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GEOMORPHOMETRIC ASSESSMENT OF THE RIVER DRAINAGE NETWORK AT AL-SHAKAK BASIN (IRAQ)

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Abstract: This paper studies geomorphometric characteristics of the Al-Shakak drainage basin, which is one of the valleys of the eastern Al-Jazirah region in the eastern parts of the Misan Governorate in southern Iraq. The natural factors, which are represented by surface, geological structure, and climate, have a direct impact on forming these characteristics, such as the stream orders, stream length, mean stream length, bifurcation ratio, stream frequency, drainage density, and channel maintenance. The values of these parameters vary at the level of the main basin and the secondary basins. The total stream orders of the Al-Shakak main basin reached five orders, and their values varied at the level of the secondary basins. As for the lengths of the streams of the main Al-Shakak basin, they reached 175.607 km, most of which were in the large basins. Regarding the average length of the streams, it is measured 0.805 km at the level of the main basin, 0.766 km at the level of the first order, and 0.445 km at the level of the fourth order. The values of the river bifurcation of Al-Shakak basin 1 amount to 3.476, which is the highest value. As for Al-Shakak basin 3, it reached 1.3, which is the lowest value. In addition, the value of the stream frequency of the Al-Shakak basin amounts to 2.253 km/km^2, and the drainage density reached 1.786 km/km^2, with the channel maintenance being 0.561 km^2/km.

Keywords: fluvial geomorphology; geomorphometry; river drainage system; geospatial techniques

1. Introduction

The morphometric analysis of river basins is one of the modern branches of geomorphology (Perucca & Angilieri, 2011). It is used to measure the geometric and mathematical dimensions of the landforms at river basins resulting from various geomorphic processes (Arunachalam & Sakthivel, 2014). It illustrates the relationship between the nature of the drainage basin's hydrological system and the natural factors that contribute to its formation in terms of the geological structure, topography, climate, soil, and natural vegetation, as well as their influence on the processes stemming from those factors (Kumar Rai et al., 2017). The latter leads to a set of physical and chemical changes that contribute to the formation of the characteristics of the basin drainage network and its landforms (Ahsan & Waqar, 2015). There is no doubt that river basins can be of various kinds, being permanent, seasonal, or temporary. The symmetry in the geomorphometric dimensions of the drainage basin indicates the similarity

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of the geomorphological factors and processes responsible for its formation (Guth, 2011). The Al-Shakak drainage basin is characterized by several morphometric characteristics of the river drainage network that distinguish it from the rest of its adjacent river basins, in terms of the number and length of stream orders, the ratio of river bifurcation, river frequency, and the density of river drainage, which together constitute the hydrological system of the basin.

The research problem is represented by identifying the morphometric characteristics of the Al-Shakak drainage basin, which is one of the river basins in the eastern region of Misan Governorate, Iraq. These characteristics involve stream order, lengths of streams, mean stream length, bifurcation rate, stream frequency, and the patterns of river drainage. The hypothesis of the study indicates that there are spatial relationships between the morphometric variables of the Al-Shakak drainage network and between the prevailing geomorphological factors and processes in the basin. The study aims to identify the most important morphometric characteristics of the drainage network of the Al-Shakak drainage basin and to study the natural factors that affect it, in addition to the hydrological and geomorphological patterns of the basin.

2. Methodology

This study uses the analytical method of the data derived from the Digital Elevation Model (DEM) type of Shuttle Radar Topography Mission (SRTM). It has a distinct accuracy of 30 m from the USGS site. In addition, it also uses the 1:100,000 scale topographic map issued by Iraqi General Survey Authority to determine the study area (Ministry of Water Resources I. G. S. A., 1992), and the geological and hydrological maps with a scale of 1:250,000, issued by the Iraqi General Survey Authority (Deikran, 1995; Sissakian & Fouad, 2015). These data have been dealt with using modern geospatial techniques through a group of programs, including ArcGIS V.10.8, GIS Earth V.1.9, Global Mapper V.11, Surfer V.10, Google Earth Pro V.7.1, and SAS Planet V.19 for downloading high-resolution satellite imagery. Moreover, several mathematical methods are used through the application of morphometric equations shown in Table 1, to determine the characteristics of the Al-Shakak drainage basin in the eastern parts of Misan Governorate, Iraq.

