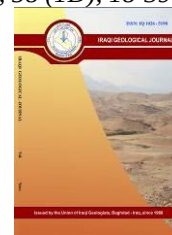




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Tectonic Evaluation by Using Morphotectonic Indices at Zurbatiyah Area, Eastern Iraq

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Abstract

This study focuses on the morphotectonic analysis of the main basins at Zurbatiyah district, eastern Iraq, to evaluate the levels of tectonic activity using morphotectonic indices, even to understand the landscape evolution by investigating how such tectonic activity influences both landscape evolution and geomorphological features. The area has complex tectonic evolution and geological conditions due to the Arabian plate's subduction process with the Eurasian plate in the Miocene-Pliocene period. Geographic information systems for geomorphic data processing and Digital Elevation Models with a resolution of 30 m were used to extract and analyze geomorphic index parameters to assess the tectonic activity in the study area. Six quantitative parameters were analyzed: The research area basin's relative tectonic activity index, which includes the following metrics: Asymmetry Factor, Transverse Topographic Symmetry Factor, Stream gradient Index, Valley floor width to valley height ratio, and Mountain Front Sinuosity. The geomorphic indices indicated that the basins of the study area reflected the tectonic forcing and changed their river network course by neo-tectonic activities and compressions of the collision zone between the Arabian and Eurasian plates, which led to the emergence of surface and subsurface folds and faults. Moreover, the regions adjacent to the collision zone exhibit more tectonic activity than those in the Mesopotamian zone.

Keywords: Tectonic Activity; Arabian plate; Geomorphic Indices; DEM; GIS; Zurbatiyah; Iraq

1. Introduction

The morphotectonic analysis includes drainage network analysis for identifying and investigating faults or fold systems (Sharma and Sarma, 2017). Fluvial systems are most sensitive in their behavior and development; they retain a past detailed record of deformation in their morphology (Bull and McFadden, 2020). Abnormal values of geomorphic indexes, particularly those concerning tectonics, have continually been utilized as a substitute for neo-tectonics activity in different sets of tectonically active areas and environments (Ramirez, 1998). Drainage network analysis contributes to understanding tectonic activity since tectonic deformation is recorded in the flow path trends and helps for identifying faults, fracture patterns, and geo-morphological anomalies (Turcotte et al., 2001; Kusak and Krbcová, 2017). Tectonic activity influences river dynamics and the evolution of drainage networks (Valdiya and Allu, 2007). Streams and rivers are important for landforms that exhibit a high sensitivity to tectonic

movement, as they are influenced by incision, diversion, and asymmetry within a tectonic context (Lehner, 2024). Many researchers are important in morphotectonic index studies, such as (Al-Musawi et al., 2020; Hidayat et al., 2021; Hamdoon et al., 2021; Jirjees et al., 2023; Othman and Omar, 2023; Darweesh, 2024). The quantitative geomorphology utilizes statistical, mathematical, and computational methods to quantitatively analyze landforms and their processes (Cavalliet al., 2020). These methods were used to obtain accurate data, make predictions, and understand the fundamental processes that shape the Earth's surface. This study addresses the interaction between tectonic processes and geomorphological evolution in the Zurbatiyah area, located within the tectonically active Zagros Fold-Thrust Belt. Employing advanced Geographic Information system (GIS) technologies and Digital Elevation Models (DEM) analysis methodologies that provides a robust framework for quantitatively assessing tectonic activity and understanding the regional landscape deformation. It also contributes to understanding neotectonic processes. This study aims to (1) Evaluate the tectonic Activity, Assess the types and levels of such tectonic activity in specific regions using morphotectonic indices, and (2) Understand the landscape evolutions and investigate how the tectonic activity influences landscape evolution and geo-morphological features.

2. The Study Area and Geological Settings

Zurbatiyah area (belongs to Wasit Governorate) is situated in the eastern part of Iraq (Fig. 1), encompassing approximately 3800 km², it is located between the latitude of 33° 40' 0" to 33° 00' 00" N and longitude 45° 30' 00" to 46° 30' 00" E. It has an arid climate with hot summers and cold, wet winters (Ali and Ali, 2014). Tectonically, it is situated in the southwestern portion of the foothill zone within the Kirkuk sub-zone marks the outer and central unit of the unstable Nubio-Arabian platform. It is part of the foreland basin of the Zagros fold and thrust belt (Fouad, 2012) (Fig. 2), situated at the extreme margin of the Low Folded Zone between the High Amplitude Mountainous and Mesopotamian Plains (Yacoub et al., 2012). The study area exhibits a notable topographic gradient, descending from the northeastern mountainous region towards the western and southwestern sections, characterized by well-developed alluvial fans and sheet runoff sediments (Fig. 3). The highest elevated point of the study area slopes reaches about (2472m) above sea level at the northeast of the studied area, while the lowest elevated point reaches about (14m) above sea level, mostly formed during the Oligo-Miocene. Hemmrin anticline that parallels the Iraqi-Iranian border is the key structure in the investigated area since late regional tectonic processes severely distorted it before the quaternary epoch (Jassim and Goff, 2006; Fouad, 2012); as well the anticline structure of the Badrah is considered an important subsurface oil field in the study area (Faisal and Mahdi, 2020). The exposed formations are Oligocene to the Pliocene–Pleistocene. They are covered by recent sediments described from older to younger are the Ibrahim, Serikagni, Dhiban, Jeribe, Fatha, Injana, Mukdadiya formations, and Quaternary deposits (Fig. 3). The stratigraphy of these formations mostly comprises alternating layers of sandstone, siltstone, and claystone, limestone with gypsum and conglomerates present at certain intervals (Jassim and Goff, 2006; Fouad 2012). These formations signify sedimentary settings affected by tectonic uplift and basin subsidence, significantly altering surface geomorphological characteristics by shaping drainage patterns and regulating erosion resistance.

The geomorphology of the research region reveals long, narrow hill chains that are elevated and encircled by low-lying folded anticlines and synclines. To the east and northeast, there is steep, rough terrain with distinctive features. Simultaneously, the gradient will be diminished in the southwestern regions. These characteristics represent the primary geological and structural reliefs, the dynamics, and the erosion of various geo-morphological processes. The primary prominent geo-morphological

characteristics are structural denudation origins, units of denudation origins, fluvial origin units, floodplains, and aeolian units (Fig. 3).

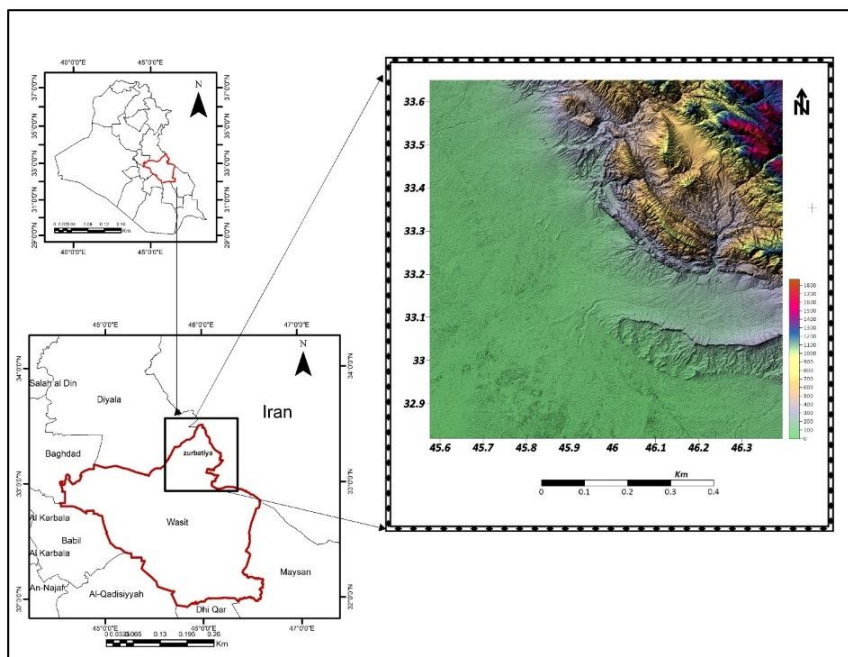


Fig. 1. The location of the study area and the Digital Elevation Model (DEM)

