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Modeling tectonic activity risks in the Sandi Plain using morphotectonic indicators

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Abstract

The study aimed to analyze the tectonic activity of the water basins in the study area, which is represented by the Sandi Plain basins located in Duhok Governorate, using some mathematical equations for morphotectonic indicators (T, Af, SL, Smf, Vf, RAT). This study relied on a Digital Elevation Model (DEM) and used the ARC GIS program to extract the water network of the region and identify the number of water basins, which amounted to 14. By applying measurements of morphotectonic indicator equations and extracting their values, it was revealed through the RAT indicator, which represents the final result of all geomorphological indicators, that the basins in the region fell into two categories. The first category exhibited low tectonic activity with values ranging from (1.5-2), including the basins of Wadi Al-Khabur and Wadi Dar Jalal. The second category displayed moderate tectonic activity with values ranging from (2-2.5), encompassing 12 basins such as Wadi Dasht Mir Al-Kabir, Wadi Dalik, Wadi Jam Kurk, Wadi Jam Sard, Wadi Rabenka, Wadi Dar Hozan, Wadi Saye Klaita, Wadi Bestadem, Wadi Jalal, Wadi Dahlik Kondil, Wadi Saffeen, and Wadi Kandil.

Keywords: Tectonic Activity, Morphotectonic Indicators, Tectonic Activity Risks.

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INTRODUCTION

In order to assess and quantify tectonic activity in the study area, several geomorphological indicators were utilized. These indicators provide insights into the role of structural deformities in shaping and evolving geomorphological units. Moreover, they aid in accelerating the dynamics of geomorphological processes such as erosion and sedimentation. Based on these indicators, the tectonic movements can be analyzed through the structural features of valleys or rivers, which reflect

the climatic changes and tectonic processes that have occurred in the region. In other words, they offer a clear picture of recent tectonic activity.

The research structure is as follows:

1-Research Problem: The research problem is defined by the following questions**:**

1- What are the methods and approaches used in identifying tectonic activity and detecting its geomorphological impact in the region?

2- Can geomorphological indicators be adopted to assess the effectiveness of tectonic activity in the area?

2-Research Hypothesis: It aims to answer the research problem, which is:

The application of geomorphological indicators is carried out using statistical equations, which are among the latest methods for determining tectonic activity and detecting its geomorphological impact in the region.

3-Research Objective: The study aims to conduct a spatial analysis of tectonic activity based on geomorphological indicators in the region's basins.

4-Research Boundaries: The research area is geographically located in the northern part of Iraq, approximately 120 kilometers north of the city of Mosul and is bordered to the south by the city of Zakho. It is defined within the latitude coordinates (37°-37.10°) and the longitude coordinates (42°-42.50°) approximately. The total area of the research region is approximately 383,356 square kilometers. (See Map 1).

1-Geomorphological Indicators of Tectonic Activity

The field of structural or tectonic geomorphology has witnessed significant advancement and innovation over the past three decades. This progress has been reflected in various ways, including the development of enhanced capabilities for conducting geomorphological surveys, the creation of computer software models for land surface forms, the determination of fault sizes and displacements along fractures, and the classification of recent tectonic activity, among other advancements. Based on these developments, the importance of tectonic geomorphology can be highlighted in the following ways:

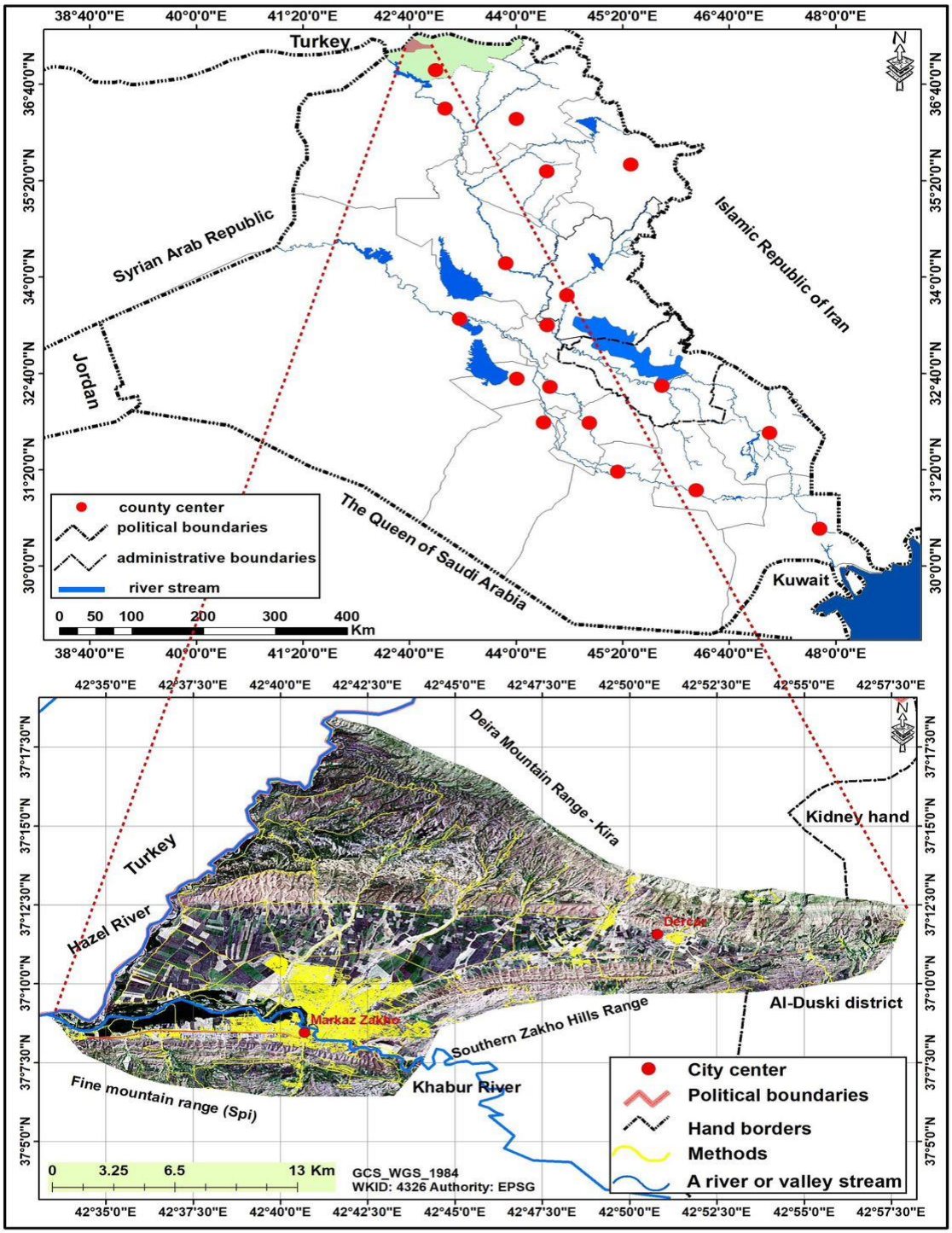
A. Studying landforms that are shaped by tectonic processes, with a focus on the forms and principles of surface features as a result of tectonic activities.

