

Geomorphic Indices of Tectonic Activity Through the Analysis of the Drainage Systems in Pera Magroon Anticline, Northeastern Iraq

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ABSTRACT

The study area (Pera Magroon) is located within Kurdistan Region, Sulaimaniyah Governorate, north and northwest of Sulaimaniyah city northeastern Iraq. Arc GIS, hydro tool is used to extract the drainage network in the area under study by using digital elevation models (DEM). The study area is covered by dendritic and parallel drainage patterns and divided into twenty sub-basins.

Three geomorphic indices, Mountain-front sinuosity (Smf), Stream-gradient index (SL) and Valley floor width-valley height ratio (V_f) were calculated for sub-basins.

Through averaging these three indices, we obtained index of active tectonics (IAT). The values of the index were divided into classes to define the degree of active tectonics. Therefore, relative tectonic activity is calculated and their values are classified and analyzed in three groups. The sub-basins were identified as very high, high and moderate levels.

Key words: Geomorphic index, Drainage basin, Tectonic activity, GIS, DEM.

استخدام المؤشرات المورفوتكتونية لدراسة النشاط التكتوني من خلال تحليل شبكة التصريف
لطيبة بيره مكرون شمال شرقي العراق

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المخلص

تقع منطقة الدراسة (بيرة مكرون) في محافظة السليمانية، شمال وشمال غرب مدينة السليمانية، شمال شرقي العراق. وقد تم استخدام نظام المعلومات الجغرافي GIS مجموعة الأدوات المائتية لرسم نظام الصرف

لكل مجرى تمت دراسته، وتم الحصول عليه من نموذج الارتفاع الرقمي (DEM)، وأثبتت الدراسة أن نظام التصريف الشجري والمتوازي هو السائد. قسمت المنطقة لعشرين حوضاً، وتم حساب معامل تعرج مقدمة الجبل (Smf)، ومؤشر الانحدار المتدرج لمقياس (SL)، ونسبة ارتفاع وادي عرض الوادي (Vf)، للأحواض الثانوية المدروسة. من خلال حساب متوسط هذه المؤشرات الثلاثة، حصلنا على مؤشر التكتونية النشطة (IAT). تم تقسيم قيم المؤشر إلى فئات لتحديد شدة النشاط التكتوني، وتم حساب النشاط التكتوني النسبي، والقيم تم تصنيفها وتحليلها الي ثلاث مجموعات، عرفت الأحواض بنشاط تكتوني عالي جداً، عالي ومتوسط. الكلمات الدالة: مؤشر جيمورفولوجي، حوض تصريف، نشاط تكتوني، نظم المعلومات الجغرافية، نموذج الارتفاع الرقمي.

INTRODUCTION

Pera Magroon anticline is a huge asymmetrical doubly plunging anticline within the High Folded Zone of the Zagros Fold Thrust Belt. The anticline is located about 10 km northwest of Sulaimani city (Jassim and Goff, 2006).

Geomorphologic indices are useful for identification of areas that underwent rapid tectonic deformation. Each of these indices provides a relative classification of the intensity of active tectonics. For a specific area, using the several indices rather than an index provide more meaningful results (Keller and Pinter, 2002).

Rivers are an important feature of most landscapes; and Landscape in tectonically active areas results from a complex integration of the effects of vertical and horizontal motions of crustal blocks and erosion or deposition by surface processes (Burbank and Anderson, 2001).

This study presents a method for evaluating relative active tectonics based on geomorphic indices useful in evaluating morphology and topography. These used indices include: Mountain-front sinuosity (Smf), stream length-gradient index (SL), and ratio of valley-floor width to valley height (Vf).

Aim of study

Applying remote sensing techniques by using image data process and geographic information systems (GIS) in the processing of spatial data in order to assess the tectonic activity of the study area by using the Geomorphic indices.

Geographical location

The study area is located at the northern part of Iraq within Kurdistan Region, Sulaimaniyah Governorate, northwest of Sulaimaniyah city between (45° 9' 00" 45° 18' 00"E) and (35° 43' 00" 35° 47' 00" N), It comprises the Pera Magroon anticline (Fig.1).

Tectonic setting

The Pera Magroon anticline is located within the northeastern part of Iraq, it's the outer part of the Arabian plate.

There are several major and minor anticlines and thrust faults existing within the High Folded Zone, the Pera Magroon anticline is located within these zones.