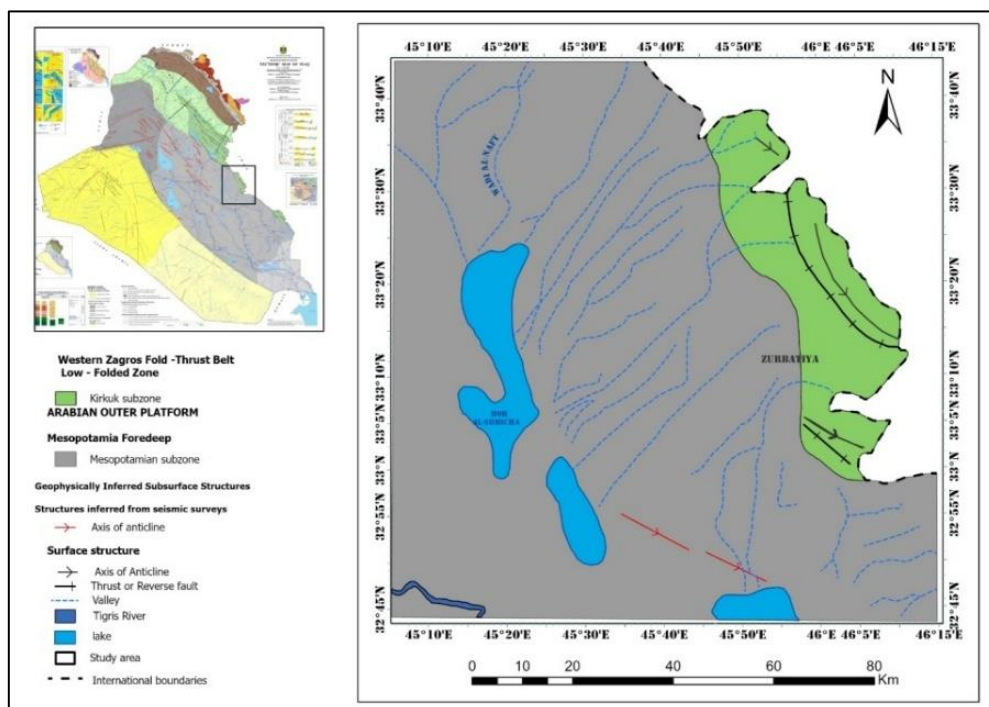


Fig. 2. The study area's tectonic map (Fouad, 2012)

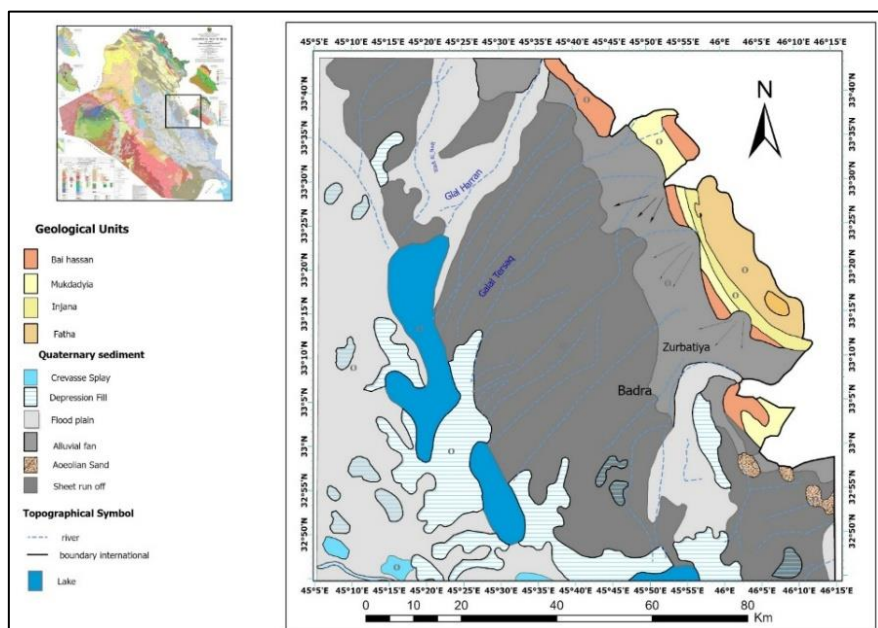


Fig. 3. The study area's geological map (Sissakian and Fouad, 2012)

3. Materials and Methods

The Shuttle Radar Topography Mission (SRTM) used a 30 m resolution digital elevation model (DEM) to delineate the basin and drainage network. The hydrological tool of Arc GIS 10.8 software helped delineate the drainage basin and drainage network through the following geoprocessing techniques:

DEM (30 m) > Filled DEM > Flow Direction > Flow accumulation > Stream network generation > Watershed extraction (Fig.4). Asymmetry Factor (AF), Transverse Topographic Symmetry Factor (T), Stream gradient Index (SL), Valley floor width to valley height ratio (VF), and Mountain Front Sinuosity (SMF) are computed using the mathematical equations presented in Table. 1. The methodology of the study is summarized in (Fig. 5).

Each basin was divided into two areas and computed using GIS tools: the right side (Ar) facing downstream and the total area (At). Then, the formula in Table. 2 was applied to extract the (AF) index. This index indicates the differential orientation of tectonic activity and the lateral tectonic tilting of the highest-order stream (Al-Maliki et al., 2023; Elitez and Yaltirak, 2024), which aids in identifying geotectonic activity in areas with weakly consolidated surficial materials (Cox, 1994). Furthermore, the asymmetry factor is responsive to tilting perpendicular to the basin's primary channel; (AF) value of 82(50) signifies a stable environment, whereas values significantly above or below (50) indicate the influence of active tectonics or substantial lithologic control (El Hamdouni et al., 2008).

The Transverse Topographic Symmetry Factor (T) was calculated to evaluate lateral tectonic tilting in the study area. Basin boundaries were determined using a (30m) DEM, and the midline was established to bisect the basin into symmetrical halves. The horizontal distance (Da) from the mainstream to the midline, together with the basin's half-width (Dd), was measured at consistent intervals of (4000 m). The (T) values were calculated using the approach shown in Table. 2. A (T-value) approaching (0) signifies symmetry, whereas values approaching (1) indicate considerable asymmetry, implying active tectonic tilting or underlying structural influences (Leeder, 2001).

The (SL) index was introduced by Troiani and Della Seta (2008). The channel slope is significantly influenced, enabling the assessment of tectonic in the region. Evenly shaped river gradients indicate the

lithological variation present in the river beds. (SL-Index) facilitates the examination of relative tectonic activity. The (SL-Index) evaluates alterations in river gradient resulting from variations in rock type or tectonic processes. Elevated values may suggest the presence of rivers traversing hard rock, indicative of tectonic uplift. Lower values indicate softer rock or meandering rivers along strike-slip faults, (Jirjees et al., 2023). The stream was divided into uniform 4-kilometer segments using GIS tools to standardize computations. Elevation differences (ΔH) were extracted between each segment's start and end points, horizontal distance (ΔL) between these points and the total river length (L) from the source to the segment midpoint were calculated (El Hamdouni et al., 2008), the (SL) Index for each segment was computed using the formula in Table 2.

