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Morphotectonic Analysis Using Geomorphic Indices of the Gumal Valley Basin, Northern Iraq

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Abstract

Geomorphological indicators are important and capable of decoding the responses of landforms to active deformation processes, and are particularly useful in tectonic studies for analyzing, interpreting, monitoring, and understanding changes in landforms because they can be used to quickly assess regional areas. Gumal valley basin is located in northern Iraq and is situated over two different tectonic zones, the High-Folded Zone and Low-Folded Zone. This study examined the status of tectonic activity through quantitative analyses using equations of geomorphological indicators of tectonic activity. A GIS program based on a digital elevation model (DEM) with a resolution of 12.5 m is used to derive sub-basins for the Gumal valley basin, where the number of derived sub-basins in the study area is 38. Five indices are selected for analysis: Stream length gradient index (SL), asymmetry factor (Af), ratio of the valley floor and valley height (Vf), Transverse Topographic Symmetry (T), and mountain front sinuosity (Smf). The results of each index are classified into three categories, and by calculating the arithmetic mean of these indices, an index of relative tectonic activity is obtained. The active tectonics index (IAT) results have been classified into four classes of too high to a little tectonic activity; this reveals that there is no area classified as class 1 (of very high activity). However, 21%, 55%, and 24% of the basin are categorized as classes 2 (of high activity), 3 (of moderate activity), and 4 (of low activity), respectively. Most of the basins are of high and moderate categories, and these basins are located in the High-Folded Zone.

Keywords:

Morphotectonic, Morphometry, Neotectonics, Geomorphic indices, RS and GIS.

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1. Introduction

Tectonic geomorphology is an emerging discipline in the earth sciences due to the emergence of new geodetic, geochronological and geomorphological tools that help obtain rates (uplift rates, erosion rates, slip rates on faults, incision rates, etc.) at varying time periods (Burbank and Anderson, 2001; Keller and Pinter, 2002; Azor et al., 2002; Bull, 2007; Thannoun et al., 2022). This specialization is significant due to the results of regional studies about neotectonics that are important for the assessment of natural risks, land use development and management in populated areas (Pedreira et al., 2007). In mountain ranges, active tectonics and recent ones can be considered the primary elements contributing to rock uplift, as current topography is the result of competition between erosional processes and tectonic (Pedrera et at., et al., 2009; Andermann and Glogouen, 2009).

The water network in tectonically active regions is sensitive to active processes, e.g., faulting and folding. This can significantly influence drainage asymmetry, drainage geometry, complication, and river deviations (Cox, 1994).

Geomorphological indices are important indicators that can decipher the responses of landforms to active deformation processes, it has been widely used as a reconnaissance tool to distinguish between areas deformed by active tectonics (Keller and Pinter, 2002; Chen et al., 2003). Geomorphological indicators are useful especially in tectonic studies as they can be used to quickly evaluate large spaces and the required data can often easily be obtained from satellite images (Keller and Pinter, 2002; Chen et al., 2003). For evaluation of the comparative degree of tectonic activity in the study area, the results of several indicators are generally integrated. Landform investigation is known to be an important instrument in tectonic investigations associated with events occurring several thousand to two million years ago. In young orogens, rapid sediments can cover small structures, in which status geomorphological indicators are more valuable for the type of operations that formed the landforms; and investigation of drainage patterns and rivers can mainly help to locate the active structures (Burbank and Anderson, 2001). This study used five criteria for geomorphological indicators, and these indicators are as follows: ratio of valley floor width to valley height (Vf), Drainage basin asymmetry (Af), Mountain front sinuosity (Smf), Stream length gradient index (SL), and Transverse topographic Symmetry (T). All geomorphic index data obtained from the DEM are then processed using the geographic information system (GIS) method. We chose the Gumal River Basin as the target of our study because of its special status within this region. This valley is located in two tectonically distinct parts, the High-Folded Zone (HFZ) and Low-Folded Zone (LFZ). Each of these zones is characterized by different geologic and geomorphological formations. These differences usually cause different behaviors along the river network system. By evaluating these behaviors, we can draw a picture of the tectonic variation of these zones.

2. Aim of Study

This research deals with the relationship and influence of each geomorphological indicator on the tectonic activity of the basin study area. The main objective of this research is to determine the tectonic activity based on the geomorphological appearance through the geomorphological indicator approach and to represent it visually through maps that provide quick discrimination and ease of interpretation.

3. Materials and Methods

To achieve the study objective, the following data are used: 1) A tectonic map of Iraq was prepared by (Fouad, 2015); 2) Geological map, with a scale of 1/1000 000 was prepared by (Sissakian and Fouad, 2015); 3) Space statement of the digital elevation model (DEM) with an accuracy (12.5) meters issued by the Alaska Satellite Facility (ASF) website of NASA; 4) Spatial of Land Sat 8 for the year 2024; and 5) Computer software with the tools of spatial analysis in the package GIS 10.3.1.

Morphometric parameters (area and linear) and geomorphological indices are extracted with the assistance of (DEM) data of the Shuttle Radar Topography Mission at 12.5 m resolution Fig. 1. Two basic layers, i.e., stream vector layers and drainage basin layers, are extracted by GIS Model Builder in ArcGIS 10.3.1. Geomorphological indicators in the study area are calculated using topographic data. Then, the area is divided into (38) subbasins based on the DEM, and the indicators are calculated; all the indicators are combined to obtain the IAT in a new way. A flow chart of the methodology followed is depicted in Fig. 2.

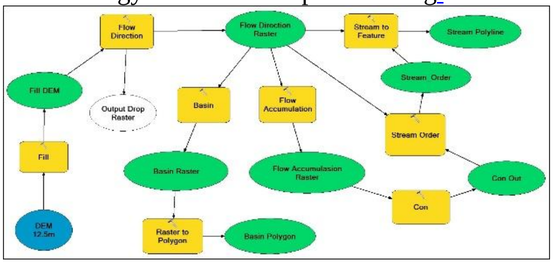

Fig. 1: Model builder in GIS for extracting subbasins and streams using DEM.