Table 1. Morphometric parameters of the river drainage network used in this study

Parameters	Symbol	Formula	Description	Reference
Stream orders	U	Hierarchical Rank	–	(Strahler, 1957)
Stream length	L_u	Length of the streams	–	(Horton, 1945)
Mean stream length	L_{sm}	$L_{sm} = L_u / N_u$	L_{sm} = Mean stream length (km) L_u = Total stream length of order (U) (km) N_u = Total number of stream segments of order (U)	(Strahler, 1957)
Bifurcation ratio	R_b	$R_b = N_u / (N_u + 1)$	R_b = Bifurcation ratio N_u = Total number of stream segments of order (U) N_u + 1 = Number of segments of the next higher-order (U)	(Schumm, 1956)

Table 1. Continued

Parameters	Symbol	Formula	Description	Reference
Stream frequency	F_s	$F_s = N_u / A$	N_u = Total number of streams of all orders A = Area of the basin (km^2)	(Horton, 1945)
Drainage density	D_d	$D_d = L_u / A$	D_d = Drainage density (km/km^2) L_u = Total stream length of all orders (km) A = Area of the basin (km^2)	(Horton, 1945)
Constant of channel maintenance	M_c	$M_c = 1/D_d$	D_d = Drainage density (km^2/km)	(Schumm, 1956)

3. Study area

The Al-Shakak drainage basin is located in the eastern parts of Misan Governorate within a part that is known as the Eastern Jazira region in south-eastern Iraq (Figure 1). It is bounded on the northeast by the Iraqi-Iranian borders, and from the north, northwest, and west, the watershed forms a dividing line of the Abu Ghraibat basin. On the east, it is bounded by the Al-Duwairij drainage basin, and on the south by Al-Sanaf marsh. The basin extends between 32°11′21.8″N to 32°21′17.2″N latitude and 47°22′2.9″E to 47°28′54.2″E longitude. Its area is 99.485 km^2 with a circumference of 53.949 km, while the total length of the basin reached 18.928 km (according to the results of this study), starting from its upper sources near the Iraqi-Iranian border and ending in Al-Sanaf marsh.

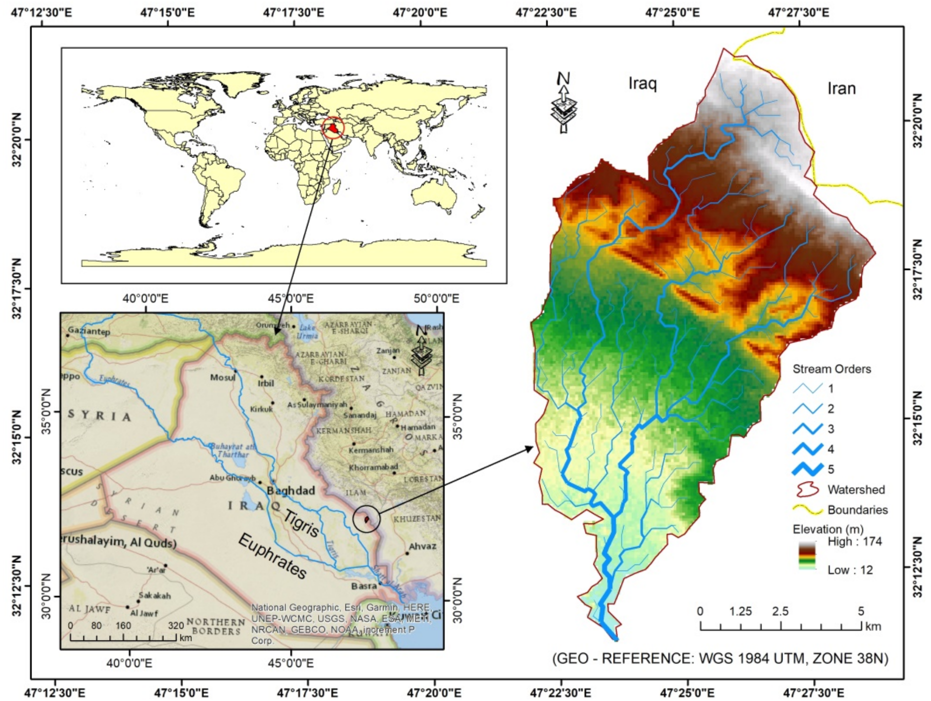

Figure 1. Location of the study area in Iraq.