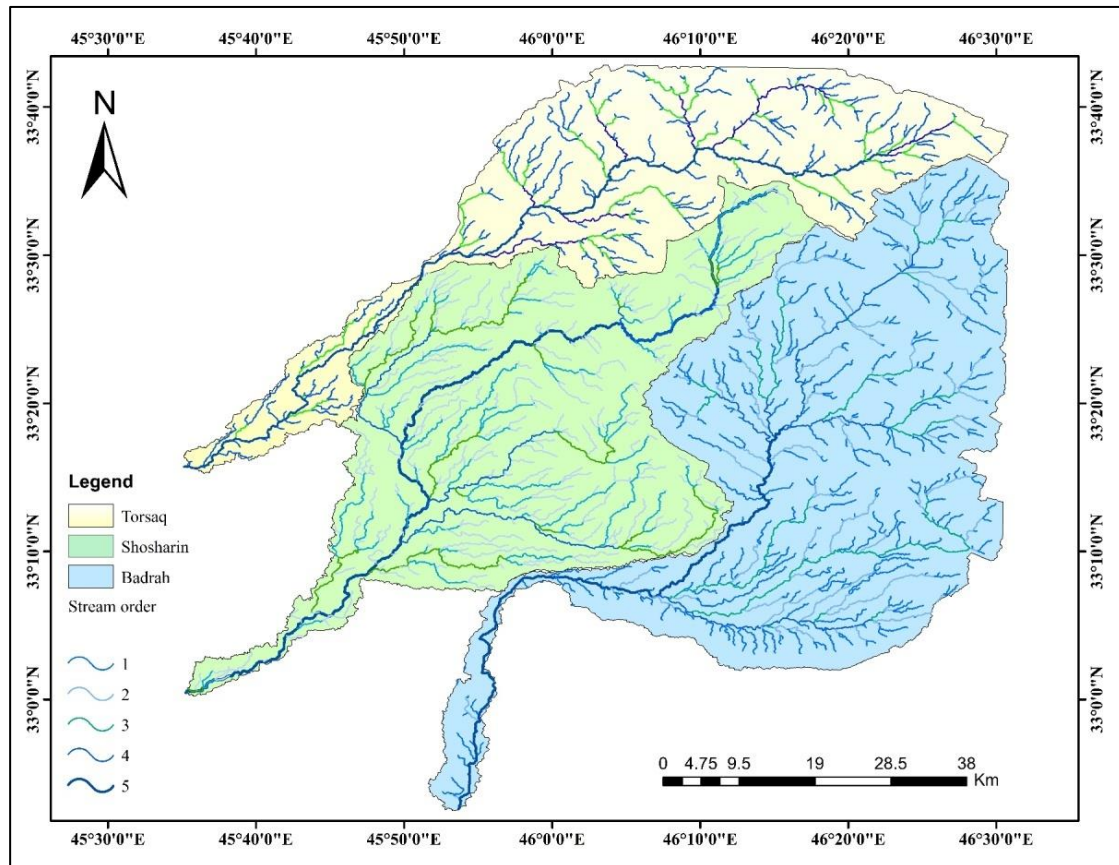


Fig. 4. Drainage system of the research area

Table 1. Category classifications for the Transverse Topographic Symmetry Factor (Leeder, 2001)

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

Table 2. Computed morphotectonics parameters

Morphotectonic Parameters	Formulae	References	Class, Values and Inferences
Asymmetry Factor (AF)	$AF = (A_r / A_t) * 100$ where A_r is the basin's overall area; A_t is the portion to the right (looking downstream) of the mainstream.	(Keller and DeVecchio, 2013)	Class1: $AF > 65$, high tectonic activity Class2: $57 \geq AF \leq 65$, moderate tectonic activity, Class3: $AF < 57$, low tectonic activity
Transverse Topographic Symmetry Factor (T)	$T = D_a / D_d$, where D_a represents the distance from the basin midline to the meander belt midline; D_d denotes the distance from the basin midline to the basin split.	(Cox, 1994)	$T = 0$, Symmetric Basin $T > 0$, Asymmetric Basin
Stream-gradient Index (SL)	$SL = (\Delta H / \Delta L) L$, where ΔH represents the change in elevation, ΔL denotes the length of a reach, and L signifies the horizontal distance from the basin divide to the midpoint of the reach.	El Hamdouni et al., 2008	Class1: $SL \geq 500$, High activity Class2: $300 \geq SL < 500$, Moderate activity Class3: $SL < 300$, Low activity
Valley floor width to valley height ratio (VF)	$VF = 2VFW / [(E_{ld} - E_{sc}) + (E_{rd} - E_{sc})]$ Where: VFW is the width of the valley floor, E_{ld} and E_{rd} are the elevations on the left and right valley divides, and E_{sc} is the elevation of the valley floor.	(Keller and DeVecchio, 2013)	Class1: $VF < 0.5$, high tectonic activity, Class 2: $0.5 \leq VF \leq 1$, moderate tectonic activity. Class3: $VF > 1$, low tectonic activity
Mountain Front Sinuosity (SMF)	L_{mf} / L_s , where L_{mf} is the length of the mountain front along the foot of the slope, and L_s is the straight- line length of the mountain front.	(Bull, 2008)	Class1: $SMF < 1.4$, Tectonically Active Class 2: $SMF = (1.4-3)$, Slightly Active. Class3: $SMF > 3$, Inactive Setting