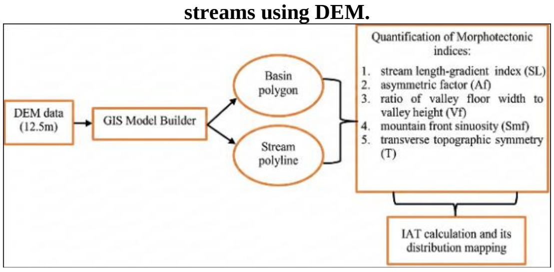

Fig. 2: A schematic diagram explaining the methodology used in the study.

4. Location of the Study Area

The study region site is in the northern part of Iraq at about 55 km northeast of Mosul City. The study includes the Gumal Valley basin, which has an area of 934.88 km^2. The study area is geographically limited between longitudes (43°0′0″) and (43°40′0″) East and latitudes (36°30′0″) and (37°0′0″) north (Fig. 3. The Gumal Valley passes through the fold anticlines of Mahad, Maqlub, Ain Safni, Sheikhan, Atrush, Swara Toka, Bekhair, Brifka, and Gara. Geomorphological changes appear in Gumal Valley along its basin.

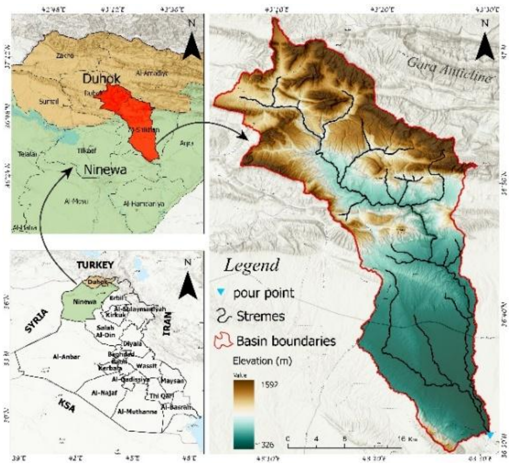

Fig. 3: Location map of the Gumal valley basin.

5. Geological Setting

The basin is situated over two different tectonic zones Fig. 4; the first is (HFZ), which is located north of the basin and occupying the largest area of the basin with an area of (659.19) km^2 and constituting (70.51) percent of the basin area; the second is (LFZ), which is located south of the basin and occupies an area of (275.7) km^2 and constitutes (29.49) percent of the basin area.

There are many main and secondary folds and thrust faults within the high fold zone, and most of the Gumal valley basin is located within this zone. These main folds are complex structures due to the deformation that occurred as a result of the collision of the Iranian plate with the Arabian plate, and they were sporadically uplifted during the Paleocene and Cretaceous, and severely distorted in the late Neogene causing regional horizontal compressive forces in the northeast-southwest direction, resulting in the emergence of folds that trend in an axial direction of northwest-southeast (Fouad, 2010).

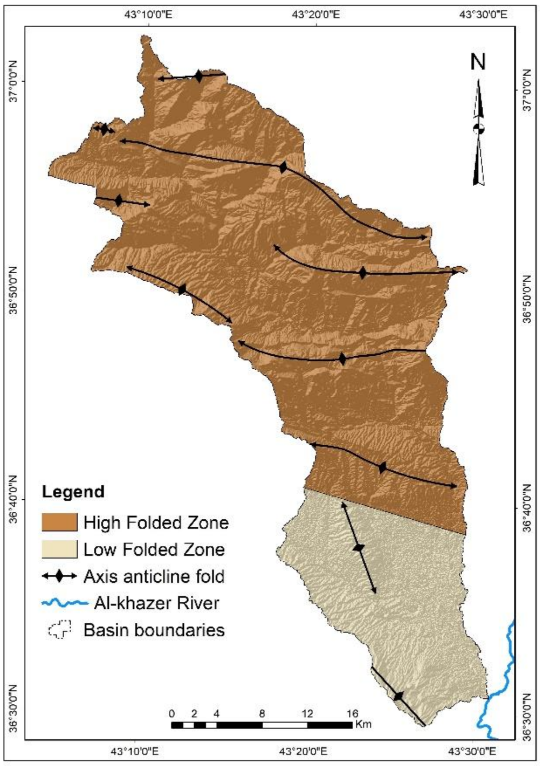

Fig. 4: Tectonic map of the study area

The study area is characterized by the diversity of its stratigraphic formations, which appeared in the form of rocky outcrops extending from the Lower Cretaceous period to the Holocene period. These formations were arranged from oldest to youngest (Fig. 5 and Table 1).

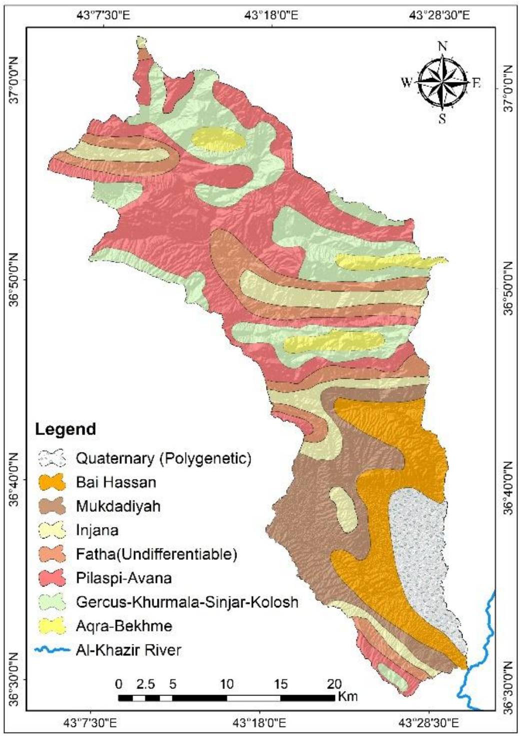

Fig. 5: Geology of the study area basin

6. RESULTS

Geomorphological indices are tools that help in identifying distortion operations beside the evolution of the landform because of dynamic operations (Raj, 2012; Bhat et al., 2020). In the current study, thirty-eight subbasins are delineated Fig. 6, and the geomorphological indices of each basin have been evaluated. Each index is classified into three tectonic categories based on the scope of values. Finally, the (IAT) values are calculated and classified into four categories for the entire area by taking the arithmetic mean of the geomorphological indicator categories.