The Al-Shakak drainage basin is distinguished by its moderately elevated hilly surface, as its elevation progresses from its upper sources near the Iraqi-Iranian border toward the northeast and toward Al-Sanaf marsh in the southwest, with a slope rate of 1.9 m/km. The highest value of height was 170 m a.s.l. in its upper sources, while the lowest value of the height was 20 m a.s.l. near its mouth in Al-Sanaf marsh (Figures 2 and 3). Based on the results of this study, a clear variation is observed in elevation levels at its central parts, which represent the stage of maturity from the geomorphological cycle ranging between contour lines of 30–70 m a.s.l.

The study area is covered with sediments of the Quaternary period, which are ancient muddy, river, and marine deposits, parts of which are windy deposits with a depth of 120 m (Al-Kaabi, 2009). The contact line between the sediments of this age and the Tertiary period is unclear due to the lack or absence of fossils, as heavy metals and some sedimentary characteristics have been relied upon (Maitham, 2015). Among the most important geological formations in the region are the Bai Hassan and Muqdadiyah Formations, dune deposits, and alluvial fan deposits (Figure 4; Jassim & Goff, 2006).

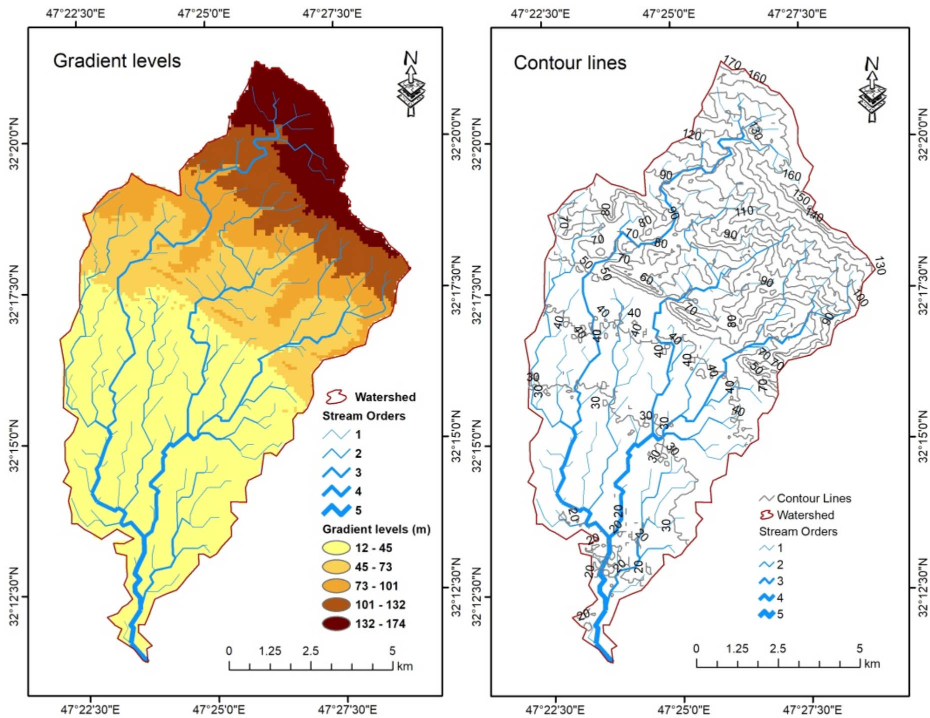

Figure 2. Contour lines and gradient levels of the study area.

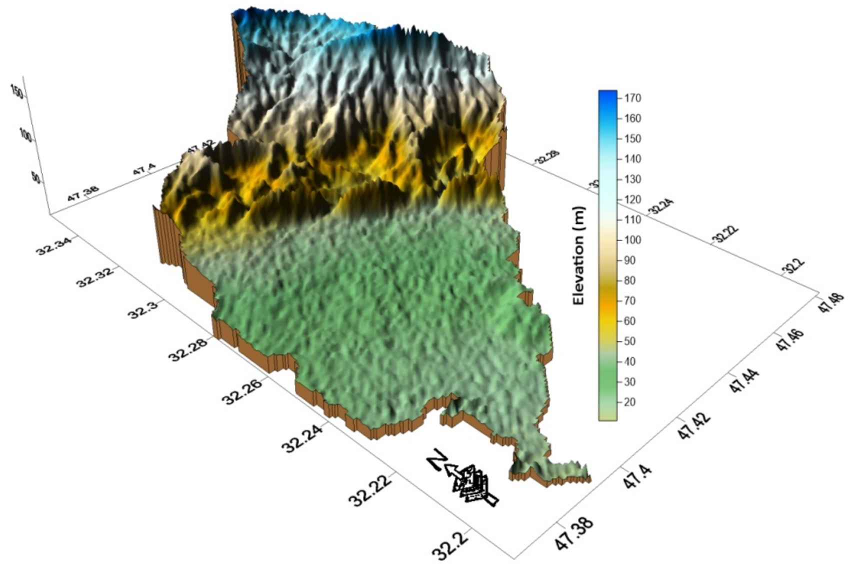

Figure 3. Topographic model of the Al-Shakak basin.

