

Morphometric Analysis of Galal Bedrah River Basin Using STRM (DEM) Data and GIS Techniques



Mohammed S. Shamkhi, Atyaf J. Mohson and Tabark J. Abdullah

Abstract A morphometric analysis of Galal Bedrah river basin was carried out by several processes that take place on STRM DEM (Shuttle Rader Topography mission), thereby employing the Spatial Analysis tool in Arc GIS (version 10.5) software for analyzing the study area. Primarily, the Arc GIS software was the basic tool used for extracting the river Basin as well as its drainage network. Upon analyzing, the drainage network was classified using Strahler's System for classification, which in turn reveals that the drainage pattern is almost dendritic, with the basin order being fifth-order. The study further evaluates the morphometric parameter and its influence on soil physical, landform, and other hydrologic characteristics. The mean bifurcation ratio (Rbm) was found to be 2.35 that have a strong effect on the runoff and its intensity, high relief value, drainage density, and stream frequency. All these values indicate that the basin exhibits erosion and sediment transfer and play a significant role in different hydrological studies.

Keywords Morphometric characteristics · Galal bedrah · Watershed · Iraq · Digital elevation model (DEM) · GIS

1 Introduction

Morphometric analysis is an important part of a various hydrological investigation, which provides valuable information regarding water management and alerts flash flood hazard that may cause a great loss in people's life as well as detraction in economic activity particularly, in the studied region (Galal Bedrah) where nowadays one can observe strong flood waves from Iranian borders. Using the morphometric techniques mainly detail analysis of geometrical drainage characteristics was carried out, which helps in examining the effect of variables such as rainfall, rock structure, lithology, the basin behavior at a series of heavy rainstorms, and the

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basin topography [8] (Esper 2008; Bali et al. 2012; [13]. Sreedevi et al. [14] mentioned that there are three basic types of the morphometric characteristics namely (i) linear parameter as stream number (Nu), stream order, and bifurcation ratio, (ii) areal parameter like drainage density, elongation ratio, circularity ratio, and others, and (iii) relief parameters such as basin relief, ruggedness number, and time of concentrations. The author basically used topographical map and DEM data to derive drainage network of Peddavanka watershed. Apart from this, the author also employed GIS which facilitates the analysis of drainage morphometric parameters (such as channel length, catchment slope, location of drainage, configuration of the channel) and in exploring the relationship between these parameters and hydrological characteristics which further renders the necessity of implementing rainwater harvesting as well as water management. On a similar note, Srivastava et al. [16] has reported that drainage area description achieved by morphometric analysis, is an important aspect of watershed characteristics. Likewise, Magesh et al. [8], have observed that various hydrologic phenomena are in correlation with the physiographic characteristics of the river basin viz. shape, size, drainage density, the slope of drainage area, etc. Moreover, María Yanina [1] chose Colangüil river basin as a study area and analyzed its various morphometric characteristics in order to predict approximate basin behavior to evaluate flood hazards. Others previous studies include (i) Kumar et al. [7], (ii) Farr and Kobrick [4], (iii) Jakob and Van Zyl [18], (iv) Reedy et al. [12], (v) Sreedevi et al. [15], (vi) Mesa [10], (vii) Grohmann et al. [6], (viii) Magesh et al. [8], and (ix) Vieceli et al. [19]. All these studies were used to obtain the morphometric analysis so as to generate the basin characteristics. Most of them employed STRM data and GIS Techniques as it is fast and inexpensive. In the present study drainage properties of Galal Bedrah basin are derived, by using STRM data and ARC GIS 10.5, with the tabulated result being based on simple mathematical equations.

2 Study Area

Galal Bedrah River basin lies in the eastern part of Iraq. The largest part of the basin lies in the Iranian areas (see Fig. 1). The area mainly covers about 4394 km between longitudes ($45^{\circ} 46' 29''$ and $46^{\circ} 43' 14''$) to the east, and latitudes ($32^{\circ} 52' 28''$ and $33^{\circ} 38' 43''$) to the north. Mostly, it stems from Bstkoh Mountain which lies in Ilam the Iranian province which then descends towards the border city of Arafat in the southern east of Iraq after being flowing for 60 km and then subsequently flows into al shwaga marsh, located in the Iraqi province. The climate in the area is almost dry, and the relative humidity varies in the north part of the basin from medium to intense humid in most of the months of the year. On the contrary, in the south part of the basin the humidity ranges from dry to wet depending on the effective meteorological stations.