Table 1: Geological formations, age, lithology, area and their percentages.

No.	Period	Formations	Geological age	Lithology	Area (Km²)	%
1	Quaternary	Residual soil	Holocene - Pleistocene	A mixture of sediments consisting of gravel, sand, clay, and silt.	57.36	6.45
2	Neogene	Bai Hassan	Pliocene – Pleistocene.	Conglomerate, sandstone, claystone.	107.53	11.49
3		Mukdadiyah	Late Miocene – Pliocene.	Sandstone, siltstone, claystone.	117.51	12.53
4		Injana	Late Miocene	sandstone	88.75	9.46
5		Fatha	Middle Miocene	Limestone, marl, gypsum	103.23	10.93
6	Paleogene	Pilaspi-Avana	Middle-Late Eocene	Limestone	249.1	26.4
7		Gercus,Khurmala, Sinjar,Kolosh	Late Paleocene-Middle Eocene	Claystone, sandstones, conglomerates	176.55	18.92
8	Cretaceous	Aqra - Bekhme	Campanian-Maastrichtian	limestones	34.83	3.77
			Total		934.86	100

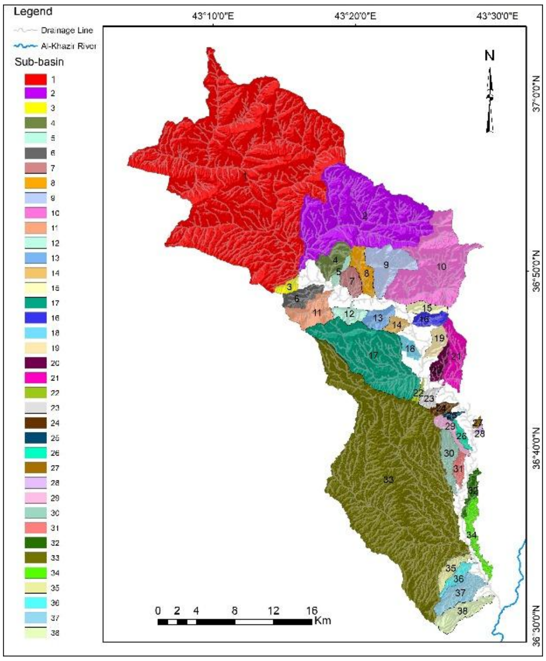

Fig. 6. Drainage basin in the study area split into thirty-eight secondary subbasins.

Methods of calculating geomorphological indicators

1. Ratio of Valley floor width and Valley height (Vf)

The (Vf) allows comparison of erosion patterns between watersheds. In this case, the drainage basin is the unit of measurement, with one Vf value per drainage basin. The factor was originally used to differentiate between U-shaped and V-shaped valleys, where U-shaped valleys represent former glacial or tectonically stable regions where stream valley bottoms will quite often be more extensive. V-shaped valleys are common in areas of active uplift, with deep linear stream slit. The (Vf) calculation can be expressed as:

$$Vf = \frac{2vf_w}{(E_{ld} - E_{sc}) + (E_{rd} - E_{sc})}$$

Where: vfw: valley width (m); Eld: valley left elevation (m); Erd: right elevation (m); Esc: valley base elevation (m).

(Silva et al., 2003) stated that this indicator is calculated over a certain distance upstream from the mountain front. In this study, the sub-basins vary in size, which led the author to use different distances ranging from 1 to 3 km or more depending on the size of the subbasin. Fig. 7 and Table 2 explain the Vf categories according to (Bull et al., 1977).

The results of the factor (Vf) are obtained and classified into three main categories as described in

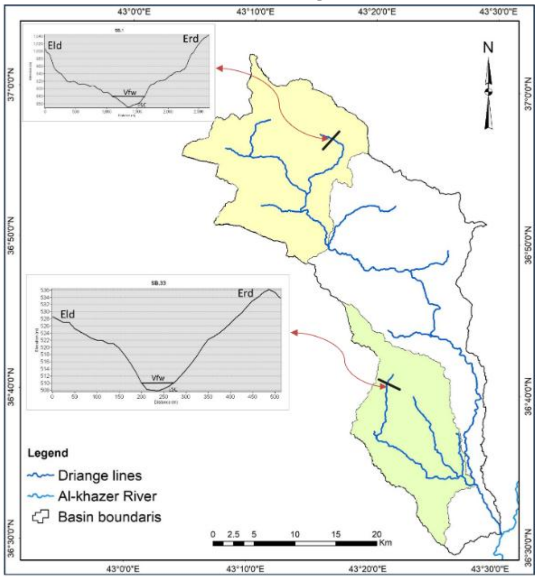

Fig. 7: Calculated (Vf) factor using the DEM with cross-section lines superimposed across Gumal Valley.

Table 3. The distribution of (Vf) classes is shown in Fig. 12a.

Table 2: Categories of Vf (Bull et al., 1977).

Degree	Class	Ranges
High	1	< 0.5
Moderate	2	0.5-1
Low	3	> 1

Table 3: Calculated values and relevant tectonic degrees of Vf

Subbasin	Vf	Class	Degree
1	2.9	3	Low
2	1.19	3	Low
3	1.92	3	Low
4	0.49	1	High
5	2.5	3	Low
6	3.04	3	Low
7	3.72	3	Low
8	0.52	2	Moderate
9	1.04	3	Low
10	2.43	3	Low
11	2.83	3	Low
12	3.53	3	Low
13	1.15	3	Low
14	1.42	3	Low
15	1.52	3	Low
16	4.07	3	Low
17	0.61	2	Moderate
18	1.42	3	Low
19	1.19	3	Low
20	3.89	3	Low
21	1.11	3	Low
22	2.3	3	Low
23	2.09	3	Low
24	3.02	3	Low
25	4.32	3	Low
26	2	3	Low
27	8	3	Low
28	4.17	3	Low
29	4.06	3	Low
30	7.29	3	Low
31	8.44	3	Low
32	3.6	3	Low
33	2.85	3	Low
34	1.87	3	Low
35	6.5	3	Low
36	13.09	3	Low
37	4.94	3	Low
38	4.44	3	Low

2. Stream Length Gradient Index (SL)

The (SL) value is strongly influenced by changes in river slope (channel slope). This sensitivity of SL could be used to evaluate the relationship between topography, active tectonics, and bedrock resistance (Keller and Pinter, 1996).