These major anticlines are considered as complex structures due to the deformation which had been caused by the collision of the Arabian plate with the Iranian plate. It was intermittently uplifted in Cretaceous and Paleocene and strongly deformed in the Late Neogene causing regional compressive horizontal forces in NE-SW direction, leading to folds trending in NW - SE axial direction (Fouad, 2010), (Fig. 2).

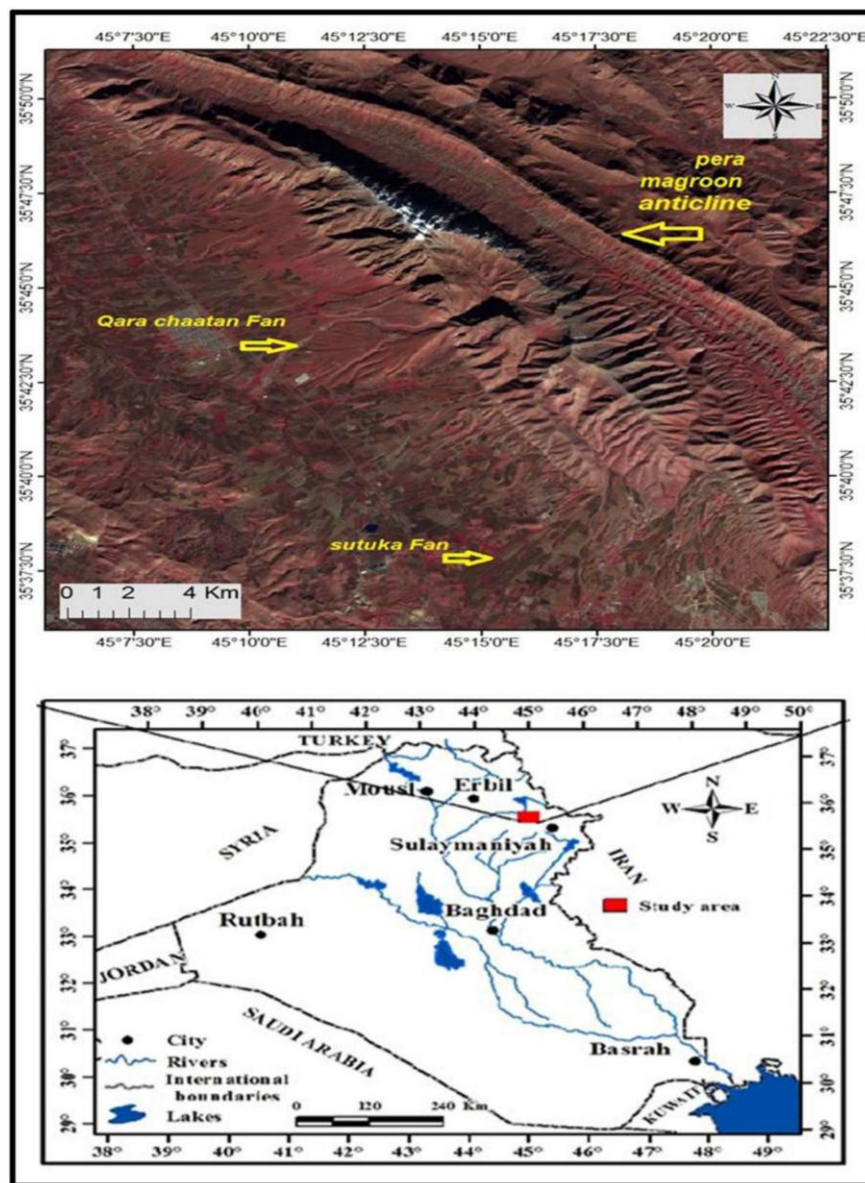


Fig. 1: Location of Study Area (Sentinel2 Image).

