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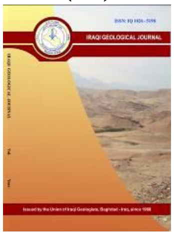

The Hydrological and Morphometric Evaluation of Al Najaf-Karbala Plateau Using Remote Sensing and GIS Methods

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Abstract

The geological processes influence the Al-Najaf-Karbala Plateau. The objective is to evaluate each fan's hydrological characteristics, such as drainage system, structural elements, and surface water flow patterns. It integrates satellite imagery and field data into a GIS framework using remote sensing methods. According to a hydrological study, the Al-Najaf-Karbala plateau drainage network primarily flows from southwest to northeast. The fan may be divided into six different watersheds, each with five stream orders, using morphometric analysis. Wsh1 has many stream orders, whereas Wsh 2 has the lowest. Floodwaters are expected to flow more quickly at Watershed 2's lowest point. Watershed 4 has the largest bifurcation ratio, indicating steep slopes and rocks with low permeability. The drainage texture value in the Al-Najaf-Karbala Plateau ranges from coarse to extremely coarse due to large and resistant rocks in the area. Watershed 1's increased stream frequency indicates lower infiltration rates and stronger surface runoff. All watersheds have extended or fern-shaped basins, which suggests a decrease in flow rate that necessitated a longer time for water to accumulate. In terms of basin relief, watershed 6 has the highest relief value among all the watersheds under study, whereas watershed 1 has the lowest relief value. Watershed 4 features longer streams and a softer gradient than Watershed 3, which is steeper.

Keywords: Hydrological analyses; Morphometric analyses; Geographical Information Systems; Najaf-Karbala Plateau

1. Introduction

A geological landmark called a Plateau develops at the bottom of inclined valleys or mountain fronts. It develops as rivers and streams decrease in speed as they reach the flatter ground and release the silt they carry. This silt accumulates along the fan's outside, forming a recognizable cone. Usually, coarse materials such as rocks carried by the flowing water create a plateau. Many variables, including the area's geography, the composition of the rocks and sediments in transit, the climate, and the dynamics of flow, affect the formation of these fans.

Furthermore, it was noted that a cluster of low hills, Tar Al-Sayed, encircled the northern and southern areas. These hills are likely influential in shaping the terrain and influencing the patterns of water movement. The mention of the Bahr Al-Najaf Valley and the city of Najaf indicates specific geographical elements within the described locality. Bahr Al-Najaf presumably represents a water feature or valley, while Najaf is a city situated on the area's western portion (Al-Sulaimi et al., 1995).

Since morphometric analysis examines the geometry of a drainage basin, the slope of the surrounding land, and the drainage density, it is crucial for understanding a range of hydrological phenomena (Al-Sulaimi et al., 1995). Several authors have examined it (Ahmad and Majad, 2015). They looked at the geomorphological features of the Al-Najaf–Karbala plateau (Ghalib, 1988). The broad Plateau of the Dibdibba Formation is thought to have arisen around the twin escarpments. In their investigation of the Karbala–Najaf area in central Iraq, Sissakian et al. (2015) explore the formative processes behind the Tar al-Sayed and Tar Al-Najaf deposits. The important aim of this study is to investigate the hydromorphometric features of the Al-Najaf-Karbala Plateau by conducting a hydrological analysis to identify the main hydrological catchments area (watersheds) and their relationship to the surface runoff flow in the area. As part of the research of morphometric analyses of the streams, the drainage network and structural analysis of the region based on geological and compositional information as well as specific data from satellite pictures will also be computed (Magesh et al., 2013). As time passes, sediment accumulation contributes to the fan's enlargement. We have also discussed the geological structures in the region, encompassing various geological formations and the impact of climate-related factors. These elements collectively contribute to the diverse range of landforms in the area. The depiction of the region as a plateau that gradually decreases in elevation from west to east signifies a gradual change in height across the landscape.

A number of researchers had executed some work on the studied area and its surroundings, but none of them dealt with the origin of the two cliffs. Most related studies are mentioned hereinafter: Ghalib (1988) mentioned that the area covered by the two cliffs is built-up by the Dibdibba Formation, representing a very large alluvial fan. Fouad 2004, and 2007 and Fouad and Sissakian (2011) did not mention about the origin of the two cliffs when reporting about the structural and tectonic evolution of the Iraqi Western Desert and the Mesopotamia Foredeep, respectively, neither mentioned about the presence nor otherwise surface faults, near the two. The hydromorphotectonic analysis of Al-Najaf-Karbala Plateau was made using remote sensing techniqe, and showed the plateau was activated from the tectonic setting. The potential areas of groundwater zones in the Najaf-Karbala Alluvial Fan wass mapped using remote sensing and GIS technology, they showed the area have a natural recharge. Sissakian et al. (2015), on the other hand, investigated the origins of Tar Al-Sayed and Tar Al-Najaf in the central region of the Najaf-Karbala 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 al., 2012).

