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Morphometric Analysis of Wadi Hasab Basin in Al-Najaf Governorate, Southwest of Iraq, Using Remote Sensing and GIS Techniques

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Abstract
Quantitative analysis of morphometric drainage systems is crucial for understanding hydrological and environmental interactions of watersheds. This study uses geospatial techniques to analyze the morphometric characteristics of watersheds, relying on ALOS World 3D DEM and topographic maps of Iraq. Key features identified include main basins, sub-basins, slopes, drainage networks, topographical patterns, flow sequences, and flow lengths. ArcGIS Pro V.3.0.2 was used to determine these characteristics. The analysis includes hydrological processes like runoff frequency, bifurcation ratio, circularity ratio, and surface runoff length. The study aims to understand how these parameters affect the regional morphological landscape and the role of watersheds in the water cycle. Quantitative measurements provide insights into watersheds' shape, size, and hydrological status. The Hasab basin is a seventh-order basin, consisting of seven sub-basins that form an almost rectangular. Hypsometric analysis reveals geomorphological characteristics and basin maturity. The Hasab basin and most sub-basins are in the late youth or maturity stage, except for SB2 and SB4, which are in the old stage. The morphometric parameters indicate that geological and geomorphological structures significantly influence the drainage network type and basin shape.

Keywords: Drainage Network, Morphometry, Hydrology, Hypsometric Analysis, Remote Sensing, GIS, Southwest Iraq

التحليل المورفومتري لحوض وادي حسب في محافظة النجف، جنوب غرب العراق، باستخدام تقنيات الاستشعار عن بعد ونظم المعلومات الجغرافية

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الخلاصة
التحليل الكمي لمورفومتري الأنظمة التصريف يُعَدُّ ضروريًا لفَهم التفاعلات والعمليات الهيدرولوجية والبيئية في الاحواض المائية. تستخدم هذه الدراسة التقنيات الجيومكانية للتركيز على الخَصائص الكمية. استخدمت الدراسة بيانات الارتفاعات الرقمية للقمر (ALOS World 3D DEM) والخريطة الطبوغرافية للعراق لتحديد

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الحَوض الرئيسي، الأحواض الثانوية، الأنحدار ، شبكة التصريف، التضاريس، نمط التصريف، ترتيب المجرى، طول المجرى. تم تحديد الخصائص المورفومترية لحوض التصريف باستخدام برنامج (ArcGIS Pro V.3.0.2) تضمن دراسة العمليات الهيدرولوجية التي تجري في الحوض، وتشمل هذه العمليات التكرار النهري، نسبة التشعب، نسبة الاستدارة، طول الجريان السطحي في الحَوض. تهدف هذه الدراسة إلى فَهم كيفية تأثير هذه العمليات على الأشكال الأرضية المحلية واستكشاف مساهمة الحَوض في الدورة الهيدرولوجية. القياس الكمي لهذه الخَصائص، يوفر تصور حول شكل وحجم والخصائص الهيدرولوجية للحوض، يصنف حوض حسب في المرتبة السابعة، ويضم سبعة أحواض فرعية، تقترب من الشكل المستطيل. يُستخدَم التحليل الهبسومتري لفَهم الخَصائص الجيومورفولوجية الكمية ومرحلة النضج للحوض ، حوض حسب ومعظم الأحواض الفرعية تكون في مرحلة الشباب أو النضج المتأخرة باستثناء SB2 و SB4 فهما في مرحلة الشيخوخة. ويشير تحليل العوامل المورفومترية إلى أن التركيب الجيولوجي والجيومورفولوجي للمنطقة يؤثر بقوة على نوع شبكة الصرف وشكل الحوض الرئيسي والحوض الفرعي. طبقا للتحليل المورفومتري فإن حوض وادي حسب هو من المرتبة السابعة ويضم سبعة أحواض فرعية، ثلاثة منها من المرتبة السادسة وخمسة من المرتبة الخامسة.

1. Introduction

Due to its methodological priority over quantitative studies, morphological studies provide an irreplaceable basis in geomorphological and hydrological studies, expressing the complex structures and diverse characteristics that characterize catchments [1-3]. Through the application of thorough quantitative techniques, these examinations portray the different geomorphological stages and hydrological capacities inborn inside stream basins, in this manner advertising a comprehensive understanding of their dynamic characteristics and utilitarian capacities [4, 5]. The remarkable nature of the study of morphometric highlights is highlighted by their essential role in shaping hydrological properties, as they have a modulated and detectable impact on the hydrological flows monitoring watersheds [6-8]. By examining the confounding interactions between surface runoff, subsurface basin stages, and associated fluvial structures, morphological studies reveal a rich work of art full of knowledge and explain the relationship between watershed morphology and Earth's surface morphology. Reveals a complex relationship with various normal factors, including geographical configuration, climatic parameters, characteristic vegetation cover, and soil properties [9-12].