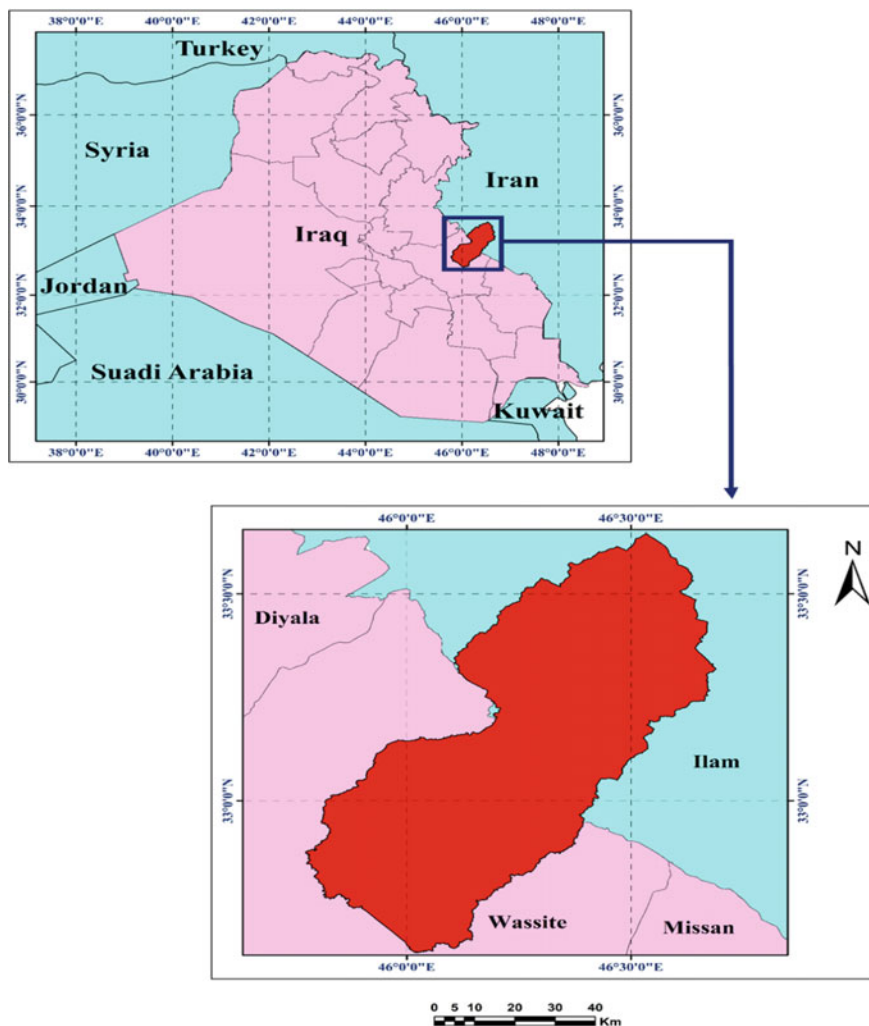


Fig. 1 Location of Galal Bedrah river basin

3 Methodology

Galal Bedrah basin extractions based on STRM DEM with a spatial resolution of 30 m, was downloaded free from the internet website (<https://earthexplorer.usgs.gov/>). Subsequently, various reprocessing was carried out on this data by using several techniques in ARC GIS 10.5. One of these techniques is watershed extraction which utilizes pour point that adjusts the cells of the highest flow

