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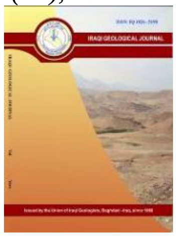

Hydromorphotectonic Analysis of Al Najaf-Karbala Plateau Using Remote Sensing Techniqe

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Abstract

Najaf-Karbala Plateau is located in the central part of Iraq with economic and environmental importance. The hydrological analyses of the plateau show six main watersheds, which provide a comprehensive examination of how surface and tectonic processes interact to shape geological structures in the area. Five morpho-tectonic parameters were applied; Asymmetry factor, Transverse topographic symmetry factor, Stream length gradient index, Mountain-front sinuosity and Elongation ratio. It was concluded that the area under study is activated tectonically to be potential watersheds, symbolized by WSh1, WSh2, WSh3, WSh4, WSh5and WSh6. The results show low tectonic activity across all watersheds based on to stream length gradient index, whereas three different levels of tectonic activity that based on the Mountain-front sinuosity. The watersheds have different tectonic levels; high activated at WSh1, WSh2, WSh4 and WSh6, while very high activated at WSh5. WSh3, on the other hand, has moderated activity over the area. However, the Elongation ratio indicated that the Najaf-Karbala Plateau exhibits elongation characteristics and more tectonic activity as well.

Keywords: Morphotectonic; lineaments; Remote sensing; GIS; Najaf- Karbala Plateau; Iraq

1. Introduction

The relationship between surface formations and geological processes is the primary concern of tectonic geomorphology. It provides an insight into the origins and configurations of various land features. It is also a useful tool for determining the extent, timing, and intensity of present tectonic movements (Burbank and Anderson, 2001). Plateau, is a unique landform which characterized by sediment deposition in the form of a cone, serves as a good example of this matter. From a central source, this sediment gradually spreads outward, taking the shape of gently sloping cone. These formations are typically found in areas with a variety of climate patterns, including mountainous regions that are arid to semi-arid and areas that receive a greater amount of precipitation (Hargitai, 2014).

Tar Al-Najaf which is located on the western border of Lake Milih, is also known as the Al-Razzaza Depression. Through a controlled outlet canal, this depression collected excess water from the Euphrates River. The lake has limited depth, which creates variation in its water level throughout the year. This lake's inception dates back to 1969. Their plan was to re-route the Euphrates River's yearly floods, so they could flow into the surrounding sand dunes rather than drowning southern Iraq. Such plateau has been studied by many researchers, such as Ghalib (1988) who found that the Dibdibba Formation represents a very large Pleatue, which has been constructed and covered by the two cliffs in the study

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area. Sissakian et al. (2015), on the other hand, investigated the origins of Tar Al-Sayed and Tar Al-Najaf in the Central Iraqi region of the Karbala-Najaf Plateau. This area is characterized by the presence of many irregular caves and others that are rectangular in shape and are covered by the Dibddiba Formation. They are exposed to natural factors that lead to their destruction, such as dissolution, soil creep and sliding (Awadh et at., 2012).

Igneous and metamorphic rocks that have been carried out by the floods coming through the northeast from Saudi Arabia, Kuwait to Iraq are the source of the sediments in the area (Awadh and Al-Ankaz., 2016).

The current study assesses the tectonic activity in the study area by using the morpho-tectonic analysis. The channels of water in the research region are evaluated using geomorphic indices. To understand how the terrain has changed, one must have a solid understanding of morpho-tectonics processes. The relationship between surface mechanisms and tectonic forces, which form geological formations is clearly made by tectonic geomorphology. In the field of geomorphology, this knowledge can also be applied to forecast the extent, dimension and intensity of continuous tectonic processes (Scheidegger, 1970).

Analyzing the morpho-tectonic characteristics of the Al Najaf-Karbala Plateau is the primary goal of this study. The objectives of this current work are to demonstrate the tectonic shifts and even to identify the linear elements underpinning the current plateau structure.

2. Location of the Study Area

The study area is located within the specific geographical coordinates, ranging approximately from north latitude N32°04'00" to N31°05'00" and east longitude E44°30'00" to E43°20'00". The northern boundary is defined by the southern limit of Al-Razzaza Lake and the northeast is bordered by the western part of Karbala. The study area is surrounded by Bahr Al Najaf to the south and Najaf to the southeast, while the western plateau is bordered from the west and the Mesopotamian Zone to the east as indicated by Jassim and Goff (2006) (Fig. 1).

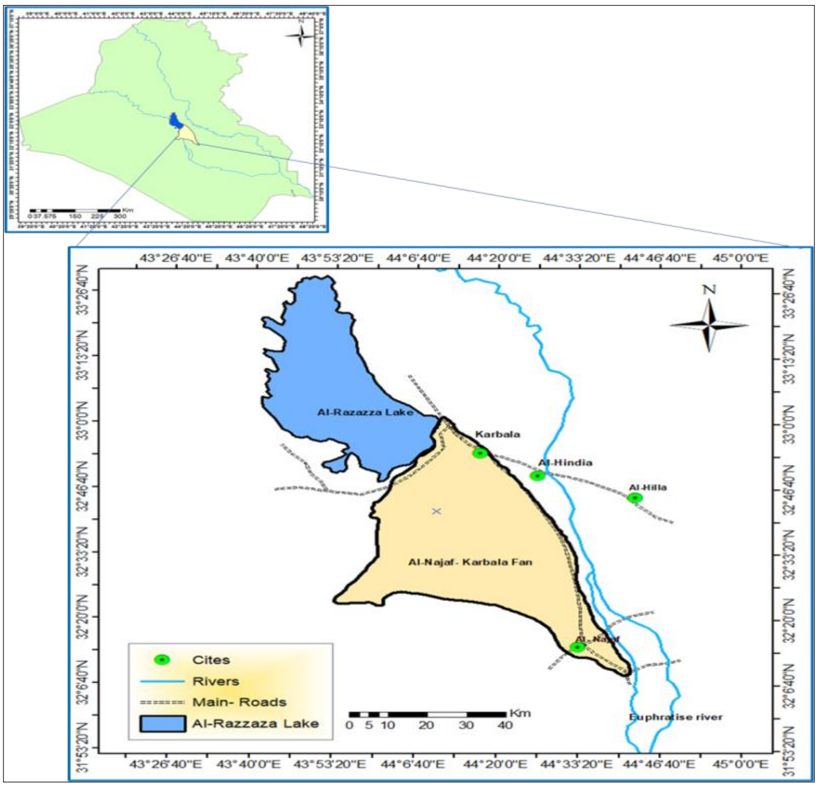

Fig.1. Location map of the study area (Al-Abadi et al., 2019)