B. Applying geological concepts to elucidate tectonic deformations, such as analyzing landforms to assess the timing, magnitude, and rate of tectonic processes (Keller, 2002, p. 123).

Geomorphic indices are important tools for evaluating tectonic activity in any region. They provide a clear picture of the morphological evolution of a river basin, and based on these indices, tectonic movements can be analyzed through the structural features of the river or the valley, which reflects climate changes and tectonic processes (G. Sarap, p2). Geomorphic indices typically require quantitative data, which can be obtained from topographic maps, aerial imagery, and satellite imagery, specifically Digital Elevation Model (DEM) data. DEM data plays a crucial role in providing the spatial information necessary for calculating these indices, primarily due to the time efficiency in interpreting images compared to ground surveys. Therefore, the application of geomorphic indices is considered a contemporary method for analyzing landforms within river drainage networks and

valley heads, providing important indicators for recent tectonic activation (K.S. Jayappa, 2012, p217). Some of the most important indices that will be used include:

Map (1) displays the location of the study area in relation to Iraq. Source: of this information indicates that various data sources and tools were utilized in the study or research. These sources and tools include Quickbird2 satellite imagery, Landsat 8 satellite imagery, a Digital Elevation Model (DEM), field studies, and the outputs of ArcGIS software version 10.8.



1-1Asymmetry factor (AF)

One of the indicators used to assess the presence of a slope in the main course of a watershed is the measurement of the lateral slope of the basin concerning the main channel in the watershed. This lateral slope is a result of the influence of forces and tectonic processes, and it is mathematically expressed by the following equation (S. Bahrami,2013, p918):

AF=100(AR/AT)

AR = The area of the right bank of the main channel downstream of the reservoir (km^2).

AT = The total drainage area (km^2)

If the value of the (AF) indicator is greater or less than 50, it indicates the possibility of a strong or weak slope. In other words, if the indicator value is higher than 50, it suggests that the tributaries or channels of the main stream will be subject to tectonic rotation or bending, which will have an impact on the lengths of tributaries on both sides of the main channel of the watershed. Consequently, it can be assumed that this indicator's activity will result in a leftward bend of the watershed, meaning that tributaries to the left of the main channel will be shorter compared to tributaries on the right side of the main channel, reflecting an asymmetry factor (S. Bahrami, 2013, p918). In 2002, Keller classified this indicator into three categories through which results can be presented to identify regions with higher or lower tectonic activity, as shown in Table 1.

Table (1) Geomorphological index categories (AF)

Ranges	Class	Degree	S
Greater than 65	1	High	**1**
57-65	2	Moderate	**2**
Less than57	3	Low	**3**

Reference: keller. E. A. and Pinter, N, Active tectonics: Earthquakes uplift and landscape, Second edition,New Jersey, Prentie Hall, 2002, p125.

Through applying the measurements of the (AF) equation to the region's 14 basins, it became evident that there is only one category of basins based on their tectonic activity, which is the Low tectonic activity basins (Low), representing values less than 57, and it includes all the basins in the region. The reason for this type of classification appearing above others is the lack of symmetry in the aquatic basins in the area. Table .(2)

Table (2) Geomorphological Asymmetry Index (AF) for Basins in the Study Area

Degree	The final result	Constant (100)	AR	AT	The names of the basins	S
Low	**53.787**	**100**	**12**	**22.310**	**Wadi Dasht-e Mir Kabir Basin**	**1**
Low	**37.812**	**100**	**5.367**	**14.194**	**Wadi Dailakh Basin**	**2**
Low	**7.203**	**100**	**0.282**	**3.915**	**Wadi Jam Kork Basin**	**3**
Low	**44.326**	**100**	**2.264**	**5.108**	**Wadi Jam Sard Basin**	**4**
Low	**46.964**	**100**	**21.214**	**45.171**	**Al-Khabour Valley Basin**	**5**
Low	**4.856**	**100**	**0.076**	**1.565**	**Wadi Rabenka Basin**	**6**
Low	**21.106**	**100**	**15.823**	**74.970**	**Wadi Dar Hozan Basin**	**7**
Low	**8.093**	**100**	**1.314**	**16.236**	**Wadi Dar Jalal Basin**	**8**
Low	**23.916**	**100**	**0.762**	**3.186**	**Wadi Say Kilta Basin**	**9**
Low	**9.826**	**100**	**2.119**	**21.566**	**Wadi Bestadim Basin**	**10**
Low	**5.376**	**100**	**2.717**	**50.544**	**Wadi Jalal Basin**	**11**
Low	**33.389**	**100**	**11.105**	**33.260**	**Wadi Dihlak Kondil Basin**	**12**

Low	**25.990**	**100**	**6.121**	**23.551**	**Wadi Safthin Basin**	**13**
Low	**5.209**	**100**	**0.747**	**14.341**	**Wadi Kandlis Basin**	**14**

Source: Based on Digital Elevation Model using ArcGIS 10.8 software.

1-2Topographic Symmetry Factor (T)

The index (T) is one of the indicators that assess the degree of deviation of a river's course within its basin. It shows how much the main channel has shifted away from the basin's axis, reflecting tectonic activity or the presence of faults beneath the surface that have influenced the channel's displacement. The values of the geomorphological asymmetry index range from 0 to 1, representing a basin that is perfectly symmetrical at 0 or relatively sinuous. The closer the index value is to 0, the closer it is to symmetry, while the closer it is to 1, the closer it is to asymmetry. The channel's displacement from the basin's axis is mathematically expressed by the following equation. (Burbank,2001, p56).

T=Da /Dd

T= is the Geomorphological Asymmetry Index

Da =is the distance from the centerline of the basin to the centerline of the main channel exposed to the basin.

Dd =is the distance from the centerline of the basin to the outer boundary of the basin at the center.

Burban (2001) classified this index into three categories based on tectonic activity, as shown in Table.(3)

Table (3) showing the classifications of the Geomorphological Index (T)

Ranges	Class	Degree	S
Greater than0.6	1	High	**1**
0.3 – 0.6	2	Moderate	**2**
Less than0.3	3	Low	**3**

Reference: Burbank. D. W. and Anderson. R. S., Tectonic Geomophology‘ Malden,Massachusetts, Black well Science, 2001,p56 .