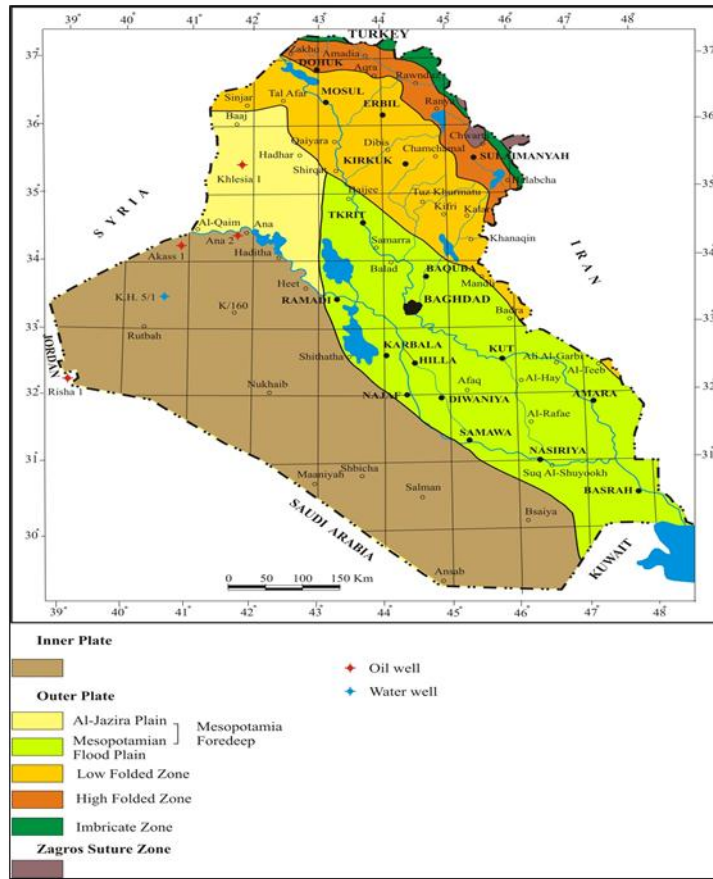


Fig. 2 : Tectonic Map of Iraq (After Fouad, 2010).

Geological Setting

The area of study contains many stratigraphic units appeared as outcrop, ranging from Lower Cretaceous to Recent age, those formations are drawn from oldest to youngest as in (Fig .3):

- 1- **Sargelu Formation (Middle Jurassic):** The total concentration of the Sargelu structure is about 120 m in Sargelu village. It consists of medium tough to tough, dark grey to black, thickly bedded in the lower (50 m) becomes thinly to medium bedded, in the upper part, fine to medium crystalline limestone and dolomitic limestone, with thin horizon of dark papery shale and bituminous limestone.
- 2- **Chia Gara Formation (Late Jurassic - Early Cretaceous):** The Formation consists of an interchange of thinly bottomed limestone and shale rich in ammonites. The maximum thickness is 232m.
- 3- **Balambo Formation (Early Cretaceous):** The formation consists of thinly bottomed limestone with intercalations of dark grey marl and or shale. The exposed thickness of this formation in the type section is 762m.
- 4- **Sarmord Formation (Early Cretaceous):** The total thickness of the formation is 450m, it consists of alternation of marl and limestone.

- 5- **Qamchuqa Formation (Early Cretaceous):** The formation consists of dark brown dolomite whereas the latter is quietly bedded inside and has light grey limestone.
- 6- **Kometan Formation (Early Cretaceous):** It consists of white limestone that is thin and well bedded, but is relatively hard and slightly stroked with marl. The formation provides the alluvial fans with sediments of medium particles sized.
- 7- **Shiranish Formation (Campanian):** It consists of blue well bottomed out thinly marl and marly limestone. The thickness of the formation varies between 200-220 m.
- 8- **Tanjero Formation (Maastrichtian):** The formation consists of an interchange of dark green and yellowish green shale, clay, mud and conglomerate.
- 9- **Quaternary Deposits (Pleistocene-Holocene):** Quaternary sediments cover a large part of the territory of the study area, particularly in the west and southern limbs of it, and also occupy the lowland region like syncline, slopes, and plains. It seems that it is the important sediments in the study area. Alluvial fans with fluvial deposits represent most of the Quaternary deposits (Sissakian and Fouad, 2014).

