IHJPAS. 36(2)2023

Ibn Al-Haitham Journal for Pure and Applied Sciences
Journal homepage:jih.uobaghdad.edu.iq

Application of GIS and Remote Sensing Techniques for Hydromorphometric Analysis of Wadi Al-Mohammadi Basin, Western Iraq

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Article history: Received 3 Augest 2022, Accepted 9 October 2022, Published in January 2023.

doi.org/10.30526/36.2.2970

Abstract
Hydromorphometric analysis as a method is considered one of the most reliable and used methods in solving hydrological problems. Where it is possible to know the volume of runoff and the rest of the elements that enter into the water balance. Geographical Information System and Remote Sensing is the technique that used the hydro-morphometric analysis of Wadi Al-Mohammadi basin. Wadi Al-Mohammadi, located in the Western Desert, is one of the main valleys that flow into Euphrates River. It is considered an important basin, because of its many characteristics, including its relatively large area and the amount of water drained through, which is used mainly in watering livestock and agriculture, in addition to industrial purposes such as the production of washed sand, gravel that scattered on both sides of the valley. The hydrological analysis included several steps, which gave the results of the flow accumulation with the highest value in the lower part of the basin. The results represented by form characteristics confirm that the shape of the basin is far from the round shape, which reflects the basin's characteristics with the regular surface flow in time and relatively low drainages. Wadi Al-Mohammadi basin has reached the 5th order to flow into Euphrates River. It has two types of drainage patterns, the dendritic pattern, and the parallel pattern. Wadi Al-Mohammadi basin is categorized as extremely low drainage density, very low drainage frequency, very coarse drainage texture, lower infiltration number, and low relief slope. Based on the results, the basin is characterized by an almost flat plateau surface, with a gradual slope homogeneous and good permeable soil conditions, and in other parts influenced by the structural phenomena under the surface, the high permeability of sediments over which streams pass, higher the infiltration and lower runoff.

Keywords: Remote Sensing, GIS, Hydromorphometric Analysis, Wadi Al-Mohammadi, Western Desert.

1. Introduction

Remote Sensing (RS) as a technique is one of the most important technologies that can provide us with information and data that cover large areas and reduce the cost of this required data [1]. In addition to Remote Sensing, Geographical Information Systems (GIS) is a tool that has a great ability to deal with the data and information we obtain from the analysis of satellite images, and thus help us in developing our understanding of the environment around us. The study of the morphometric characteristics of water basins is of great importance in water harvesting studies, because of its hydrological indications represented by the characteristics of water drainage, which in turn affects the activity of various geomorphological processes in the water basin. The quantitative description of the geometry of the drainage basins is a major advance in the field of the development of morphometric techniques. These parameters help identify basins and compare their characteristics, [2]. This description helps identify the drainage network, compare the characteristics of several drainage networks and examine the impact of variables such as rainfall, lithology, rock structure, etc. on the drainage network, [3].

The geomorphometry for a basin is applied to the analysis of the earth's surface in a quantitative term, and therefore it is a science concerned with the study of the morphometric characteristics of water basins. It is considered a modern analytical approach to the representation of the terrain through mapping by modern programs such as ArcGIS. Morphometric analysis is a method that analyzes the measurements and shape of the Earth as a mathematical evaluation [4]. Morphometric analysis is very necessary for any basin, especially in hydrological studies, as it can determine the locations of water availability and quality, as well as to make plans and develop them for the management of water resources in the basin.

Many researchers have studied morphometric analysis using these new techniques like [5] studying Alluvial Fan of Wadi Al-Batin from the perspective of hydro-morphometric analysis. [6] they presented a detailed work of the morphometric measurements of the El-Arish basin in central and North Sinai. [7] using hierarchical process and prioritization to study Hydro-morphometric of upper Rihand basin, India. In Wadi Al-Mohammadi basin, there are no studies concerned with hydro-morphometric analysis, especially the use of the remote sensing technique. Although it is rich in studies that have examined it, such as a study that was presented by [8] studied the suitability of groundwater and surface water resources in the Western Desert. Determine the hydrogeologic conditions and characteristics of aquifers in Western Iraq were studied by [9,10]. [11,12] focus on the analysis of climatic parameters to determine the water balance and groundwater recharge. [13] Estimate the annual runoff of Wadi Al-Mohammadi basin using SWAT model.

Digital Elevation Model (DEM) was used widely in the analysis of drainage basins. Landform changes in the Wadi Al-Mohammadi basin are identified using morphometric analysis of the basin, in addition to their evaluation and description over millions of years. These landforms were formed by the influence of climate, the nature of rocks, and other major elements capable of forming geomorphological processes. The analysis of the hydro-morphometric characteristics of Wadi Al-Mohammadi basin is the main objective of this study and the extraction of the main hydrological watersheds by conducting hydrological analysis and knowing the nature of their relationship with the movement of surface runoff in the basin. In addition to the structural analysis and study of the drainage network of the study area based on the structural and geological information and available data from satellite images.

2. Study Area

Wadi Al-Mohammadi is one of the seasonal (ephemeral) valleys in Western Desert that drains into the Euphrates River. It is located 15.1 km south of Heet. The western border of the basin is represented by the area of the Kilo-160, while the eastern border is represented by the Euphrates River, and the basin is bounded from the north by Wadi Al-Hajiya of the Kubaisa basin, and the Abu-Jir depression represents the southern border of the basin.