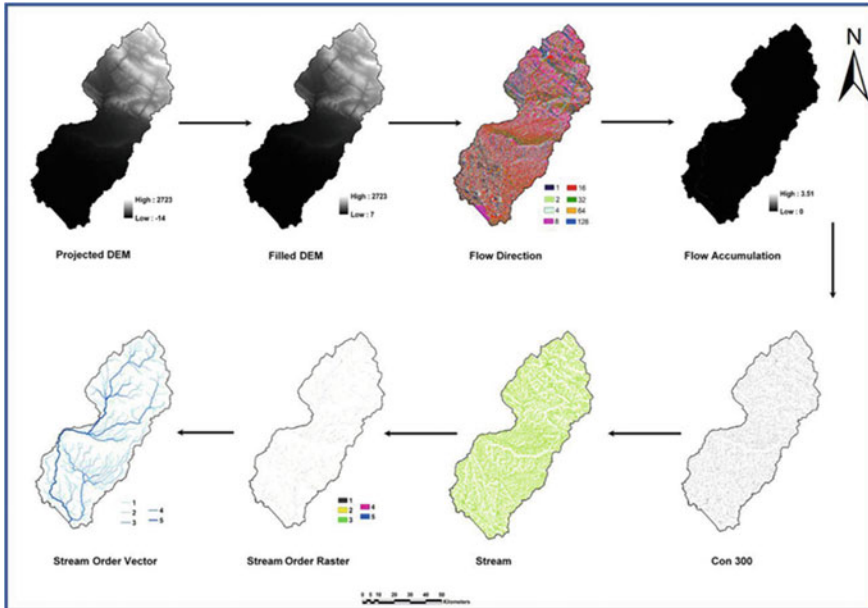


Fig. 2 Demonstrates the extraction of drainage networks from DEM

accumulation. Further, it was observed that the extraction of both basin and stream network depends on the regional projection (WGS 1984 UTM Zone 38 N). Notably, several steps preceded the basin extraction such as filled, flow direction, flow accumulation, con-300, stream order, and converting raster to vector. These tools existed in spatial analyst tools within toolbox. Eventually, at the end, polygon of the watershed gets created, from which one can conclude that the basin stream order depends on Strahler's system classification [17] as shown in Fig. 2.

To evaluate the basin morphometric, watershed parameters such as; (i) perimeter, (ii) area, (iii) length, (iv) stream order, and (v) stream length, were calculated. Later, various influential factors were determined depending upon the last parameters and by applying mathematical formula shown in Table 1. These factors are (a) bifurcation ratio, (b) stream frequency, (c) stream length ratio, (d) drainage density, (e) total relief, (f) relief ratio, (g) circulatory ratio, (h) elongation ratio, and (i) texture. Moreover, slope and aspect map was derived using STRM DEM and spatial analyst tool in ArcGIS 10.5 [9]. Several type of these parameters are consider an important input for many hydrological prediction models and also give enough description for the area under study.

Table 1 The linear and areal morphometric parameter

S. no.	Parameters	Formulae	Cited by
1	Stream order (U)	Hierarchical rank	Magesh et al. [9]
2	Stream length (Lu)	Length of the stream	Rai et al. [11]
3	Mean stream length (Lsm)	$Lsm = Lu/Nu$	Magesh et al. [9]
4	Bifurcation ratio (Rb)	$Rb = Nu/Nu + 1$	Singh et al. [13]
5	Mean bifurcation ratio (Rbm)	Rbm = average of bifurcation ratios of all order	Magesh et al. [9]
6	Drainage density (Dd)	$Dd = Lu/A$	Rai et al. [11]
7	Drainage texture (T)	$T = Nu/p$	Rai et al. [11]
8	Stream frequency (Fs)	$Fs = Nu/A$	Rai et al. [11]
9	Elongation ratio (Re)	$Re = D/L = 1.128\sqrt{A/L}$	Wilson and Ch [21], Magesh et al. [9]
10	Circularity ratio (Rc)	$Rc = 4\pi A/P^2$	Rai et al. [11]
11	Form factor (Ff)	$Ff = A/L^2$	Wilson and Ch [21]
12	Relief	$R = H - h$	Wilson and Ch [21]
13	Relief ratio	$Re = R/L$	Magesh et al. [9]

4 Results and Discussion

Tables 2 and 3 presents the results of Galal Bedrah river basin. The drainage patterns of the basin are of several types, such as parallel, orthogonal, radial, and dendritic pattern, with the most common one being dendritic. Further, based on the drainage stream order, Galal Bedrah watershed is classified as fifth order stream basin.