By applying the (T) indicator to the basins of the region, it became clear that there are three categories based on their tectonic activity, as shown in table (4) and map (2), and these categories are as follows:

1- High Tectonic Activity Basins (High): This category represents values exceeding 0.6. If this category is assigned, it indicates a high displacement of the river channel. It includes six basins: Mir Al-Kabeer Basin, Jum Sard Basin, Al-Khabour Basin, Rabenka Basin, Sai Kilita Basin, and Safthin Basin. The reason for the river's main channel displacement from the basin's axis is attributed to the influence of folding in the lower layer of the basin, due to the intersection of subsurface faults that affect the surface, resulting in high tectonic activity. This category covers an area estimated at 100.891 km² of the total area of the region, Table.(5)

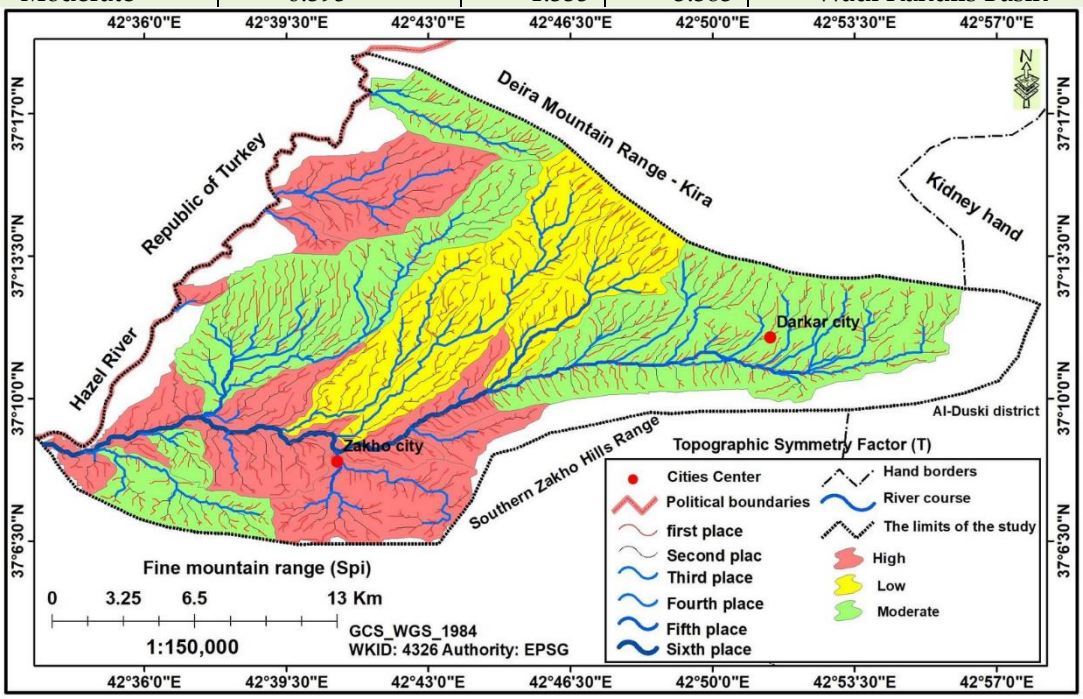
2- Moderate Tectonic Activity Basins (Moderate): This category represents values ranging from 0.6 to 0.3. It includes five basins: Daliakh Basin, Jum Kork Basin, Dar Hozan Basin, Jalal Basin, and Kendlis Basin. These basins exhibit moderate tectonic activity and indicate relatively moderate topographic symmetry due to the mild impact of changes in river valleys resulting from subsurface geological structure movements, such as folds and ancient faults. This category covers an area estimated at 157.963 km².

3-Low Tectonic Activity Basins (Low): This category represents values less than 0.3. It includes three basins: Dar Jalal Basin, Bestadim Basin, and Dihlak Kondil Basin. These basins signify topographic symmetry due to low tectonic activity or the absence of significant tectonic influence on

river channels, or their exposure to minimal impact. This lack of subsurface faults has led to minimal deviations in the river channels from their assumed directions. This category covers an area estimated at 71.062 km².

Table (4) related to the Topographic Symmetry Index (T) for the study area

Degree	The final result	Dd	Da	The names of the basins	S
High	1.374	3.667	2.669	Wadi Dasht-e Mir Kabir Basin	**1**
Moderate	0.452	1.754	3.881	Wadi Dailakh Basin	**2**
Moderate	0.434	0.922	2.122	Wadi Jam Kork Basin	**3**
High	0.613	1.317	2.15	Wadi Jam Sard Basin	**4**
High	0.693	3.203	4.624	Al-Khabour Valley Basin	**5**
High	0.697	0.692	0.993	Wadi Rabenka Basin	**6**
Moderate	0.438	3.549	8.1	Wadi Dar Hozan Basin	**7**
Low	0.289	1.343	4.64	Wadi Dar Jalal Basin	**8**
High	0.876	1.254	1.432	Wadi Say Kilta Basin	**9**
Low	0.283	1.229	4.35	Wadi Bestadim Basin	**10**
Moderate	0.566	3.534	6.244	Wadi Jalal Basin	**11**
Low	0.293	1.304	4.455	Wadi Dihlak Kondil Basin	**12**
High	0.683	2.266	3.316	Wadi Safthin Basin	**13**
Moderate	0.395	1.335	3.383	Wadi Kandlis Basin	**14**



Source: Based on Digital Elevation Model using ArcGIS 10.8 software.

Map (2) related to the Topographic Symmetry Index (T) for the study area . Source: Based on data from Table (4) and the outputs of ArcGIS 10.8 software.

Table (5) Area of the Topographic Similarity Index (T)

Area Km2	Topographic Similarity Index	S
100.891	High	1
157.963	Moderate	2
71.062	Low	3
329.917	The Sun	4

Source: Based on Digital Elevation Model using ArcGIS 10.8 software.

1-3 Floor width to valley height ratio valley (V)

The (V) index reflects the extent to which the shapes of valleys, either in the form of a "V" or "U," are influenced by variations in the effectiveness of tectonic processes. It indicates the intensity of exogenic processes such as weathering and erosion. This is determined by comparing valleys with a "V" shape, formed during their youth due to steep slopes and in response to increased tectonic activity in the subsurface bedrock layer, as highlighted by the valley's morphology. On the other hand, valleys with a "U" shape result from reduced slopes and increased lateral erosion in valleys sloping down from hills, indicating a decrease in tectonic activity and dominance of fluvial processes (weathering, transportation, and erosion). The (VF) index is mathematically expressed as follows (Al-Jubouri, 2019, p. 24-25).

V_F = 2VFW / [(Eld - Esc) + (Erd – Esc)

VFW = Valley Floor Width - Eld = Left-side Elevation of the Valley

Erd = Right-side Elevation of the Valley- Esc = Elevation of the Valley Floor

The (VF) index values indicate the effectiveness of tectonic activity. If the index value is less than 0.5, it suggests high tectonic activity, reflecting a valley shape closer to "V." Conversely, if the index value exceeds 1, it indicates weak tectonics and a valley shape closer to "U." For precise results, cross-sectional profiles of all major basins were extracted at their exits from highland areas. Elements of this equation were applied to all the basins. It's worth noting that the results of this index reflect drainage energy and the resistance of bedrock to weathering processes. Higher (VF) values indicate weaker tectonics as we approach the end of the valleys (the outlet), while lower values indicate higher tectonic activity as we move towards the source. Classification of tectonic activation ratios was carried out based on the criteria of Vertis and Kokalas in 2004, which classified them into three categories as shown in Table.(6)

Table (6) for the geomorphological index (VF)

Ranges	Class	Degree	S
Less than0.5	1	High	**1**
1 – 0.5	2	Moderate	**2**
Greater than1	3	Low	**3**

Reference: Verrios, Z. and kokalas, morphotectonic Analysis in the Eliki fault Zone (Gulf of Corinth, Greece), Bulletin of The Geological Society of Greece international Congress, 2004, p1708.