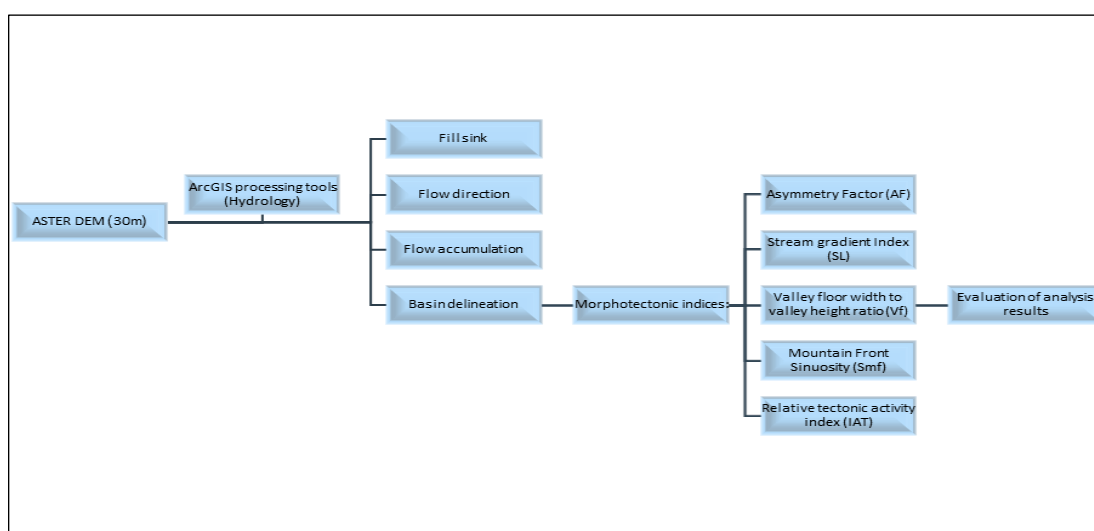


Fig. 5. The flowchart of Morphotectonic analysis

The ('VF') index was originally employed to differentiate U-shaped valleys from V-shaped valleys (Bull and McFadden, 2020). Elevated ('VF') index values correlate with mountain fronts that exhibit moderate to low activity, signifying reduced uplift rates and broad, flat valley bottoms influenced by base-level erosion. In contrast, diminished values are associated with dynamically elevating V-shaped valleys (Bull, 2008). Because incision correlates to uplift, the index is considered a proxy for active tectonics, where higher rates of incision and uplift are linked to low values of (VF). In an equilibrium state, incision and uplift are almost equal, but the index measures incision rather than uplift (El Hamdouni et al., 2008). This measure signifies the maturity of a river valley and facilitates the assessment of the relative rate of tectonic uplift of the mountain face (Kale and Shejwalkar, 2008). The (VF) ratio was determined using four cross-sections (VF locations) for each basin at equal intervals along the mainstream of each basin. Then, the (VF) for each location was computed using the approach in Table 2. The (SMF) index is predicated on the notion that actively tectonic mountain fronts are often more linear than those in regions where erosion predominates (Hadji et al., 2024). This index illustrates the complex equilibrium between erosion-inducing irregular/sinuuous fronts and tectonic forces generating linear mountain fronts aligned with an active boundary fault range (Raj et al., 2003). The (Smf) value is less than (1.4), indicating strong tectonic activity associated with vast plains, narrow valleys, and steep hills (Sunan et al., 2023). Mountain front sinuosity was measured for basins using a hill shade derived from a (30 m) resolution (DEM). The values of (Smf) were calculated for the mountain fronts using (Lmf) and (Ls) values (Fig. 6) and (Table. 2) describes their classes and degrees.

4. Results

The results showed that the study area's (AF) values show a low grade of less than 50 for the Torsaq. At the same time, the Shosharin has a moderate grade of (61.91) and a high (AF) value of (67.9) Badrah basin, indicating an unstable setting (Table. 3) and (Fig. 7). The T-index for the three basins ranges from (0) (indicating perfect symmetry and low activity) to (0.9) (indicating asymmetry and high activity) (Fig. 7) and (Table 4 A, B, C). The (T) values signify the asymmetric characteristics of the basins affected by neo-tectonics.

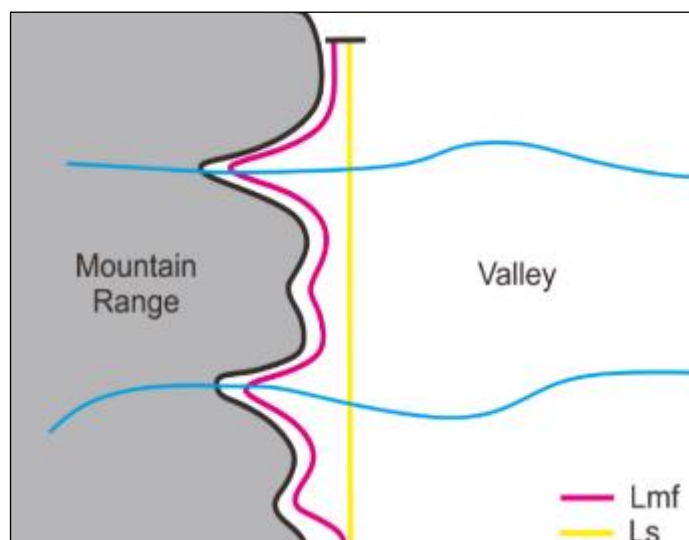


Fig. 6. Mountain Front Sinuosity (SMF) calculation, after (Keller and Pinter, 2002)

Table 3. AF (drainage basin asymmetry) values with its degree

Region	AT (km ²)	AR (km ²)	AF	Degree	Class
Torsaq	1112.4	393.5	35.3	Low	3
Shosharin	1560.9	966.5	61.9	Moderate	2
Badrah	1863.8	1265.7	67.9	High	1

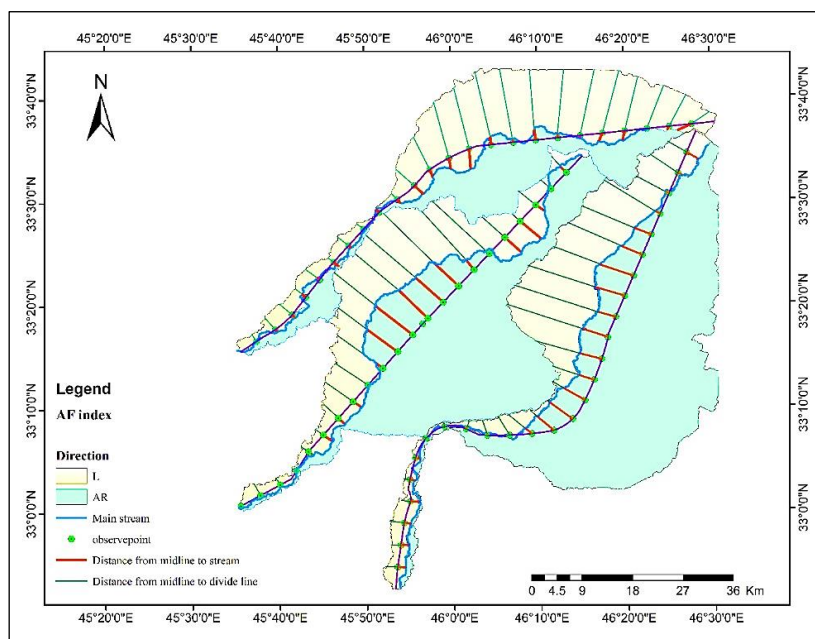


Fig. 7. Asymmetry of the drainage basin (AF) and the transverse topography symmetry factor (T)

Table 4A. The classes of (T) factor of the Torsaq mainstream

Segment	Da	Dd	T
1	2.7	6.6	0.4
2	0.8	7.3	0.1
3	0.2	8.5	0
4	1.7	11.6	0.1
5	1.6	13.1	0.1
6	0.5	12.5	0
7	0.7	12.2	0.1
8	1.9	12.7	0.1
9	0.6	13.2	0
10	1.4	13.3	0.1
11	3.6	14.8	0.2
12	2	12.3	0.2
13	1.4	7.8	0.2
14	2.2	6.5	0.3
15	1	2.3	0.4
16	0.8	0.9	0.9
17	0.1	1.6	0.1
18	0.6	3.2	0.2
19	1.2	2.5	0.5
20	0.6	3.1	0.2
21	0.9	2.4	0.4
22	0.9	3.8	0.2
23	0.6	3.3	0.2
24	0	1.5	0
Min	0	0.9	0
Max	3.6	14.8	0.9
Average	1.2	7.3	0.2

Table 4B. The classes of (T) factor of the Shosharin mainstream

Segment	Da	Dd	T
1	2.1	4	0.5
2	2	2.3	0.8
3	4.9	6	0.8
4	4.1	6.8	0.6
5	0.8	9.4	0.1
6	2.2	14	0.2
7	6.2	14.1	0.4
8	6.7	19.5	0.3
9	7.2	18.4	0.4
10	8.3	17.5	0.5
11	6.8	18	0.4
12	1.9	13.4	0.1
13	0.2	9.9	0

14	1.9	7.1	0.3
15	1.7	8	0.2
16	2.1	5.2	0.4
17	1.1	3.8	0.3
18	0.1	2.6	0
19	0.4	0.8	0.5
20	0.5	1.8	0.3
21	0.3	2.8	0.1
22	0.2	0.6	0.4
Min	0.1	0.6	0
Max	8.3	19.5	0.8
Average	2.8	8.5	0.34

Table. 4C. The classes of the (T) factor of the Badrah mainstream

Segment	Da	Dd	T
1	2.4	6.3	0.4
2	0.8	6.7	0.1
3	0.7	6.6	0.1
4	1	11.7	0.1
5	3.3	13.4	0.2
6	4	14.5	0.3
7	6.3	15.2	0.4
8	5.6	18.1	0.3
9	3.3	19	0.2
10	4.7	19	0.2
11	4.1	12.4	0.3
12	2.8	7.8	0.4
13	4.4	6.7	0.7
14	5.2	5.6	0.9
15	3.9	5.5	0.7
16	1.6	5.4	0.3
17	0	3.9	0
18	0.3	2.8	0.1
19	0.4	1.5	0.3
20	0.2	0.8	0.2
21	0.1	0.7	0.2
22	0.9	1.4	0.6
23	1	2	0.5
24	1.5	3.2	0.5
25	1.2	3.9	0.3
26	1.5	3.3	0.5
27	1.5	3.6	0.4
Min	0	0.7	0
Max	6.3	19	0.9
Average	2.3	7.4	0.34