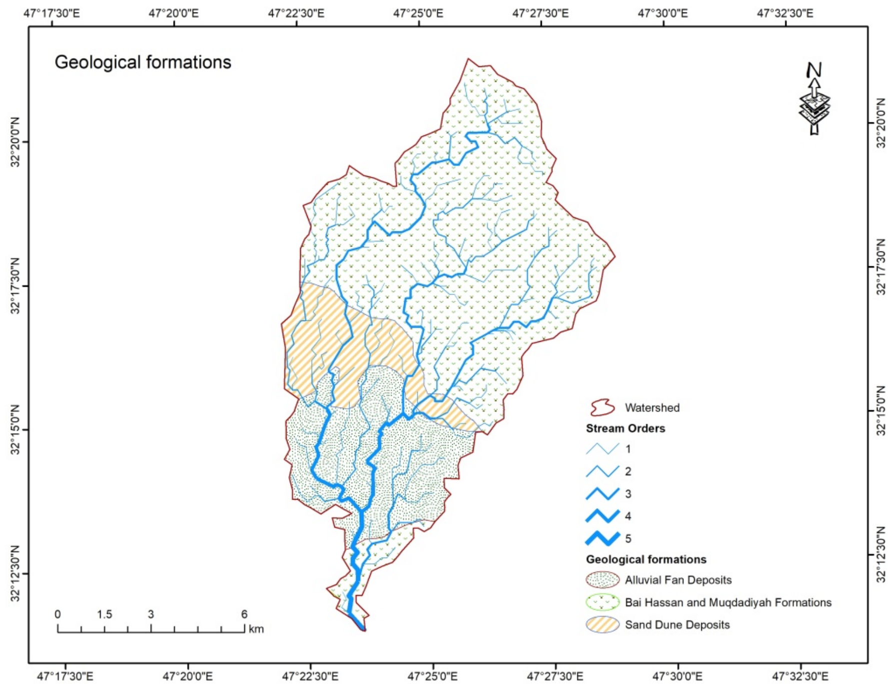

Figure 4. Geological formations in the study area.

The data presented in Table 2 for Al-Amarah weather station shows that there is a seasonal variation in climate elements. As temperatures increase in the summer months (June, July, and August) and reach their highest rate in July (29.1 °C), with their moderate relative temperature in the winter season and its tendency to decline. The lowest temperature was recorded in January and it reached 6.3 °C. There is a clear fluctuation of rain characterized by its seasonal fall, as it falls on relatively spaced periods and forms showers that quickly turn into sweeping torrents. These contribute to the sculpting of the earth's surface and the formation of landscapes. Its lowest value is in May (2.1 mm).

Table 2. The climate elements of the study area, according to Al-Amarah weather station for the period (1980–2009)

Months	Average temperature (°C)	Rainfall (mm)
January	6.3	34.5
February	8.2	22.6
March	12.2	31.7
April	18.4	13.3
May	23.8	2.1
June	27.2	–
July	29.1	–
August	27.9	–
September	24.1	–
October	18.9	5.7
November	14.1	14.5
December	7.9	19.7

Note. Data in columns are author's calculation based on: [Meteorological data], by Ministry of Transportation, Iraqi Meteorological Organization and Seismology, Baghdad, n.d., (http://meteoseism .gov.iq/), in the public domain; "Characteristics of climate variation indices in Iraq using a statistical factor analysis," by R. M. Shubbar, H. H. Salman, & D. I. Lee, 2017, *International Journal of Climatology, 37*(2), pp. 918–927 (https://doi.org/10.1002/joc.4749).