Dibdibba unconfined aquifer is one of the significant aquifers in the area. The sustainable management of this aquifer is essential to prevent its depletion and the deterioration of water quality, given the growing amount of water used for agricultural and industrial reasons and the absence of regulatory restrictions on water usage (Al-Abadi et al., 2019). Six watersheds have been identified from the hydrological analysis of this study as shown in Fig. 2.

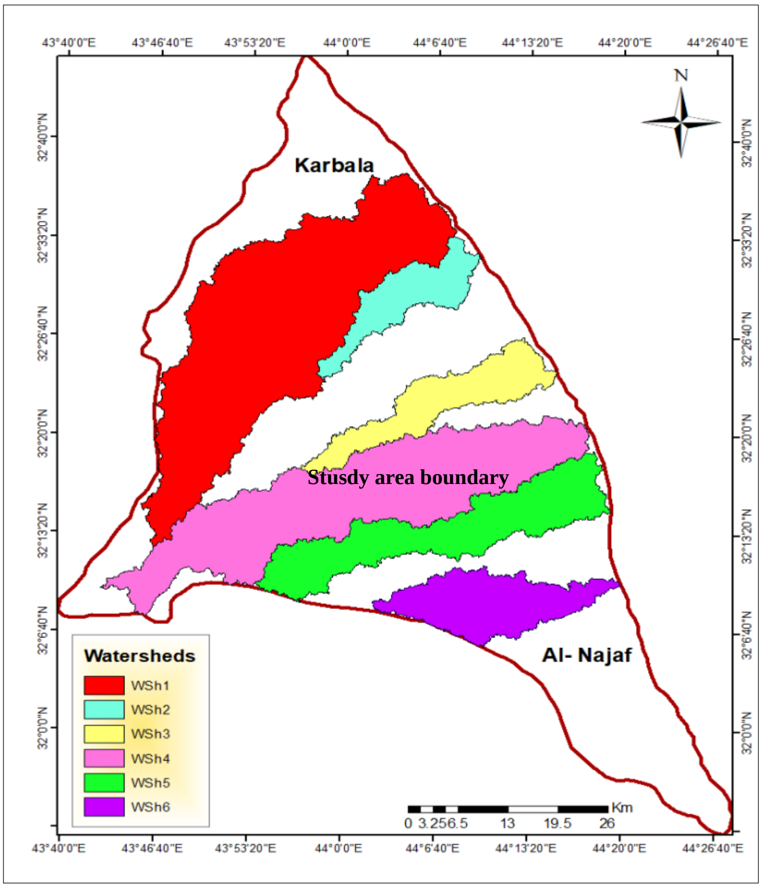

Fig.2. Watersheds map in Karbala-Najaf Plateau.

3. Geological Setting of the Study Area

The study area is located within the stable shelf region of the Arabian Plate. It is significantly influenced by prominent fault lines represented by Abu Jir and Euphrates, adding to other secondary faults. This area is characterized by numerous major, secondary, linear and transverse faults that have a notable impact on the terrain to form depressions and ridges (Fouad, 2007). The Arabian Plate's Inner and Outer Platforms are both crossed by the Najaf-Karbala Plateau, with the convergence of these two platforms occurring in the vicinity of the plateau's apex (Jassim and Goff, 2006). In terms of geology, the research area encompasses formations ranging from the middle Miocene to quaternary sediments, the geological formation successions in the region include Injana, Nfayil, and Dibdibba, as shown Figs. 3, and 4, while Fig. 5 revealed the elevation map of the study area.

4. Material and Methods

To get valuable insights into the rates of tectonic processes and the intervals between seismic events, various geomorphological indicators have been developed. These indicators help in assessing the geological characteristics linked to ongoing tectonic activity and its relative magnitude. Deformation can be evaluated through field measurements on-site or by utilizing topographic maps.

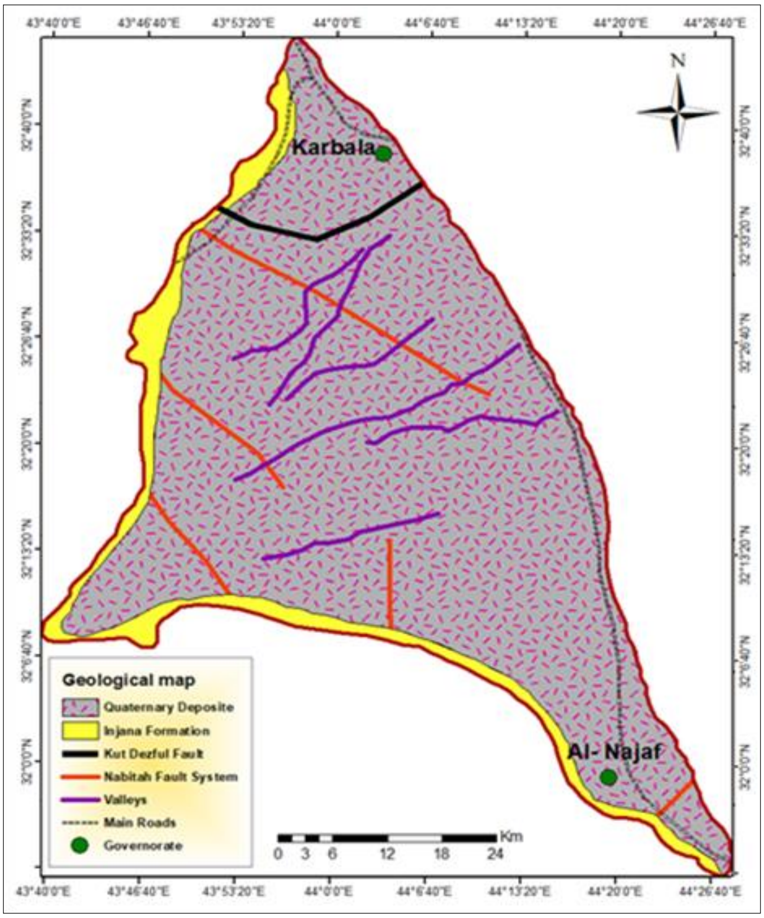

Fig.3. Geological map of Al Karbala-Najaf Plateau.