The international highway (Baghdad-Syria, and Jordan) passes through the center of the basin. The basin coordinates are: Latitudes 33° 34′ 18.10″N–33° 4′ 44.40″N and longitudes 41° 55′ 3.80″E–42° 56′ 31.60″E **Figure 1**. The perimeter of the basin is estimated at 487.0 km, while the total basin covers an area of 2286.82 km^2. The study area gradually rises towards the west, where it ranged in elevation from 52.0 to 367.0 m above sea level.

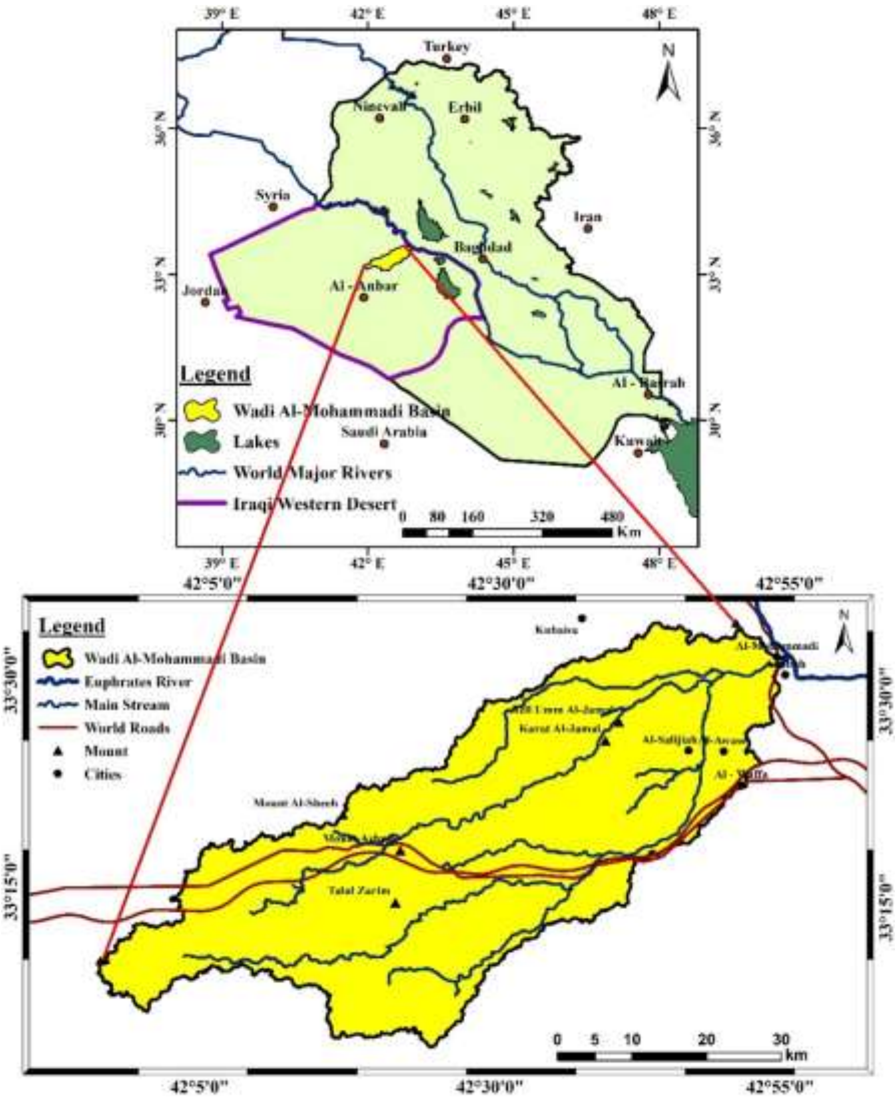

Figure 1. Location map of the study area

3. Geological Setting

The study area was characterized by the presence of several outcrop formations configured from the oldest to the youngest, it's Ms`ad Formation (Late Cretaceous, Cenomanian – Turonian) with an area of about 96 $km^2$, Euphrates Formation (Early Miocene) with an area of about 591 $km^2$, Fat`ha Formation (Middle Miocene) with an area of about 56 km^2, Nfayil Formation (Middle Miocene) with an area of about 939 km^2, Zahra Formation (Pliocene – Pleistocene?) with an area of about 594.8 km^2 and in addition to Quaternary Deposits with an area of about 10 km^2 [14] **Figure 2**.

Stratigraphically, the wells of the study area penetrate many stratigraphic sequences dating back to different geological periods, and the deepest of these wells is the exploration well (KH7/7), which was carried out by the company of Consortium Yugoslavia [15] with a depth of 863 m and shows deposits from the Jurassic to the Miocene periods. According to the information of this company, the most important stratigraphic sequences penetrated in the basin are the Tertiary sequences. A fencing diagram has been drawn for the basin and the adjacent areas for some keyholes belonging to the company of Consortium [15] **Figure 3**.