Moreover, the morphometric examination of bone-dry valleys accepts specific noteworthiness inside the broader logical talk because it serves as a linchpin interfacing different intrigue ponders extending from water asset administration and soil sciences to designing hones, geographical examinations, as well as rural and infrastructural improvement wanders [13-15]. Through its orderly examination and fastidious analysis, morphometry considers outfit a clear and comprehensive depiction of the subject beneath examination, illustrating its inherent morphology, portraying its geomorphological qualities, and unraveling its perplexing interrelationships with plenty of natural factors [16, 17]. Additionally, these ponders clear the way for a more profound understanding of the potential linkages between quantitative geomorphological traits, utilizing explanatory techniques that saddle information determined from topographic mappings or numerical definitions extrapolated from digital elevation models [18, 19]. This analytical system, not as it were, encourages optimizing land utilization techniques but also outfits priceless bits of knowledge that support the effective implementation of differing endeavors over different spaces [20].

Furthermore, the recognizable proof and characterization of secondary and virtual basins within the morphological context are essential for systematically categorizing drainage basins, providing a solid system for their comprehensive analysis, application, and comparison [21, 22]. It is essential to recognize that the explanation and investigation of morphometric properties are unexpected upon several characteristic determinants, including topographical compositions, surface landforms, climatic dynamics, soil properties, and vegetative cover, near the characteristic temporal changes that characterize these dynamic systems [23-25]. Thus, morphological studies confirm the multifaceted exchange between characteristic phenomena and human activities, advertising profound experiences into the complex elements forming our earthly landscapes and educating sustainable management practices for the benefit of present and future generations [13, 26, 27]. The main researchers on morphometric analysis have focused on assessing the characteristics of watersheds using Geographic Information System (GIS) and remote sensing data [28-30]. These studies typically measure sub-basins linear, areal, and relief aspects to understand their erosion susceptibility, flood hazards, and overall hydrological behavior [31]. Utilizing tools like QGIS and Arc GIS software, researchers analyse morphometric parameters to prioritize sub-basins for conservation and management strategies, highlighting the importance of GIS in watershed evaluation and resource planning [5, 32].

The study aims to search for the region's most important watersheds, characteristics, and natural areas and invest in their geological, geomorphological, and climatic components.
The Tigris and Euphrates rivers and their tributaries represent the primary water source for all state sectors. Recently, Turkey, Syria, and Iran have built a series of dams and reservoirs, leading to a decrease in Iraq's water revenues from these two rivers and an increase in population and water consumption. Let us not forget the climate changes and fluctuations that the world has witnessed, including the region and the study area, in shedding light on the water shortage problem (surface - groundwater).

2.1 Study area and geological setting

The Basin area is situated in the southwestern part of Iraq, within Al-Najaf Governorate, on a gentle to moderate slope terrain with geographic coordinates ranging from 43°.0 to 44°.20 longitude and from 30°5 to 30°40 latitude Figure 1. The basin length from the high point to the mouth of the main stream is 136.81 km with an area of 3628 km^2. The elevation in the main basin ranged from 43 to 397 m. The study area is tectonically located within the inner platform of the Arabian platform [33].

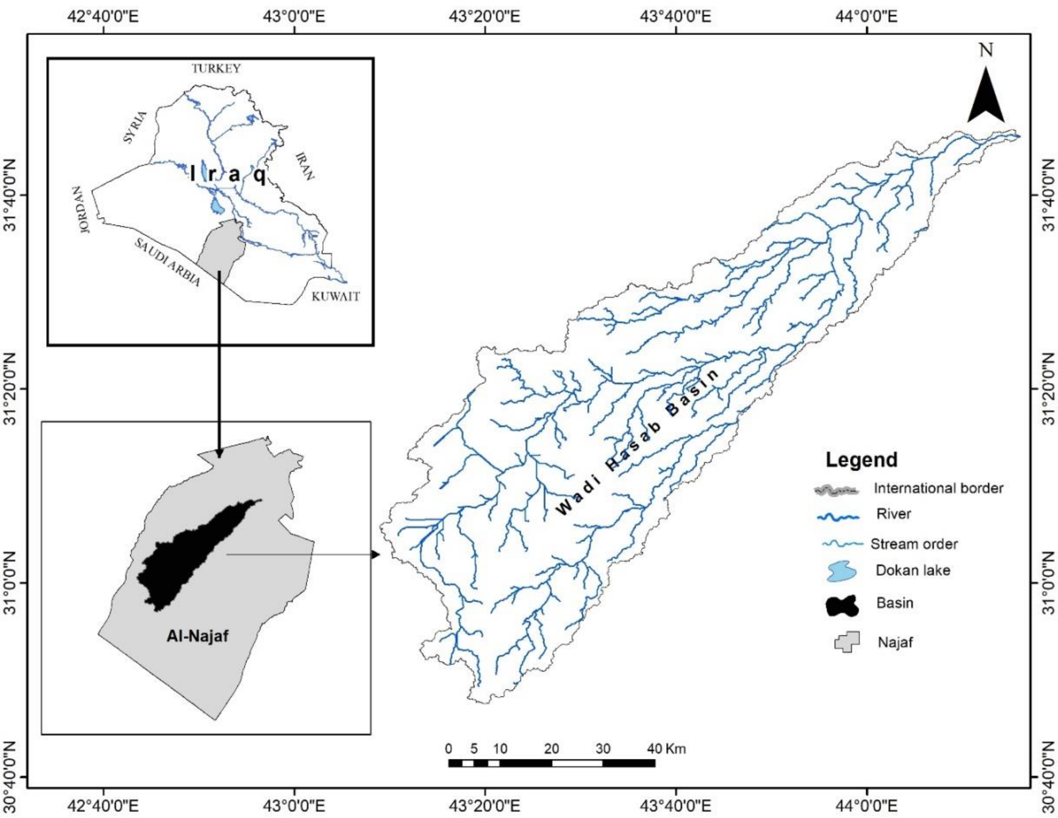


Figure 1: Location map of the Hasab basin

The Hasab basin area has diverse geological deposits, including Pleistocene and recent Holocene Quaternary deposits such as valley fills, valley terraces, slope deposits, and depression fill sediments [34]. The exposed formations in the study area include Umm Er-Radhuma (Middle-Upper Palaeocene), Dammam (Middle-Upper Eocene), Euphrates (Lower-Middle Miocene), Nfayil (Middle Miocene), and Zahra (Pliocene-Pleistocene), Figure 2.