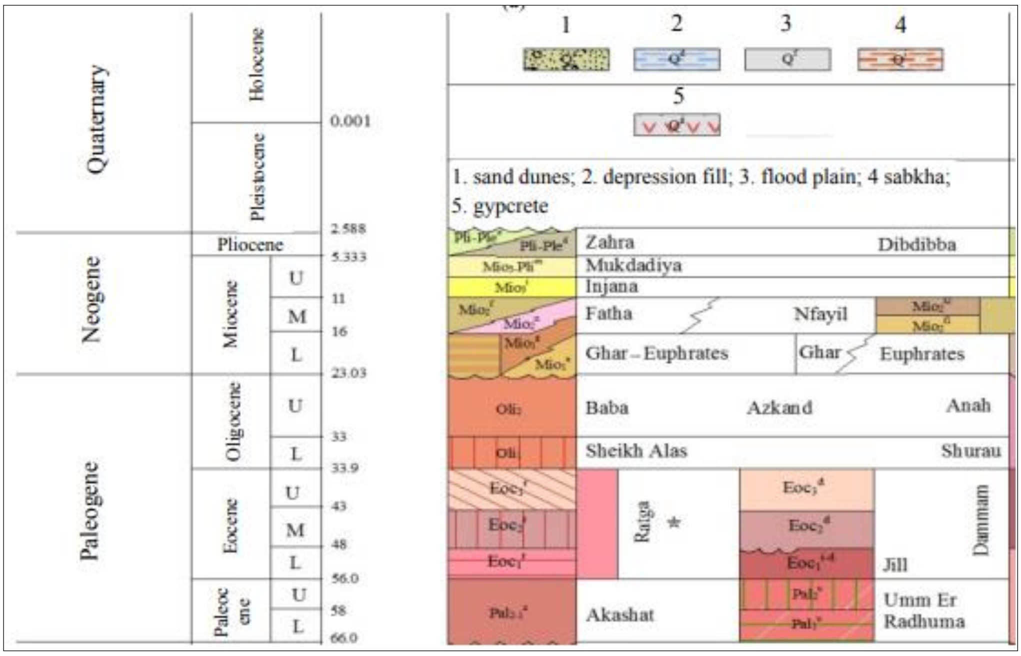

Fig.4. Stratigraphic column of the study area after (Sissakian. et al., 2015)

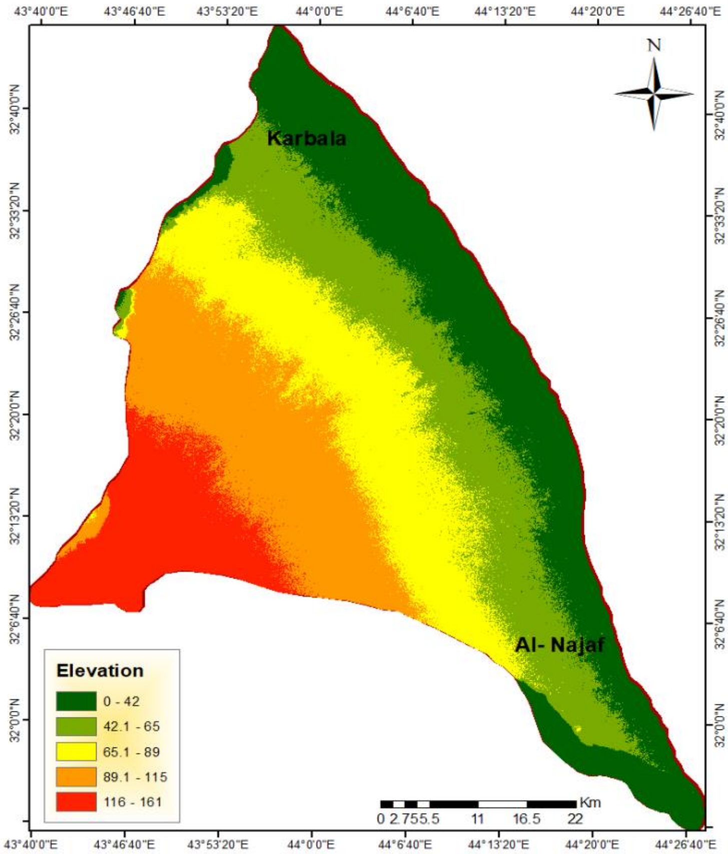

Fig.5. Elevation map of the study area.

Displacements can manifest in different geological features such as altered stream channels, elevated marine terraces, and contorted or folded Pleatue deletes (McFadden, 1977). The morpho-tectonic analysis involves a comprehensive examination of how surface and tectonic processes interact with the shape of the geological structures (Lone, 2017). The formulas are given in Table. 1 are used to compute the morpho-tectonic parameters.

Table 1. The following methodology was used to compute the morphotectonic parameters.