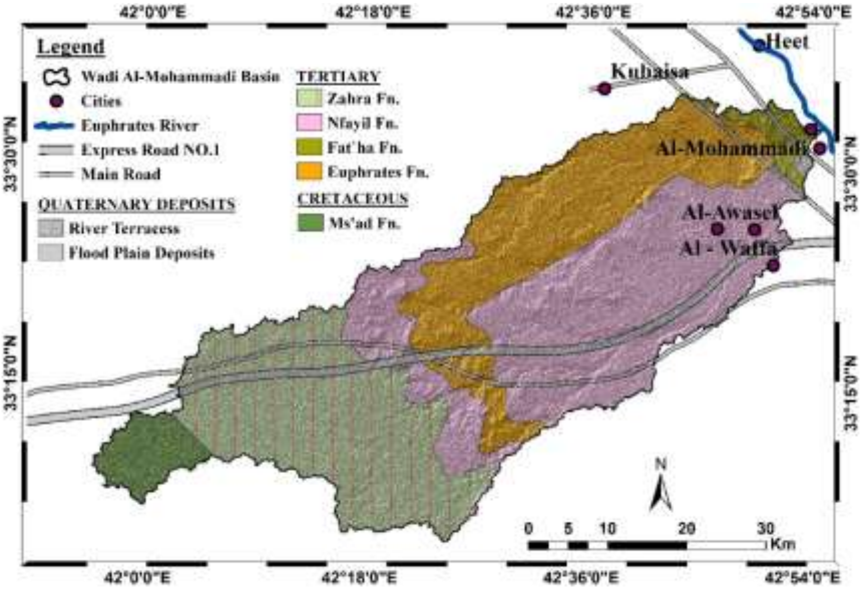

Figure 2. Geological map of the study area modified from [14]

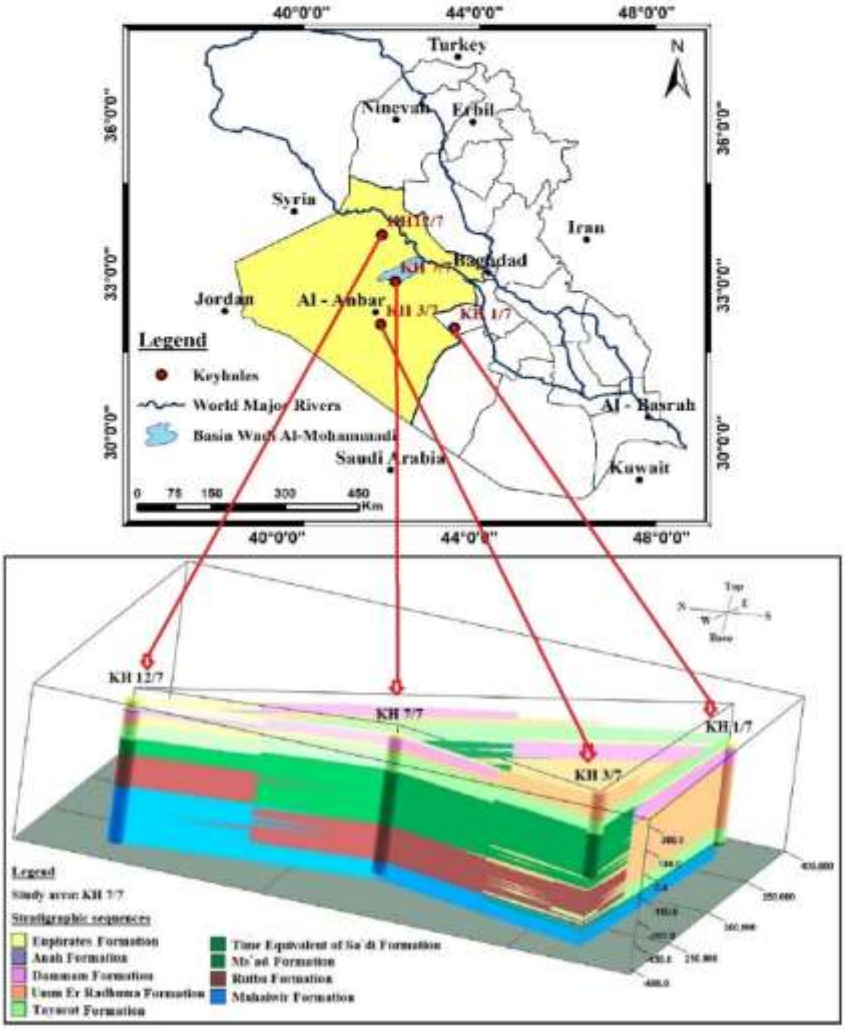

Figure 3. Fence diagram for the basin and the adjacent areas

4. Materials and Methods

Hydromorphometric analysis mainly relies on the DEM raster data to create a hydrological system. In this study, the DEM of the SRTM type was downloaded with a spatial resolution of 30 m from the USGS website. Essentially, the image interpretation of the Digital Elevation Model creates a very important tool for researching water harvesting solutions. LANDSAT 8 satellite images it is also the data used for Hydromorphometric analysis, Wadi Al-Mohammadi basin is covered by one Landsat satellite scene zone (Path 170 and Row 37 of the scene) with a spatial resolution of 30 m and 15 m were downloaded from http://earthexplorer.usgs.gov/. The morphometric and hydrological analyses were done using GIS and Remote Sensing techniques. Geographic Information system (ArcGIS) version 10.8 is used for drawing the thematic maps. Remote sensing techniques (RS) using satellite images are used as a suitable tool for morphometric analysis, by including basin features such as main channel gradient and elevation, predictions of stream discharge, and precipitation.

The morphometric analysis of the Wadi Al-Mohammadi basin has been achieved through measurements of basin characteristics (catchment area, basin length, basin width, basin form factor, compactness coefficient, circularity ratio, elongation ratio) and water network characteristics (stream order, stream number, stream lengths, bifurcation ratio, drainage density, drainage frequency, drainage texture, and infiltration number) and relief characteristics (basin relief, relief ratio, and ruggedness number). The GIS program environment and mathematical formulae are utilized to calculate morphometric parameters utilizing the fundamental mathematical techniques **Table 1**.