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

2. Location of the Study Area

In terms of geography, Najaf-Karbala Plateau is located between specific coordinates, ranging from east longitude E44030'00" to E43020'00" to north latitude N32045'00" to N31054'00" (Fig. 1). The southern parts of Al-Razzaza Lake to the north, the western parts of Karbala City to the northeast, and the Najaf Depression to the south are some of the notable features that define the study region, the Najaf City to the southeast, the western plateau to the west, and the transition into the Mesopotamian zone to the east (Jassim and Goff, 2006) (Figs. 1, and 2).

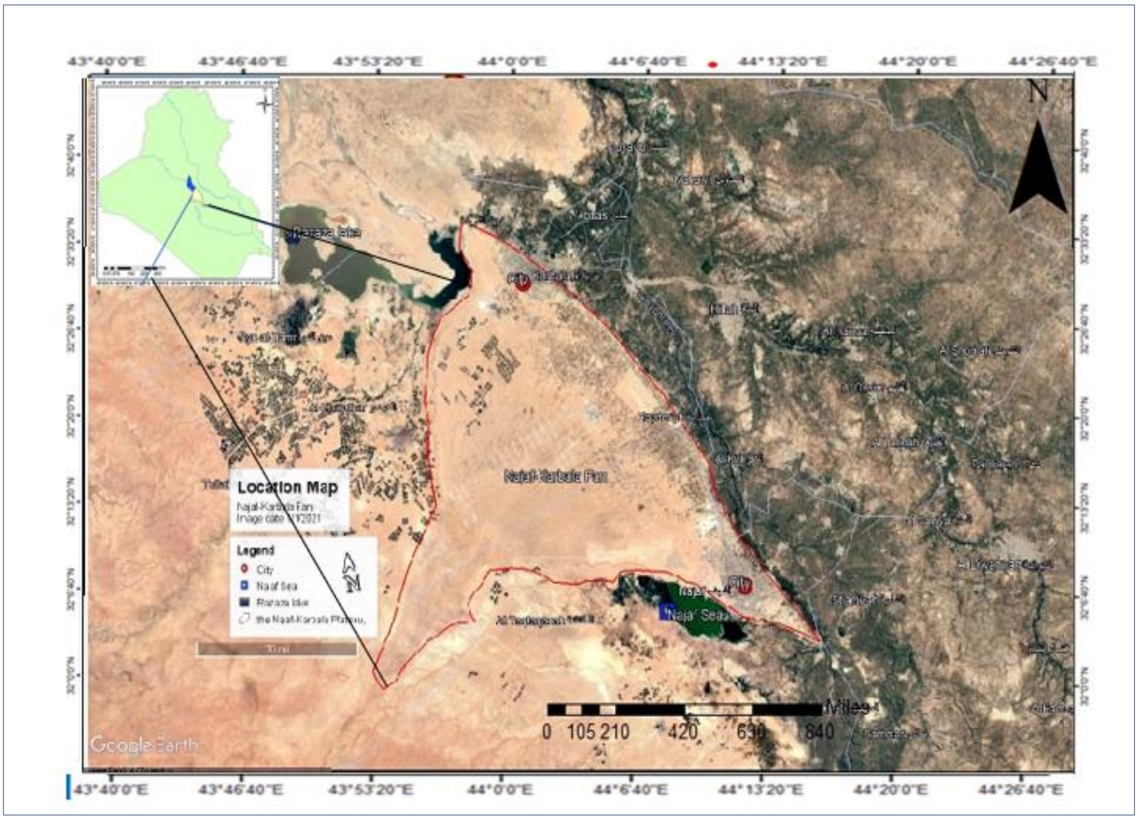

Fig.1. Location map of the study area

3. Geological and Tectonic Setting

The Al-Najaf-Karbala Plateau is geographically between the Arabian Plate's outer and inner Platforms. These platforms' convergence is most noticeable around the fan's apex, and it has significant ramifications for the area's tectonic activity, sediment deposition, and geomorphological characteristics. The Plateau is formed by the accumulation of sediments caused by rivers and streams moving from higher to lower elevations. This natural phenomenon often results in the characteristic fan-shaped landform. Numerous fault systems significantly affecting the landscape are part of the Arabian Plate's well-known complicated tectonic dynamics.

The Euphrates and Abu-Jir faults play a central role in shaping the region's tectonics and geology. Along with their subsidiary fault networks, these principal structures strongly govern the landscape's morphology, giving rise to the ridges and basins described above. The intricate relationships between these major and secondary fault systems demonstrate the region's complex geology. Along these fault lines, movements can result in the formation of ridges and depressions like the Al-Razzaza Lake. They can also have a major impact on the sedimentation patterns in the area (Fouad, 2007) (Fig. 2).

The geological formations in the studied region range in age from the Middle Miocene to the Quaternary. The most exposed geological formations are Injana, Nfayil, and Dibdibba.

3.1. Injana Formation

The Injana Formation consists of a sequence of sedimentary rocks found in Iraq. The Injana Formation is characterized by a various of sediment types, including unconsolidated sediments, mudstone, sandstone, and clay-limestone layers (Sissakian et al., 2015). The dominant rocks in the areas of Tar Al-Najaf and Tar Al-Sayed are representative of the Injana Formation.