Morphometric parameters	**Formula**	**References**
`Asymmetry factor (AF)	AF=100(Ar/At): Ar is the basin's downstream-facing portion to the right of the Watershed. The drainage basin's entire area is: At.	Hare and Gardner, 1985
Transverse topographic symmetry factor(T)	T=Da/Dd: Da is the distance between the midline of the drainage watersheds and the active belt's midline, and Dd is the distance between the midline and the basin's edge.	Cox, 1994
Stream length gradient index (SL)	SL is equal to (ΔH/ΔL). L: The overall channel length from the watershed's midpoint is represented by SL (Stream	Hack, 1973

	Length-Gradient Index), ΔH (Elevation Change), and ΔL (Watershed Horizontal Length).	
Mountain-front sinuosity (Smf)	Smf=Lmf/Ls, where Ls is the length of the entire mountain front in a straight line and Lmf is the length of the piedmont.	Bull and McFadden, 1977
Elongation ratio (Re)	Re is equal to 2 √ ((Ba /π)) / Lb, where Ba is the basin's area (km2) and Lb is its length.	Schumm, 1956

5. Result and Discussion

5.1. Longitudinal and Cross-Section Profiles

Streams have undergone tectonic uplift, alterations in climate patterns and modifications in watershed conditions. Understanding the longitudinal profiles of these streams provides important information on the region's tectonic and structural features (Albhadili et al., 2023)

The Najaf-Karbala Plateau exhibits a longitudinal profile that undergoes a transition, starting as concave in the proximal part of the plateau and gradually becoming convex towards the distal end. This transition leads to a notable reduction in the slope of the plateau. At the plateau's center, there are two prominent cliffs, Tar Al-Najaf is on the right, and Tar Al-Sayed is on the left. These cliffs have a convex profile and distinct steep sections at their respective ends. Moreover, this profile reveals smaller-scale features in the head region of the plateau, especially on the right side, which could be associated with processes of uplift and erosion (Fig. 6).

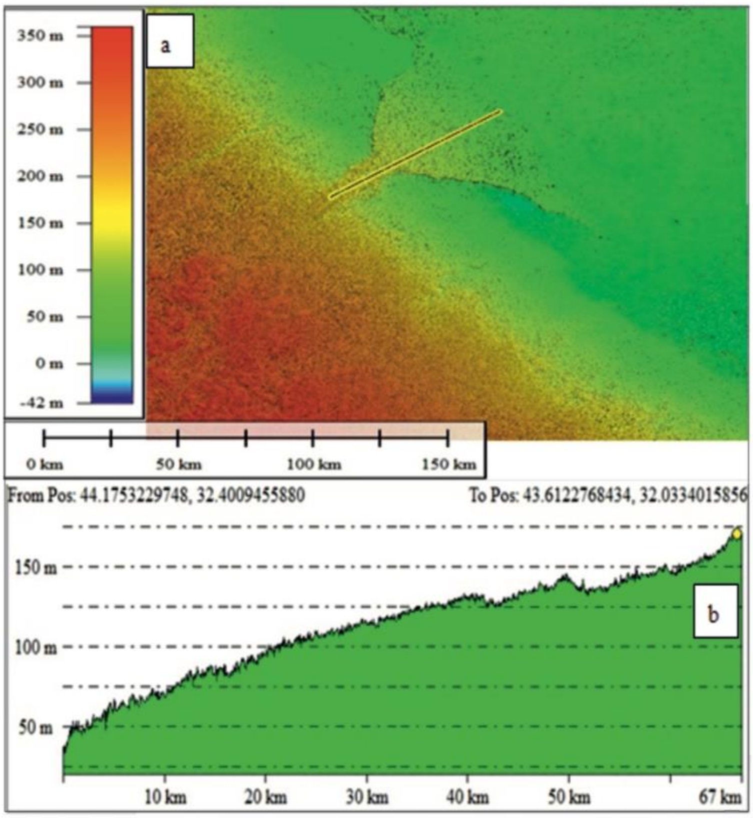

Fig.6. Longitudinal section of Karbala-Najaf Plateau

When examining a cross-section from south to north (S-N), it becomes apparent that the elevation of the plateau gently declines from its edges toward the lower central area. Additionally, two linear structures originate from the northwest corner of the plateau, indicating a potential extension of the Al-Razzaza that might continue through the central part of the Najaf-Karbala Plateau. Fig. 7 provides a visual representation of a valley that bears a similarity to Al-Khir Valley when viewed from the southeast of the region.