Fig. 8, illustrates the graphical depiction of a longitudinal profile and (SL) index for the mainline of all basins. The findings demonstrate that the (SL) value escalates in the northeastern region of the basins and diminishes towards the southwest (Table. 5A, B, C). The (VF)ratio results indicate significant tectonic

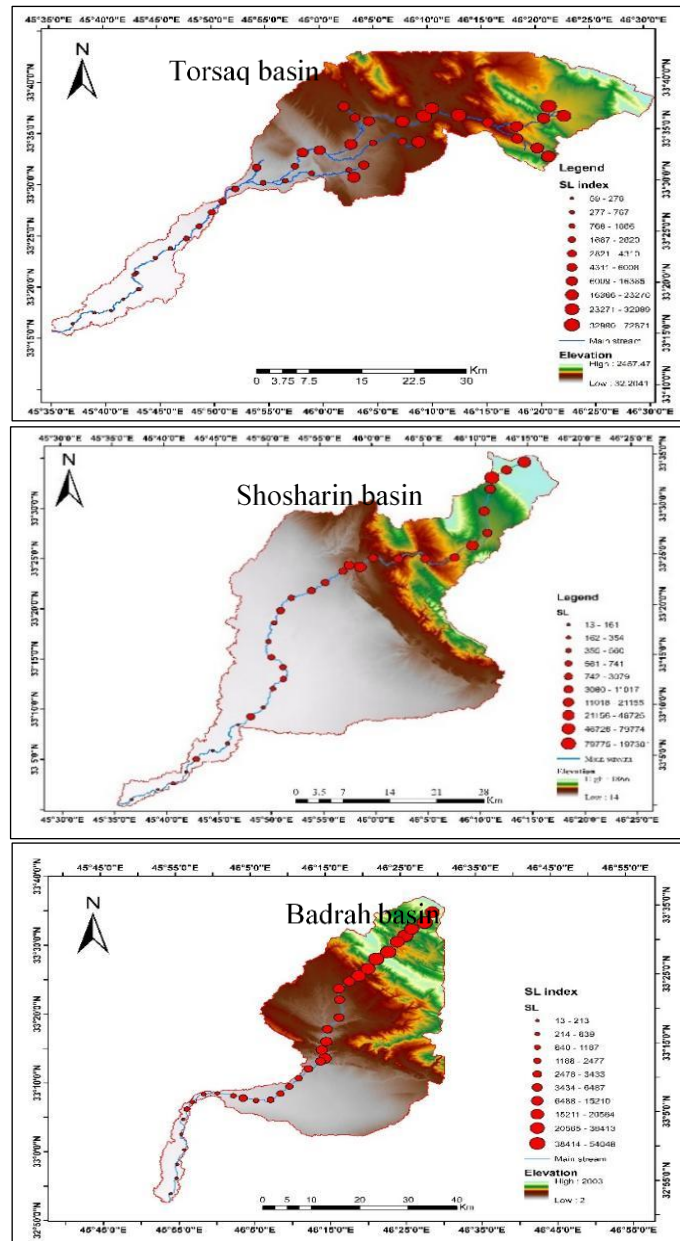


Fig. 8. The three basin maps' Stream Length Gradient Index (SL) findings

activity in the northeastern region of the basins. As one moves downstream, the activity diminishes (Table 6) and (Fig. 9A, B, C). The findings indicate that (SMF) exhibits low values (5.1) in the Torsaq basin. Conversely, Shosharin and Badrah document exhibits (0.8, 0.4) in succession as active tectonically (Table 7) and (Fig. 10).

Table 5A. The Torsaq stream length-gradient index (SL) calculation

Segments Number	$\Delta L(m)$	$\Delta H(m)$	L(m)	SL Index
1	4100	970	58120.5	13750.7
2	1905	900	67514.3	31896.9
3	1973	1755	81679.9	72670.7
4	7134	740	57918.5	6007.7
5	3363	720	59030.8	12640.0
6	1905	875	62721.9	28809.6
7	1905	1280	65778.1	44197.9
8	1905	1220	69910.6	44772.6
9	5844	1315	72721.1	16364.8
10	5844	1605	75913.0	20850.5
11	6179	1735	80017.5	22467.9
12	5233	1670	82742.4	26405.1
13	1905	520	48124.1	13136.4
14	1905	615	50240.5	16219.5
15	1905	640	54382.1	18270.3
16	14780	610	57021.2	2353.3
17	11315	805	60582.9	4310.0
18	2471	1305	62470.4	32988.6
19	7996	1720	74940.0	16120.2
20	5491	1665	76737.3	23269.6
21	4825	420	41536.4	3615.7
22	8501	525	45659.7	2819.8
23	17131	480	46727.7	1309.3
24	16206	490	51370.4	1553.2
25	6018	630	53659.1	5617.7
26	4407	1835	77543.1	32285.8
27	3183	245	36638.0	2820.4
28	11062	325	40276.2	1183.3
29	8501	330	42927.4	1666.4
30	1889	710	51245.4	19265.0
31	1905	140	31296.7	2300.0
32	1905	145	33750.4	2569.0
33	1905	85	25437.3	1135.0
34	1905	100	28228.4	1481.8
35	1905	60	19789.0	623.3
36	1905	65	22489.7	767.4
37	1905	50	15523.9	407.5
38	1905	55	15928.7	459.9
39	1905	45	11692.9	276.2
40	1905	55	14500.5	418.7
41	1905	35	3228.9	59.3
42	1905	40	6888.1	144.6
43	1905	45	9192.4	217.1
Average				12802.3

Table 5B. The Shosharin stream length-gradient index (SL) calculation.

Segments Number	$\Delta L(m)$	$\Delta H(m)$	L(m)	SL Index
1	532.425	1280	82068.7	197300.8
2	5811.924	1190	84590.6	17320.1
3	1825.979	1665	87486.4	79773.5
4	4618.021	795	80367.4	13835.4
5	4549.404	780	76835.6	13173.5
6	5337.622	790	74437.5	11017.2

7	5144.371	295	59278.8	3399.3
8	5610.039	535	61623.3	5876.7
9	6294.88	690	64440.3	7063.5
10	6410.1	655	67768.7	6924.8
11	2192.123	650	71215.3	21116.5
12	780.224	980	55951.4	70277.8
13	528.611	160	56780.1	17186.2
14	3635.752	270	51258.0	3806.5
15	5111.906	435	54518.2	4639.2
16	5999.323	95	46028.5	728.9
17	2509.075	130	48854.2	2531.2
18	4375.046	60	40825.1	559.9
19	1113.633	75	43197.7	2909.2
20	4660.388	55	37534.5	443.0
21	2466.883	50	35510.6	719.7
22	3222.431	55	35336.0	603.1
23	3459.072	50	31499.7	455.3
24	2511.394	55	33836.5	741.0
25	416.128	50	25628.5	3079.4
26	5115.727	50	28101.0	274.7
27	6502.562	45	23200.7	160.6
28	952.965	40	14413.0	605.0
29	5509.666	35	17321.8	110.0
30	1962.543	35	19877.4	354.5
31	5817.382	30	11888.1	61.3
32	5563.001	30	2323.0	12.5
33	5495.428	30	6645.7	36.3
34	729.124	25	9174.4	314.6
Average				14335.6