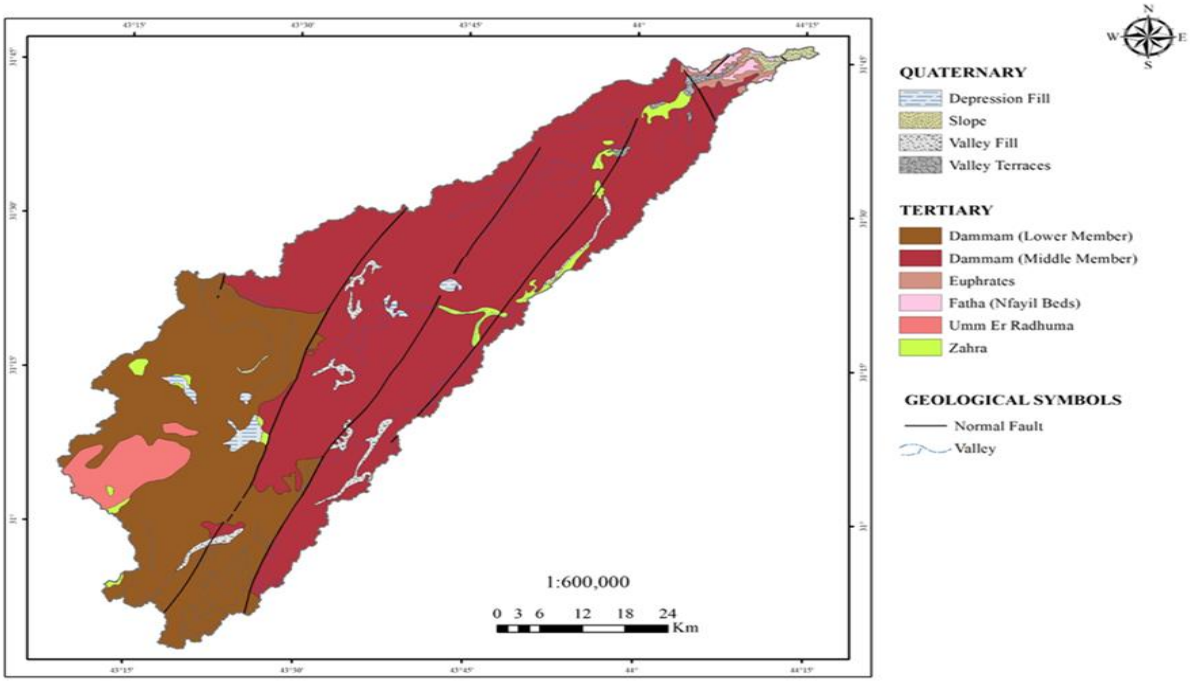


Figure 2: Geological map of the Hasab basin [34]

Within the basin region, the essential aquifer is the Dammam arrangements, as portrayed in Figure 3. Over the western and southern desert locales, most aquifers recharge from precipitation and runoff starting from discontinuous aqueducts. These channels contribute to spillage losses into porous strata, breaks, gaps, joints, and cavities, particularly within shallow aquifers. There are accepted to be a few hydraulic networks between aquifers [35]. The direction of water spillage, whether descending or upward, depends on different variables, including the piezometric relationship of aquifers, lithology, structural characteristics, and the conveyance of water-bearing horizons.

The climate in this range is arid, with overwhelming hot summers and constrained seasonal rainfall. The rainfall season extends from November to April, with an annual optimum temperature ranging from 18.1 to 31.8 °C. The rainfall was the primary water source when considering storage capacity above and below the surface, given an average yearly precipitation of 94.5 mm.