A high value indicates that drainage flow passes through an active uplifted region via the most resistant rocks, while a low value identifies rivers or streams that flow through an area consisting of lower-resistant and soft rocks (Keller and Painter, 1996; Matthew, 2016). The SL can be expressed as:

$$SL = \left(\frac{\Delta H}{\Delta L}\right) * L$$

Where: ΔH: The difference in elevation between the top and bottom of the reach (m); ΔL: length of the reach (m); L: channel length from the split to the midpoint of the channel reach for which the indicator is calculated (m).

SL values are classified into three categories according to (El Hamdouni et al., 2008) as shown in Fig. 8 and Table 4; and the SL coefficient results for the study area are obtained and classified into three main categories as described in Table 5 and Fig. 12b.

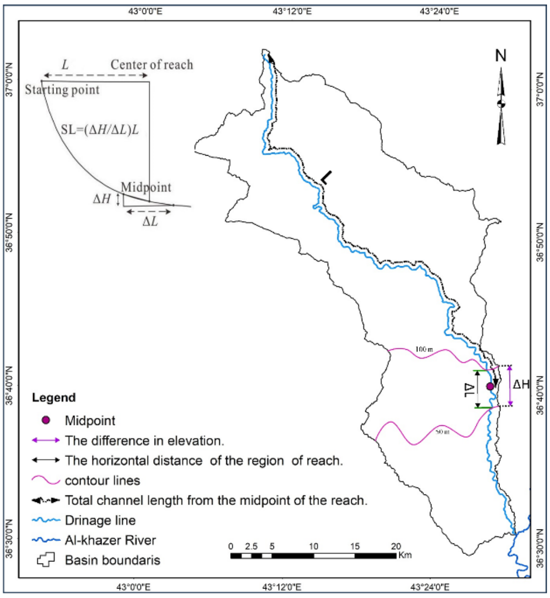

Fig. 8: A graph representing the calculation of the SL in the Gumal Valley.

Table 4: SL categories (El Hamdouni et al., 2008)

Degree	Class	Ranges
High	1	SL ≥ 500
Moderate	2	300 ≤ SL < 500
Low	3	SL < 300

Table 5: Calculated values and related tectonic classes of SL index

Subbasin	SL	Class	Degree
1	159.23	3	Low
2	124.91	3	Low
3	40.01	3	Low
4	20.98	3	Low
5	3.55	3	Low
6	65.96	3	Low
7	3.5	3	Low
8	106.97	3	Low
9	80.4	3	Low
10	53.79	3	Low
11	76.61	3	Low
12	104.88	3	Low
13	159.12	3	Low
14	179.3	3	Low
15	118.99	3	Low
16	233.69	3	Low
17	45.15	3	Low
18	87.5	3	Low
19	75.56	3	Low

20	14.56	3	Low
21	47.33	3	Low
22	121.74	3	Low
23	44.14	3	Low
24	112.46	3	Low
25	69.37	3	Low
26	29.2	3	Low
27	3.49	3	Low
28	7.31	3	Low
29	97.4	3	Low
30	8.41	3	Low
31	14.15	3	Low
32	7.62	3	Low
33	39.15	3	Low
34	21.22	3	Low
35	7.46	3	Low
36	3.53	3	Low
37	22.36	3	Low
38	19.98	3	Low

3. Asymmetric factor (Af)

The Af is one of the basic parameters of basin drainage, and specifies the presence of tectonic tilting of the basin. Tilt in the basin occurs because of tectonic disturbances, and causes the main river channel to deviate from the centerline of the basin in the direction in which the tilt occurred (Matthew, 2016). It can be applied to the basin drainage scale as well as to a large area, and can be expressed by the equation:

$$Af = \left(\frac{Ar}{At}\right) * 100$$

Where: Ar: basin area to the right of the mainstream in the downstream direction (km^2); At: total area of the basin (km^2).

The Af values are classified into three degrees (El Hamdouni et al., 2008) as shown in Fig. 9 and Table 6, and the Af coefficient results for the study area are obtained and classified into three main degrees as described in Table 7 and Fig. 12c.

Table 6. Af categories (after Keller and Pinter, 2002)

Degree	Class	Ranges
High	1	Af > 65
Moderate	2	57 ≥ Af ≤ 65
Low	3	Af < 57

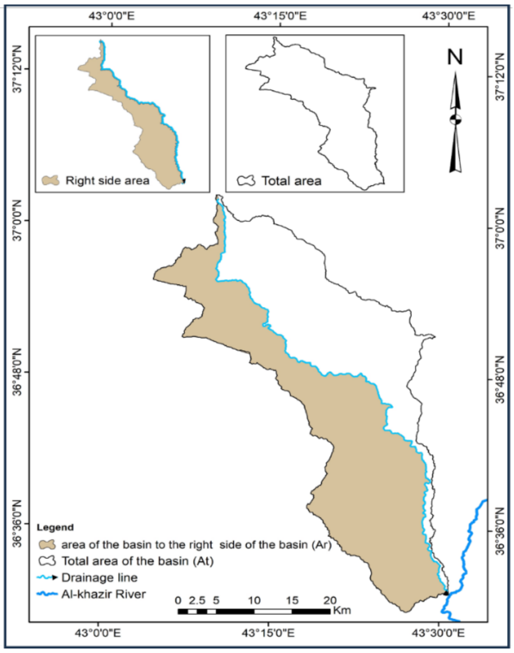

Fig. 9: Representative diagram for Af calculation (Keller and Pinter, 2002).

Table 7: Calculated values and relevant tectonic classes of Af factor.