Table. 5C. The Badrah stream length-gradient index (SL) calculation

Segments Number	$\Delta L(m)$	$\Delta H(m)$	L(m)	SL Index
1	4639.9	1880	94805.2	38413.3
2	4231.0	1495	88697.5	31341.1
3	2806.2	1655	91644.9	54048.4
4	4048.2	1505	84191.7	31300.2
5	2534.7	1425	86395.4	48571.9
6	3147.2	1725	77964.1	42733.0
7	3363.4	1780	80864.3	42795.1
8	2251.9	1000	72156.8	32042.0
9	3491.3	1460	74842.0	31297.6
10	3231.1	660	67081.3	13702.4
11	3591.7	745	69848.9	14488.4
12	5371.6	490	64656.7	5898.1
13	5899.5	435	60617.9	4469.7
14	5246.3	600	56720.6	6486.9
15	2590.8	765	51511.9	15210.0
16	2807.2	725	53866.5	13912.0
17	5037.2	475	48961.4	4617.0
18	1243.5	510	50140.0	20563.6
19	3784.1	220	42603.9	2476.9

20	3337.8	250	45828.4	3432.5
21	2659.1	75	29733.2	838.6
22	4726.3	95	30776.0	618.6
23	3044.1	115	31405.9	1186.5
24	3168.8	170	37021.7	1986.1
25	3404.5	190	39666.5	2213.7
26	1414.8	60	25132.0	1065.8
27	3721.9	75	27190.3	547.9
28	1744.8	160	31749.9	2911.6
29	4822.4	165	32597.5	1115.3
30	3062.1	165	34465.8	1857.2
31	5245.6	50	22296.4	212.5
32	5495.1	45	18323.1	150.1
33	4839.5	40	14279.3	118.0
34	5143.5	35	10197.7	69.4
35	5245.3	30	6474.4	37.0
36	5021.7	30	2226.3	13.3
Average				13131.7

Table 6. The categories of (VF) within the study area

Basins	Segment	VFW (m)	2*(VFW) (m)	Eld (m)	Erd (m)	Esc (m)	VF (m) ratio	Class
Torsaq	A	55.46	110.9	1600	1700	1100	0.1	1
	B	40.4	80.8	1000	1100	500	0.07	1
	C	69.4	138.8	380	320	260	0.77	2
	D	21.3	42.6	46	49	43	4.73	3
Average							1.41	3
Shosharin	A	62.2	124.4	940	1020	870	0.56	2
	B	37.9	75.96	650	670	560	0.38	1
	C	75.6	151.36	250	320	210	1.0	2
	D	28	56	47	49	42	4.6	3
Average							1.6	3
Badrah	A	27.02	54.04	1110	1140	1090	0.7	2
	B	16.83	33.6	1400	1500	700	0.02	1
	C	33.42	66.8	500	470	420	0.5	1
	D	78.37	156.7	245	235	215	3.1	3
Average							1.08	3

The relative Tectonic Activity Index (IAT) employs five geomorphic index parameters to generate a relative tectonic activity index. The (IAT) is derived from the various type averages of each geomorphic index (S/n) parameter. The (S) value represents the total of tectonic active class values divided by the number of geomorphic index parameters (n). The (IAT) value is classified into four categories to determine the level of active tectonic relativity: Class 1: (1.0 - 1.5) very high; Class 2: (1.5 - 2) high; Class 3: (2 - 2.5) moderate; Class 4: (2.5 - 3) low (El Hamdouni et al., 2008). The (IAT) value indicates that the Shosharin and Badrah basins are classified as class (2), whereas Torsaq is classified as class (4) (Table 8).

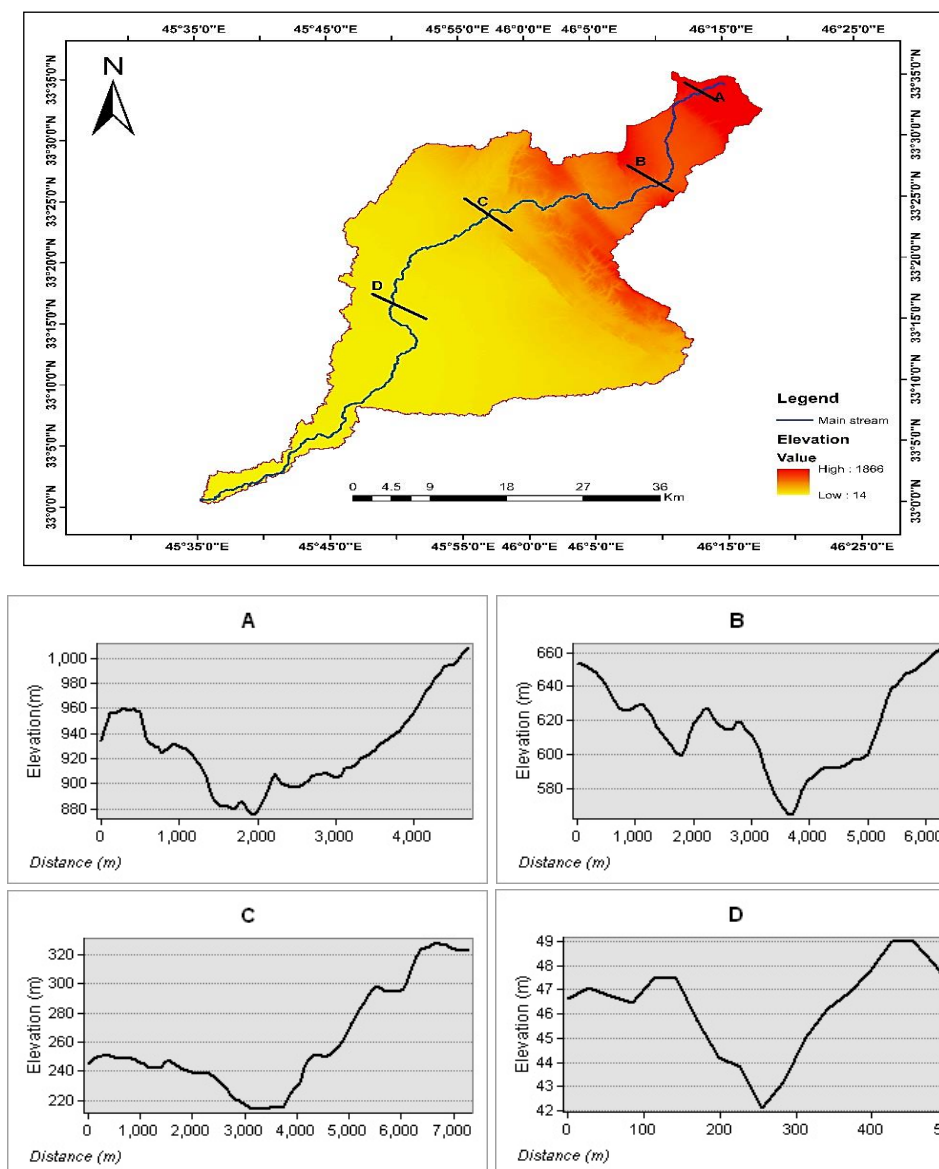


Fig. 9A. Cross-section locations for the computation of ('VF') of Torsaq. (VFW) Width of the valley floor, (Eld) Elevation of the left ridgeline, (Erd) Elevation of a right ridgeline, (Esc) Elevation of the valley floor