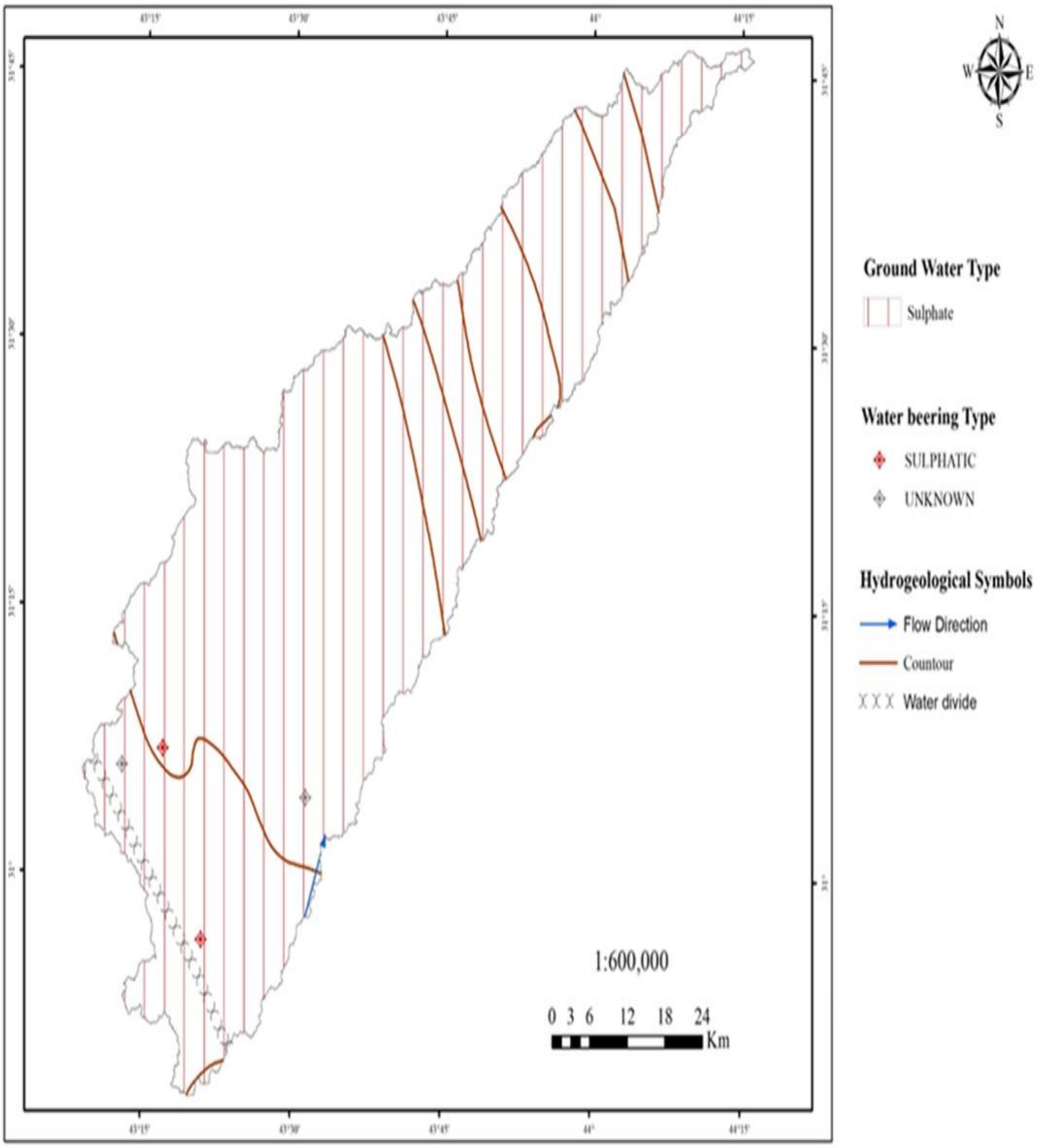


Figure 3: Hydrological map of the Hasab basin[34]

3. Materials and methods

In the current work, morphometric attributes such as relief aspect parameters, aerial characteristics, and linear characteristics were prepared based on digital satellite images and auxiliary data. GIS and remote sensing techniques aid in detecting spatial variations in morphometric parameters. The data was collected by remote sensing equipment, such as the Japan Aerospace Exploration Agency (2021). Version 3.2 of the ALOS World 3D Digital Elevation Model (DEM) features a 30-meter grid spacing. Additional resources, counting topographic maps at a scale of 1:2,500,000 and geographical maps, were utilized to bolster

the morphometric analysis of the main basin and its sub-basins. Notably, the geometry of the basin and its sub-basins was delineated utilizing the hydrology module inside the ArcGIS Professional program.

4. Results and discussion

4.1 Morphometric parameters

The study categorizes morphometric parameters into linear, areal, and relief aspects. These parameters were then calculated to assess both morphometric and hydrologic characteristics. Morphometric analysis centers on hydrological processes like stream recurrence, bifurcation proportion, circulatory proportion, and overland stream length inside the watershed, shaping neighborhood landforms. Quantitatively measuring these features makes a difference in evaluating the basin’s part within the hydrological cycle and understanding the shape, measure, and arrangement of the region's landscapes. Hypsometric analysis and the hypsometric integral were utilized to get most watersheds' quantitative geomorphological features and sub-basins. Hypsometric analysis of watersheds determines the complexity of denudation processes and the rate of morphological changes. It is valuable to compare the erosion status of watersheds and prioritize them for undertaking soil and water conservation measures. The relationship between morphometric parameters appears to be the solid impact of geological and geomorphological structures on the drainage network, with streams taking after a dendritic drainage pattern. This study included measuring morphometric aspects in linear, areal, and relief measurements utilizing particular scientific equations recorded in Table 1.

4.1.1 Linear Aspects of the

The normal scientific formulae recorded in Table 2 were utilized to compute the parameters considered when assessing the linear aspects parameters. In the quantitative analysis, a range of linear aspect parameters are assessed to gauge the linear morphometric features of both the main basin and its sub-basins. Figure 4. These parameters include stream hierarchical orders, length of overland flow, Stream length (Lu), Mean stream length (MSL), Stream length ratio (RL), Basin length (Lb), Bifurcation ratio, and (Rb)/mean bifurcation ratio (Rbm), Tables 2, 3 and 4.