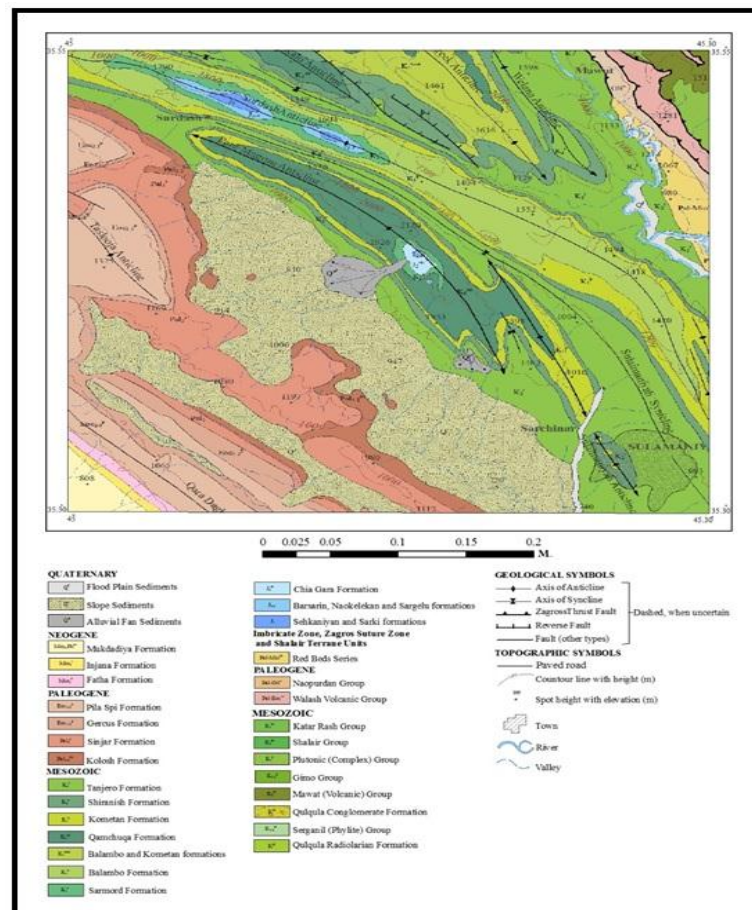


Fig. 3: Geological Map of Study Area (Sissakian and Fouad, 2014).

MATERIALS AND METHODS

The digital elevation model (DEM), sentinel2 image and image processing software (Arc GIS V 10.3) are used to calculate geomorphic indices, which are suitable for assessment of tectonic activity of Pera Magroon anticline.

Geomorphic indices are calculated in study area by using topographic data. On the other hand, the area is divided into 20 sub-basins, based on digital elevation model for each one, indices were calculated, and then all of the indices were combined to obtain index of active tectonics (IAT) by new method.

Drainage networks:

A strong tectonic control on drainage lines were reflected in some landscapes. Structural and tectonic features, such as joints, faults, and lineaments, that may produce essentially straight rivers, i.e. rivers with limited meander development (Arian and Aram, 2014). Depending on the DEM, the drainage network of the area under investigation was extracted by using GIS technology; Mostly the area of study was covered by dendritic and parallel patterns as shown in (Fig. 4).