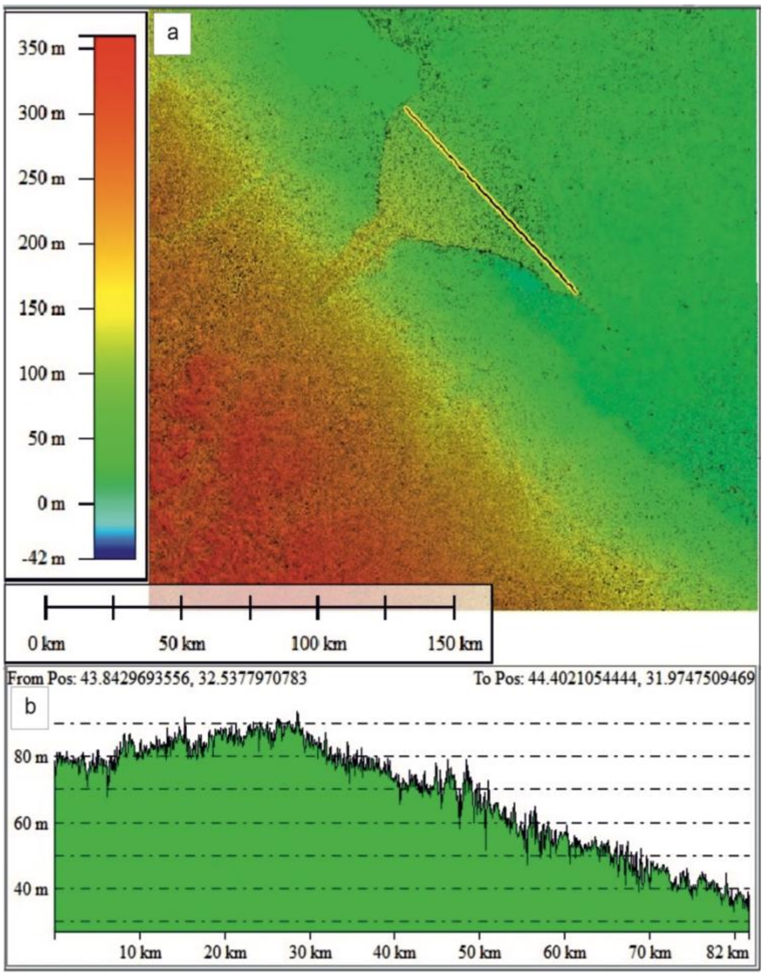

Fig. 7. Cross-section of Karbala-Najaf Plateau

5.2. Morpho-Tectonic Parameter Result

5.2.1. Asymmetry factor (AF)

The area of the right bank of the stream as seen downstream is divided by the total area of the drainage basin which then yields the asymmetry factor (AF). At different scales, this component has been used to evaluate the tectonic tilting of the drainage basins (Lone, 2017). The process involves outlining the watershed and the primary channel, typically located on the right side of each watershed. Tectonic forces have had a notable impact on the AF and the results are shown in Fig. 8, which has been calculated according to the equation given by Hare and Gardner (1985).

The AF values are also influenced by the region's lithology and environmental conditions that characterized by a desert climate and a mixture of gravel, sandstone, and ill-sorted sand. All the watersheds in the study area have experienced tectonic activity, resulting in imbalanced watershed characteristics, which is evident in the AF values and presented in Table 2. These AF values consistently indicate ongoing tectonic activity throughout the watersheds.

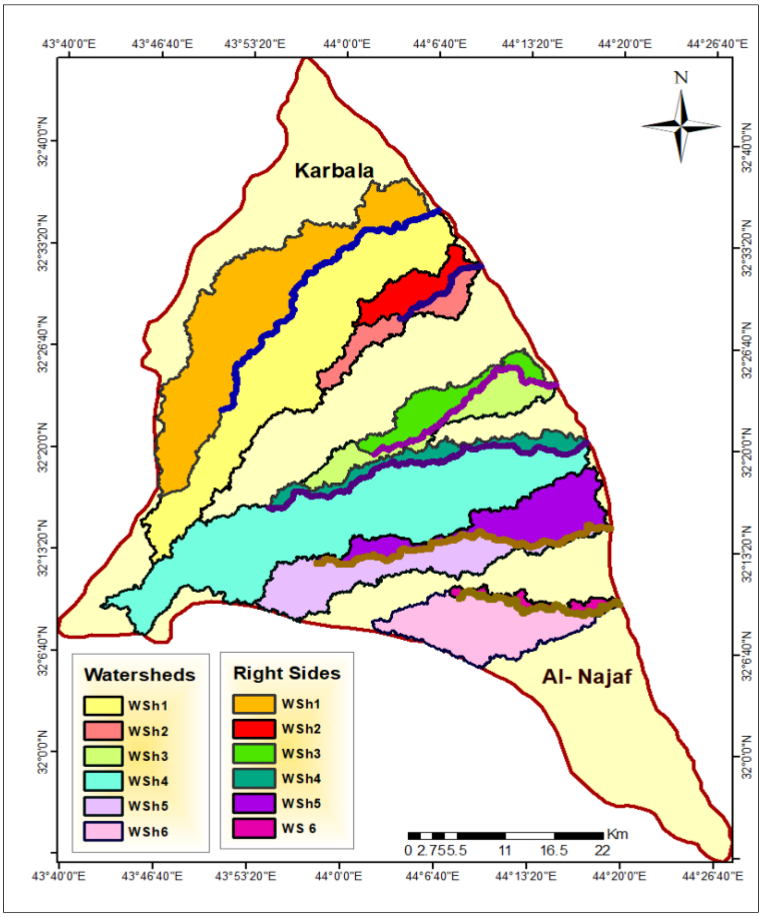

Fig. 8. Right side for each watershed in Karbala-Najaf Plateau.

Table 2. Value of the asymmetry factor of study area for six watersheds

Watersheds	AF	Tectonic Activity
WSh1	47.19	Activated Tectonically
WSh2	48.44	Activated Tectonically
WSh3	45.80	Activated Tectonically
WSh4	11.44	Activated Tectonically
WSh5	47.26	Activated Tectonically
WSh6	12.51	Activated Tectonically

5.2.2. Transverse Topographic Symmetry Factor (T)

Another quantitative metric used to assess basin asymmetry is the transverse asymmetry factor (T). It is computed by evaluating the offset between the midline of the drainage basin and the midline of the active meander belt. This calculation is performed using the formulas outlined by Cox (1994). The T value in an asymmetric basin is 1, whereas it is 0 in a symmetric basin. Fig. 9 provides a visual representation of how Da value i. e the density from the midline to the main channel) and (Dd) i. e the density from the midline to the outside boundary of the watershed) are determined, and then used in the computation of the T index.

It's essential to note that neither the asymmetry factor nor the transverse asymmetry factor directly indicates ground tilting. As the data presented in Table 3, the watersheds within the Najaf-Karbala Plateau have experienced two distinct periods of tectonic activity. Moderate activity is observed in watersheds WSh1, WSh2, and WSh3, while high activity is evident in watersheds WSh4, WSh5, and WSh6.