Stream length (Lu) It is one of the most essential hydrological features as it reflects the characteristics of the surface runoff of the streams. It is an essential indicator for knowing the flood's peak within the waterways and the time the water travels to reach the downstream area. As the length of the stream increases, the amount of water reaching the downstream area decreases because it was lost during the flow, either through leakage or evaporation, which reduces Flood risk, as well as its relationship to groundwater recharge the more extended the stream, the greater the potential for groundwater recharge.

Table 1: Methodology adopted for computation of morphometric parameters

Morphometric Computation		parameters	References
Linear Aspect	Stream order	Hierarchical rank	[36]
	Stream length ($L\mu$)	Length of the stream	[37]
	Mean stream length (L_{sm})	$L_{sm}=L\mu/N\mu$ ($N\mu$=total no. of stream segments of a given order)	[36]
	Stream length ratio (R_L)	$R_L=L_u / L_u - 1$ (Lu=total stream length of a given order; and L_u-1=total stream length of its next lower order)	[37]
	Bifurcation ratio (Rb)	$R_b=N\mu / N\mu+1$ ($N\mu$=total no. of stream segments of a given order; and $N\mu+1$=no. of segments of the next higher order)	[38]
	Mean bifurcation ratio (R_{bm})	R_{bm} =average of bifurcation ratios of all orders	[39]
Areal Aspect	Drainage density (D)	$D=L_u/A$ (L_u=total stream length of all orders; and A=area of the basin)	[40]
	Stream frequency (F_s)	$F_s=N_u/A$ (N_u=total no. of streams of all orders; and A=area of the basin)	[40]
	Drainage texture ratio (R_t)	$R_t=N_u/P$ (N_u=total no. of streams of all orders; and P=perimeter of the basin)	[37]
	Infiltration no. (I_f)	$I_f=R_t\times F_s$ (R_t=drainage texture ratio; and F_s=drainage frequency)	[41]
	Length of overland flow (L_g)	$L_g=1/D\times 2$ (D=drainage density)	[37]
	Circulatory ratio (R_c)	$R_c=4\pi\times A/P2$ (π=3.14; A=area of the basin; and P2=square of the perimeter)	[42]
	Form factor (R_f)	$R_f=A/L^2_b$ (A=area of the basin; and L^2_b=square of basin length)	[40]
	Elongation ratio (R_e)	$Re=\sqrt[2]{\left(\frac{A}{\pi}\right)}/L_b$ (A=area of the basin π=3.14; and L_b=basin length)	[38]
Relief aspect	Relative relief (R_r)	Maximum elevation minus minimum elevation of the basin	[23]
	Relief ratio R_h	$R_h=H/L_b$ (H=total relief (relative relief) of the basin in kilometers; and L_b=basin length)	[38]
	Ruggedness no. (R_n)	$R_n=D\times T_r/1000$ (D=drainage density; and T_r=total relief)	[36]
	Hypsometric Integral	$HI=\frac{mean\ elevation-minimum\ elevation}{maximum\ elevation-minimum\ elevation}$	[23, 36]
	Stream gradient (S_g)	$S_g=\frac{E1-E2}{L}=\frac{\Delta H}{\Delta L}$ E1−E2=difference in the elevation between two points on the stream (ΔH) SL=Stream length (ΔL)	[43]

Table 2: Stream number (Nu) and stream length (Lu) of and its sub-basins

Basin	Stream order (U) (Number)								Stream order Length (Lu) in Km							
	1	2	3	4	5	6	7	Sum	1	2	3	4	5	6	7	Total Lu
Hasab Basin	5287	1207	276	68	13	3	1	6855	4023.09	2042.76	955.71	505.57	235.01	85.98	142.44	7990.56
SB1	1225	288	63	15	4	1	-	1596	909.53	467.94	189.37	104.81	52.09	75.17	-	1798.91
SB2	840	197	48	13	2	1	-	1101	739.75	317.19	162.53	60.75	65.21	8.05	-	1353.48
SB3	736	161	43	9	1	-	-	950	554.31	290.3	152.07	101.75	46.3	-	-	1144.74
SB4	315	87	19	4	2	1	-	428	249.43	142.54	61.28	22.82	16.83	2.45	-	495.35
SB5	342	69	17	3	1	-	-	432	225.94	112.33	67.73	51.32	14.07	-	-	471.39
SB6	179	37	13	4	1	-	-	234	135.04	69.04	35.38	13.35	13.83	-	-	266.64
SB7	160	36	10	2	1	-	-	209	127.48	63.47	31.33	5.70	17.66	-	-	245.65

Stream order (U) and stream number (Nu) It represents the first step in the quantitative analysis of rivers, as it expresses the hierarchical relationship between the number of river streams and their classification into river classes according to the Strahler method. The grade for each stream was estimated based on the presence of subsidiary tributaries and the gradual gradient of currents until reaching the mainstream. The drainage design inside the basin area takes after a dendritic design, where streams start from different parts of the basin and stream in a southwest-to-northeast direction. Concurring with Strahler's ordering system, the study range comprises seven progressive orders. The region's topography, structure, and lithology are the main controlling factors in the shape of watershed and drainage patterns. The merging makes the essential drainage network of the basin of two noteworthy tributaries, recognized as SB1 and SB2 in Table 2. The main tributaries discharged into Bahr Al-Najaf represent a natural depression located at the West Euphrates River in the western part of the Al-Najaf governorate, center of Iraq.