3.2. Nfayil Formation

It is exposed in the study area, having three sedimentary cycles and two members: An upper member and a lower member: A higher member and a lower membership. The Nfayil Formation's Lower Member is the first section of the formation and is uniquely located within the research region. Upper Member of the Nfayil Formation: The upper member is made up of three sedimentary cycles, which most likely reflect recurrent patterns of deposition and changes in the environment over time. Green Marl: Green marl is a sedimentary rock comprising each cycle.

3.3. Dibdibba Formation

The formation is made up of coarse and white sandston as well as a rare conglomerate.

3.4. Quaternary Sediment

In the studied area, various Quaternary sediments like the depositional forms of gypcrete, sabkha, sand dunes, fans of water, riverbanks, depression fill, and valley fill. Nonetheless, most of the Najaf-Karbala Plateau is shaded by gypcrete, which is the most prevalent sediment.

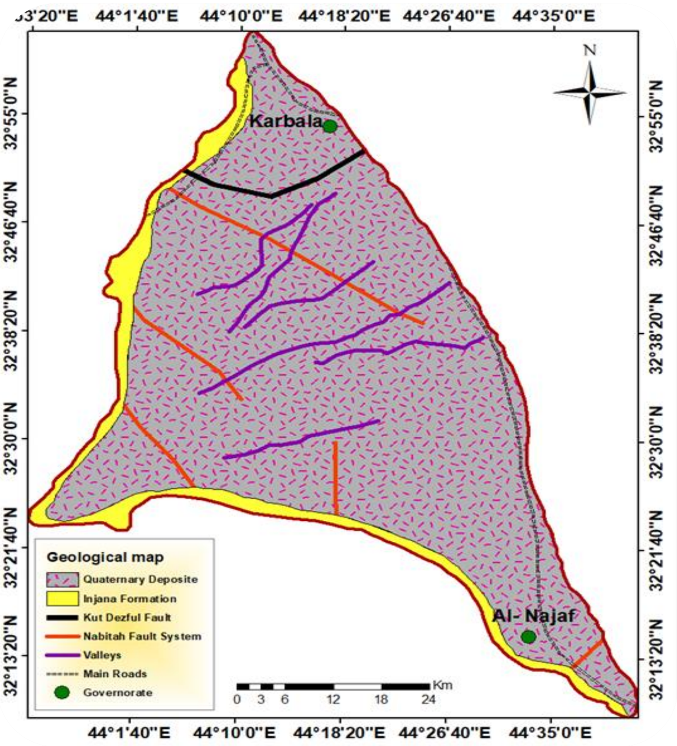

Fig. 2. Geological map of the Najaf-Karbala Plateau (Jassim and Goff, 2006)

4. Materials and Methods

The study area used a variety of methodologies and tools to analyze the hydrology and morphometry of the Al-Najaf - Karbala plateau. Hydrological analysis entails classifying streams into different orders and identifying the main drainage basins to understanding the patterns of water transport within the study area. This is accomplished by using Digital Elevation Model (DEM) raster data, which gives elevation information about the landscape. This DEM data offers a foundation for understanding the water dynamics on the Al-Najaf-Karbala plateau by simplifying the process of identifying watershed borders and categorizing stream orders. The description of hydrological analysis and process is illustrated in Fig. 3.

Morphometric analysis is the quantitative assessment of landforms' physical properties, known as morphometric analysis. This comprises information on basin area, slope gradients, and water flow patterns. Important details regarding the connections between various topographic features, such as the basin and Plateau formation and the division of watercourses into different stream orders, are revealed by this study (Table 1).

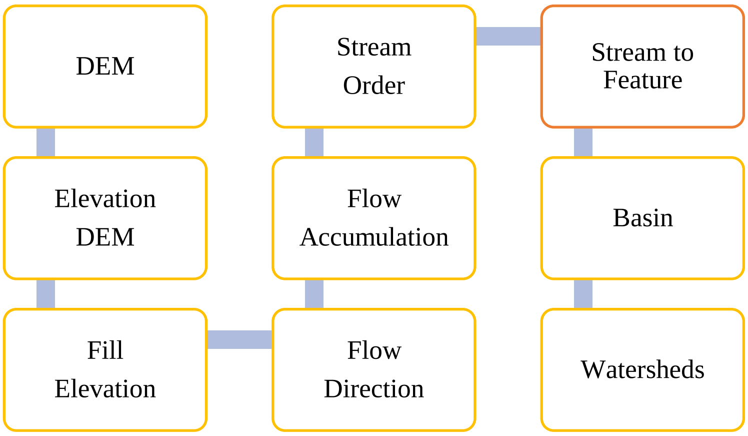

Fig. 3. Hydrological analysis of the Najaf-Karbala plateau

Table 1. Morphometric parameters mathematical equations

Parameters	Formula	Preface
Stream order (U)	Hierarchical rank	Strahler (1964)
Stream length (Lu)	Length of the stream	Horton (1945)
Bifurcation ratio	(Rb) Rb = Nu / Nu + 1; Nu = Total no. of stream segments of order 'u'; Nu + 1 = No. of segments of next higher order	Schumm (1956)
Perimeter (P)	The horizontal projection of its water divide	Zavoianu
Basin area (Ba)	The entire area is drained by a stream or system of streams	GIS
Drainage density (Dd)	Dd = Lu / Ba; Lu = Total stream length of all orders; Ba = Area of the basin (km^2)	Horton (1932)
Stream Frequency (Fs)	Fs = Nu / Ba ; Nu = Total no. of streams of all orders Ba = Area of the basin (km^2)	
Drainage texture (Dt)	Dt = Nu / P; Nu = Total no. of streams of all orders; P = Perimeter (km)	Horton (1945)
Form factor (Rf)	Rf = Ba / Lb^2; Ba= Area of the basin (km^2); Lb^2 = Square of basin length	
Basin Relief (R)	R = Hmax – Hmin/ length	Strahler (1952)