Through the application of geomorphological index (V) to the basins in the region, it became apparent that there are three categories based on their tectonic activity, as shown in Table (7) and Map (3). These categories are as follows:

1 .High Tectonic Activity Basins (High): Represented by values less than 0.5, this category includes 4 basins: Dasth-e Mir, Jom Korok, Jom Sard, and Rabanka. This category covers an area of approximately 32,898 square kilometers of the total area of the region, as indicated in Table.(8)

2 .Moderate Tectonic Activity Basins (Moderate): Represented by values ranging from 0.5 to 1, this category comprises 3 basins: Dazhlik, Say Kelita, and Kandlis. These basins occupy an area of approximately 31,721 square kilometers of the total region.

3 .Low Tectonic Activity Basins (Low): Represented by values exceeding 1, this category includes 7 basins: Khabor, Dar Hozan, Dar Jalal, Duhlek Kondal, Jalal, Bestadim, and Safthin. This category covers an area of approximately 265,298 square kilometers of the total region.

Table (7) represents the index of the width of the valley to the valley height (Vf) for the basins in the study area

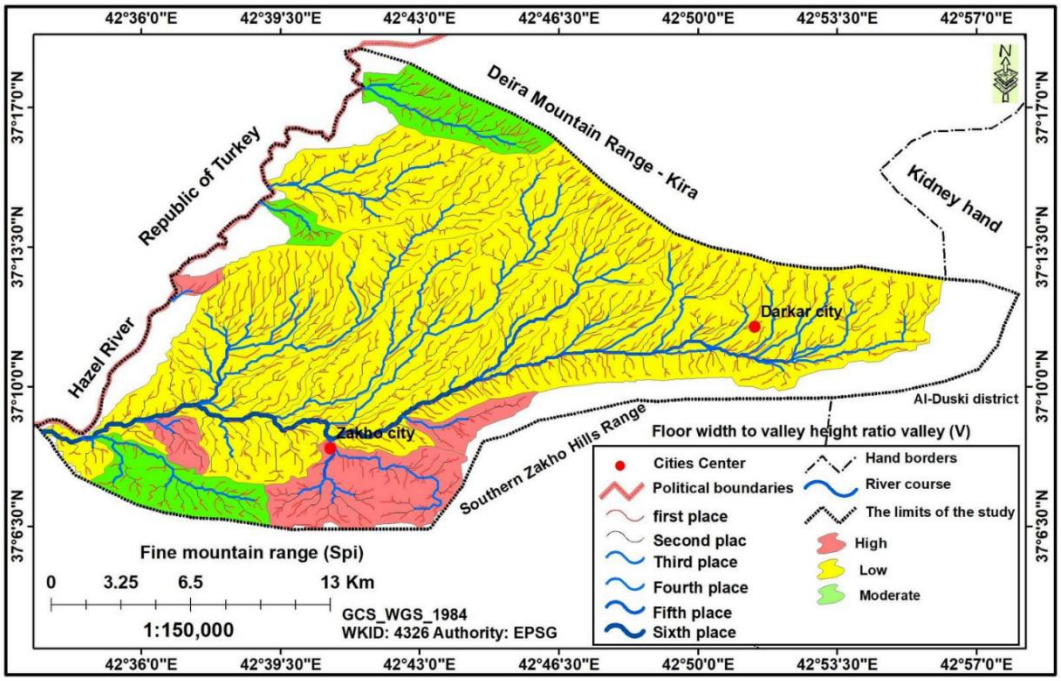
Degree	The final result	ESC	(ELD-ESC)+(ERD-ESC)	(ELD-ESC)	(ERD-ESC)	ERD	EID	2VFW	Constant	VFW	The names of the basins	S
High	0.219	620	70	40	30	650	660	15.346	2	7.673	Wadi Dasht-e Mir Kabir Basin	1
Moderate	0.753	392	7	3	4	396	395	5.268	2	2.634	Wadi Dailakh Basin	2
High	0.274	400	12	7	5	405	407	3.29	2	1.645	Wadi Jam Kork Basin	3
High	0.480	459	8	5	3	462	464	3.838	2	1.919	Wadi Jam Sard Basin	4
Low	2.035	388	6	4	2	390	392	12.208	2	6.104	Al-Khabour Valley Basin	5
High	0.114	445	15	5	10	455	450	1.708	2	0.854	Wadi Rabenka Basin	6
Low	1.761	495	9	2	7	502	497	15.846	2	7.923	Wadi Dar Hozan Basin	7
Low	1.080	416	4	1	3	419	417	4.32	2	2.16	Wadi Dar Jalal Basin	8
Moderate	0.821	454	4	3	1	455	457	3.282	2	1.641	Wadi Say Kilta Basin	9
Low	1.445	492	5	4	1	493	496	7.226	2	3.613	Wadi Bestadim Basin	10
Low	3.594	408	3	2	1	409	410	10.782	2	5.391	Wadi Jalal Basin	11
Low	1.512	433	4	3	1	434	436	6.046	2	3.023	Wadi Dihlak Kondil Basin	12
Low	1.857	459	4	3	1	460	462	7.426	2	3.713	Wadi Safthin Basin	13
Moderate	0.855	505	6	1	5	510	506	5.13	2	2.565	Wadi Kandlis Basin	14

Source: Based on Digital Elevation Model using ArcGIS 10.8 software.

)Smf (1-4Valley Basin Fore Zigzag Indicator

The (Smf) index is one of the geomorphological indicators widely used to assess seismic activity in the region. It reflects the balance between uplift processes on one hand and denudation processes resulting from erosion on the other hand. These processes can lead to anomalies in the topography of the landscape. With tectonic activation over time, a sinuous topographic state

develops. Therefore, the (Smf) index is an expression of the equilibrium between erosion processes and tectonic forces shaping the valley's landscape. The (Smf) index is mathematically represented by the following equation (Bull, 1977, p. 116).



Map (3) showing the relationship of river width (Vf) to valley elevation for basins in the study area .Source: Based on data from Table (7) and the outputs of ArcGIS 10.8 software.

Table (8) Area of the river width to valley elevation index (Vf)

Area Km2	The translation Valley width-to-height ratio	S
32.898	High	1
31.721	Moderate	2
265.298	Low	3
329.917	The Sun	4

Source: Based on Digital Elevation Model using ArcGIS 10.8 software.

Smf = Lmf / Ls

Lmf = Length of the sinuous reach of the valley.

Ls = Length of the straight line of the valley's interface .

In 1977, Bull and Madden classified this index into three categories based on tectonic activity. If the values of the (Smf) index range between (3-5), they indicate active tectonic processes (erosion, ruggedness, and sinuosity of the valley's front). If the values range between (1.6-3), it suggests moderate tectonic activity, while values between (1-1.6) indicate relatively low tectonic processes.