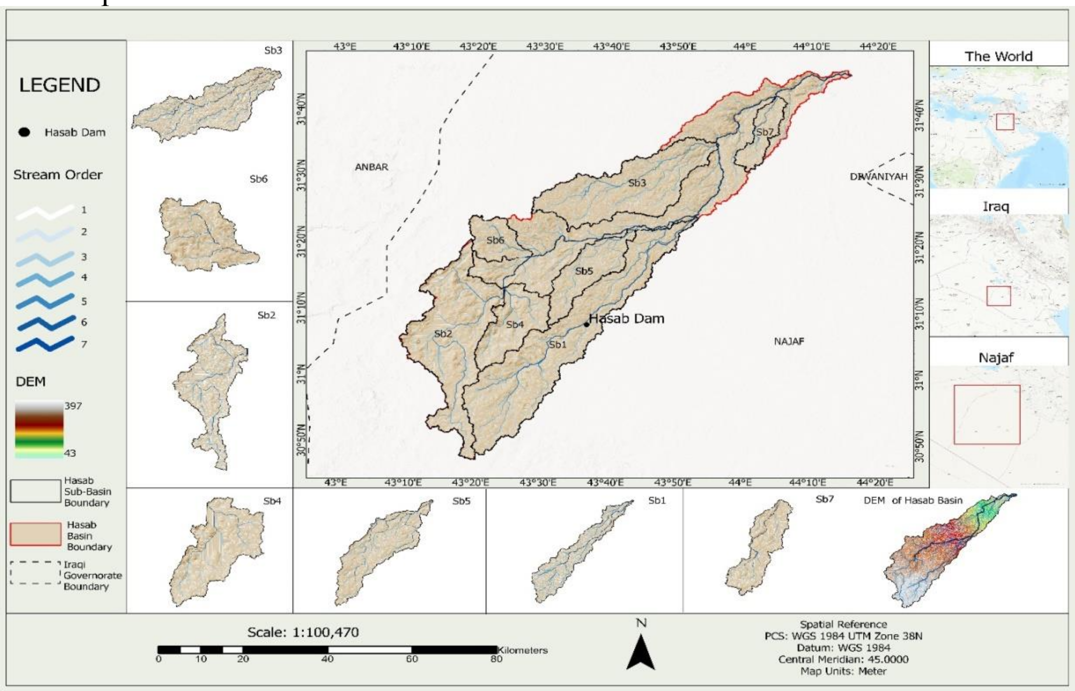


Figure 4: Drainage network map of the Hasab basin

Mean stream length (MSL) The whole Lu of a specific arrange partitioned by the whole stream number in that arrange yields the MSL. The mean stream length (MSL) of the Basin is 142.44 Km.

Stream length ratio (RL), According to [40], is the ratio of the total length of streams within the taking after arrangement to the individual lengths of streams within the current arrangement.

Basin length (Lb) is a variable related to many drainage basin characteristics.
It was depicted as a linear extension following the main stream from its outlet to the highest point within its boundary, positioned at the water parting line. There are many ways to measure the length of a water basin, including the Schaum method adopted in this study, represented by measuring the distance extending from the mouth of the mainstream to the farthest point on its circumference, provided that this line is parallel to the mainstream. Length was considered one of the essential standard units for hydrological studies, where the rates of seepage and evaporation are directly proportional to the basin's length. The Basin is 136.81 km long, and the two main subbasins' lengths, SB1 and SB2, are 82.41 km and 54.34 km, respectively (Table 3). This variety contrasts within the stream number of portions between 1^{st}-order and 2^{nd}-order streams, showing the predominance of primary streams inside the study zone. This concentration of stream portions inside the drainage network can impact the entire watershed's morphological characteristics. Also, these streams' shape, estimates, and dissemination may give clues regarding variables such as water runoff and surface runoff, particularly in slope-sensitive provinces. These variables are primarily affected by land use and land cover, highlighting the complex intuition between hydrological morphology and natural variables.

Bifurcation ratio (Rb)/mean bifurcation ratio (Rbm) It represents an important morphometric measure. According to Strahler, the bifurcation ratio is the ratio of the number of tables in a certain rank (Nu) to the number of tables in the next rank (1+Nu). Bifurcation ratio values indicate water discharge rate, with high values showing a higher water drainage rate due to a large surface area. In contrast, lower values indicate higher water infiltration, higher permeability, fewer water channels, and no structural deformations in the basin. The values of the bifurcation ratio usually range between 3 and 5 in regular basins. The importance of flood risks increases as the bifurcation rate decreases due to the speed of arrival of water waves from the upstream area. Generally, there are two classes of Rb: low class, which means the drainage pattern is not affected by the geologic structures, and high class, which means the geologic structures control the drainage pattern. Bifurcation values reflect the area's geological, topographic, climatic, soil, and vegetation characteristics, and based on some papers, it can be concluded that less than five may be classified as low and more than five as high [44]. Hence, only subbasin SB3 is within the high class, and the main basin and subbasin are within the low class Table 4.