Remote sensing collecting data from a distance, usually via satellite or aerial photography, whereas Geographic Information Systems (GIS) offer a framework for organizing, analyzing, and displaying spatial data. These remote sensing and GIS methods are used to collect and analyze data for hydrological and morphometric evaluations. The study specifically makes use of Landsat OLI 8 and ASTER GDEM data, which offer incredibly comprehensive geographical information, to aid with the investigation. Data processing and analysis for the study are done using software programs such as ArcGIS version 10.4.1 and ERDAS IMAGINE version 14. In particular, ArcGIS's Hydrology toolkit extract data on geometric characteristics and stream orders. In zone 38N, the UTM coordinate system with the WGS-1984 datum is used to guarantees accurate georeferencing and spatial analysis (Al-Bhadili et al., 2022)

5. Results and Discussion

5.1. Hydrological Analysis

Using this process, the drainage systems, the main basin's boundaries, the fan's watersheds, and the stream order are described. The summary of the hydrological analysis exhibit in Fig. 4. The initial stages of this analysis encompass elevation assessment, fill elevation calculation, determination of flow direction, evaluation of flow accumulation, stream order classification, mapping of stream features, basin identification, and demarcation of watersheds, as illustrated in Fig. 4A to G. The flow direction within each cell is determined by the steepest descent, generally following a southwest-to-east direction. This analysis reveals that the drainage network's water divide, situated between the cities of Najaf and Karbala, splits the Al-Najaf-Karbala Plateau into six distinct watersheds (Huggett and Cheesman, 2002).