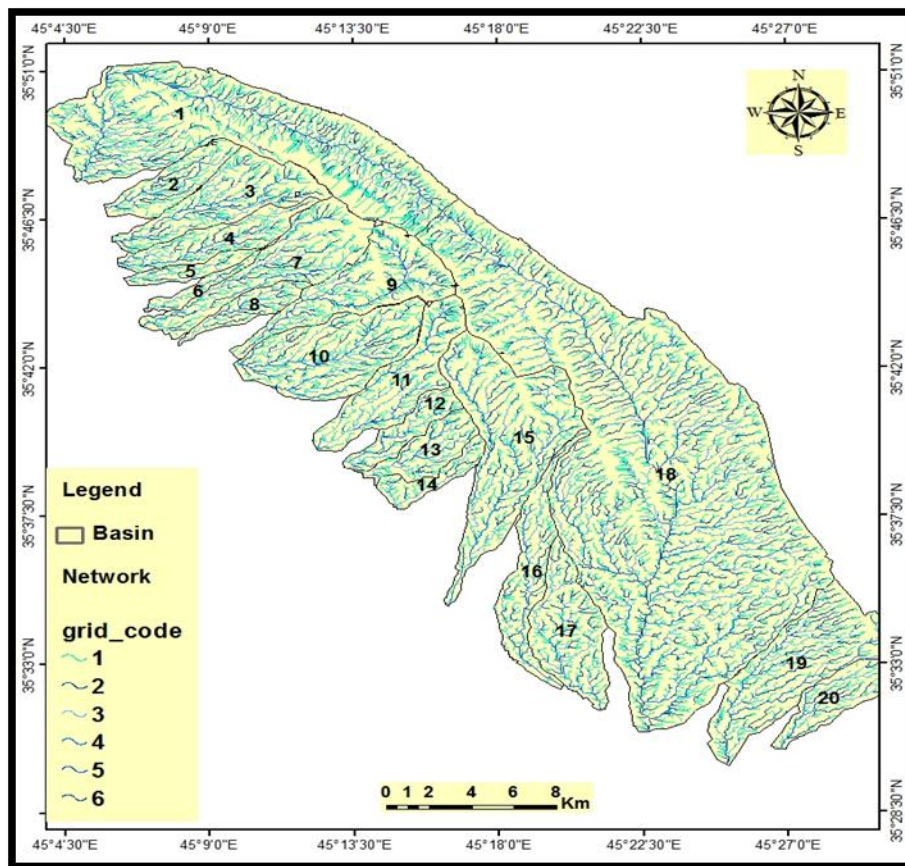


Fig. 4: The Drainage Basin of the Study Area Divided to Twenty Secondary Sub-Basins.

Mountain – Front Sinuosity (S_{mf}):

This index represents a balance between stream erosion processes tending to cut some parts of mountain front and active vertical tectonics that tend to produce straight mountain fronts. Mountain front sinuosity is defined by the equation:

$$S_{mf} = L_{mf} / L_s$$

Where: S_{mf} is the mountain-front sinuosity; L_{mf} is the length of the mountain front along the foot of the mountain, at the severe break in slope; and L_s is the straight-line length of the mountain front (Keller and Pinter, 2002) (Bety, 2015) (Fig .5).

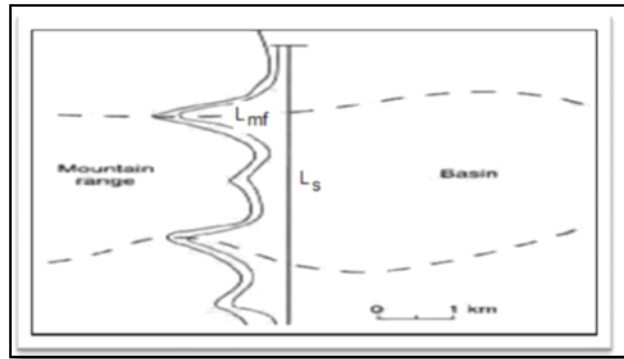


Fig. 5: Calculation of Mountain Front Sinuosity (Keller and Pinter,2002).

The description of mountain front sinuosity with their classes and degrees was set in the Table (1) (Arian, and Aram, 2014). The results of the S_{mf} factor for the study area was acquired and classified into the three main categories as shown in the Table (2).

Table 1: The Categories of the Mountain S_{mf} (Arian and Aram, 2014).

Value of S_{mf}	Description	Class	Degree
1.0 – 1.6	Active mountain front	1	High
1.6 – 3.0	Lesser activity	2	Moderate
3 - 5	Inactive mountain - fronts	3	Low

Table 2: The Results of the S_{mf} Within Study Area.

Basin	L_{MF}	L_S	S_{MF}	class	Degree
1	16372	16024	1.02	1	High
2	1669	1633	1.02	1	High
3	4518	4160	1.08	1	High
4	1880	1851	1.01	1	High
5	976	958	1.01	1	High
6	678	663	1.02	1	High
7	4066	3686	1.10	1	High
8	1376	1362	1.01	1	High
9	5252	5001	1.05	1	High
10	3132	3067	1.02	1	High
11	2600	2355	1.10	1	High
12	1738	1724	1	1	High
13	1780	1757	1.01	1	High
14	1297	1270	1.02	1	High
15	8372	7955	1.05	1	High
16	2830	2802	1	1	High
17	5508	5480	1	1	High
18	28791	27748	1.03	1	High
19	4873	4775	1.02	1	High
20	2168	2125	1.02	1	High

The stream length-gradient index (SL):

The SL index remains approximately constant along a graded stream, and variations in the SL index appear to be attributed to tectonic or to structural and lithological controls (Hack, 1957).

The stream length-gradient index SL is calculated by using the formula:

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

where $\Delta H / \Delta L$ is the channel slope or gradient of the reach, (ΔH) is the change in elevation of reach and ΔL is the length of reach, and L denotes the total upstream length (Fig. 6).