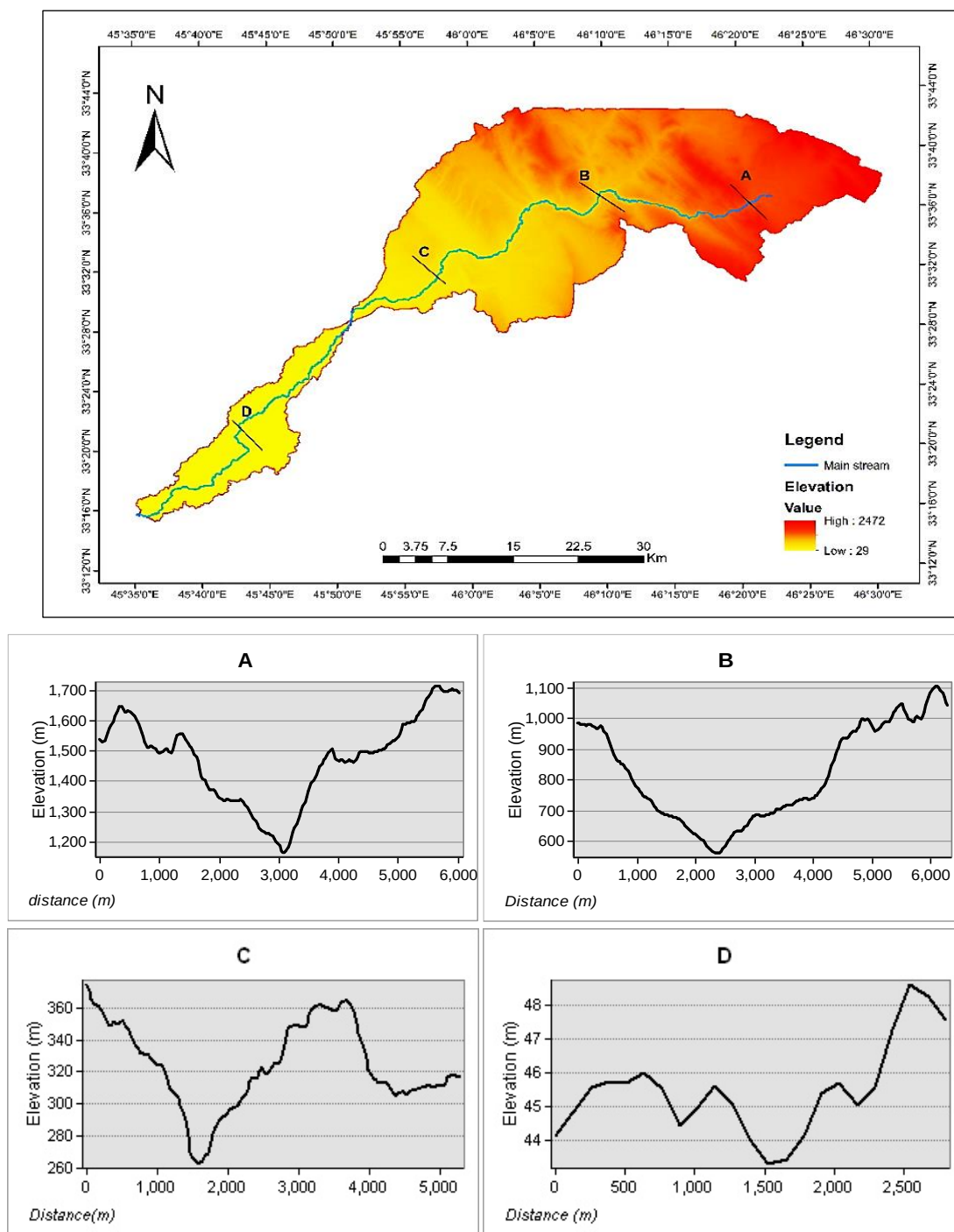


Fig. 9B. Cross-sections location of the computation of ('VF') of Shosharin

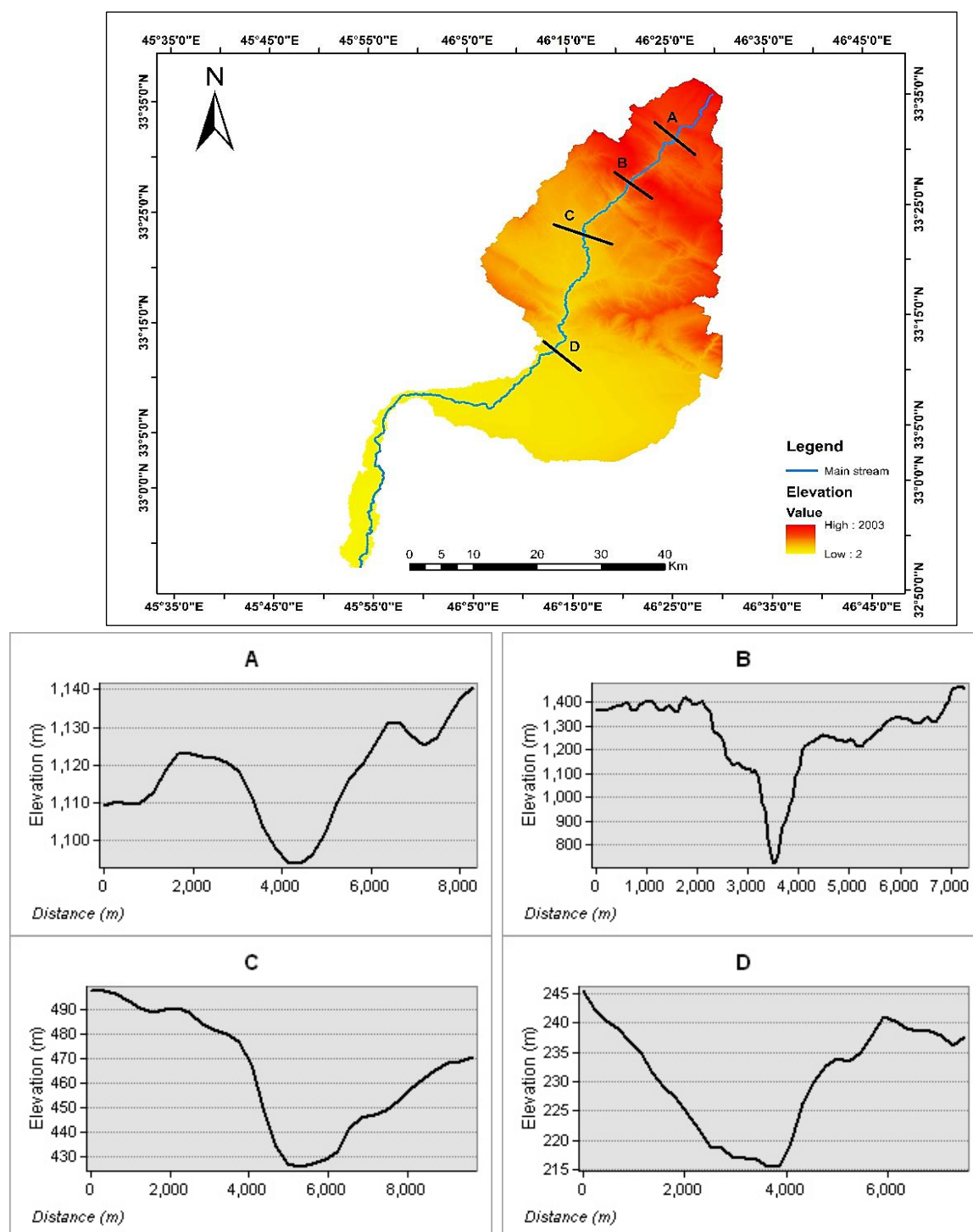


Table 7. (SMF-index) values of the study area.