The Al-Shakak drainage basin is divided into four secondary basins (Table 3, Figure 5) that have the following characteristics:

1. Al-Shakak basin 1: This basin is located in the northwestern parts of the study area, and its area is 32.277 km^2, with a perimeter of 34.754 km, and a maximum length of 13.361 km;

2. Al-Shakak basin 2: This basin is located in the eastern parts of the study area. It has an area of 39.471 km^2, with a perimeter of 28.357 km, and a maximum length of 9.686 km;

3. Al-Shakak basin 3: This basin is located in the southeastern parts of the study area, specifically to the east of the Al-Shakak basin 4. It has an area of 8.457 km^2, with a perimeter of 14.632 km, and its maximum length is 5.796 km;

4. Al-Shakak basin 4: This basin is located in the southern to southwestern parts of the study area, and its area is 19.755 km^2. As for its perimeter, it reaches 34.754 km, and its maximum length is 12.521 km.

Table 3. The area, perimeter, and length of the Al-Shakak drainage basin and its secondary basins

The Name of basin	Area (km^2)	Perimeter (km)	Maximum length (km)
Al-Shakak Basin 1	32.277	34.754	13.361
Al-Shakak Basin 2	39.471	28.357	9.686
Al-Shakak Basin 3	8.457	14.632	5.796
Al-Shakak Basin 4	19.755	34.754	12.521
The main Al-Shakak drainage basin	99.485	53.949	18.928

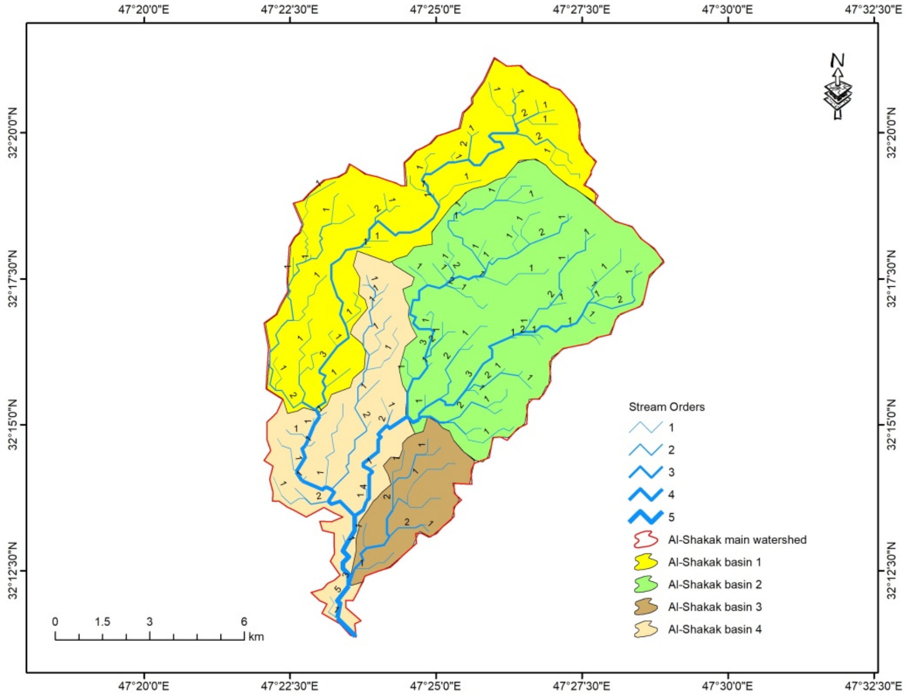

Figure 5. Stream orders of the main and secondary basins in the study area.

4. Results

4.1. Stream orders (U)

The total number of stream orders for the Al-Shakak drainage basin is five, which may vary from one order to another. According to Horton's Law of Waterways (Horton, 1945), which confirms that waterways in their order follow a geometric sequence, the upper bound starts like the first, after which it begins to decrease with the increase in stream orders. The numbers of the first order reached 115 with a percentage of 50%, while the numbers of the second-order reached 54 at a rate of 23.48%, and the third-order numbers are 54, reaching a rate of 23.48%. As for the fourth order, the numbers of the orders reached 7 with a percentage of 3.04%, as shown in Table 4.