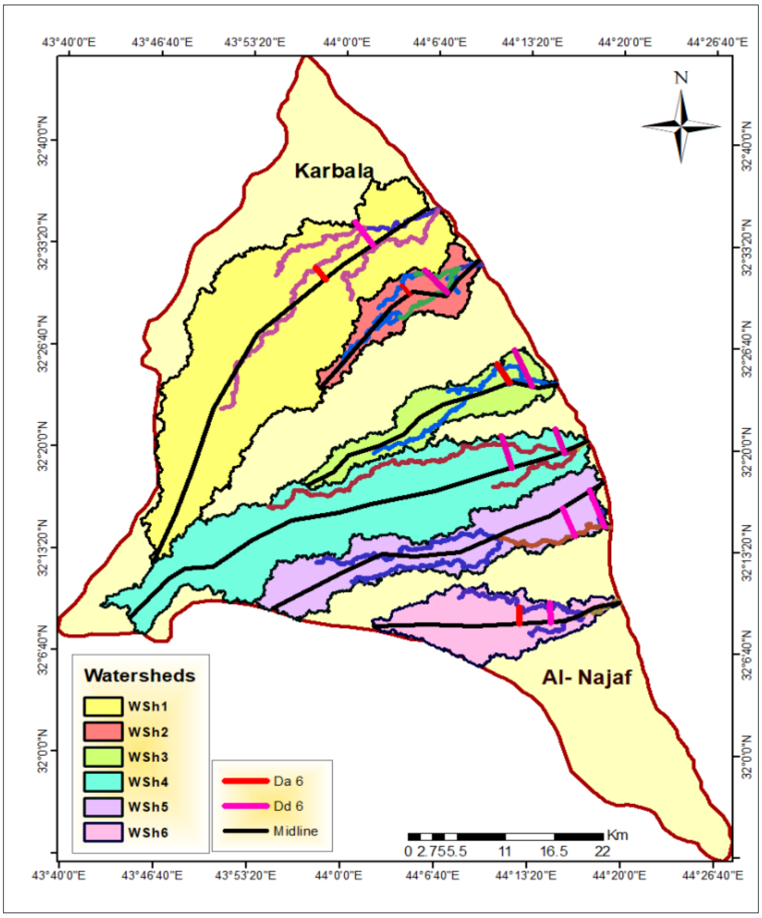

Fig. 9. The T index for each watershed in Karbala-Najaf Plateau

Table 3. T value for five watersheds

Watersheds	Da	Dd	T	Watersheds' forms	Tectonic Activity
WSh1	1.84	3.40	0.54	Asymmetric	Moderate
WSh2	1.34	3.68	0.3	Asymmetric	Moderate
WSh3	2.52	4.76	0.52	Asymmetric	Moderate
WSh4	4.00	3.02	0.9	Asymmetric	High
WSh5	3.61	4.68	0.7	Asymmetric	High
WSh6	1.98	2.40	0.8	Asymmetric	High

5.2.3. Stream Length Gradient Index (SL)

One of the most crucial factors in determining whether a region is influenced by tectonics or by lithology is its control. To assess this, the length of rivers is measured using digital elevation and contour maps of the area. This measurement is essential for understanding the interplay between factors such as rock resistance, topography, potential tectonic activity, and river length, as emphasized by Keller and Pinter (2002).

Tectonic activity categorizes the Stream Length Gradient Index into three distinct classes: $SL > 500$, $300 \leq SL \leq 500$, and $SL < 300$, which represents the high, moderate, and low-risk levels, respectively. Lower values of the index (SL) are observed when rivers flow through softer rock types like weathered limestone and alluvium, whereas higher (SL) values are associated with rivers flowing through hard rock formations.

The results of the study indicate that in the Najaf-Karbala Plateau, there is low tectonic activity across all watersheds, as illustrated in Table 4 and Fig. 10.

Table 4. SL index value for six watersheds.

Watersheds	L	ΔH	ΔL	SL	Active Tectonics
WSh1	47.05	30	11.14	126.70	Low tectonic activate
WSh2	14.00	20	5.58	47.88	Low tectonic activate
WSh3	30.03	20	7.14	84.11	Low tectonic activate
WSh4	46.29	20	8.37	110.60	Low tectonic activate
WSh5	42.04	20	9.88	85.10	Low tectonic activate
WSh6	26.59	20	7.65	69.51	Low tectonic activate

Where L: is the length of the river, ΔH: is the change in elevation, ΔL: is the difference between two contour lines.

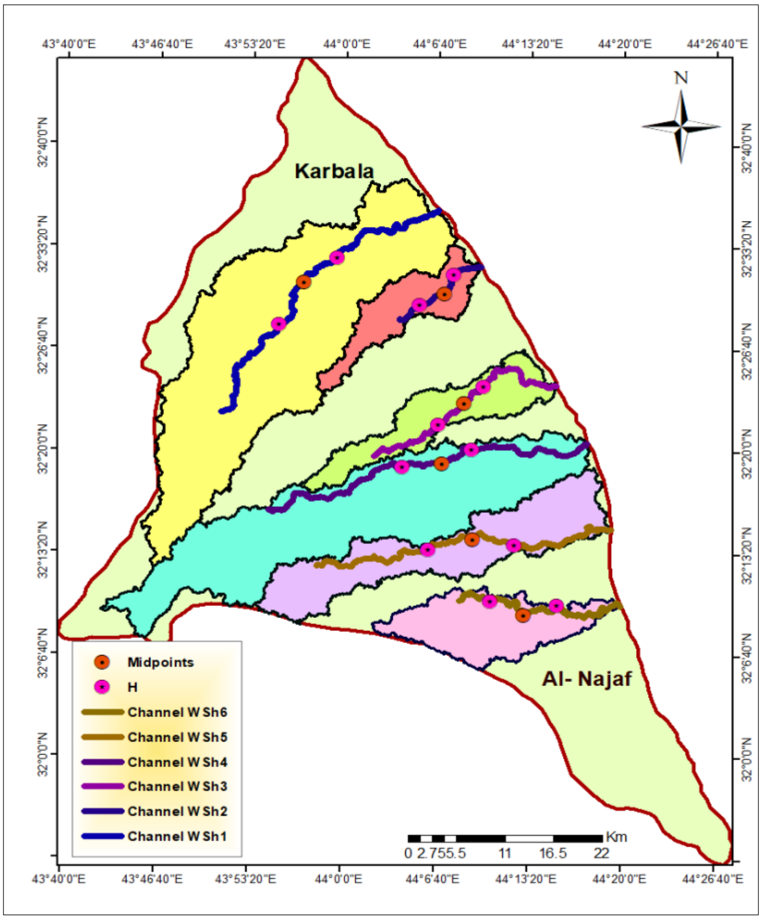

Fig. 10. SL index for each watershed in Al-Najaf -Karbala Plateau.