Subbasin	Af	Class	Degree
1	48.81	3	Low
2	68.77	1	High
3	76.16	1	High
4	44.85	3	Low
5	60.74	2	Moderate
6	39.47	3	Low
7	49.38	3	Low
8	46.05	3	Low
9	49.64	3	Low
10	42.34	3	Low
11	77.38	1	High
12	49.37	3	Low
13	51.68	3	Low
14	39.54	3	Low
15	38.35	3	Low
16	39.69	3	Low
17	35.1	3	Low
18	41.43	3	Low
19	45.89	3	Low
20	79.11	1	High
21	43.48	3	Low
22	48.05	3	Low
23	52.94	3	Low
24	67.83	1	High
25	58.45	2	Moderate
26	51.79	3	Low
27	14.36	3	Low
28	11	3	Low
29	44.41	3	Low
30	45.37	3	Low
31	48.32	3	Low
32	36.47	3	Low
33	44.09	3	Low
34	62.87	2	Moderate
35	67.2	1	High
36	38.98	3	Low
37	37.05	3	Low
38	35.26	3	Low

4. Mountain front sinuosity (Smf)

The (Smf) is used to assess active tectonics on the stretch mountain fronts (Bull et al., 1977).

This is based on the note that tectonically active mountain fronts are often straighter than mountain fronts in regions where erosion dominates tectonics (Wells et al., 1988). Low values (Smf) are directly related to tectonic activity and uplifting. If the uplift rate is low, the erosion process will cut the mountain face irregularly, and the Smf value will increment:

$$Smf = \frac{L_{mf}}{L_s}$$

Where: Lmf: The length of the mountainous front is zigzag (km); Ls: Straight Mountain front length (km) Fig. 10.

The Smf index is divided into three classes according to (Bull et al., 1977).

As shown in Table 8, the Smf coefficient results for the study area are obtained and divided into three main degrees as described in Table 9 and Fig. 12d.

Table 8. Categories of the mountain front sinuosity (Smf)

Degree	Class	Ranges
High	1	1 - 1.6
Moderate	2	1.6 - 3
Low	3	3 - 5

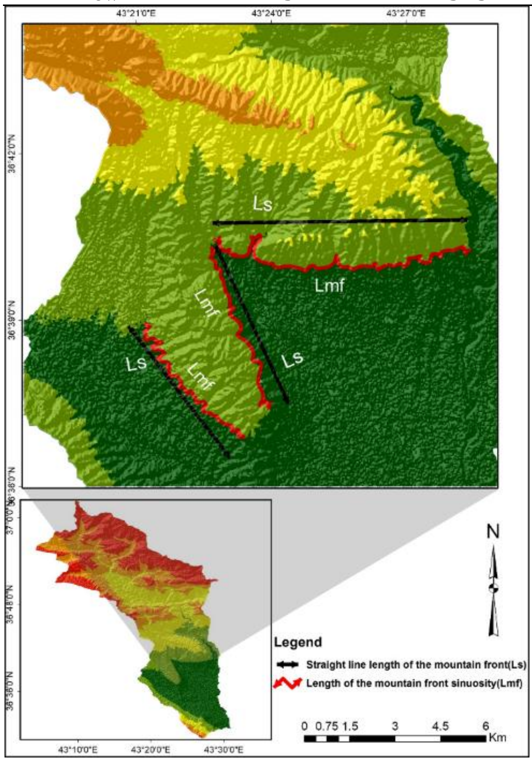

Fig. 10: Calculation of Smf.

Table 9: Resultant values and tectonic classes relevant to the Smf.

Subbasin	Smf	Class	Degree
1	1.02	1	High
2	1.02	1	High
3	1.04	1	High
4	1.02	1	High
5	1.02	1	High
6	1.05	1	High
7	1	1	High
8	1.01	1	High
9	1.01	1	High
10	1.02	1	High
11	1.01	1	High
12	1.02	1	High
13	1.04	1	High
14	1	1	High
15	1.03	1	High
16	1	1	High
17	1.03	1	High
18	1.03	1	High
19	1	1	High
20	1.01	1	High
21	1	1	High
22	1.01	1	High
23	1.01	1	High
24	1.01	1	High
25	1	1	High
26	1	1	High
27	1.01	1	High
28	1	1	High
29	1	1	High
30	1	1	High
31	1	1	High
32	1	1	High
33	1	1	High
34	1	1	High
35	1	1	High
36	1	1	High
37	1.01	1	High
38	1.08	1	High

5. Transverse topographic symmetry (T)

It is calculated to describe the tilt of the basin due to tectonic activity (Cox, 1994). The (T) factor is calculated based on the symmetry vector data of the basin, which includes the deviation of the meander belt from the centerline of the basin. It ranges from 0 to 1. The following equation is used for (T) calculation:

$$T = \frac{D_a}{D_d}$$

Where: Da: deviation of the river course from the midline of the basin (km); Dd: distance between the basin midline and basin boundaries (km) Fig. 11.

The (T) factor is divided into three classes as shown in Table 10, and (T) coefficient results for the study area are listed in Table 11 and shown in Fig. 13e.

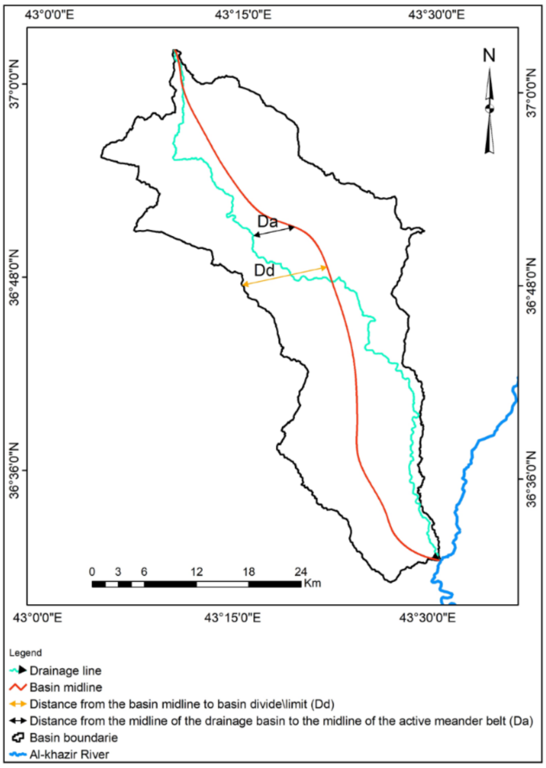

Fig. 11: Representative diagram for Transverse topographic symmetry calculation.