Table 4. Stream orders for secondary basins of the Al-Shakak drainage basin

Name of basin	First order	Second order	Third order	Fourth order	The total number of stream orders
Al-Shakak Basin 1	31	14	15	1	61
Al-Shakak Basin 2	52	27	21	2	102
Al-Shakak Basin 3	9	4	4	-	17
Al-Shakak Basin 4	23	9	14	4	50
The main Al-Shakak basin	115	54	54	7	230
Percentage	50	23.48	23.48	3.04	100

4.2. Stream length (L_u)

The total length of streams for the Al-Shakak drainage basin reached 175.607 km. Most of the lengths were found in large-sized basins, where the percentage of the secondary Al-Shakak basin 2 was 37.751%, with a total length of 66.294 km. The secondary basins of Al-Shakak 1 came in the second place with a percentage of 31.643%, with a total of 55.569 km. As for the remaining secondary basins represented by (Al-Shakak 3 and 4), their proportions reached 8.628% and 21.975% with a total length of 15.153 km and 38.591 km, respectively, as shown in Table 5. As for the level of the stream orders, the total lengths of the first order reached 81.608 km, a ratio of 46.471% of the total lengths of the stream, while the length of the second-order stream reached 46.582 km, or 26.526%, as for the rest of the other orders (third and fourth), their lengths reached 42.579 km and 4.833 km, respectively, with a percentage of 24.246% and 2.752%, respectively.

Table 5. Lengths of streams for the Al-Shakak drainage basin and secondary basins according to their orders

Name of basin	First order (km)	Second order (km)	Third order (km)	Fourth order (km)	The total length of streams (km)	Percentage (%)
Al-Shakak Basin 1	27.138	12.867	15.536	0.027	55.569	31.643
Al-Shakak Basin 2	29.565	21.301	14.998	0.428	66.294	37.751
Al-Shakak Basin 3	8.016	4.051	3.085	–	15.153	8.628
Al-Shakak Basin 4	16.889	8.363	8.960	4.378	38.591	21.975
The main Al-Shakak basin	81.608	46.582	42.579	4.833	175.607	100
Percentage (%)	46.471	26.526	24.246	2.752	100	100

4.3. Mean stream length (L_{sm})

Strahler (1957) states that when amending the law on streams lengths, it is affirmed that a constant percentage exists for the increase in stream length from one order to another, which is equal to three times the smaller order (Mahala, 2020). He suggested that the sum of the average lengths of watercourses in the successive order tends to form a geometric sequence that begins with the average length of watercourses in the first order and rises with a constant length ratio. After applying the above equation shown in Table 1 to the study area basins in all its orders, it is observed that the average stream length of the first and second order increases with the increase in the order in form of a geometric sequence. This corresponds to what was mentioned by Strahler, as the lower orders are characterized by small average stream lengths, while the higher orders are characterized by large average stream lengths (Bali et al., 2012). However, this matter only applied to the first and second orders, and did not apply to the third and fourth orders, due to the basin's exposure to tectonic activation processes and the accompanying renewal processes in the average lengths of waterways.

The average of the first order is 0.766 km, followed by the second order with 0.912 km. The average for the third order is 0.790 km, while the fourth order is 0.445 km. As for the secondary basins, the variation is clear in the average length of the streams. Al-Shakak basin 1 reached 0.910 km, which is the highest recorded length in the study area, while the Al-Shakak basin 2 was 0.571 km, which is the lowest rate in the study area. The other basins varied between these two values, as shown in Table 6.

Table 6. Lengths of streams for the Al-Shakak drainage basin and secondary basins according to their orders

Name of basin	First order (km)	Second order (km)	Third order (km)	Fourth order (km)	Average length (km)
Al-Shakak Basin 1	0.875	0.919	1.035	0.027	0.910
Al-Shakak Basin 2	0.568	0.788	0.714	0.214	0.571
Al-Shakak Basin 3	0.890	1.012	0.771	–	0.891
Al-Shakak Basin 4	0.734	0.929	0.640	1.094	0.849
General Average	0.766	0.912	0.790	0.445	0.805

4.4. Bifurcation ratio (R_b)

This parameter expresses the ratio between the number of watercourses for a given order and the number of water channels for the next level that follows directly (Schumm, 1956). It is one of the important measures by which it is possible to identify the rate of discharge and the time required for the torrents to reach their estuaries. It can be stated that the higher the bifurcation rate is, the greater the drainage will be, and vice versa (Abboud & Nofal, 2017). The average river bifurcation for the basins of the study area indicates that most streams of the first order develop into the second-order through regressive erosion or river capture operations, as the first order exceeds other orders in terms of number, length, and proportion of bifurcation (Das & Pardeshi, 2018). This indicates the lack of proportionality between the lengths and numbers of streams at lower levels and the main streams. This is a result of the great change that these streams are subjected to after water erosion (Evans, 2012).