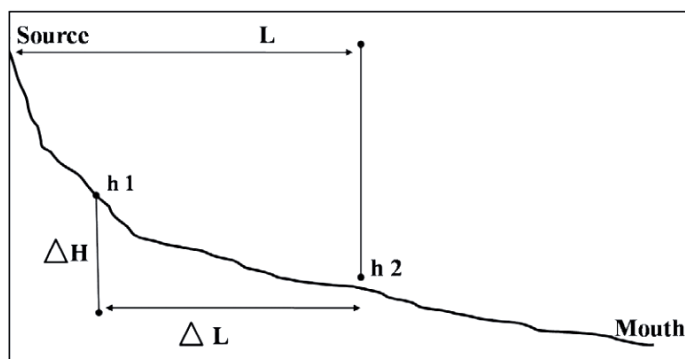


Fig. 6 : Showing the Calculation of the SL Index.

These parameters are measured by topographic maps and digital elevation model (DEM), this index is calculated along the master river. The values of SL index were classified into three categories (El Hamdouni, *el at.*, 2008), shown in table (3). The results of the SL factor for the study area was acquired and classified into three main categories as shown in the Table (4).

Table 3 : The categories of the (SL) (El Hamdouni, *el at.*, 2008).

Range	Class	Degree
(SL ≥ 500),	1	High
300 ≤ SL < 500)	2	Moderate
(SL < 300)	3	low

Table 4: The Results of the SL Within Study Aarea.

Basin	L	ΔH	ΔL	SL	Class	Degree
3	19164	25	789	607,22	1	High
2	6983	39	883	308.42	2	Moderate
4	9936	27	857	313.03	2	Moderate
9	12546	46	1347	428.44	2	Moderate
10	10788	23	711	348.97	2	Moderate
15	14107	38	1678	319.46	2	Moderate
18	32548	23	2191	341.67	2	Moderate
20	6953	39	879	308.49	2	Moderate
1	21429	5	956	112.07	3	Low
5	5662	18	706	144.35	3	Low
6	5780	20	840	137.61	3	Low
7	11484	26	1091	273.67	3	Low
8	6753	11	545	136.29	3	Low
11	10163	26	1447	182.12	3	Low
12	6861	6	561	73.37	3	Low
13	6062	11	884	75.43	3	Low
14	5567	22	842	145.45	3	Low
16	15767	12	1937	97.67	3	Low
17	10532	9	1078	87.92	3	Low
19	10581	16	1584	106.87	3	Low

Ratio of valley floor width to valley height (V_f):

The Valley Width-to-Height Ratio (V_f) allows comparison of erosional patterns between watersheds. The watershed in this case is the unit of measure; one V_f value per watershed.

The index was originally used to distinguish V-shaped valleys from U-shaped valleys, where V-shaped valleys are common in areas of active uplift and deep, linear stream incision (low V_f values, often close to 0). U-shaped valleys are

representative of formerly glaciated or tectonically stable areas where stream valley bottoms tend to be wider (higher V_f values).

The ratio of valley floor width to valley height (V_f) can be expressed as

$$V_f = 2V_{fw} / (E_{ld} - E_{sc}) + (E_{rd} - E_{sc})$$

where V_f is the valley floor width to height ratio; V_{fw} is the width of valley floor; E_{ld} and E_{rd} are elevations of the left and right valley divides respectively and E_{sc} is the elevations of the valley floor (Bull and McFadden, 1977). (Fig. 7). Table (5) shows the categories of V_f according to Bull and Mcfadden (1977). The results of the V_f factor for the study area is acquired and classified into three main categories as shown in Table (6).

Table 5: The Categories of V_f , (Bull and Mcfadden, 1977).

Range	Class	Degree
< 0.5	1	High
0,5 - 1	2	Moderate
> 1	3	Low

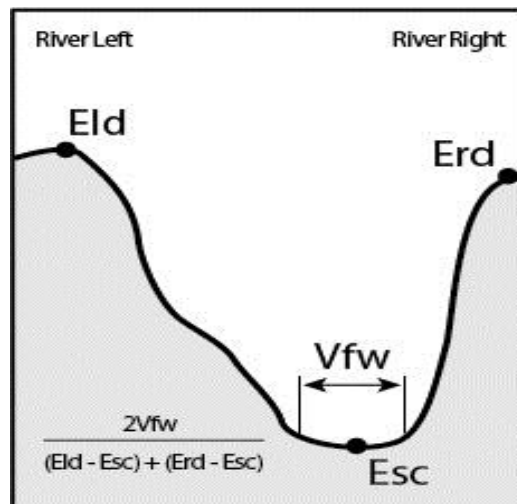


Fig. 7: The Four Inputs to the Valley Width to Height Ratio Equation (Bull and Mcfadden, 1977).