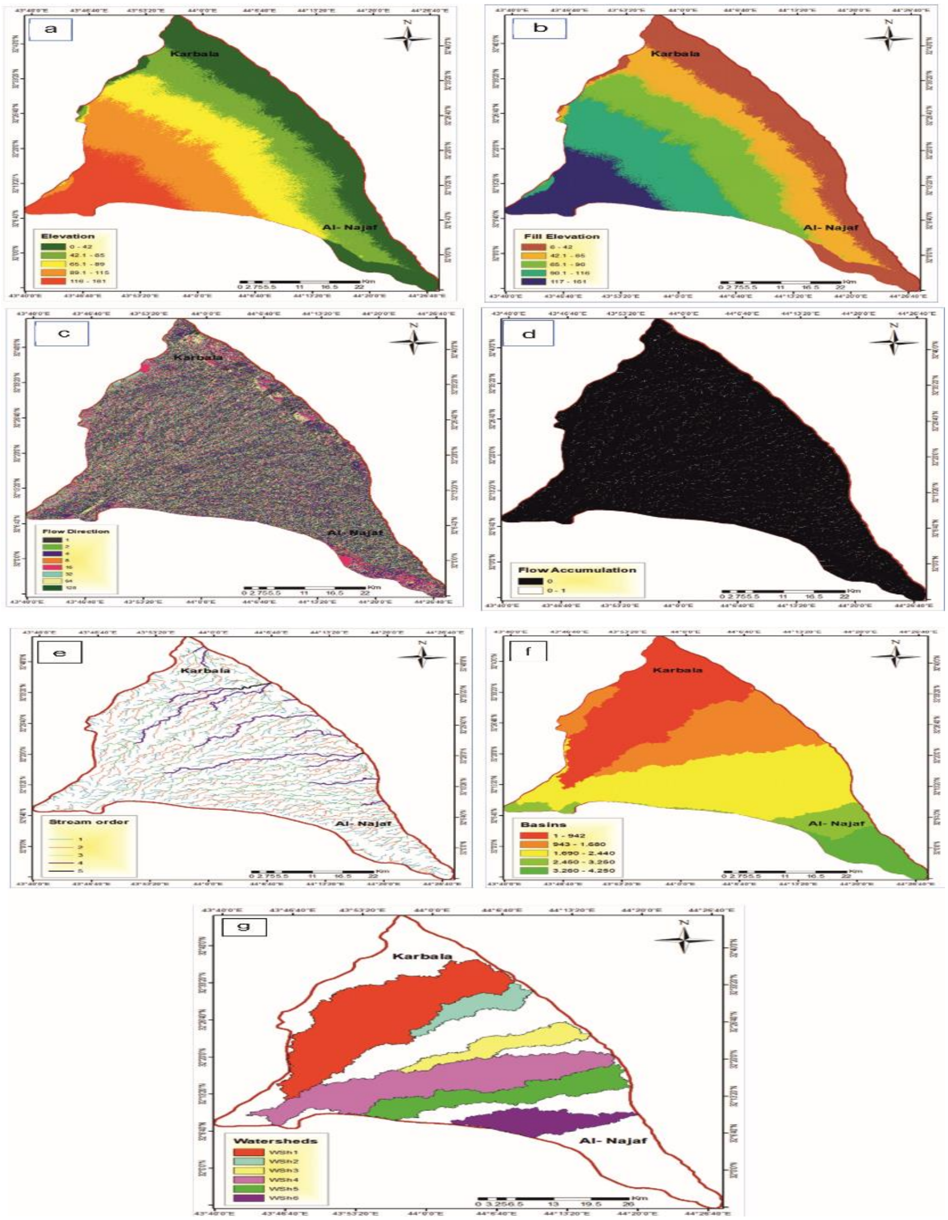

Fig. 4. a) Elevation b) Fill elevation c) Flow direction d) flow accuum e) Stream order f) Basin g) Watersheds

5.2. Morphometric Analysis

It is an analysis that makes use of mathematical formulas created by hydrological engineers to extract several watershed lengths, areas, and ratios. Using the GIS software environment, the morphometric variables are calculated using algorithms (Table 1). The parameters for morphometry were computed and presented in Table 2.

5.2.1. Stream order

Assigning stream orders, which aim to convey the hierarchical relationship among segments, is the first stage in evaluation of reservoirs for drainage. The number of streams is arranged in this study using Strahler's approach. The research area's stream ordering reveals that first-order streams have the highest intensity, which decreases as stream length (Lu) grows with stream order. In Wsh 1, there are more stream orders (431) than in Wsh 2, whereas in Wsh 2, there are fewer (63). Due to the greater slope between the fan's head and toe, this region is characterized by many stream orders. Stream ordering in the basin is chiefly governed by the geomorphology, elevation variations, and structural setting; specifically, many stream orders develop in response to gentle relief, homogeneous lithologies, nearby fault frameworks, and readily erodible sedimentary layers (Jasim and Goff, 2006) (Fig. 5).

Table 2. The morphometric parameters value for each watershed

Morphometric Parameter	Wsh 1	Wsh 2	Wsh 3	Wsh 4	Wsh 5	Wsh 6
Stream order (U)	431	63	89	281	121	95
Stream length (Lu)	52.42	23.32	29.79	56.68	40.62	27.19
Bifurcation Ratio (Rb)	2.26	1.68	2.25	2.43	2.13	2
Perimeter (P)	195.33	81.35	101.53	195.08	144.38	90.25
Basin Area (Ba)	596.75	92.51	127.69	447.16	225.32	141.16
Drainage density (Dd)	1.01	1.06	1	1.07	1.11	1.12
Stream Frequency (Fs)	0.72	0.68	0.69	0.62	0.53	0.67
Drainage Texture (Dt)	2.20	0.77	0.87	1.44	0.83	1.05
Form factor (Rf)	0.21	0.17	0.14	0.13	0.13	0.19
Basin Relief (R)	2.36	3.08	2.98	2.52	2.85	3.53

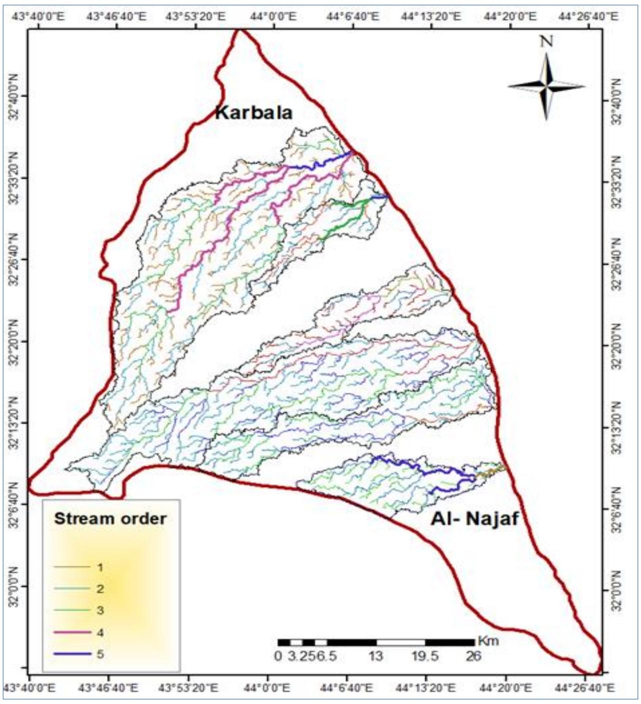

Fig. 5. Stream order map of the study area

5.2.2. Stream length (Lu)

Lu in hydrology and geomorphology alludes to the sum measurement of all the separate segments that make up a stream or river within a given watershed region. this evaluation is frequently carried out with GIS and uses information from DEM maps. In order to determine the interconnected network of streams and rivers within a defined watershed, elevation data must be analyzed as part of the GIS stream length calculation procedure. Several distinct stream segments, each with a unique length, make up this network. The cumulative stream length is calculated by adding the lengths of each individual segment (Al-Bhadili et al., 2022). It is evident from the data in Table 2 that Wsh 2 is the smallest watershed and Wsh 4 is the largest. This significant discrepancy results from Wsh 4's flatter gradient compared to Wsh 2's higher gradient. Because of this, Wsh 2's streams are somewhat shorter than Wsh 4's, which have longer stream. Additionally, it's critical to keep in mind that systemic factors such as fault lines and geological folding significantly influence the sizes, shapes, and patterns of watersheds, hence influencing their extend.