Table 10. Categories of T (Burbank and Anderson, 2001).

Tilting Degree	Class	**Ranges**
High	1	T > 0.6
Moderate	2	0.3-0.6
Low	3	T< 0.3

Table 11: Classes and degrees of T.

Subbasin	T	Class	Degree
1	0.28	3	Low
2	0.29	3	Low
3	0.68	1	High
4	0.61	1	High
5	0.34	2	Moderate
6	0.13	3	Low
7	0.41	2	Moderate
8	0.67	1	High
9	0.25	3	Low
10	0.38	2	Moderate
11	0.45	2	Moderate
12	0.06	3	Low
13	0.06	3	Low
14	0.16	3	Low
15	0.68	1	High
16	0.28	3	Low
17	0.32	2	Moderate
18	0.25	3	Low
19	0.58	2	Moderate
20	0.49	2	Moderate
21	0.44	2	Moderate
22	0.51	2	Moderate
23	0.24	3	Low
24	0.40	2	Moderate
25	0.07	3	Low
26	0.61	1	High
27	0.70	1	High
28	0.77	1	High
29	0.64	1	High
30	0.36	2	Moderate
31	0.22	3	Low
32	0.5	2	Moderate
33	0.39	2	Moderate
34	0.94	1	High
35	0.54	2	Moderate
36	0.79	1	High
37	0.28	3	Low
38	0.80	1	High

6. Active Tectonics Index (IAT)

In this study, five geomorphological parameters are used to calculate the IAT. This category provides a comprehensive view of all parameters affected by the geomorphological tectonic activity in the research area. The IAT is obtained by calculating the arithmetic mean of each class of geomorphological indices according to the following equation:

$$IAT = \frac{S}{N}$$

Where: ***S***: Sum of the tectonic active class values; ***N***: Number of geomorphic indices.

To assess the last classification of the extent to which the research area is affected by tectonic activity, the classification of (El Hamdouni et al., 2008) is adopted as presented in Table 12. The calculated values are described in Table 13. The distribution of IAT classes shows the variable range of tectonic activity Fig. 12f.

Table 12: Degrees of IAT classification (after Eynoddin et al., 2017; El Hamdouni et al., 2008).

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

Table 13: IAT degrees in the study area

Subbasin	T	Af	SMF	SL	VF	S	N	IAT=S/N	Class	Degree
1	3	3	1	3	3	13	5	2.6	4	Low
2	3	1	1	3	3	11	5	2.2	3	Moderate
3	1	1	1	3	3	9	5	1.8	2	High
4	1	3	1	3	1	9	5	1.8	2	High
5	2	2	1	3	3	11	5	2.2	3	Moderate
6	3	3	1	3	3	13	5	2.6	4	Low
7	2	3	1	3	3	12	5	2.4	3	Moderate
8	1	3	1	3	2	10	5	2	2	High
9	3	3	1	3	3	13	5	2.6	4	Low
10	2	3	1	3	3	12	5	2.4	3	Moderate
11	2	1	1	3	3	10	5	2	2	High
12	3	3	1	3	3	13	5	2.6	4	Low
13	3	3	1	3	3	13	5	2.6	4	Low
14	3	3	1	3	3	13	5	2.6	4	Low
15	1	3	1	3	3	11	5	2.2	3	Moderate
16	3	3	1	3	3	13	5	2.6	4	Low
17	2	3	1	3	2	11	5	2.2	3	Moderate
18	3	3	1	3	2	12	5	2.4	3	Moderate
19	2	3	1	3	2	11	5	2.2	3	Moderate
20	2	1	1	3	3	10	5	2	2	High
21	2	3	1	3	2	11	5	2.2	3	Moderate
22	2	3	1	3	3	12	5	2.4	3	Moderate
23	3	3	1	3	1	11	5	2.2	3	Moderate
24	2	1	1	3	1	8	5	1.6	2	High
25	3	2	1	3	3	12	5	2.4	3	Moderate
26	1	3	1	3	3	11	5	2.2	3	Moderate
27	1	3	1	3	3	11	5	2.2	3	Moderate
28	1	3	1	3	3	11	5	2.2	3	Moderate
29	1	3	1	3	3	11	5	2.2	3	Moderate
30	2	3	1	3	3	12	5	2.4	3	Moderate
31	3	3	1	3	3	13	5	2.6	4	Low
32	2	3	1	3	3	12	5	2.4	3	Moderate
33	2	3	1	3	3	12	5	2.4	3	Moderate
34	1	2	1	3	3	10	5	2	2	High
35	2	1	1	3	3	10	5	2	2	High
36	1	3	1	3	3	11	5	2.2	3	Moderate
37	3	3	1	3	3	13	5	2.6	4	Low
38	1	3	1	3	3	11	5	2.2	3	Moderate