Table 6 :The R of V_f in Study Area.

Basin	Vfw(m)	Esc(m)	Erd(m)	Eld(m)	Vf	class	Degree
1	43	1170	1323	1365	0.24	1	High
4	28	1140	1220	1182	0.45	1	High
15	39	1319	1470	1448	0.27	1	High
18	106	1140	1380	1638	0.28	1	High
3	40	1102	1194	1141	0.61	2	Moderate
7	24	982	1033	1014	0.6	2	Moderate
11	10	894	904	905	0.95	2	Moderate
12	34	960	982	1022	0.8	2	Moderate
2	95	880	885	882	27.14	3	Low
5	37	845	851	853	5.28	3	Low
6	17	839	850	846	1.88	3	Low
8	42	875	884	889	3.65	3	Low
9	20	821	823.5	823	8,8	3	Low
10	30	920	940	945	1.3	3	Low
13	43	968	984	976	3.58	3	Low
14	30	950	964	961	2.4	3	Low
16	38	1050	1057	1063	3.8	3	Low
17	120	758	774	772	8	3	Low
19	43	839	846	852	4.5	3	Low
20	55	1097	1172	1130	1.04	3	Low

Active Tectonics Index (*Iat*):

Iat index is achieved from the average of different geomorphic indicator classes according to the following equation:

$$Iat = S \setminus N$$

S: Total classes geomorphic indicators that is calculated, N: Number of indicators.

For the purpose of establishing the final classification of the extension of the study area affected by tectonic activity, the combined analyzed indices represent the relative active tectonics (*Iat*). The area is divided into four regions as classes according to the values of *Iat*. These classes are class 1 (of very high activity), class 2 (of high activity), class 3 (of moderate activity), and class 4 (of low activity). The regions with relatively high tectonic activity correspond mostly to the active structures in the basin (Eynoddin, 2017) which are shown in Table (7).

Table 7: The Categories of IAT Classification (Eynoddin,2017).

Degree	Class	Range
Very High	1	$1 < IAT \leq 1.5$
High	2	$1.5 < IAT \leq 2$
Moderate	3	$2 < IAT \leq 2.5$
Low	4	$2.5 < IAT$

To explain the effect of tectonic activity for each index of the prior indicators alone, results are collected for all indicators in one table (Table 8), in order to produce a final map, which shows the final combination of the tectonic activity indicators to explain the distribution of tectonic activity in the study area (Fig. 8).

Table 8: The Iat Classes of Tectonic Activity in the Study Area.

Basin	SL	V _f	SMF	IAT	S/N	CLASS LAT	Degree
3	1	2	1	4	1.3	1	Very High
4	2	1	1	4	1.3	1	Very High
15	2	1	1	4	1.3	1	Very High
18	2	1	1	4	1.3	1	Very High
1	3	1	1	5	1.6	2	High
2	2	3	1	6	2	2	High
7	3	2	1	6	2	2	High
9	2	3	1	6	2	2	High
10	2	3	1	6	2	2	High
11	3	2	1	6	2	2	High
12	3	2	1	6	2	2	High
20	2	3	1	6	2	2	High
5	3	3	1	7	2.3	3	Moderate
6	3	3	1	7	2.3	3	Moderate
8	3	3	1	7	2.3	3	Moderate
13	3	3	1	7	2.3	3	Moderate
14	3	3	1	7	2.3	3	Moderate
16	3	3	1	7	2.3	3	Moderate
17	3	3	1	7	2.3	3	Moderate
19	3	3	1	7	2.3	3	Moderate