Table 2 Results of morphometric analysis (Linear aspects) of Galal Bedrah watershed

S. no.	Parameters	Stream orders				
		I	II	III	IV	V
1	Stream order (total)	1090	583	300	4	1
2	Stream length (lu) km	854	454	169	122	118
3	Mean stream length km	0.78	0.77	0.56	0.66	118
4	Bifurcation ratio (Rb)		I/II	II/III	III/IV	IV/V
			1.86	1.94	1.63	4.0
5	Mean bifurcation ratio (Rbm) for all order		2.35			

Table 3 Results of morphometric analysis (Areal parameters) of Galal Bedrah watershed

S. no.	Parameters	Values
1	Perimeter (p) (km)	442
2	Basin length (Lb) (km)	122.2
3	Basin area (km ²)	4394
4	Total relief (R)	2717
5	Relief ratio (Rh)	22.23
6	Elongation ratio (Re)	0.61
7	Drainage density (Dd) (km/km ²)	0.39
8	Stream frequency (Fs)	0.45
9	Form factor (Rf)	0.29
10	Circulatory ratio (Rc)	0.28
11	Drainage texture (T)	4.47

4.1 Slope and Aspect

Slope map provides data for morpho-conservation practices, planning of engineering structures, etc. Therefore, it has become essential to understand the slope distribution, [15]. Magesh et al. [9] defined the term “slope” as the maximum rate of change in value from each cell to its neighbors. Many factors affect the slope shape, assigned by Megash et al. [9] like terrain, geomorphologic processes, land cover, and soil. On the other hand, the term “aspect” reported by Magesh et al. [8] refers to the direction to which a mountain slope faces. The slope and aspect maps shown in Figs. 3 and 4 depicts, which is prepared based on STRM data with the help of the spatial analysis tool in ArcGIS 10.5 software.

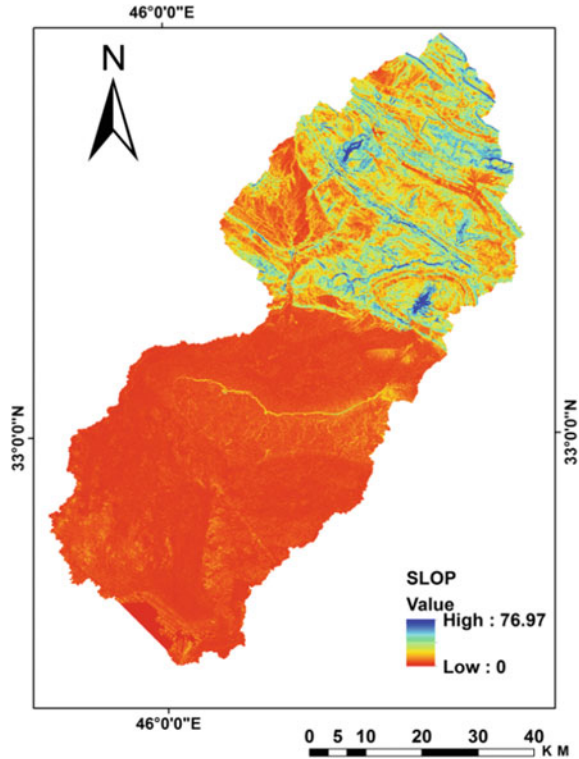
4.2 Basin Length (Lb)

The basin river is characterized by its axial length, which can be defined as the longest straight line from the basin headwaters to its estuary point [15]. Fundamentally, the basin length influences the time required by the waves to reach the flood peaks. From Table 3, one can observe that the basin length, for the studied area, is 122.2 km.