Segment	LS (m)	LMF(m)	SMF = LMF/LS	Class
Torsaq	8.7	45.4	5.1	3
Shosharin	41.4	34.6	0.8	1
Badrah	53.1	25.2	0.4	1

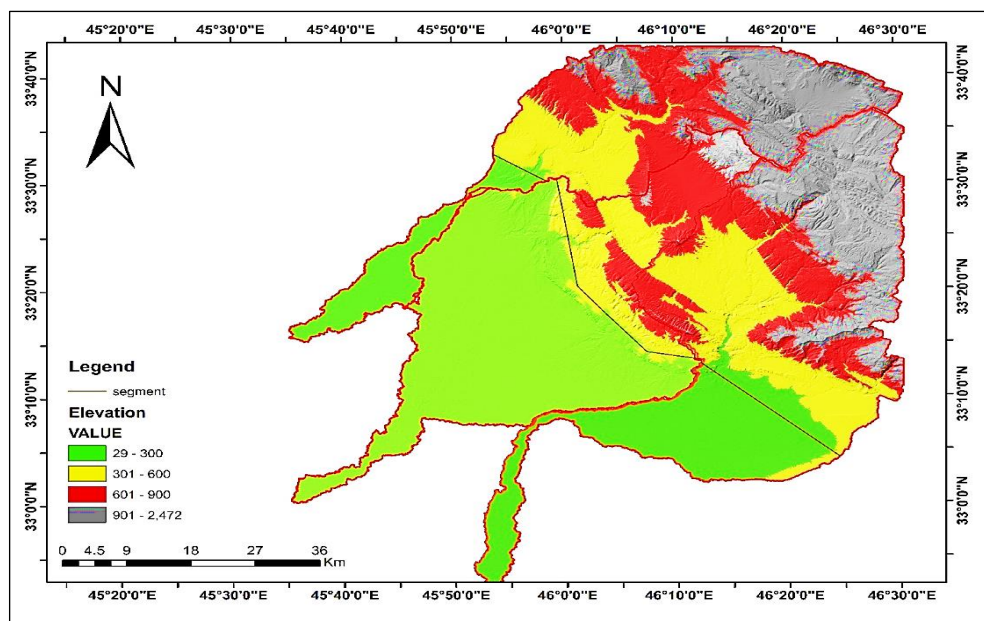


Fig.10.The basins (SMF) front indices within the study area

Table. 8. Index of Relative Tectonic Activity (IAT) for the study area

Basin Name	SL	AF	VF	T	SMF	LAT	S/N	Degree	Class LAT
Torsaq	1	3	3	3	3	13	2.6	Low	4
Shosharin	1	2	3	2	1	9	1.8	High	2
Badrah	1	1	3	2	1	8	1.6	High	2

5. Discussion

Drainage networks are the region most responsive to tectonic activity by changing geomorphological patterns (Struth et al., 2019). The findings of the (AF) indicate the asymmetry of the studied region basins owing to tectonic uplift processes resulting from the collision of the Arabian and Eurasian plates, which led to a change in the morphology and behavior of river channels and the effect of erosion processes in the uplift and sedimentation areas on the opposite side, as well as the high (AF) values over (50) indicate severe regression in the basin area, which means the main tributaries or drainage channels are convex and will have longer tributaries on either side of the main channel. This suggests that tributaries to the left of the basin grow faster than those to the right one, reflecting the asymmetry (Keller and Pinter, 2002). Resistant rock formations may maintain steep inclines, evidence of tectonic activity, but less durable rocks are more vulnerable to erosion, increasing the basins' asymmetry. The (T) values indicate the asymmetric nature of basins affected by neo-tectonics and regional tilt processes that cause one side of the basin to rise against the other, causing the main channel to move away from the basin axis. (T) and (AF) exhibit deviation in the basin due to the geological tilt caused by tectonic activity. These high values indicate that the terrain is inclined, and the axes of the basins have been altered due to folding and faulting. The (SL) results showed high values in the upper mainstream in the Zagros fold-thrust belt (Collision zone), characterized by several regional folds and faults. At the same time, they decreased lower towards the Mesopotamia subzone, which is considered away from the collision region and characterized by thick quaternary sediments; the high-value result

from uplift processes caused by tectonic activity at the collision zone, which resulted in dynamic alterations in the stream length gradient index (SL) throughout time through ongoing uplift, fault effects, and sediment transport dynamics. As for the decrease in values, it is the result of a change in elevations that decreased towards the Mesopotamian plain. (VF) value demonstrates significant variance in study basins, with lower levels at the top of the mainstream indicating an interaction between tectonic activity, rocks, and erosion. The low value reflects the high rate of uplift, the presence of deep and narrow V-shaped valleys, and the increased river activity associated with this uplift, which is associated with active tectonic uplift and possibly influenced by folding or faulting and resistant rocks such as sandstone. Moderate values imply a balance between tectonic deformation and erosion, indicating moderate activity and varying rock resistance. (VF's) higher value indicates a wide U-shaped valley due to low tectonic activity and erosion, which may be caused by mudstone or limestone and these values were shown in the Mesopotamian zone. This diversity shows the basins' complex geo-morphological evolution, where tectonic uplift is unequal. The (SMF) values of the Shosharin and Badrah basins show high tectonic activity, associated with large plains, narrow valleys, and steep hills, suggesting that tectonic activities are shape the study area's morphology. The Torsaq Basin's high (SMF) value suggests low tectonic activity and extensive erosion, resulting in mature landscapes with less steep and uneven mountain fronts. The high values indicate that erosion precedes tectonic uplift, transforming steep mountain slopes into U-shaped valleys or plateaus. In locations with low tectonic forcing, erosion has softened and altered mountain fronts' sharp morphology, increasing sinuosity. The (IAT) index integrates different geo-morphological indicators and parameters to assess how tectonic processes affect landscape features comprehensively. According to the (IAT) results, the Badrah and Shosharin basins were affected by continuous tectonic forces resulting from the collision process. This led to uplift processes, changing the landscape, and developing faults and folds affecting the study area. There are likely factors that have hidden the tectonic activity of the Torsaq Basin, such as the geology of rapid erosion of the highlands, (Montgomery and Brandon, 2002; Thiede, 2005). The age of the modern landforms in the region may not have developed prominent geo-morphological features yet, despite the region being tectonically active or these landforms being resistant to tectonic activity. So, tectonic activity is the main driving force behind the terrain formation. Its impact on the region is the formation of concave and convex folds, such as the Badrah and Hemmrin folds, and deep valleys due to tectonic uplift. As for erosion, climates play a complementary role in reshaping and refining the terrain, making them decisive factors in the later stages of terrain development.

6. Conclusions

Geo-morphological indices serve as valuable instruments for evaluating active tectonics in the Zurbatiyah region and their correlation with geology and geomorphology. According to the morphotectonic index maps of the studied region, high activity is detected in the Badrah and Shosharin in contrast to the Torsaq basins. This relates to the neo-tectonics processes in the study region and the tectonic compressive forces at the collision zone of the Arabian and Eurasian plates, which controlled the emergence of the subsurface and surface structures (anticline Badrah structure and the Hemmrin anticline) respectively and the normal, reverse and the thrusting faults types. These reasons led to a transformation in the path of the river channels. It also concludes that the basin's upper region near the collision zone within the Zagros Fold-Thrust Belt in the study area is distinguished by high tectonic activity, while their lower parts, situated far away within the Mesopotamian Zone, are distinguished by a lower tectonic activity due to the neo-tectonics processes. These findings demonstrate the complex relationship between tectonic processes, lithology, and surface dynamics. In active locations, resistant

lithologies support steep, rugged topography, while less resistant rocks eroded more, exacerbating geomorphic asymmetries. The results of the data also show that tectonic activity dominates landscape evolution, with climate influences and erosion processes changing and stabilizing the ground. This study provides a comprehensive understanding of the tectonic dynamics of the region and offers valuable insights for hazard assessment, resource management and land-use planning

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