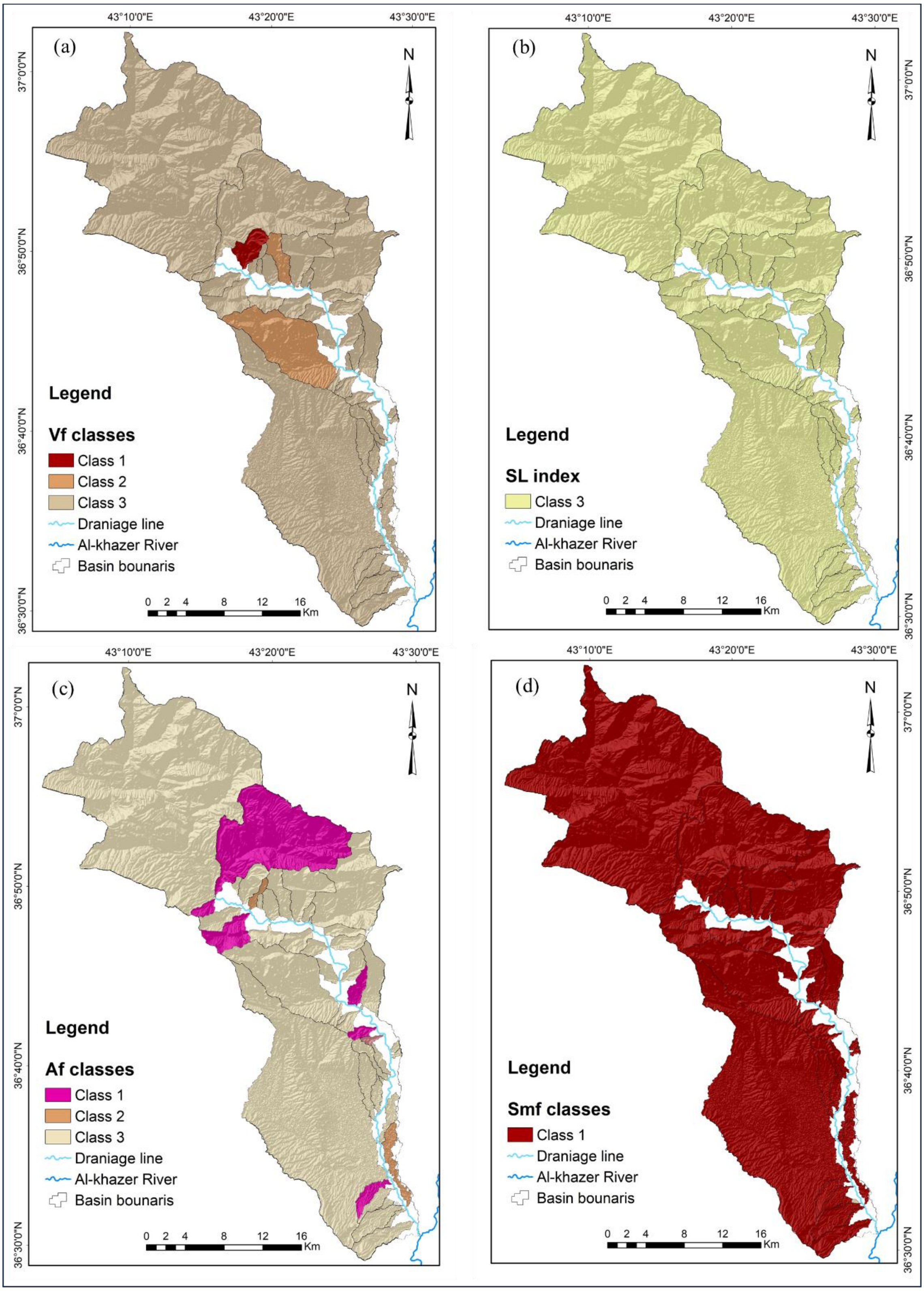

Fig. 12: Maps showing indicator classes and their associated tectonic intensity., a) Vf, b) SL, c) Af, d) Smf.

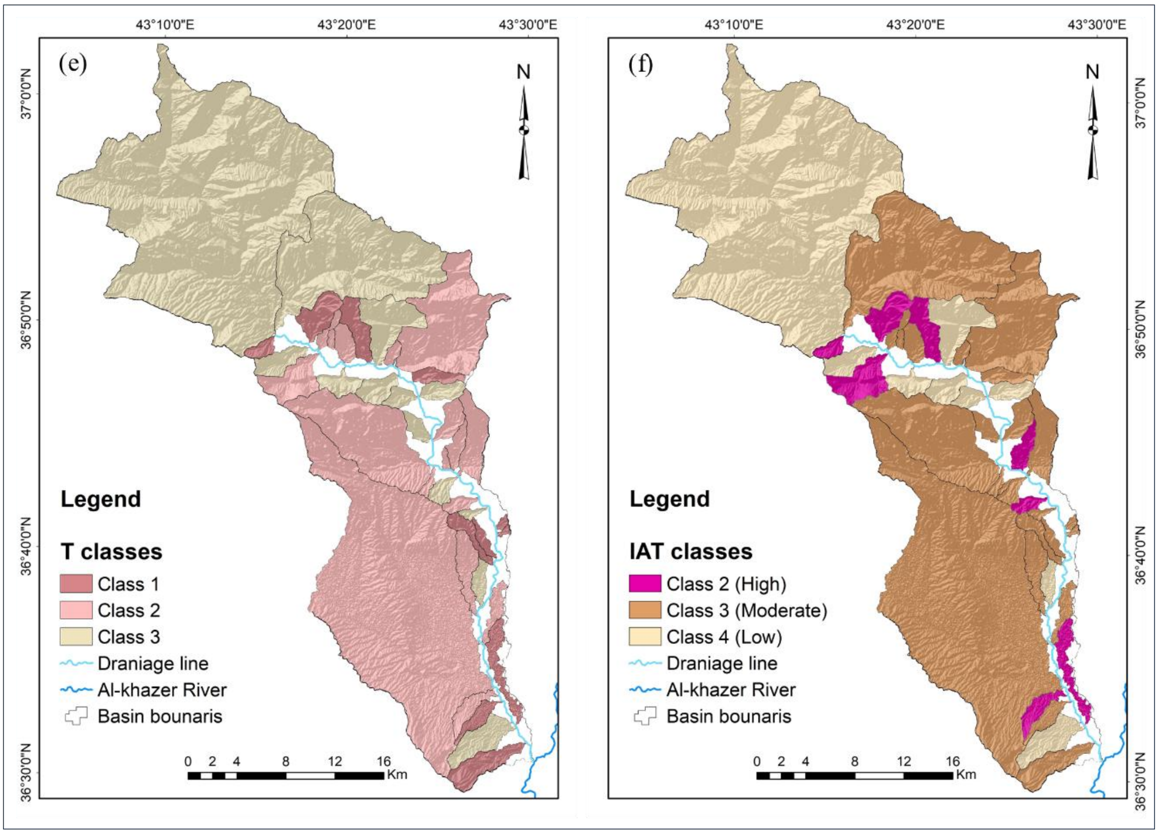

Fig. 12: Continued. e) T; f) IAT map of Gumal Valley showing the intensity of active tectonics.