5.2.4. Mountain front sinuosity (Smf)

Mountain front sinuosity (Smf) acts as a sign of the relationship between the erosional forces that shape mountain fronts and the tectonic forces aligning them with active faults. It is calculated by dividing the mountain front's length at the Piedmont (Lmf) by the mountain front's total straight-line length. Smf is typically calculated within a Geographic Information System (GIS) surroundings by utilizing a digital elevation map (DEM) and remote sensing data to produce a contour map.

Smf is typically categorized into three levels: high, moderate, and low, based on specific value ranges. These categories are defined as follows: 1-1.5 for high, 1.5-2.5 for moderate and >2.5 for low values, as outlined in the study by El-Hamdouni et al. (2008).

Table 5 illustrates the Smf values for the Najaf-Karbala Plateau, revealing that it experiences three levels of tectonic activity: high in WSh1, WSh2, WSh4, and WSh6, moderate in WSh3 and very high in WSh5 (Fig. 11).

Table 5. Value of SMF for six watersheds

Watersheds	Segment	Lmf	Ls	Smf	Smf mean	Active Tectonics
	1	14.98	12.11	1.23		
WSh1	2	23.97	16.98	1.41	1.29	High
	3	14.41	11.53	1.24		
	1	2.43	2.75	0.88		
WSh2	2	6.71	5.19	1.29	1.09	High
	3	9.26	8.38	1.10		
	1	4.98	3.21	1.55		
WSh3	2	9.10	4.41	2.06	1.71	Moderate
	3	9.86	6.40	1.54		
	1	9.76	8.72	1.11		
WSh4	2	10.15	10.12	1.00	1.18	High
	3	13.54	9.38	1.44		
	1	7.37	6.25	1.17		
WSh5	2	5.02	9.03	0.55	0.83	Very high
	3	8.23	10.52	0.78		
	1	9.56	10.57	0.90		
WSh6	2	9.71	7.88	1.23	1	High
	3	5.23	6.05	0.88		

5.2.5. Elongation Ratio (Re)

The elongation ratio, initially proposed by Schumm (1956), is calculated by dividing the maximum length of the basin by the diameter of a circle having the same area as the basin. In terms of the characteristics related to the discharge and the runoff, most people believe that a circular basin is more efficient than an extended one, as explained by Lone (2017). This ratio typically falls within the range between 0.6 and 1.0 and can vary across diverse climatic and geological conditions.

The index of the elongation ratio can be employed to classify watershed slopes into several categories, including less elongated (0.7-0.8), elongated (0.5-0.7), circular (0.9-0.10), oval (0.8-0.9), and more elongated slopes (less than 0.5), in accordance with the work of (Pareta and Pareta, 2012).

Table 6 indicates that the watersheds within the Najaf-Karbala Plateau exhibit elongated characteristics and are also more tectonically active.

5.3. Lineaments in the Study Area

The studied region is geologically situated in the midst of stable shelf and unstable shelf tectonic terrains, along with the presence of the Najaf Abu Jir tectonic range. This region is characterized by the Abu Jir Euphrates and several significant primary and secondary fault systems. The geomorphology of the area, including the formation of depressions and hill chains within the region and its vicinity, is profoundly influenced by a network of major, secondary, longitudinal and transverse faults that traverse the studied area, as depicted in Fig. 12.

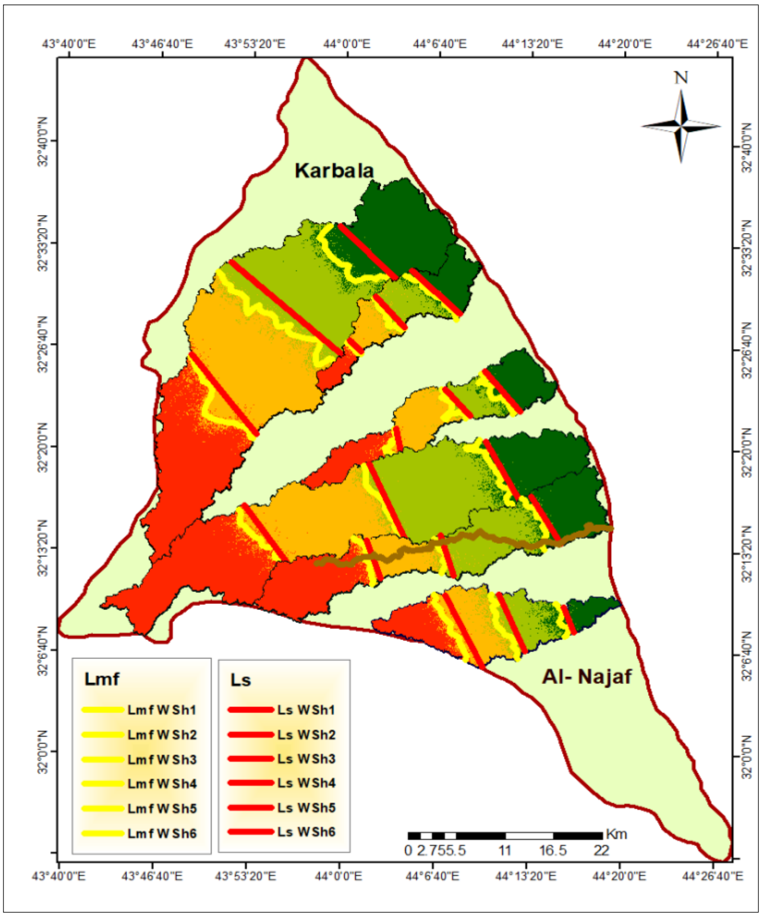

Fig.11. Smf index for each watershed in Al Najaf-Karbala Plateau .

Table 6. Six watersheds' values for the elongation ratio.