Table (9) displays the categories of the geomorphological index (Smf)

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

Reference: Bull. W. B. and Mcfadden. L. D, Tectonic geomorphology north and south of the Garlock fault, California, Ed. D. O. Doehring, 1977, p116.

Through the application of geomorphological index (Smf) measurements in the study area, it became evident that there are two categories based on their tectonic activity, as shown in Table (10) and Map (4). These categories are:

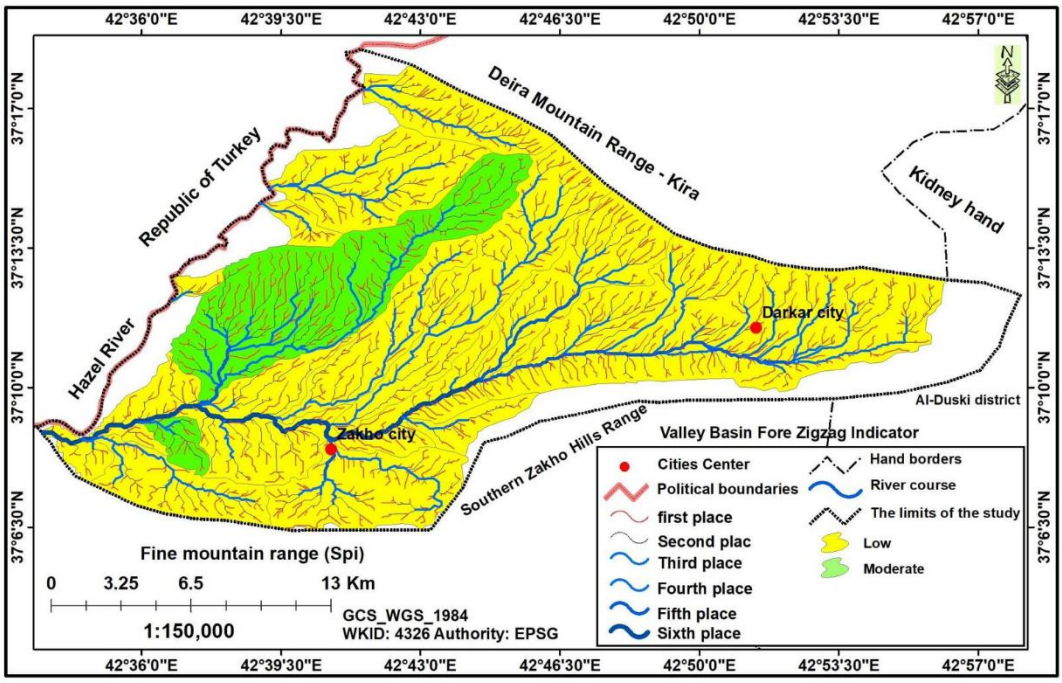
1- Basins with Moderate Tectonic Activity: Represented by values ranging from (1.6-3), including two basins - Wadi Jam Cork and Wadi Jalal. This category covers an area estimated at 54.458 square kilometers, as shown in Table.(11)

2-Basins with Low Tectonic Activity: Represented by values ranging from (1-1.6) and encompassing 12 basins: Wadi Dasht Mir al-Kabir, Wadi Dalikh, Wadi Jam Sard, Wadi al-Khabour, Wadi Rabenka, Wadi Dar Hozan, Wadi Dar Jalal, Wadi Say Klita, Wadi Bistadim, Wadi Dihlak Kondal, Wadi Safthin, and Wadi Kandili. This category occupies an area estimated at 275.458 square kilometers of the total study area.

Table (10) of the Smf Front Slope Indices for Basins in the Study Area

Degree	The final result	Ls	Lmf	The names of the basins	S
Low	1.168	9.423	11.009	Wadi Dasht-e Mir Kabir Basin	1
Low	1.007	6.967	7.013	Wadi Dailakh Basin	2
Moderate	1.791	1.719	3.079	Wadi Jam Kork Basin	3
Low	1.062	4.081	4.332	Wadi Jam Sard Basin	4
Low	1.470	4.279	6.289	Al-Khabour Valley Basin	5
Low	1.146	2.347	2.69	Wadi Rabenka Basin	6
Low	1.118	17.201	19.232	Wadi Dar Hozan Basin	7
Low	1.323	2.799	3.703	Wadi Dar Jalal Basin	8
Low	1.218	2.097	2.555	Wadi Say Kilta Basin	9
Low	1.019	3.001	3.058	Wadi Bestadim Basin	10
Moderate	1.736	5.575	9.676	Wadi Jalal Basin	11
Low	1.015	3.031	3.075	Wadi Dihlak Kondil Basin	12
Low	1.102	6.667	7.347	Wadi Safthin Basin	13
Low	1.092	2.45	2.676	Wadi Kandlis Basin	14

Source: Based on Digital Elevation Model using ArcGIS 10.8 software.



Map (4) of the Smf Front Slope Indices for Basins in the Study Area.Source: Based on data from Table (10) and the outputs of ArcGIS 10.8 software

Table (11) Area of the Smf Front Slope Index

Km2	Indicator	ت
54.458	Moderate	1
275.458	Low	2
329.917	المجموع	3

Source: Based on Digital Elevation Model using ArcGIS 10.8 software.

1-5Basin Shaps index (Bs)

The relatively newer drainage basins in active tectonic regions tend to become more elongated compared to their natural shape on the topographic slope of the mountain. The elongated shape tends to develop further into a more rectangular form. This is one of the morphometric indices used to indicate the impact of tectonic movements on the shape of drainage basins and how close they are to a rectangular shape. It is expressed by the following equation (Al-Tai, 2022, p. 95):

Bs = BL / BW

Bs = The shape of a drainage basin. -BL = The length of the basin.

BW= The width of the basin.

This indicator is used to indicate the morphological variations of the study area basins. High values of this indicator (Bs) represent high tectonic activity, meaning the closer the shape is to a rectangle. Conversely, a low value of the indicator (Bs) indicates the absence of tectonic activity, meaning the basin shape is closer to a circle. The global classification was relied upon to classify the region's basins according to their tectonic activity, as shown in Table.(12)

Table (12) Categories of the Geomorphological Index (Bs)

Ranges	Class	Degree	S
Greater than**4**	**1**	**High**	**1**
4 –2	**2**	**Moderate**	**2**
Less than**2**	**3**	**Low**	**3**

Source: Ali Talib Hamza Al-Taie, "Hydrogeomorphological Hazards in Eastern Iraq between the Diyala and Karkh Rivers Using Modern Geographic Technologies," Unpublished Doctoral Thesis, College of Arts, University of Basra, 2022, p. 95.