7. Discussion

From the above, and by using indicators of Neo-tectonic activity (SL, T, Af, SMF, VF) to infer tectonic activity, it is clear that the study area falls within a tectonically active category with a medium to high degree in certain areas. This is in response to the ongoing collision between the Arabian Plate and the Eurasian Plate, which has created numerous deformations and anomalies to prepare a morphotectonic environment susceptible to tectonic activity.

Quantitative analyses of geomorphological indicators provide insights into the relative degree of tectonic activity in Gumal valley. The basin lies on two different tectonic zones, the HFZ and the LFZ. The impact of this location on fracture and fault systems is a clear reflection of the current tectonic situation in the region.

The (Smf) represents a balance between current erosion processes, which tend to cut off some parts of the mountain front; and active tectonics, which tends to produce straight mountain fronts. The (Smf) results fall into the category of high tectonic activity, indicating the dominance of tectonic activity relative to this index. The value of (Smf) is less than
(1.6) for the study area, indicating active tectonic processes.

The calculated (VF) ratio is obtained from generated cross-sections using DEM and GIS, and all sub-basins fall into category (3) except three basins; this indicates severely degraded sub-basins and valleys with U- shapes, while the three high and medium activity basins show V-shaped valleys; this indicates tectonic activity in the area.

The (SL) index is used to determine recent tectonic activity by identifying abnormally high index values over a specific type of soft rock. A region with high (SL) index values may indicate recent tectonic activity. Relatively low (SL) index values in the study research suggest that the rock type is soft.

Based on the analysis of the (T) results, the basin shows a medium to low displacement or migration of the main basin channel, and active to moderately active basins appear in the center and south of the basin. The displacement or migration of the main basin channel is due to the presence of thrust faults accompanying the folds or due to the effect of meandering in the lower layer of the basin resulting from active tectonic activation (subsurface faults).

Most of the basins are characterized by a low (Af) factor (less than 50), except for some basins that showed high to medium tectonic activity located north and south of the basin, which caused the sides of the basin to be tilted relative to the main channel. As a result, the tributaries to the left of the main channel will be shorter compared to the tributaries on the right side of the main channel, which reflects the asymmetry factor. This explains the influence of these basins on the surface and subsurface geological structures that led to the presence of high and medium tectonic activity.

The final (IAT) tectonic activity map shows that none of the basins in the study area fall into category (1) (of very high tectonic activity), while 21%, 55%, and 24% of the basins fall into categories (2, 3, and 4) (of high, moderate, and low tectonic activity), respectively. Based on the obtained results, the final (IAT) tectonic activity map shows that the majority of the basins with high and medium tectonic activity fall within the high fold zone. The study reveals that the region is exposed to medium to high tectonic activity, resulting in the formation of diverse geological structures such as folds, faults, and surface and subsurface fractures.

8. Conclusion

- The study area is a unique location situated in two distinct zones: the high fold zone and the low fold zone, showing a clear difference through the presence of medium to highly active basins located within the high fold zone.
- The impact of this location on the fracture and fault systems represents a clear reflection of the current tectonic situation in the region.
- (IAT) scores show that none of the study areas falls in class (1) (of very high activity).
- 21%, 55%, and 24% of the area belong to classes (2, 3, and 4), respectively.
- This tectonic activity has left its mark on erosion and sedimentation processes within the basin, shaping its current morphotectonic features.

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The authors wish to express their sincere gratitude to the Department of Applied Geology, College of Science at Tikrit University for providing the necessary facilities and technical support. Special thanks are also extended to our supervisors for their invaluable guidance, insightful comments, and continuous support throughout the various stages of this research, which significantly enriched the findings.

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التحليل المورفوتكتوني باستخدام المؤشرات الجيومورفولوجية لحوض وادي الكومل، شمالي العراق

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الملخص

المؤشرات الجيومورفولوجية مهمة وقادرة على فك رموز استجابات أشكال الأرض لعمليات التشوه النشطة، ومفيدة بشكل خاص في الدراسات التكتونية لأجل اجراء التحليل والتفسير ومراقبة وفهم التغيرات الحاصلة في الاشكال الارضية، لأنه يمكن استخدامها لتقييم المناطق الاقليمية بسرعة. يقع حوض وادي الكومل في شمالي العراق ويتموضع فوق نطاقين تكتونيين مختلفين، هما نطاق الطيات العالية ونطاق الطيات الواطئة. تناولت هذه الدراسة حالة النشاط التكتوني من خلال تحليلات كمية باستخدام معادلات المؤشرات الجيومورفولوجية للنشاط التكتوني. تم استخدام نظم المعلومات الجغرافية (GIS) بناءً على نموذج الارتفاع الرقمي (DEM) بدقة تمييز 12.5 مترًا لاشتقاق الأحواض الثانوية لحوض وادي الكومل، حيث تم اشتقاق 38 حوضًا ثانويًا في منطقة الدراسة. اختيرت خمس مؤشرات للتحليل: مؤشر طول المجرى ودرجة انحداره (SL)، عامل عدم التماثل (Af)، نسبة عرض قاع الوادي إلى ارتفاع الوادي (Vf)، التماثل الطبوغرافي العرضي (T)، وتعرج جبهة الجبل (Smf). تم تصنيف نتائج كل مؤشر إلى ثلاث فئات، ومن ثم تم حساب المتوسط الحسابي لهذه المؤشرات للحصول على مؤشر النشاط التكتوني النسبي. كشفت نتائج مؤشر النشاط التكتوني النسبي(IAT)، المصنفة إلى أربع فئات من النشاط التكتوني المرتفع جدًا إلى المنخفض، أنه لم يتم تصنيف أي منطقة ضمن الفئة 1 (ذات نشاط مرتفع جدًا). ومع ذلك، تم تصنيف 21٪ و55٪ و24٪ من الاحواض ضمن الفئات: 2 (ذات نشاط مرتفع) و3 (ذات نشاط متوسط) و4 (ذات نشاط منخفض) على التوالي. تقع غالبية الأحواض ضمن الفئتين المرتفعة والمتوسطة، وتوجد هذه الأحواض في نطاق الطيات العالية.

الكلمات المفتاحية:

مورفوتكتونك، جيومورفولوجي مورفومتري، المؤشرات الجيومورفيه، حوض الكومل.

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