5. Results and Discussion

5.1 Hydrological Analysis

Hydrological analysis can be summarized in several steps, the first of which is to extract the DEM for the study area, then fill elevation, flow direction, flow accumulation, stream order, stream to feature, basin, and watersheds. Most topographic surfaces have low points (which may sometimes be processing errors during the conversion of the surface to matrix format) that must be filled before any analysis can be carried out, this is called the process of filling the sinks (fill elevation) as shown in **Figure 4**. The Fill tool is used to reset the values of all craters and abnormal concavities that the program will find. So that the water can slope through the heights from one cell to another within the model in a way that enables all cells to drain their water to other cells in a smooth manner in line with the topography of the land. The failure of this process will lead the program to search for the next place to drain the water within the same cell, and will not find it, which will make the statistical operations of the program in calculating the terrain rotate in an infinite vicious circle and will not achieve a result.

The direction of flow determines the direction in which the water will flow in a given cell, based on the direction of maximum drop in each cell [16]. The flow direction in the Wadi Al-Mohammadi basin is from the southwest to the northeast, that is, towards the Euphrates River. Whereas, the direction of a flow corresponds to the general direction of surface water flow in valleys **Figure 5**.

Flow accumulation is the tool that calculates the total flow in the output raster for all cells flowing into each downslope cell. For each cell, it is possible to determine its flow accumulation value by counting the number of cells that pass through that cell, it will be harder to induce runoff in the area if the flow accumulation value is smaller [17]. Greater flow accumulation values will make runoff simpler to form in the area. The direction of travel from each cell is shown in the top left image of **Figure 6**, and the number of cells flowing into each cell is shown in the top right image of **Figure 6**. The higher value of flow accumulation of the Wadi Al-Mohammadi basin is in the lower part of the basin as shown in **Figure 7**.

Table 1. Mathematical equations for calculating morphometric parameters

Morphometric parameters		Symbol	Equations	References
Basin characteristics	Catchment Area	A	The entire area.	Authors by GIS
	Basin Length	Lb	Distance in a straight line from the mouth of a basin to the place where the direction of the line via the main stream's source intersects the water divide.	Authors by GIS
	Basin Width	Wb	$Wb\ (km) = \frac{A\ (km^2)}{Lb\ (km)}$; A: Catchment area (km^2); Lb: Basin length (km).	Authors by GIS
	Basin Form Factor	Rf	$Rf = \frac{A}{Lb^2}$; A: Catchment area (km^2); Lb: Basin length (km).	[18]
	Compactness Coefficient	Cc	$Cc = \frac{P}{Pc}$; P: Basin perimeter (km); Pc: The perimeter of a circle has the same area as the basin (km).	[18]
	Circularity Ratio	Rc	$Rc = \frac{A}{Ac}$; A: Catchment Area (km^2); Ac: The area of a circle equals the perimeter of the basin itself (km^2).	[18]
	Elongation Ratio	Re	$Re = \frac{Dc}{Lb}$; Dc: The length of the diameter of a circle having the same area as the drainage basin (km); Lb: The maximum length of the basin (km).	[18]
Water network characteristics	Stream Orders	U	Hierarchical rank.	[19]
	Stream Number	Nu	The number of streams.	Authors by GIS
	Stream Length	Lu	Length of the stream.	Authors by GIS
	Bifurcation Ratio	Rb	$Rb = \frac{Nu}{Nu+1}$; Nu: The number of streams of a given order; Nu+1: The number of streams of the next order	[20]
	Drainage Density	Dd	$Dd = \frac{\sum Lu}{A}$; Lu: The total lengths of the streams (km); A: The total catchment area (km^2).	[21]
	Drainage Frequency	Fd	$Fd = \frac{\sum Nu}{A}$; Nu: The number of streams; A: The total catchment area (km^2).	[21]
	Drainage Texture	Td	$Td = \frac{\sum Nu}{P}$; Nu: Number of streams; P: Basin perimeter (km).	[2]
	Infiltration Number	If	$If = Dd * Fd$; Dd: Drainage Density (km/km^2); Fd: Drainage Frequency (km^{-2}).	[22]
Relief Characteristics	Basin Relief	H	$H = H_{max} - H_{min}$; Highest and lowest point of the valley basement.	[23]
	Relief Ratio	Rh	$Rh = \frac{H}{Lb}$; H: Basin Relief (m); Lb: The maximum length of the basin (km).	[20]
	Ruggedness Number	Nr	$Nr = H * Dd$; H: Basin Relief (km); Dd: The Drainage density (km^{-1}).	[24]