5.2.3. Watersheds area and perimeter (P)

Watershed area influences the surface stream flow volume ratio more than any other landform feature (Murphey et al., 1977). It significantly impacts the discharge point per unit area, where the smallest basin area experiences faster floodwater movement. Wsh1 has the largest watershed area, whereas Wsh 2 has the smallest, per Table 2. One important number that may be utilized to determine a watershed's size and shape in quantitative morphometric research is the watershed's perimeter (P). Table 2 shows that watershed 1 has the largest perimeter, while watershed 2 has the smallest.

5.2.4. Bifurcation ratio (Rb)

The bifurcation ratio (Rb) is a crucial geomorphological measure for analyzing and describing the branching pattern of streams within a drainage basin or watershed (Krenkel, 2012). Strahler (1964) estimates Rb by dividing the number of stream or channel segments of a certain order (usually lower order) by the number of stream segments of the next higher order. A branching pattern where smaller streams (lower order) are more prevalent than larger streams (higher order) is indicated if Rb is less than 1. A watershed's drainage pattern and network properties can be inferred from the value of Rb (low Rb).

This suggests a more distributed and dendritic drainage pattern typical of regions with high Rb geology and topography. When Rb is greater than 1, it is hypothesized that there are larger streams than microscopic ones. This implies a drainage system that is more hierarchical or trellis-like, which is characteristic of regions with more complex geology and tectonics (Strahler, 1964). Table 2 shows that Wsh 2 has the lowest Rb value (1.68), whereas Wsh 4 has the highest value (2.43). Steep slopes and low-permeability rocks are indicated by a high Rb value, which is also associated with the lithology and sediments of the area.

5.2.5. Drainage density (Dd)

Dd is a basic geomorphic characteristic that characterizes the system of rivers and streams that make up a watershed or drainage basin. Drainage density quantifies how extensively stream channels are distributed across a landscape; it is calculated by summing the lengths of all channels in a catchment and dividing that total by the basin's surface area (Deju, 1971). It is calculated by dividing the total length of all streams by the flow basin's whole area.

In Table 2, the Dd ratios vary from 1 to 1.12. Fig. 6 shows how Dd is distributed throughout the fan. The fan's center and lower sections contain the bigger value, while the upper part has the lesser value. As per Horton (1945) Dd comes in three different grades: bad, medium, and outstanding, ranging from 0.5 to 1.5 and 1.5 correspondingly. In contrast to the lower part, which is characterized by messing or impervious geomorphological materials, few plants, a decrease in reliefs and basins, and higher drainage density values, increases in topography, the density of underneath rocks (lineaments), and the strength of material can all be linked to lower drainage density levels.