The data in Table 7 indicate a clear difference in the percentages of bifurcation, as it reached 3.476 in Al-Shakak basin 1, which is the highest value recorded in the basin, while it reached 1.3 in Al-Shakak basin 3, which is the lowest value. The rest of the secondary basins varied between these values, reaching 3.356 and 1.9 for Al-Shakak Basins 2 and 4, respectively.

Table 7. Bifurcation ratio of the Al-Shakak drainage basin and its secondary basins

Name of basin	Order	Number of streams	Bifurcation ratio	Average
Al-Shakak Basin 1	1	31	2.06	3.476
	2	14	0.87	
	3	15	7.5	
	4	1	-	
Al-Shakak Basin 2	1	52	1.85	3.356
	2	27	1.22	
	3	21	7	
	4	2	-	
Al-Shakak Basin 3	1	9	1.8	1.3
	2	4	0.8	
	3	4	-	
	4	-	-	
Al-Shakak Basin 4	1	23	2.3	1.9
	2	9	0.6	
	3	14	2.8	
	4	4	-	

4.5. Stream frequency (F_s)

This parameter indicates the frequency of streams in a given unit area, usually measured by the number of streams / total area of the basin sq. km (Horton, 1945). The high values of this parameter indicate a high potential for water accumulation in the drainage basin, and then the occurrence of surface runoff (Kumar Rai et al., 2017). The values of this parameter decrease in large basins and they increase in small basins. The latter phenomenon can be traced back to the fact that large basins have lost large quantities of their rocky content, which leads to a reduction in the number of water drainage paths per unit area, and the opposite happens for small basins (Altin & Altin, 2011).

The numerical drainage density of the Al-Shakak main basin is 2.253 km/km², and the secondary basins differ from this average. The value of this coefficient is 2.584 km/km² in Al-Shakak Secondary Basin 2, which is the highest value recorded in the basin. Moreover, it reached 1.889 km/km² in Al-Shakak secondary basin 1, which is the lowest value recorded in the basin, as presented in Table 8.

Table 8. Bifurcation ratio of the Al-Shakak drainage basin and its secondary basins

Name of the basin	Area (km²)	Number of streams	Stream frequency (km/km²)
Al-Shakak Basin 1	32.277	61	1.889
Al-Shakak Basin 2	39.471	102	2.584
Al-Shakak Basin 3	8.457	17	2.01
Al-Shakak Basin 4	19.755	50	2.531
Total and Average	99.485	230	2.253

4.6. Drainage density (D_d)

This parameter shows the extent to which the surface of river basins is exposed to intermittent erosion processes (Horton, 1945). It is a reflection of the rocky nature, structure system, and prevailing climatic conditions (Bahrami, 2013). The average drainage density for all the secondary basins is 1.786 km/km², and the other basins had differing rates, ranging between 1.953 km/km² in the secondary basins, which is the highest value, and 1.679 km/km² which is the lowest value (Table 9).

Table 9. Bifurcation ratio of Al-Shakak drainage basin and its secondary basins

Name of the basin	Area (km²)	Total lengths of streams (km)	Drainage density (km/km²)	Channel maintenance (kms²/km)
Al-Shakak Basin 1	32.277	55.569	1.721	0.581
Al-Shakak Basin 2	39.471	66.294	1.679	0.595
Al-Shakak Basin 3	8.457	15.153	1.791	0.558
Al-Shakak Basin 4	19.755	38.591	1.953	0.512
Total and Average	99.96	175.607	1.786	0.561

4.7. Constant of channel maintenance (M_c)

This coefficient indicates the average unit area required to feed one linear unit from the network's streams (Schumm, 1956). The higher the value of this parameter, the larger the basin area is at the expense of its network streams (Drăguţ et al., 2011). There is a convergence between the values of the channel maintenance coefficient for the basins of the study area, as follows: The average of the secondary basins reached 0.561 km^2/km, with values ranging between 0.595 km^2/km in Al-Shakak secondary basin 2, and 0.512 km^2/km in Al-Shakak secondary basin 4 (Table 9).