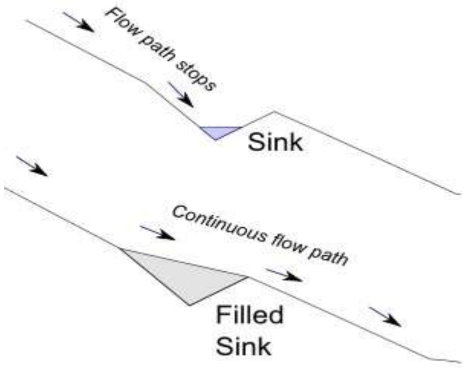

Figure 4. The process of filling the sinks

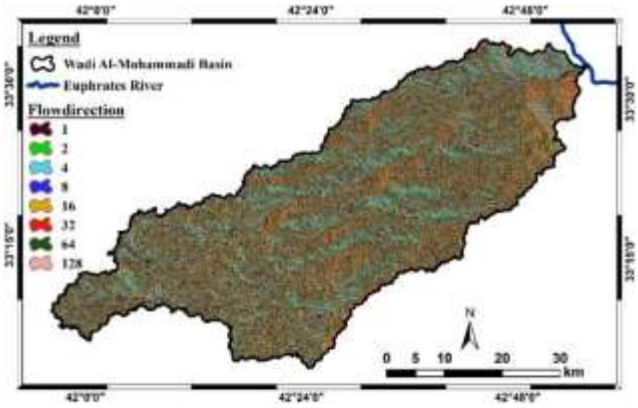

Figure 5. Flow direction map of the Wadi Al-Mohammadi basin

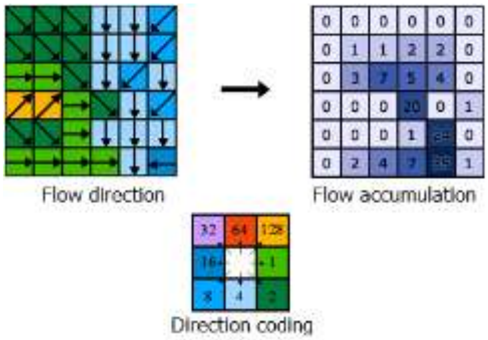

Figure 6. Determining the accumulation of flow

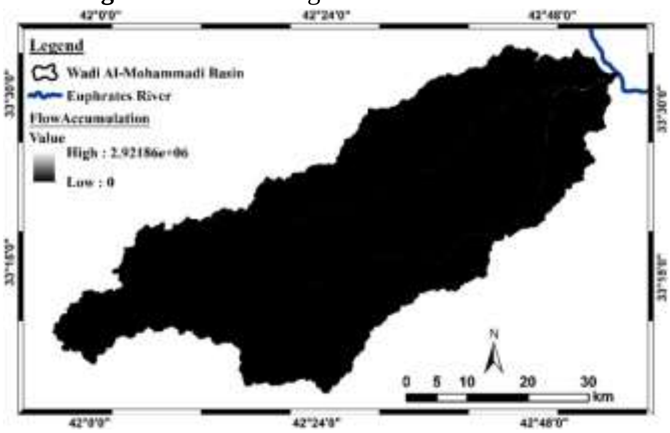

Figure 7. Flow accumulation map of the Wadi Al-Mohammadi basin

5.2 Morphometric Parameters

5.2.1 Basin Characteristics

These characteristics include the study of the catchment area and form dimensions of the basin for their close relationship in determining the water collected in the basin.

5.2.1.1 Catchment Area (A)

The total area of Wadi Al-Mohammadi basin is about 2286.8 km^2, calculated by the GIS program by using the DEM layer. It consists of seven sub-basins **Figure 8** and **Table 2**, these basins varied in the ratio of their area to the total area of the basin. Highest percentage was recorded in the sub-basin (SB3), which scored 27.82%, with a total area of 636.12 km^2. While sub-basin (SB1) recorded the lowest percentage, and scored 3.49%, with a total area of 79.79 km^2.

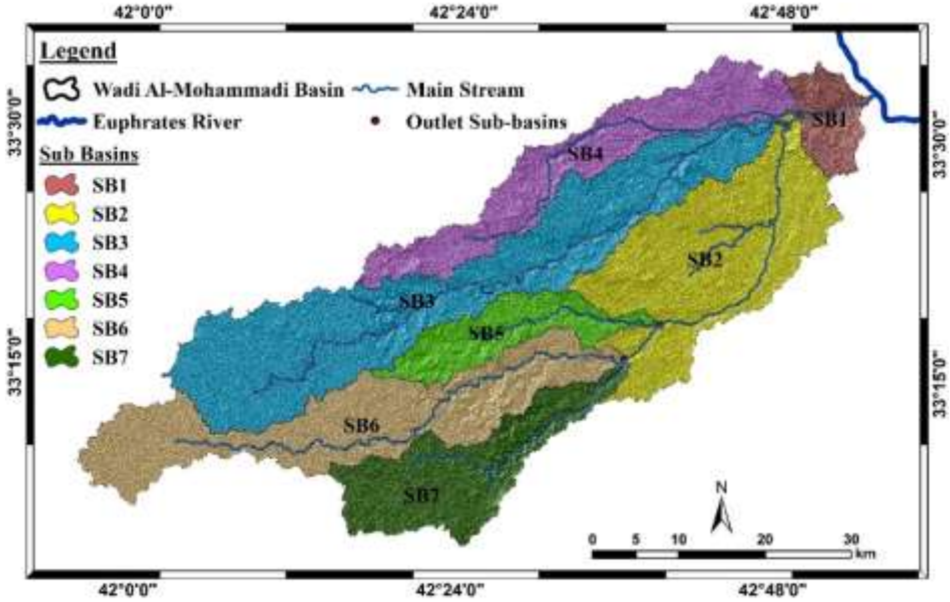

Figure 8. Sub-basins of Wadi Al-Mohammadi basin

Table 2. Area and perimeter of Wadi Al-Mohammadi Sub-basins

Sub Basin	Area km^2	Area %	Perimeter km
SB1	79.79	3.49	69.00
SB2	453.84	19.85	216.00
SB3	636.12	27.82	331.00
SB4	290.03	12.68	232.00
SB5	143.57	6.28	136.00
SB6	431.39	18.86	289.00
SB7	252.09	11.02	166.00
SUM	2286.82	100.00	

5.2.1.2 Basin Length (Lb)

The length of Wadi Al-Mohammadi basin was measured from its mouth point on the right bank of the Euphrates River to the farthest point in the perimeter, where its length reached 101 km **Figure 9**.