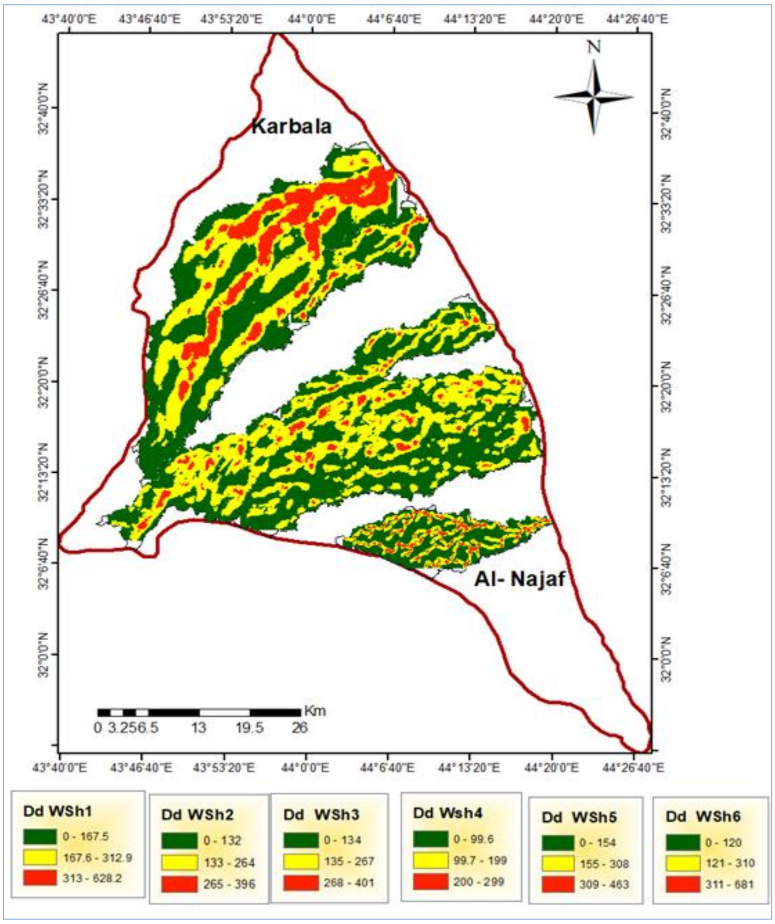

Fig. 6. Drainage density map study area

5.2.6. Drainage texture (Dt)

One important idea in lithology that illustrates the drainage texture is the approximate distance between drainage channels. It displays the total number of stream segment for every region perimeter (Horton, 1945). The mean dimension of the elements that comprise a certain geography is known as its texture. The drainage texture (T) is influenced by typical environmental factors such as temperature, precipitation, vegetation cover, soil type, infiltration rate, relief, and development stage. A low drainage density results in a coarse drainage texture, whereas a high drainage density creates a fine drainage texture (Deju, 1971).

Deju (1971) classified drainage network distances as fine (6–8), very fine (number >8), medium (4-6), coarser (2-4), and very coarse (number <2). King and Dornkamp (1971) In the early stages of the eroding process, it is regarded as coarse, and in the mature stage, as fine sediment. While large and resilient rocks form coarse textures, delicate or weak rocks uncovered by plants produce fine textures. Similar rocks produced in arid regions have finer textures than those produced in humid climates (Strahler, 1964).

According to Table 2, the Dt value in the Al-Najaf-Karbala Plateau ranges from coarse to extremely coarse, with the maximum value in Wsh 1 being 2.20 and the lowest in Wsh 2 being 0.77 (Smith, 2003).

5.2.7. Stream frequency (Fs)

Stream frequency, a vital component of morphometric analysis, represents the density of stream channels within a designated area. It is determined by calculating the total number of stream segments, encompassing all stream orders. Horton (1932) first introduced the stream frequency notion, represented as Fs. Stream frequency, which is sometimes called drainage frequency, is the overall quantity of streams sections in a given location, spanning all orders. It is highly correlated with drainage density. Among the factors influencing stream frequency are precipitation levels, lithology (rock composition), permeability, infiltration capacity (the land's ability to absorb water), relief (changes in landscape height), drainage basin morphology, and structural elements. These factors work together to influence the density and distribution of streams in a certain region.

Fig. 7 shows that the Fs values in the research region fluctuate, with 0.72 for Wsh 1, 0.68 for Wsh 2, 0.69 for Wsh 3, 0.62 for Wsh 4, 0.53 for Wsh 5, and 0.67 for Wsh 6. These Fs values demonstrate a strong relationship between drainage basin characteristics and stream frequency across all watersheds in the research. Higher Fs values indicate the presence of impermeable materials. More surface runoff and lower infiltration rates could be the outcome of these conditions, as well as a particularly steep basin gradient and lower drainage density (Dd) and Fs values. Rekha et al. (2011) state that these conditions could increase the risk of flooding and landslides

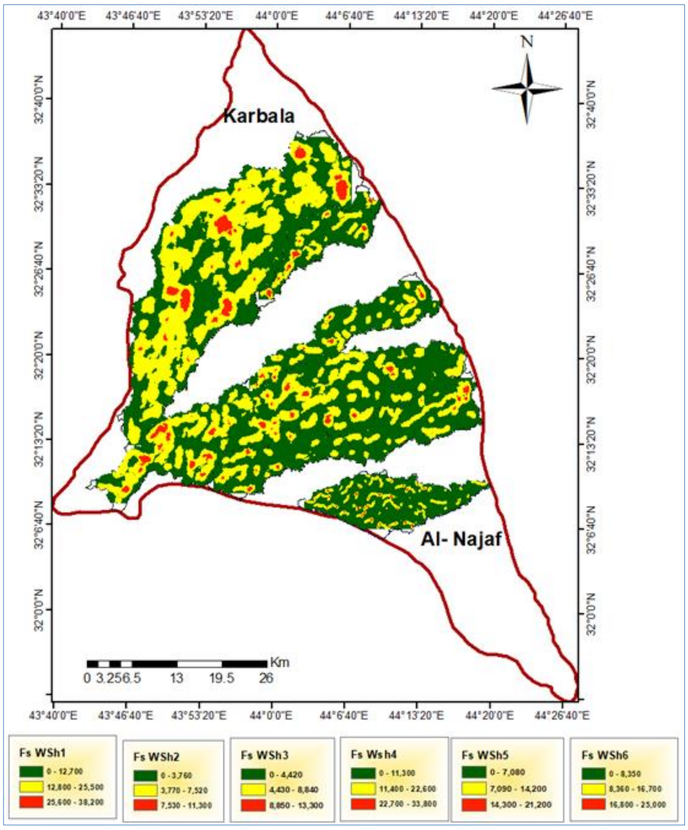

Fig. 7. Stream frequency map of the study area

5.2.8. Form factor (Rf)

The measure of the basin's area to its length squared is known as the formal parameter (Rf). Higher Rf values suggest larger basins, while smaller basins typically have lower Rf values. A wider basin has a higher Rf value than an elongated basin, which typically has a lower Rf value, claims Deju (1971). Table 2 lists the Rf values for the six watersheds (Wsh 1 through Wsh 6). For Wsh 1, Wsh 2, Wsh 3, Wsh 4, Wsh 5, and Wsh 6, the corresponding values vary from 0.17 to 0.21. All these watersheds exhibit an elongated or fern-like structure, characterized by Rf values below 0.5. This configuration implies that, despite having streams of similar length, a fan-shaped watershed generates increased runoff. However, the fern-shaped basin suggests a decreasing discharge rate, requiring more time for accumulation (Raghunath, 2006).