Watersheds	Re	Basin's form	Tectonic Activity
WSh1	0.53	Elongated	Slightly active
WSh2	0.46	More elongated	Active
WSh3	0.42	More elongated	Active
WSh4	0.43	More elongated	Active
WSh5	0.40	More elongated	Active
WSh6	0.50	Elongated	Slightly active

According to Fouad (2007) and Fouad (2012), the Arabian Plate's Inner Platform and Outer Platform are separated by the Najaf-Karbala Plateau. The Abu Jir-Euphrates Fault Zone marks the boundary between these two platforms and is positioned at the apex of the Najaf-Karbala Plateau. The obscured Al-Razzaza Pleatue in contrast, is located on the Arabian Plate's outer platform. Late Pleistocene and/or Early Holocene geologic activity, attributed to the ongoing activity of the Abu Jir – Euphrates Tectonic Zone, that has led to the rising of the Najaf-Karbala Plateau and its surrounding areas, as discussed by Fouad (2004) and (2007).

- One of these fault systems traverses the central part of the Plateau and corresponds to the path of the Al-Khir valley. This shift in the valley's trajectory towards the right side of the plateau (known as Bahir Al-Najaf) highlights the influence of both significant and minor basement faults that intersect the entirety of the Najaf-Karbala Plateau.
- In the northern region of the plateau, there are two prominent linear features originating from the western side of the plateau. These structures suggest that the obscured Al-Razzaza might extend

significantly within the plateau area, influenced by the network of linear features that have a significant impact on the plateau's surface morphology.

- The configuration of the terrain, especially in the vicinity of the Al-Khir Valley within the Najaf-Karbala Plateau -head, distinctly reflects the impact of significant faults, particularly in the Al-Lisan area.

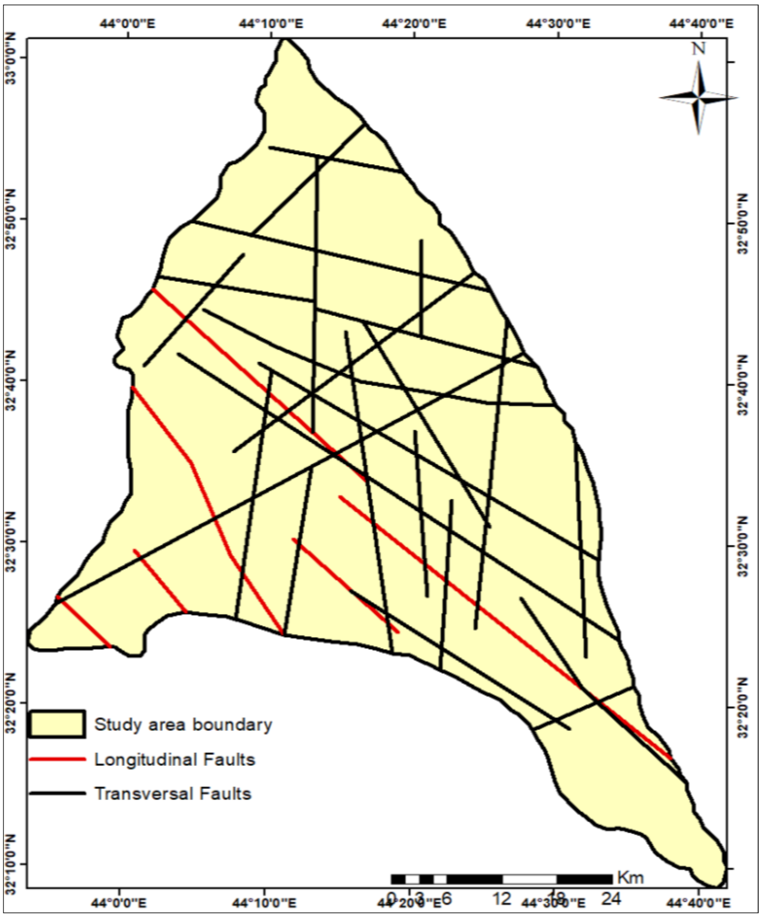

Fig.12. Lineament's map of Al Najaf-Karbala Pleatue.

6. Conclusions

According to the obtainable results mentioned above, many conclusions may given:

The area is intersected by numerous significant, secondary, linear, and transverse fault lines that significantly influence the region's topography, particularly the formation of depressions and ridges. It lies within the stable shelf region of the Arabian Plate, which is notably affected by the primary faults like Abu Jir and Euphrates faults, along with a multitude of secondary fault systems. Among the geological formations in the area, the most prominently exposed ones are Injana, Nfayil, and Dibdibba.

The longitudinal profile of the Najaf-Karbala Plateau exhibits a distinctive transition from concave in its proximal region to convex towards the distal end. When observed from a cross-sectional perspective, the Plateau's elevation gradually decreases from the sides to its lower central portions. Additionally, it is possible that the obscured Al-Razzaza could extend extensively within the Najaf-Karbala Plateau area, where two linear structures also extend from the plateau's northwest corner.

Morpho-tectonic analysis, derived from remote sensing data ASTER GDEM and GIS methodologies, elucidates the interplay between tectonic forces and surface processes in shaping the landscape's features. This analytical approach proves to be an immensely valuable tool in understanding the region's geomorphological attributes.

Tectonic tilting of drainage basins was assessed by using the asymmetry factor at different scales, revealing that all watersheds experienced tectonic activity, leading to an unbalanced watershed configuration. This observation suggests that the tectonic activity is still ongoing.

The Najaf-Karbala Plateau exhibits two distinct periods of tectonic activity, with a moderate level of activity observed in watersheds WSh1, WSh2, and WSh3, while watersheds WSh4, WSh5 and WSh6 indicate a high level of tectonic activity, as indicated by the T factor data.

The SL index helps establish the connection between rock durability, topographical features, the likelihood of tectonic activity, and the length of streams. Based on the SL index findings, it is evident that the Najaf-Karbala Plateau experienced minimal tectonic activity across all its watersheds.

Mountain-front sinuosity (Smf) is calculated by dividing the length of the mountain front at its Piedmont (Lmf) by the length of the mountain front revealed as a straight line. In the case of the Najaf-Karbala Plateau, there are three levels of activation observed: high levels in WSh1, WSh2, WSh4, and WSh6; moderate levels in WSh3; and exceptionally high levels in WSh5.

Elongation ratio results indicated that the Najaf-Karbala Plateau exhibits elongation characteristics and more tectonic activity as well.

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