According to the measurements and the geomorphological index (BS) applied to the basins in the region, it was found that there are three categories based on their tectonic activity, as shown in Table (13) and Map (5). These categories are:

1 .High Tectonic Activity Basins (High): Represented by values exceeding 4. This category includes two basins, namely the Dar Jallal Basin and the Dahlik Kondl Basin. These basins are characterized by their elongated shape, indicating their high tectonic activity. This category covers an area of approximately 49,496 square kilometers, as shown in Table.(14)

2 .Moderate Tectonic Activity Basins (Moderate): Represented by values ranging from 2 to 4. This category includes 11 basins, namely the Daliakh Basin, Jum Kork Basin, Jum Sard Basin, Khabor Basin, Rabenka Basin, Dar Hozan Basin, Say Klita Basin, Bestadem Basin, Jallal Basin, Safthin Basin, and Kandlis Basin. These basins cover an area of approximately 258,110 square kilometers.

3 .Low Tectonic Activity Basins (Low): Represented by values below 2. This category includes one basin, which is the Dasht Mir Al-Kabir Basin. This basin is characterized by its shape approaching a rectangle, indicating low tectonic activity. This category covers an area of approximately 22,310 square kilometers.

Table (13) Basin Shape Index (Bs) for the study area basins

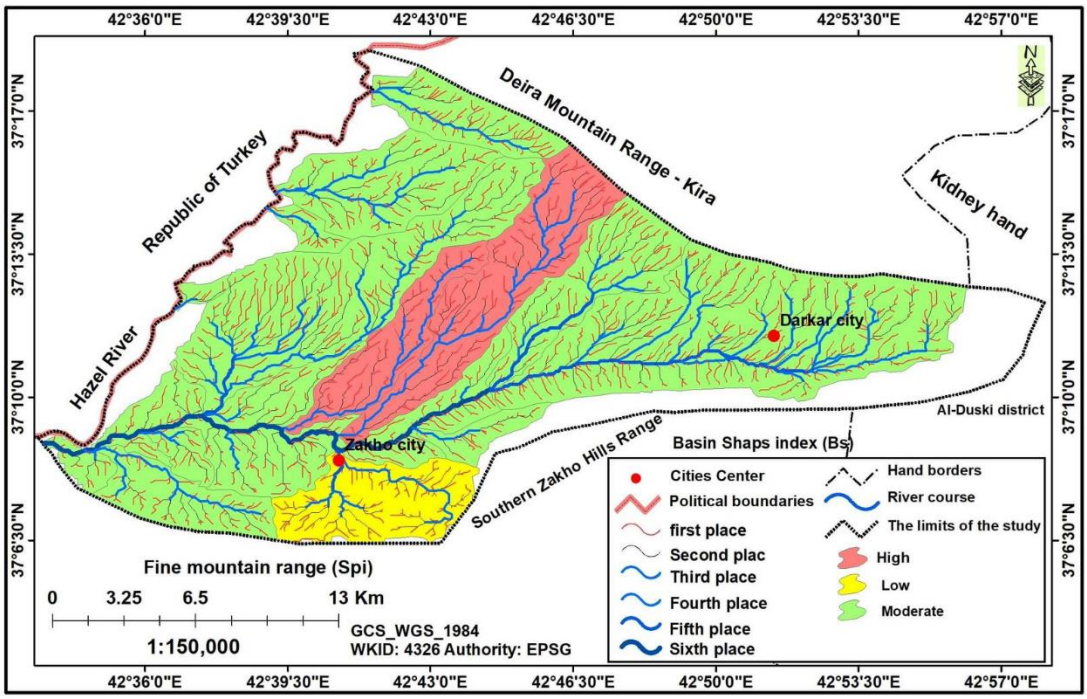
Degree	The final result	BW	BL	The names of the basins	S
Low	0.693	7.673	5.319	Wadi Dasht-e Mir Kabir Basin	**1**
Moderate	2.869	2.634	7.556	Wadi Dailakh Basin	**2**
Moderate	2.157	1.645	3.549	Wadi Jam Kork Basin	**3**
Moderate	2.792	1.919	5.358	Wadi Jam Sard Basin	**4**
Moderate	3.133	6.104	19.12	Al-Khabour Valley Basin	**5**
Moderate	2.998	0.854	2.56	Wadi Rabenka Basin	**6**
Moderate	2.250	7.923	17.82	Wadi Dar Hozan Basin	**7**
High	5.279	2.16	11.4	Wadi Dar Jalal Basin	**8**
Moderate	2.074	1.641	3.404	Wadi Say Kilta Basin	**9**
Moderate	2.723	3.613	9.837	Wadi Bestadim Basin	**10**
Moderate	3.115	5.391	16.79	Wadi Jalal Basin	**11**
High	5.073	3.023	15.34	Wadi Dihlak Kondil Basin	**12**
Moderate	2.293	3.713	8.515	Wadi Safthin Basin	**13**
Moderate	3.044	2.565	7.808	Wadi Kandlis Basin	**14**

Source: Based on Digital Elevation Model using ArcGIS 10.8 software.

Table (14) Area of Basin Shape Index (Bs) for the basins

Area Km2	Basin Shape Index	S
49.496	High	1
258.110	Moderate	2
22.310	Low	3
329.917	The Sun	4

Source: Based on Digital Elevation Model using ArcGIS 10.8 software



Map (5) Basin Shape Index (Bs) for the study area basins.Source: Based on data from Table (13) and the outputs of ArcGIS 10.8 software.

1-6 Stream longh - Gradient Index (SL)

The index (SL) represents the calculation of the channel length and is used to determine the resistance of rocks to water erosion processes, and its relationship with tectonic activities. This index is influenced by the channel's slope and curvature, making it a valuable assessment tool (Luay, 2016, p. 22).

The (SL) index is strongly linked to the overall stream power, as the total stream power indicates the length of the drainage channel, which is associated with the stream's ability to erode and transport sediments. Therefore, the total stream power is considered a significant hydrological variable and estimates the steepness of the slope and water discharge. (SL) index values are applied to characterize tectonic activity by classifying index values. High values of the index indicate high tectonic activity, highlighting the presence of hard rocks in the riverbed, while low index values distinguish low tectonic activity, reflecting the presence of easily weathered rock types (Al-Kraei, 2013, p. 53).

Moreover, when (SL) index values are close to each other, they represent a relatively uniform water discharge. Deviations in index values, whether high or low, indicate changes in discharge quantity, reflecting the influence and control of geological or tectonic factors on the slope within the river valley. High index values also suggest that sediment deposition in the river channel is far from the mountain front, specifically at the end of the valley. The main channel's shape at the base of the slope is typically straight, and gravel bars form away from the slope. This serves as an indicator of active tectonics. Conversely, if tectonic activity decreases, sediment deposition in the river channel moves back towards the source or the slope, and gravel fans form at the bottom of the mountain front or slope. The (SL) index can be expressed mathematically by the following equation (Kleython, 2010, p. 536):

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

(ΔH) =represents the difference between the highest and lowest points in the specified estuary area.

(ΔL) = is the length of the straight line within the specified estuary area.

The (L) is the total length of the valley channel to the midpoint of the estuary. The (1973 Hack.j.T.) classified this index into three categories based on tectonic activity.

