in the fold hinge and less symmetric and asymmetric tributaries in different parts of the range.

6 Discussion

Geomorphologic indicators are used in this study for evaluation of the fold growth and drainage basin in Dohuk, Al-Qosh and Duhkan folds. The drainage patterns are divided in to three parts along the fold. The first part is tributary run sub parallel, the second part is less asymmetry and third parts is asymmetry. The change in the width of the fold is caused by fold growth and its impact on the drainage pattern. These impacts led to the development of drainage tributary form asymmetry to sub parallel in response to the growth of folds and fold front sinuosity. More fold front sinuosity is in the eastern plunge of the fold, is casing by fold growth. So the drainage tributaries in the eastern plunge of the fold are follow the slope and run almost sub parallel to the fold axis. The less fold front sinuosity is in the centre part of the fold and the drainage tributaries are response by asymmetry and less asymmetry.

7 Conclusions

Variability of the tectonic activity and evaluation of the drainage basin in Dohuk, Al-Qosh and Duhkan folds are addressed. Different shapes and areas of sub basins occur in wider folds. The Aspect ratio of the study area formed is a thrust-cored or forced fold in Dohuk fold and buckling in Al-Qosh and Duhkan folds. The Fold symmetry index yielded perfectly symmetrical fold in Al-Qosh fold and near-perfect symmetry in Dohuk and Duhkan folds. The Fold front sinuosity is higher in southeastern end of Al-Qosh fold, and north eastern end of Dohuk fold exhibiting higher fold front sinuosity than the north western halves. The south eastern part of Al-Qosh fold also is more sinuous than the other parts. The south western part of Duhkan fold is sinuous more than other parts and the central part of Dohuk is more sinuous than the other parts.

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