5.2.9. Relief aspect

The relief aspect factors encompass several elements, including the highest and lowest elevations in the study area and the relief of the catchment area, or the variation among the basin's two highest points. Basin relief values can vary in regions with complex topography, hilly terrain, or flat landscapes. Increased relief is associated with higher flow rates, subsidence, and reduced infiltration rates, as discussed by Patton and Baker (1976). In the Al-Najaf-Karbala plateau, the highest elevations are found in the northern and northeastern parts, reaching up to 180 m, while the lowest elevations are situated in the central and southwestern portions (Table 2). The relief aspect values for the six watersheds (Wsh 1 to Wsh 6) range from 2.36 to 3.53, with each watershed exhibiting distinct relief characteristics, as shown in Fig. 8.

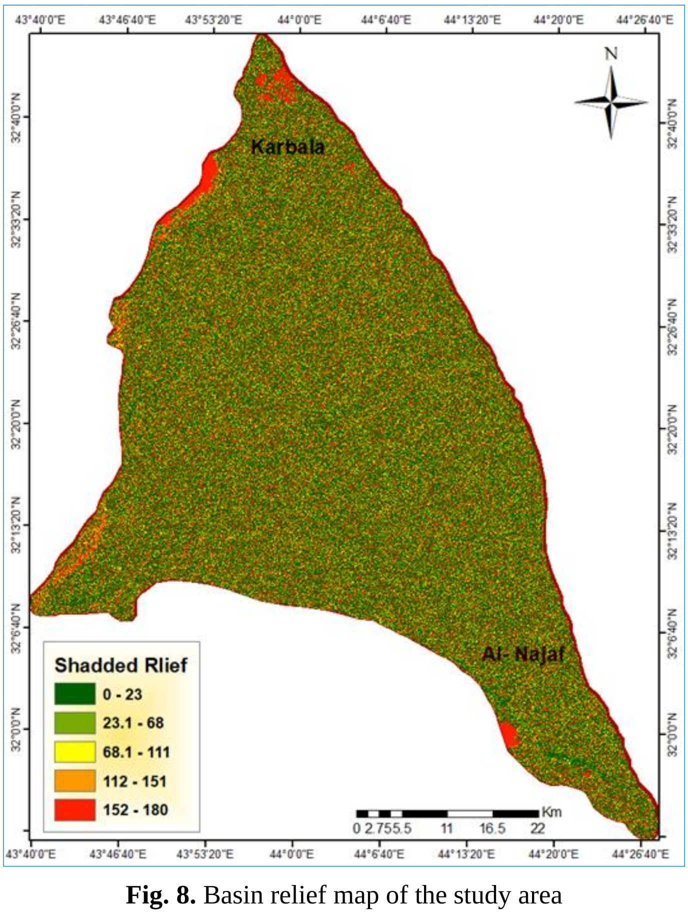

Fig. 8. Basin relief map of the study area

6. Conclusions

- The morphotectonic and hydrological analyses were applied using DIM from the remote sensing data and GIS (Arc toolbox, Spatial Analyst tool).
- The hydrological analysis reveals that the Al-Najaf-Karbala Plateau comprises six primary watersheds, with Wsh 1 being the largest and Wsh 2 the smallest. Additionally, the predominant flow direction within this fan is from southwest to east.

- The morphometric analysis highlights a noteworthy association between the quantity of stream orders and the morphological attributes within the watersheds of this plateau. It is observed that the watersheds in this area have a maximum of five stream orders.
- Area and perimeter analyses reveal that Wsh 1 is the largest watershed in the study area, whereas Wsh 2 is the smallest. These size disparities reflect the combined influence of surface topography and underlying structural controls.
- The Al-Najaf-Karbala fans exhibit a notably high bifurcation ratio, which can be attributed to the robust connection between this ratio and the steepness of the slope in the field of study.
- The greater drainage density was noted in the central and lower regions of the fan, whereas the lower drainage density was noted in the upper portion of the fan.
- The Dt value spanned from coarse to extremely coarse within the Al-Najaf-Karbala plateau. The stream frequency exhibits a robust correlation with the drainage basin across all watersheds in the study area, with higher values indicating the presence of impermeable primary minerals.
- Watersheds characterized by an RF value below 0.5 display an elongated or fern-like configuration. In contrast, a fan-shaped watershed generates increased runoff since its streams are relatively uniform in length. However, the fern-shaped basin implies a gradual decrease in the discharge rate, resulting in a longer time for water accumulation.

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