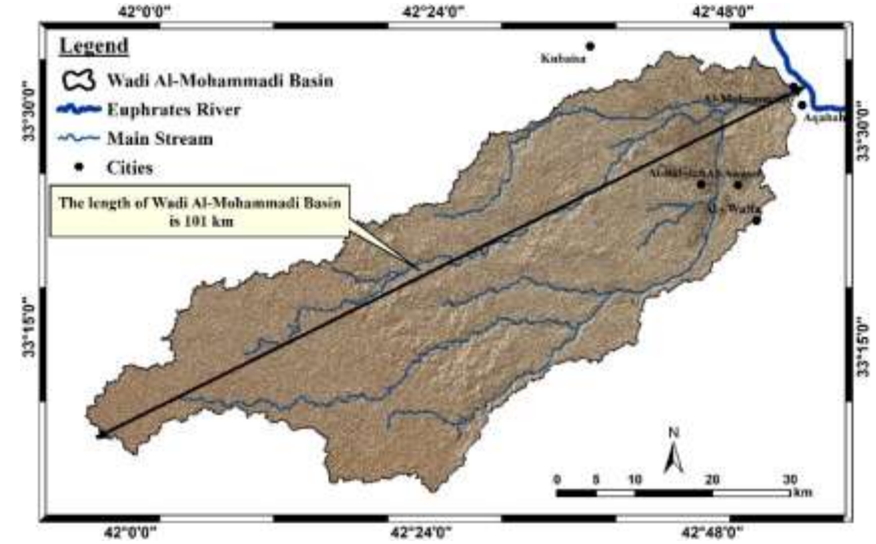

Figure 9. The length of Wadi Al-Mohammadi basin

5.2.1.3 *Basin Width (Wb)*

Basin width is the straight transverse distance between the two furthest points on the basin perimeter. Wadi Al-Mohammadi basin, the average width of the basin was 22.64 km.

5.2.1.4 *Basin Form Factor (Rf)*

Wadi Al-Mohammadi basin, the basin form factor is 0.22. This value indicates that it is far from round basin shapes, and this is due to the nature of the rocks and the prevailing climate in those regions.

5.2.1.5 *Compactness Coefficient (Cc)*

Wadi Al-Mohammadi basin, the compactness coefficient is 2.87. The increase in the ratio of the cohesion of the perimeter confirms that the shape of the basin is closer to a rectangular shape than to a regular circular shape. This is due to the fact that most of the basin valleys, whose long axes coincide with the directions of the lineament structures accompanying the main faults, led to an increase in their lengths at the expense of their width.

5.2.1.6 *Circularity Ratio (Rc)*

Wadi Al-Mohammadi basin, the circularity ratio is 0.12. This low value indicates that the basin is generally away from the circular shape, which makes the possibility of floods low.

5.2.1.7 *Elongation Ratio (Re)*

Wadi Al-Mohammadi basin, the elongation ratio is 0.53. This ratio indicates the basin is elongated. It indicates that the Wadi Al-Mohammadi basin extends longitudinally, and this may be attributed to the hard rock formations represented by carbonate rocks with a wide spread in the study area, as well as the cracks and faults scattered in the basin, all of which made the basin tend to have a rectangular shape.

5.2.2 Water Network Characteristics

Studying the characteristics of the drainage network contributes to knowing the characteristics of the water basin area, by finding the relationship between the stream orders and their drainage area on the one hand, and between the drainage network and its relationship to the basin dimensions and natural properties (geology, climate, slope, soil, etc.) on the other hand.

5.2.2.1 *Stream Orders (U)*

The study of stream orders is useful in knowing the volume of water discharge, estimating the velocity of flow, and possibly predicting flood risks. Strahler's system [19] of ordering streams, which is a slightly modified Hortons's system, has been followed because of its simplicity and it is one of the most common and widely used methods for determining the stream orders of water basins in arid and semi-arid areas. It became clear through the analysis of the drainage network in

Wadi Al-Mohammadi basin that it has reached the 5th order to flow into Euphrates River, and this indicates the large and wideness of the drainage network throughout the basin **Figure 10**.