4.3 Stream Number (Nu)

According to the result shown in Table 2 a disparity in the number of streams of different orders was observed, which was further cited by Rai et al. [11] who believed that the total number of streams decreases gradually with increasing stream

Fig. 3 Illustrates the slope map

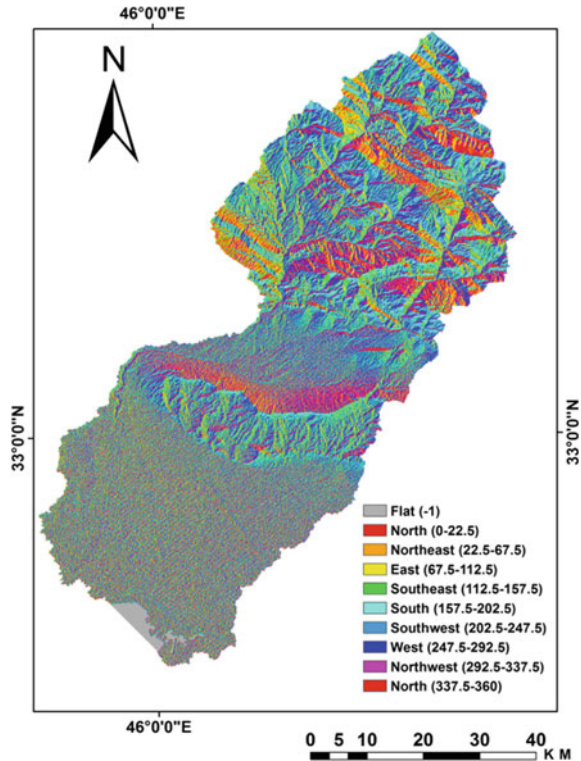


order. The total number of stream segments that were recognized, in Galal Bedrah watershed were 1978 out of which 50.1% (1090) was of first-order. The higher values of first-order segments illustrate the possibility of flash floods after rainfall storms [3].

4.4 Stream Length

It is consider one of the most important features of the basin. Stream with small length is indicative of areas with finer texture and steep slope, whereas streams with longer length are representative of areas with low gradients. Generally, there is inverse relationship between the streams length and their orders (Sethupathi et al. 2011) [11]. As indicated by the result shown in Table 2, the maximum value of total stream length is possessed by first-order streams, which further decreases with increasing stream order.

Fig. 4 Illustrates the aspect map of the study area



4.5 Mean Stream Length (Lsm)

Mean stream length is a property that reveals the characteristic of the drainage network. Principally, it is found to be allied with basin size, basin topography, and the contributing drainage surface. Furthermore, it can be computed, mathematically, by dividing the segment length of itemized order by the number of stream segments of the same order cited by Strahler [17]. Table 2 further shows that, in the present study, the Lsm values for Galal Bedrah River basin varies from 0.78 to 118.

4.6 Bifurcation Ratio (Rb)

According to Singh et al. [13], the bifurcation ratio (Rb) refers to the ratio between the number of specific stream order to the number of next order. Importantly, it is one of the most influential ingredients that control the average discharge, besides increasing the flow duration and causing its intensity to grow. Upon comparing the different values of bifurcation ratio for different streams orders, shown in Table 2, one can deduce that the bifurcation ratio ranges from 1.86 to 4.0.

4.7 Relief (R) and Relief Ratio (Rh)

Reddy et al. [12] and Sreedevi (2012) stated that the basin relief refers to the maximum differences between the lowest and the highest point of the basin. Primarily, the basin relief plays a significant role in denudational characteristics, landform development, the terrain erosional properties, drainage development, surface water flow, and the permeability of the Terrain [8, 9]. For the study area, the relief value is 2717 (see Table 3). On the other hand, the relief ratio can be defined as a ratio between relief and the horizontal distance of the river basin [9, 2] In the present study, the basin relief ratio is very high (23.23) which is considered as an indicator of bestows the water courses with the capacity to erode and carry out sediment transfer of different sizes, with movement being directed to downstream estuary [2].