Table 3: MSL, stream length ratio (RL), basin length (Lb), and its sub-basins

Basin	Mean stream length (MSL) in km							Stream length ratio RL							
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	Lb (km)
Hasab Basin	0.76	1.69	3.46	7.43	18.08	28.66	142.44	0.51	0.47	0.53	0.46	0.37	1.66	56.10	136.81
SB1	0.74	1.62	3.01	6.99	13.02	-	-	0.51	0.40	0.55	0.50	-	-	-	82.41
SB2	0.88	1.61	3.39	4.67	32.6	8.05	-	0.43	0.51	0.37	1.07	0.12	-	-	54.34
SB3	0.75	1.80	3.54	11.31	46.3	-	-	0.52	0.52	0.67	0.46	-	-	-	47.54
SB4	0.79	1.64	3.23	5.71	8.42	2.45	-	0.57	0.43	0.37	0.74	0.15	-	-	26.92
SB5	0.66	1.63	3.98	17.11	14.07	-	-	0.50	0.60	0.76	0.27	-	-	-	33.22
SB6	0.75	1.87	2.72	3.34	13.83	-	-	0.51	0.51	0.38	1.04	-	-	-	17.92
SB7	0.80	1.76	3.13	2.85	17.66	-	-	0.50	0.49	0.18	3.10	-	-	-	22.34

Table 4: Showing Bifurcation Ratio (Rb)/Mean Bifurcation Ratio (Rbm) of the and its sub-basins

Basin	Bifurcation Ratio (Rb)							
	1	2	3	4	5	6	7	Mean Rbm
Hasab Basin	4.38	4.37	4.06	5.23	4.33	3	-	4.23
SB1	4.25	4.57	4.20	3.75	-	-	-	4.19
SB2	4.26	4.10	3.69	6.5	2	-	-	4.11
SB3	4.57	3.74	4.78	9	-	-	-	5.52
SB4	3.62	4.58	4.75	2	2	-	-	3.39
SB5	4.96	4.06	5.67	3	-	-	-	4.42
SB6	4.84	2.85	3.25	4	-	-	-	3.73
SB7	4.44	3.60	5.00	2	-	-	-	3.76

Table 4- Continues.

4.1.2 Areal aspects

Areal aspects of a watershed include the description of areal elements such as the watershed area, shape, perimeter, drainage density, drainage texture, and stream frequency; these aspects can be reflected by parameters such as shape factor, form factor, elongation ratio, circulatory ratio, and compactness coefficient. Areal aspects of the basin show a high potential for flooding and soil erosion. This indicates that runoff from the upland area of the watershed is partially infiltrated in the gentle downstream part, contributing to the potential for groundwater recharge, and most of the water is directly discharged to the low land area downstream of the basin.

Table 5: Aerial aspect parameters of the and its sub-basins

Basin	Ba (km^2)	Lb (km)	P (km)	Dd	Dt	Fs	Di	Rf	Cc	Rc	Re	Ls	Lg	C
Hasab Basin	3628.07	136.81	614.19	2.20	11.16	1.89	0.86	0.19	2.90	0.12	0.50	4.05	0.23	0.45
SB1	827.81	82.41	264.50	2.17	6.03	1.93	0.89	0.12	2.61	0.15	0.39	6.44	0.23	0.46
SB2	625.08	54.34	218.74	2.17	5.03	1.76	0.81	0.21	2.49	0.16	0.52	3.71	0.23	0.46
SB3	511.55	47.54	218.73	2.24	4.34	1.86	0.83	0.23	2.75	0.13	0.54	3.47	0.22	0.45
SB4	227.21	26.92	96.75	2.18	4.42	1.88	0.86	0.31	1.82	0.30	0.63	2.50	0.23	0.46
SB5	209.58	33.22	99.58	2.25	4.34	2.06	0.92	0.19	1.95	0.27	0.49	4.13	0.22	0.44
SB6	122.84	17.92	62.99	2.17	3.72	1.90	0.88	0.38	1.61	0.39	0.70	2.05	0.23	0.46
SB7	107.72	22.34	73.36	2.28	2.85	1.94	0.85	0.22	2.01	0.25	0.52	3.64	0.22	0.44