5. Discussion

There is a marked variation in the number of tributaries from one basin to another, and this is normal according to Strahler's description, that waterways consisting of streams and small watercourses that do not meet a tributary from above are classified as first-order tributaries, at the confluence of two first-order streams a course is formed as a second-order watercourse, at the confluence of two second-order streams a stream of third order arises, and so on for the rest of the other series. In addition to being directly proportional with the bottom, the larger the area, the greater the number of valleys is in the river plains. The variation in the river levels of the Al-Shakak drainage basin is due to the fact that the hard rocks resist erosion processes, whereas the less rigid rocks are subject to these processes and thereby lead to the formation of more levels. Also, the intensity of precipitation, slopes, and the shape of the basin all affect the variation in valley orders.

The more water produced by rain during a rainstorm, the greater the possibility of widespread rain erosion in the basin, especially in the areas of rocky weakness, which is what was observed in Al-Shakak secondary basins 1 and 2. The slopes also played a major role in increasing the number of river orders, as the greater the slope was, the greater was the possibility of water erosion and the formation of new orders, which was clearly observed in all the parts of the basin, especially in Al-Shakak secondary basins 1 and 2.

The reason for the fluctuations in river length rates in the study area can be attributed to several reasons, including the diversity of geological formations, which in turn was reflected in the rock diversity in the region, the latter ranging from bedrock (resistant to geomorphological processes) and other types with lower hardness (with weak resistance to the above processes). The reason for the discrepancy in the values of the bifurcation ratio is attributed to the varying effect of the natural factors that influence the geomorphology of the basin, especially the climate and the geological structure, which result in different conditions for the formation of the geomorphological characteristics of all the secondary basins. The variation in the values of stream frequency is attributed to local differences in the topography of the basins—the greater the slope, the higher is the landmark density that indicates a stream bifurcation and a relatively large stream frequency, as in the case of Al-Shakak secondary drainage basin 1. In addition, the variation in geological formations between solid resistance to erosion processes greatly affects the river frequency. The high values of drainage density in basins are due to the nature of their rocks' hardness and their high content of clay, these aspects reduce water permeability, increase the volume of surface runoff, and increase the slope.

6. Conclusion

The total stream orders of the Al-Shakak drainage basin reached five orders, and their numbers varied from one order to another. The numbers of the first order reached 115, while the numbers of the second order reached 54, and the third-order numbers were 54. As for the fourth order, the numbers of the orders reached seven. The total length of the streams of the Al-Shakak drainage basin reached 175.607 km, and most of the lengths were found in large-sized basins. On the other hand, we find that the lengths of the stream decrease in the basins of the smallest area, as in Al-Shakak drainage basins 3 and 4. The average length of the order increases with the increase in the order in the form of a geometric sequence, and this corresponds to what was mentioned by Strahler (1957), as the lower orders are characterized by small average stream lengths, while the higher orders have rather larger average stream lengths.

The data indicate a clear difference in the percentages of bifurcation, as it reached 3,476 in Al-Shakak basin 1, which is the highest value recorded in the basin, while it reached 1.3 in Al-Shakak basin 3, which is the lowest value, while the rest of the secondary basins ranged between these values. The numerical drainage density of the main Shakak basin was 2.253 km/km², and the secondary basins differed from this average. The value of this coefficient was 2.584 km/km² in Al-Shakak secondary basin 2, which is the highest value recorded in the basin, while it reached 1.889 km/km^2 in Al-Shakak secondary basin 1, which is the lowest value recorded in the basin.

The variation in the stream frequency values is related to the local differences in the geological structure and topography of the basin, which controls the number of tributaries and streams. In addition to the spatial characteristics of the basins, where the large-area basins were characterized by low stream frequency values, as in Al-Shakak drainage basin 1, while the values increased in the small basins, as in Al-Shakak drainage basins 2 and 4, and the effective rain has a main role in increasing the density, which increases with the increase in the slope and the dominance of hard rocks in the basin. The average drainage density for all the secondary basins was 1.786 km/km², and the basins differed from this rate, ranging between 1.953 km/km^2, which is the highest value, and 1.679 km/km², which is the lowest value.

There is a convergence between the values of the channel maintenance coefficient for the basins of the study area, as the average of the secondary basins reached 0.561 km/km², and the values ranged between 0.595 km/km² in Al-Shakak secondary basin 2, and 0.512 km/km² in the secondary basin 3. It seems that the geomorphological stage has been controlled to some extent by the high values of the basins, which indicates that the river network of these basins has not yet been completed in its final form, thus, the number of its streams is smaller, compared to those valleys that have advanced their geomorphological stage and whose river network has been completed in its final form. It is possible that the type of rock played an important role in the rise in some values of the basins with this parameter.

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