4.8 Drainage Density (Dd)

According to Mesa [10] the drainage density can be defined as the ratio between the total length of the stream of particular basin to the total area of the same basin. Fundamentally, Basin with the higher value of drainage density leads to high runoff, fine drainage texture, and erosion potential of the basin area.

4.9 Stream Frequency (Fs)

The definition of stream frequency as stated by Magesh et al. [9], is the number of all stream segments concentrated per basin area. There are several factors that affect the stream frequency such as the amount of rainfall, and physiography of the region, with the effect being reflected on the subsurface permeability and drainage network texture. In the present research, the stream frequency value for the studied area was found to be 0.162.

4.10 Drainage Texture (T)

Drainage texture (T) is a ratio between the total number of the stream of whole orders to the perimeter of the specific area. Natural factors that affect this value are (i) rainfall, (ii) soil type, (iii) vegetation, (iv) stage of development, and (v) infiltration capacity [20]. Smith (1950) asserted the texture classification, with $T < 4$

indicating coarse texture; T falling in the range of 4.0–10.0 refers to intermediate texture, and $T > 10$ refers to fine texture. According to the above classification, the texture of studied area (4.47) is found to be of intermediate type.

4.11 Form Factor (F_f)

The form factor is a ratio between the basin area to its square length [11]. Principally, it is a dimensionless value. Further, smaller form factor value implies that the basin is narrow and long. Flood flow for such basin can be recognized, as a flood with flatter peak for long duration which one can control easily. On the other hand, the largest value indicate the existence of short and wide basin. Moreover, if the value of the form factor is close to one, the basin appears circular in shape [20]. The value of F_f for the study area is 0.28 which means that the basin is elongated with lower peak flows.

4.12 Circulatory Ratio (R_c)

The circulatory ratio defined by Gajbhiye et al. [5] is the ratio of the watershed area to the area of a circle having a perimeter equal to the perimeter of the watershed. One of the most influential parameters is the lithological characteristics of the basin. If R_c value is less than 0.5, then the basin gets elongated. However, R_c indicates the dendritic stage of the basin in the report published by Srivastava et al. [16]. The circulatory ratio of the study area is 0.34 which elucidates the youth stage of the tributary of the watershed.

4.13 Elongation Ratio (R_e)

According to Wilson and Ch [21], the elongation ratio (R_e), is defined as a ratio between the diameter of a circle having the same area of the basin and the maximum basin length. Generally, R_e value controls the basin shape and varies from 0.6 to 1.0 in almost all basins. However, when this value comes close to 1.0, it implies that the basin is circular in shape with very low relief. The discharge in such basin occurs more efficiently during the runoff, indeed, more than the elongated basin. The elongation ratio of the study area was found to be 0.6 due to which the area falls in the elongated category.

5 Conclusion

The present study reveals the efficiency of ArcGIS software in analyzing the STRM DEM data, instead of using the traditional technique, in which the evaluation of the catchment boundaries and the morphometric parameters of the drainage mainly depends on the topographic map. The evaluation of these parameters generally includes the evaluation of such drainage morphometric parameters that strongly affect hydrological characteristics such as surface runoff, infiltration capacity, landforms, etc. Further, the morphometric analysis unveils the existence of different types of drainage network pattern, of which the dendritic pattern is the most common one. Additionally, the classification of the basin, based on the highest stream order number, was identified as fifth-order. The total number of streams segment was 1978, with the first-order stream occupying most of this value, which further indicated the possibility of flash floods. The R_c value of the watershed is <0.5 . On the other hand, R_e is 0.61; while F_f value is 0.28. These values are indicative of the elongated shape of the basin. Further, the variation observed in the case of streams length for different orders is allied with the change witnessed in slope and topography of the basin. The stream frequency value (0.45) and the drainage density (0.39), both suggest the association of intermediate drainage texture with the basin. All the values mentioned above, in addition to, other parameters control the flow characteristics as well as shows that the basin is at flood risk. Thus, there is an urgent need to predict the increasing risk beforehand, which will assist the decision makers in developing and managing the basin as it Provides a description of the hydrological properties of the area.

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