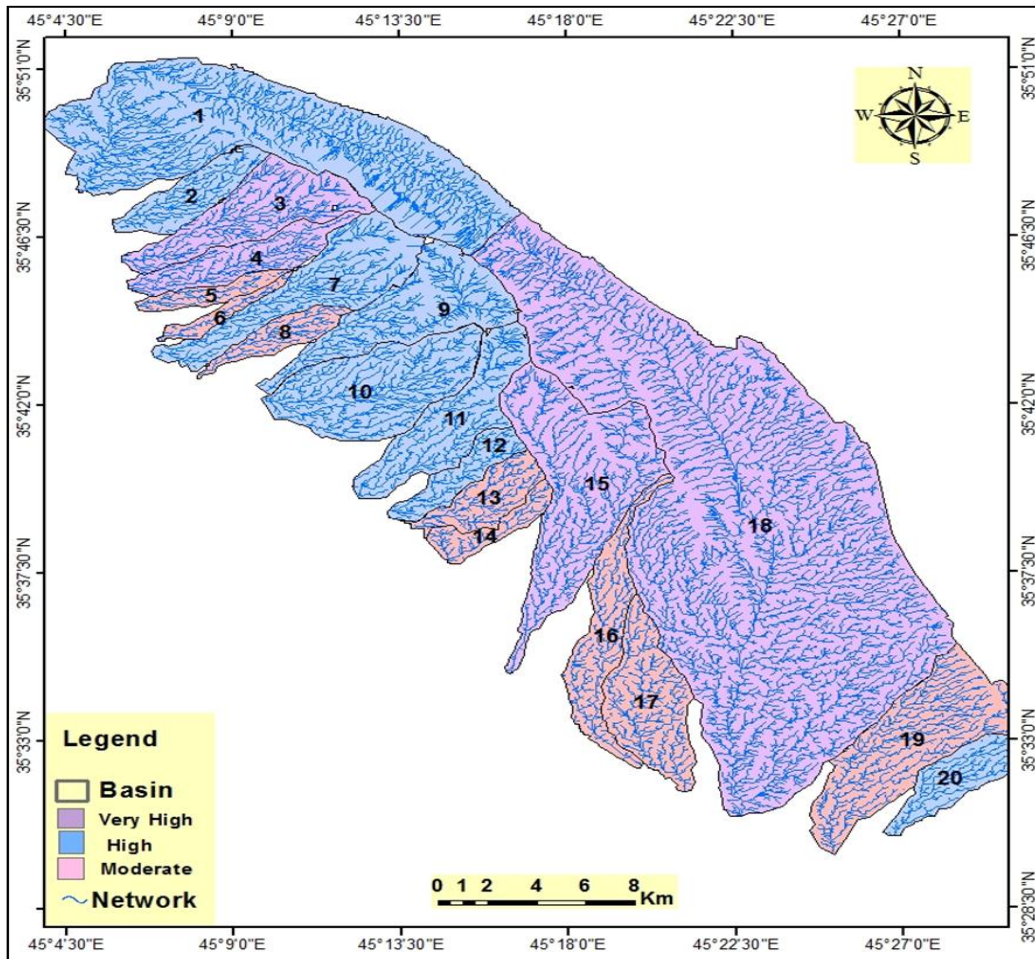


Fig. 8: The IAT Classes of Tectonic Activity in the Study Area.

Discussion of Results

The study area located at northeastern part of Iraq. its known to be tectonically an active area due to its position in the northeastern marginal part of the Arabian Plate, which is in collision with the Eurasian (Iranian) Plate. Thus, the whole area that referred to the High Folded Zone is consequently active, and then discussion of geomorphical indicators of a neo-tectonic activity such as mountain front sinuosity, the stream length-gradient index and ratio of valley floor width to valley height shows that the area is submitted to high tectonic activities.

Mountain front sinuosity (S_{mf}) represents a balance between stream erosion processes tending to cut some parts of mountain front and active vertical tectonics that tend to produce straight mountain fronts. The index value (S_{mf}) is less than (1.6) within study area; it indicates to the active tectonic processes. The stream length - gradient index (SL) is used to identify recent tectonic activity by identifying anomalously high index values on particular soft rock type of an area of high SL indices may indicate recent tectonic activity. SL index values are relatively low in the study area, indicating that the rock type is soft.

The valley floor width-valley height ratio (V_f) differentiates between broad - floored canyons and V- shaped valleys. Low values of (V_f) in the study area is associated with active tectonism.

CONCLUSION

Geomorphic indices provide useful tools for studying intensity of tectonic activity.

- 1- GIS techniques are proved as highly efficient in the analysis and interpretation of the results.
- 2- Drainage networks have been extracted automatically from DEMs.
- 3- The study area is located within the High Folded Zone, where several major and minor anticlines and thrust faults exist within.
- 4- The area is generally affected by modern tectonic activity according to the results obtained by geomorphological factors.

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