Based on the application of measurements of the (SL) index to the basins in the region, it has been revealed that there are three categories based on their tectonic activity, as described in Table (16) and illustrated on Map (6). These categories are as follows:

1-High Tectonic Activity Basins (High): Represented by values exceeding 500. This category includes six basins: Dar Hozan Basin, Bestadim Basin, Jalal Basin, Dahlik Kundal Basin, Safthin Basin, and Kundli Basin. These basins are characterized by the formation of alluvial fans relatively distant from the mountain front, indicating their high tectonic activity. This category covers an area estimated at 218,231 square kilometers out of the total area of the region, as shown in Table.(17)

Table (15) Categories of Channel Length and Slope Index (SL)

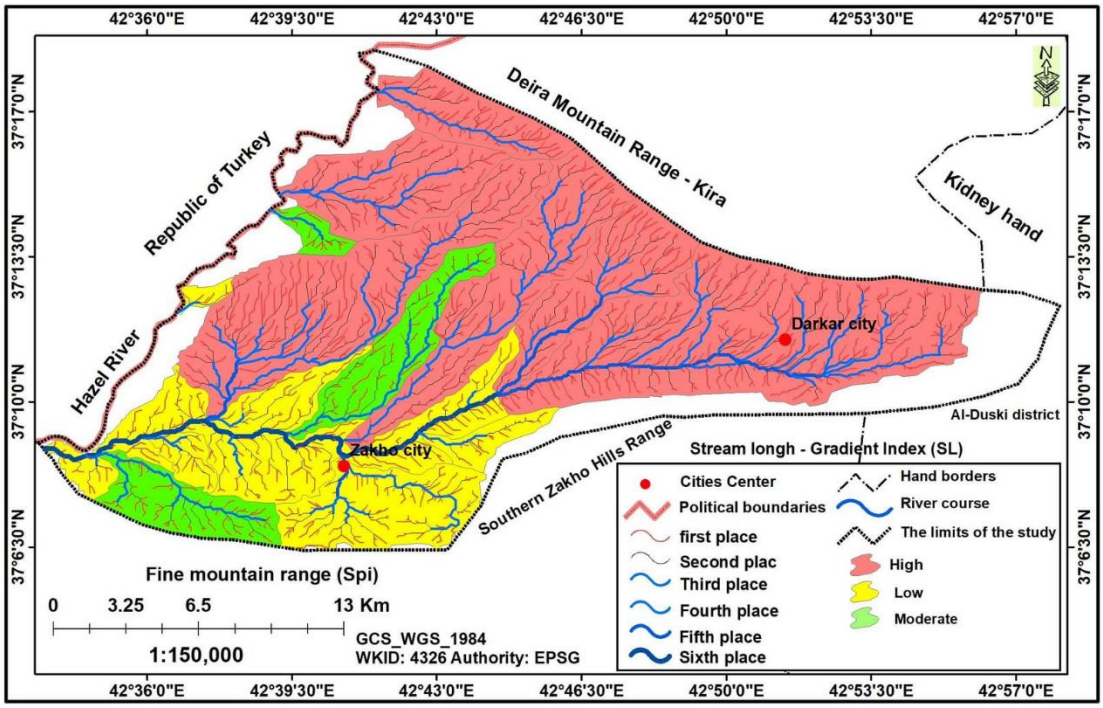
Ranges	Class	Degree	S
Greater than500	1	High	1
500 – 300	2	Moderate	2
Less than300	3	Low	3

Reference:Hack, J. T. Stream - profile analysis and stream-gradient index, Journal Research of united States Geological Survery, 1973, p421-429.

Table (16) shows the Channel Length and Slope Index (SL) for the basins in the study area

Degree	The final result	L	ΔL	ΔH	Lowest point	Highest point	The names of the basins	S
Low	125.610	2.039	1.883	116	428	544	Wadi Dasht-e Mir Kabir Basin	1
Moderate	324.682	4.034	3.454	278	395	673	Wadi Dailakh Basin	2
Low	198.629	1.222	1.132	184	400	584	Wadi Jam Kork Basin	3
Low	234.637	2.771	2.421	205	458	663	Wadi Jam Sard Basin	4
Low	214.990	21.22	16.28	165	389	554	Al-Khabour Valley Basin	5
Low	240.902	0.893	0.86	232	427	659	Wadi Rabenka Basin	6
High	896.418	13.54	11.66	772	494	1266	Wadi Dar Hozan Basin	7
Moderate	396.043	6.383	5.238	325	418	743	Wadi Dar Jalal Basin	8
Moderate	389.440	2.486	2.247	352	459	811	Wadi Say Kilta Basin	9
High	732.310	6.566	5.828	650	494	1144	Wadi Bestadim Basin	10
High	518.878	3.335	2.963	461	408	869	Wadi Jalal Basin	11
High	892.606	13.44	11.94	793	245	1038	Wadi Dihlak Kondil Basin	12
High	563.117	5.215	4.436	479	406	885	Wadi Safthin Basin	13
High	583.394	1.032	1.003	567	499	1066	Wadi Kandlis Basin	14

Source: Based on Digital Elevation Model using ArcGIS 10.8 software



Map (7) of the channel length and its slope index (SL) for the study area basins.Source: Based on data from Table (16) and the outputs of ArcGIS 10.8 software

2- Moderate Tectonic Activity Basins (Moderate): Represented by values ranging from 500 to 300. This category includes three basins: Daliakh Basin, Dar Jalal Basin, and Say Kulita Basin. The valleys in these basins are characterized by the formation of alluvial fans relatively close to the mountain front, indicating moderate tectonic activity. This category covers an area estimated at 33,616 square kilometers out of the total area of the region.

3-Low Tectonic Activity Basins (Low): Represented by values less than 300. This category includes five basins: Dasht Mir Al-Kabir Basin, Jam Kork Basin, Jam Sard Basin, Al-Khabour Basin, and Rabenka Basin. These basins are characterized by low tectonic activity. This category covers an area estimated at 78,069 square kilometers out of the total area of the region.

Table (17) Area of the channel length and its slope index (SL)

Area Km2	Area of the channel length and its slope index	S
218.231	**High**	**1**
33.616	**Moderate**	**2**
78.069	**Low**	**3**
329.917	**The Sun**	**4**

Source: Based on Digital Elevation Model using ArcGIS 10.8 software.

1-7 Relative Tectonic Active (RAT)

The RAT index is based on the classifications of previous geomorphological indices. It reflects the tectonic activity ratio for all the indices and all the basins in the study area, derived from the Digital Elevation Model (DEM). This provides a clear picture of how tectonic activities affect the values of geomorphological indices. The goal is to provide a final classification for all the indices, representing the overall outcome of all the previous classifications, through the mathematical equation (Al-Juboori, 2013, p. 27).

RAT=S/N

RAT = is the final classification of the cumulative indices for tectonic activity.

S = the sum of the index values for each watershed.

N =the number of indices.

The classification of the RAT index was based on Keller and Pinte's (2002) work, which categorized this index into four classes based on tectonic activity, as shown in Table (18). When the value falls between 1 and 1.5, it indicates very high tectonic activity, while if it exceeds 2.5, it suggests a decrease in tectonic activity.