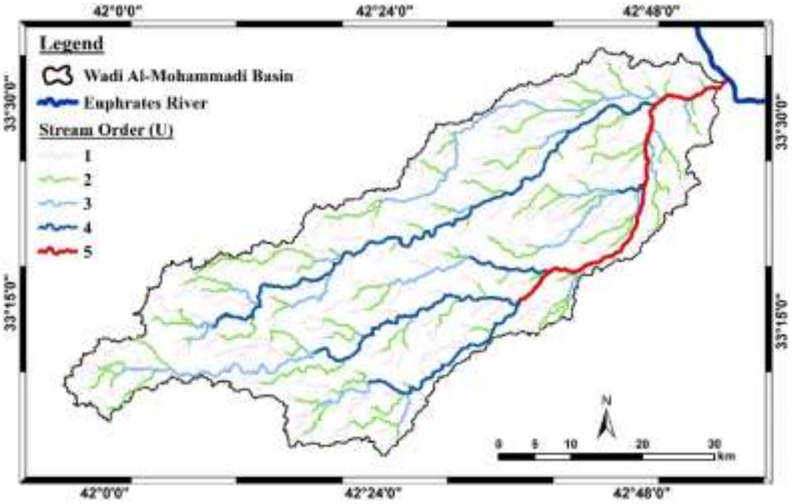

Figure 10. The stream orders of Wadi Al-Mohammadi basin

5.2.2.2 *Stream Number (Nu)*

The study of the number of streams is an integral part of the study of stream orders, which are of interest to morphometric studies. The total number of streams in Wadi Al-Mohammadi basin amounted to 471 streams, of which 353 streams represent the first order, the second order represents 88 streams, the third-order represents 24 streams, and the fourth-order represents 5 streams, and 1 stream in the fifth order. Drainage patterns of stream networks from Wadi Al-Mohammadi basin have been observed mainly of two types. They are the dendritic pattern that reflects homogeneous and good permeable soil conditions, and the parallel pattern, which indicates the influence of the structural phenomena under the surface, which are abundant in the study area.

5.2.2.3 *Stream Length (Lu)*

The study of the lengths of the stream is useful in determining the velocity of flow, which decreases with the increase in lengths, especially if these lengths are coupled with widening, they increase the percentage of the amount of water lost through evaporation or infiltration, and the opposite occurs (Increase flow velocity) in the decrease of stream length. The total lengths of the streams in Wadi Al-Mohammadi basin amounted to 1684 km, of which 765 km are the lengths of the first order, while the lengths of the second-order represent 453 km, the lengths of the third-order represent 228 km, the lengths of the fourth-order represent 183 km and 55 km of the fifth order.

5.2.2.4 *Bifurcation Ratio (Rb)*

The bifurcation ratio represents the relationship between the number of streams for two successive orders, as it is one of the important characteristics of the drainage network as it is one of the factors controlling the rate of water discharge. Higher values of the bifurcation ratio indicate a higher density of the discharge. The bifurcation ratio of Wadi Al-Mohammadi basin ranged between 3.67 and 5, and the rate of bifurcation ratio is 4.42.

5.2.2.5 *Drainage Density (Dd)*

Wadi Al-Mohammadi basin, the drainage density is 0.74 km^{-1}. According to [25] the drainage density of Wadi Al-Mohammadi basin is categorized as extremely low, and this low value indicates a high infiltration capacity of the soil in which the streams run, with little variation in the topographic heights and a lack of vegetation cover. The drainage density is increased from southwest to northeast with a higher value in the eastern part of the basin, **Figure 11**.

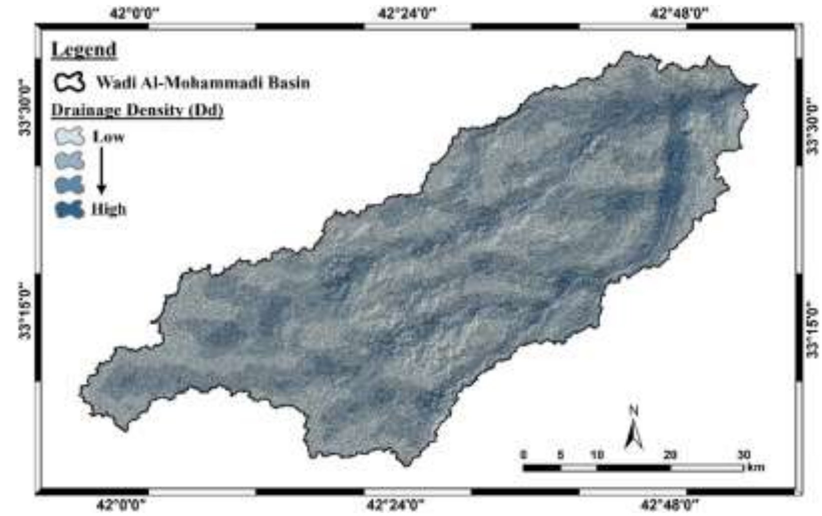

Figure 11. Drainage density of Wadi Al-Mohammadi basin

5.2.2.6 *Drainage Frequency (Fd)*

It is expressed as the ratio between the number of streams (Nu) for all stream orders of a given basin to the area of the basin (A) [2]. It reflects the abundance of streams per square kilometer, and it is possible to identify many hydrological and geomorphological characteristics, as the values of drainage frequency are related to the rocky nature, climate, terrain factor, and the abundance and presence of natural vegetation. Wadi Al-Mohammadi basin, the drainage frequency is 0.206 km^{-2}. According to [25] the drainage frequency of the Wadi Al-Mohammadi basin is categorized as very low, and this low value indicates the high permeability of sediments over which river streams pass.

5.2.2.7 *Drainage Texture (Td)*

It is the total number of stream segments of all orders in a basin per perimeter of the basin. It depends upon several natural factors such as rainfall, climate, vegetation, infiltration capacity, rock and soil type, relief, and stage of development [2]. Strahler [19] has classified drainage texture into five different textures i.e., very coarse <2, coarse 2 - 4, moderate 4 - 6, fine 6 – 8, and very fine >8. The drainage texture of the Wadi Al-Mohammadi basin is 0.967 and categorized in nature as very coarse.