Table (18) Relative Tectonic Active (RAT)

Ranges	Class	Degree	S
1.5-2	**1**	**High**	**1**
2-2.5	**2**	**Moderate**	**2**
Greater than**2.5**	**3**	**Low**	**3**

Reference: Keller. E. A. and pinter, N, Active tectonics, Earth quakes, uplift and land scape, edition, New Jersey, prentie, hall, 2002, p125.

Based on the application of the RAT (Tectonic Activity Rating) equation to the basins of the region, it has become clear that there are two categories based on their tectonic activity, as shown in Table.(19)

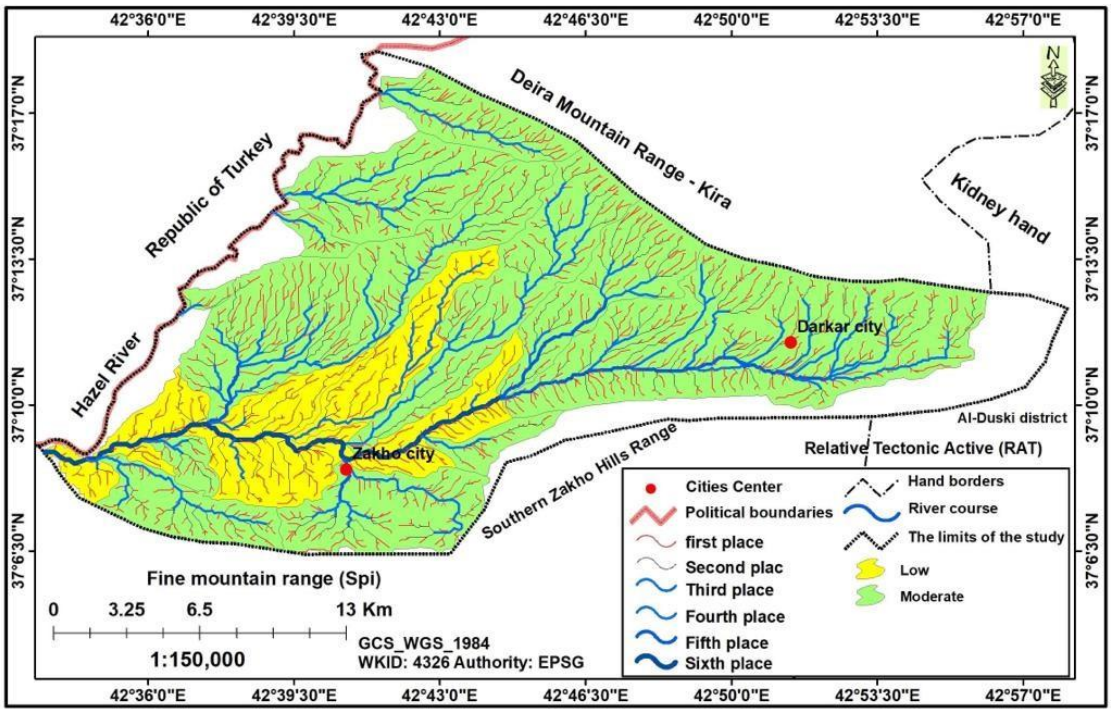
1-Basins with Moderate Tectonic Activity: Represented by values ranging from 2 to 2.5. This category includes 12 basins such as the Wadi Dasht Mir Kabir, Wadi Daliakh, Wadi Jam Kurk, Wadi Jam Sard, Wadi Rabenka, Wadi Dar Hozan, Wadi Sai Klita, Wadi Bestadim, Wadi Jalal, Wadi Dihlak Kondel, Wadi Safthin, and Wadi Kondeli. This category occupies an area of approximately 286,510 square kilometers out of the total area of the region, as indicated in Table.(20)

2-Basins with Low Tectonic Activity: Represented by values ranging from 1.5 to 2. This category includes two basins: Wadi Al Khabor and Wadi Dar Jalal. It occupies an area of approximately 61,407 square kilometers out of the total area of the region .

Table (19) Final Ranking Index of the Indicator (RAT) for the Study Area Basins

Degree	RAT	S	N	The names of the basins	S
Moderate	**2.333**	**14**	**6**	**Wadi Dasht-e Mir Kabir Basin**	**1**
Moderate	**2.333**	**14**	**6**	**Wadi Dailakh Basin**	**2**
Moderate	**2.167**	**13**	**6**	**Wadi Jam Kork Basin**	**3**
Moderate	**2.167**	**13**	**6**	**Wadi Jam Sard Basin**	**4**
Low	**2.500**	**15**	**6**	**Al-Khabour Valley Basin**	**5**
Moderate	**2.167**	**13**	**6**	**Wadi Rabenka Basin**	**6**
Moderate	**2.333**	**14**	**6**	**Wadi Dar Hozan Basin**	**7**
Low	**2.500**	**15**	**6**	**Wadi Dar Jalal Basin**	**8**
Moderate	**2.167**	**13**	**6**	**Wadi Say Kilta Basin**	**9**
Moderate	**2.500**	**15**	**6**	**Wadi Bestadim Basin**	**10**
Moderate	**2.167**	**13**	**6**	**Wadi Jalal Basin**	**11**
Moderate	**2.333**	**14**	**6**	**Wadi Dihlak Kondil Basin**	**12**
Moderate	**2.167**	**13**	**6**	**Wadi Safthin Basin**	**13**
Moderate	**2.167**	**13**	**6**	**Wadi Kandlis Basin**	**14**

Source: Based on the previous indicator table and the digital elevation model using ArcGIS 10.8 software.



Map (7) Final Ranking Index of the Indicator (RAT) for the Study Area Basins Source: Based on Digital Elevation Model using ArcGIS 10.8 software.

Table (20) Final Ranking Index of the Indicator (RAT)

Area Km2	Final Ranking Index of the Indicator (RAT)	S
268.510	Moderate	1
61.407	Low	2
329.917	The Sun	3

Source: Based on Digital Elevation Model using ArcGIS 10.8 software.

Conclusions:

1-The final outcome of all geomorphological indicators, represented by the index (RAT), reveals that the basins in the region fall into two categories. The first category is characterized by low tectonic activity, representing values ranging from 1.5 to 2. This category includes two basins, which are the Habor Basin and the Dar Jalal Basin. The second category is characterized by moderate tectonic activity, representing values ranging from 2 to 2.5, and it includes twelve basins: Mir Al-Kabeer Valley, Daliakh Valley, Jam Kork Valley, Jam Sard Valley, Rabanka Valley, Dar Hozan Valley, Say Klita Valley, Bestadim Valley, Jalal Valley, Dahlik Kondel Valley, Safthin Valley, and Kendli Valley".

Recommendations:

1- It is essential to conduct similar studies to identify areas of active tectonic activity and to investigate the geomorphological impact on changing the morphology of drainage basins, as well as to explore the subsurface resources of the land.

2- The use of modern geographic techniques for analysis and interpretation to establish a database that can be utilized in subsequent studies.

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