5.2.2.8 *Infiltration Number (If)*

Infiltration Number is defined as the product of Drainage Density (Dd) and Drainage Frequency (Fd) [22]. Wadi Al-Mohammadi basin has a low infiltration number with a value was 0.0605 km^{-2}. The lower the infiltration number the higher will be the infiltration and consequently, the lower will be the runoff.

5.2.3 Relief Characteristics

The study of relief characteristics is of great importance in morphometric studies, as a result of its important implications in knowing the erosion capabilities of streams and estimating the volume of sediments transported by streams, which increases with the increase in the degree of erosion. This is in addition to knowing the nature and quality of the landforms associated with them, the geomorphological stage that these water basins pass through it, and their relationship to other basin characteristics represented by the water network of each basin and the areal and morphological characteristics, etc.

5.2.3.1 *Basin Relief (H)*

It is the elevation variation between the highest and lowest point of the valley basement [23]. Wadi Al-Mohammadi basin ranges from 52 to 367 m, therefore the relief of Wadi Al-Mohammadi basin is 315 m. It shows the different values of the relief basin **Figure 12**.

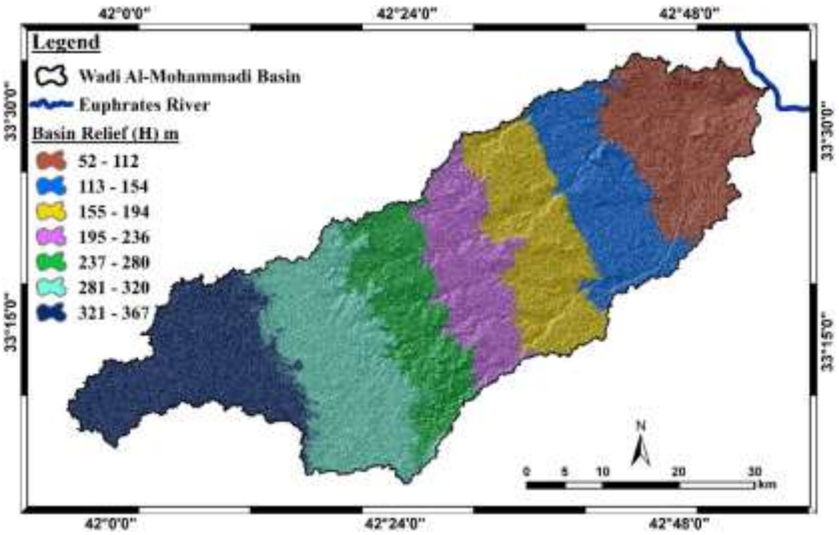

Figure 12. The relief of Wadi Al-Mohammadi basin

5.2.3.2 *Relief Ratio (Rh)*

The relief ratio is an important measure to know the topographical nature of any region or water basin. It has a direct effect on the speed of flow, the number of materials transported, and the increase or decrease in the rate of erosion. It is defined as the ratio between the total relief of a basin, and the longest dimension of the basin parallel to the principal drainage line, [20]. Wadi Al-Mohammadi basin, the relief ratio is 0.003. This ratio indicates a low relief slope, due to the basin located in the Lower Wedian Province, which is characterized by its almost flat plateau surface, with a gradual slope.

5.2.3.3 *Ruggedness Number (Nr)*

This coefficient indicates the extent of the relief in the basin and the lengths and slopes of the drainage network, as the high values of this coefficient indicate the severity of relief and the prevalence of water erosion that transfers rocky fragments from the upper sources to the lower areas of the basin. It is defined as the product of basin relief and drainage density, [24]. It usually joins slope steepness with its length. The extremely high values of this coefficient occur when slopes of the basin are not only steeper but long, as well. For Wadi Al-Mohammadi basin, the Nr was 0.232, this value indicates a low basin relief with a gradual change in slope of uniform nature.

6. Conclusion

GIS and remote sensing techniques have proven to be very useful tools in calculating morphometric characteristics and the hydrological drainage network. Most of the sub-basins have an area below the general average of 327 km^2 and are represented by basins SB1, SB4, SB5, and SB7, while the other sub-basins recorded a greater percentage of the general average and were represented by basins SB2, SB3, and SB6, respectively.

It is evident from all the results represented by the area and form characteristics that they confirm that the shape of the basin is far from the round shape, which reflects the basin's characteristics with the regular surface flow in time and relatively low drainages, due to the long-distance traveled by the water waves during their movement from the feeding areas towards the mouth of the valley, which provides a greater chance for the loss of quantities from this water by infiltration and evaporation processes.

Wadi Al-Mohammadi basin has reached the 5^{th} order to flow into Euphrates River, and this indicates the large and wideness of the drainage network throughout the basin. Two types of drainage patterns for Wadi Al-Mohammadi basin, the dendritic pattern which reflects homogeneous and good permeable soil conditions, and the parallel pattern, which indicates the influence of the structural phenomena under the surface, which are abundant in the study area. The drainage density is categorized as extremely low and increased from southwest to northeast with a higher value in the eastern part of the basin. Wadi Al-Mohammadi basin is categorized as very low drainage frequency, and this low value indicates the high permeability of sediments over which streams pass. Wadi Al-Mohammadi basin has a drainage texture that is categorized in nature as very coarse. It is having a lower infiltration number and consequently, the higher the infiltration and the lower will be the runoff. Wadi Al-Mohammadi basin has a low relief slope, due to the basin located in the Lower Wedian Province, which is characterized by its almost flat plateau surface, with a gradual slope.

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