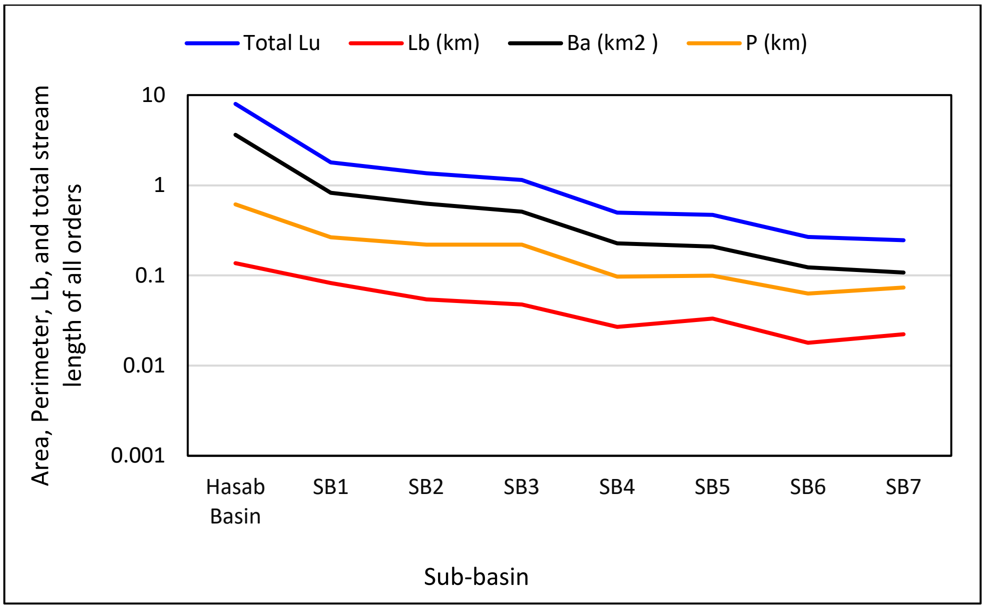


Figure 4: Relationship between Area, Perimeter, Lb, and total stream length of all orders

Basin area (Ba) and *Perimeter (P)* The river basin's area was directly related to the most morphometric characteristics of water discharge volume and speed and the rainfall amount received. The basin covers 3628.7 km^2, with the largest sub-basin, SB1, covering 827.81 km^2. *Basin* circumference was related to many morphometric characteristics, such as the shape of the basin, its roundness, and its elongation. The more it spread and expanded, the greater its geomorphological development.

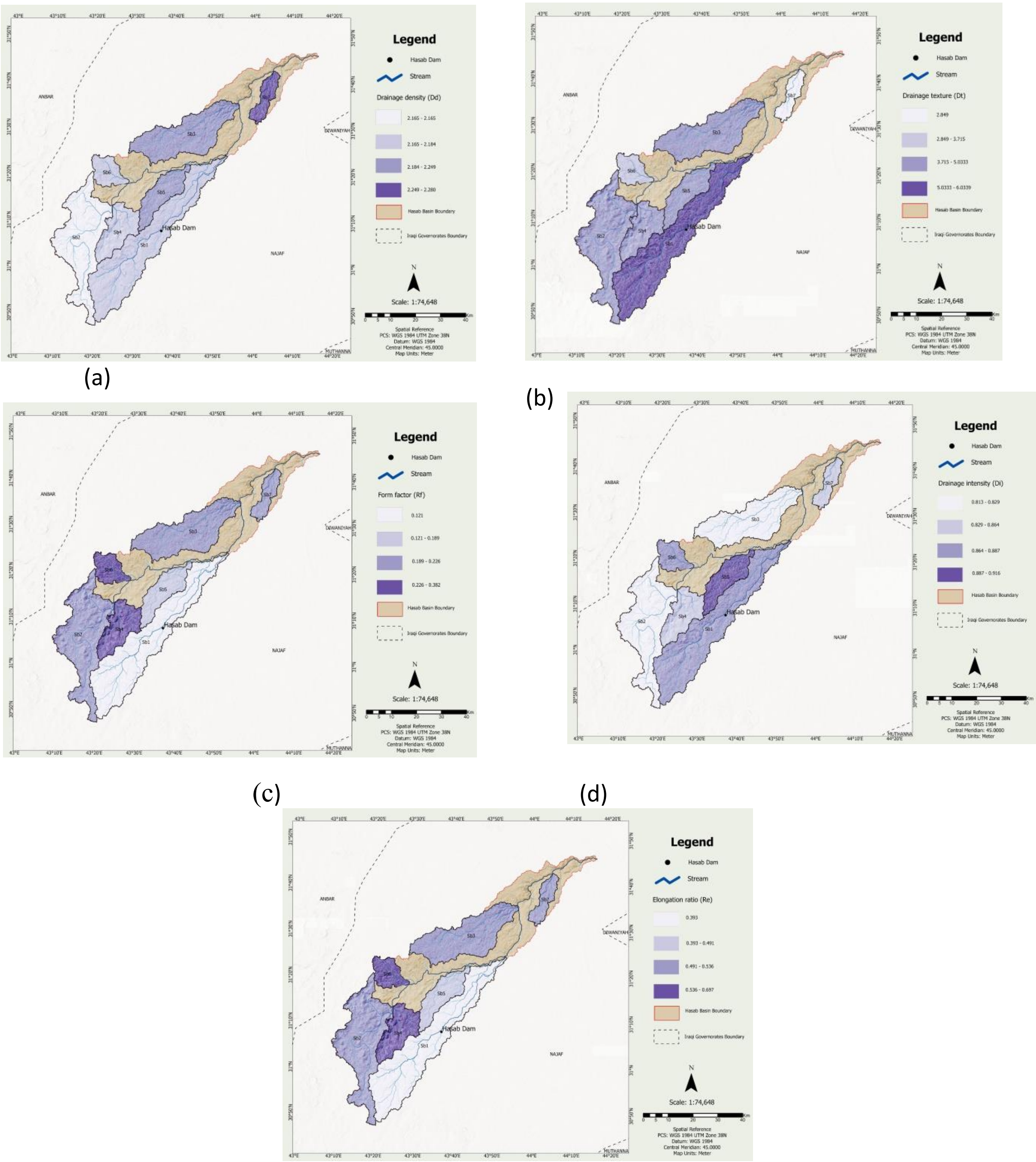


Figure 5: Spatial distribution of (a) Dd, (b) Dt, (c) Fs, (d) Di, (e) Rf, (f) Re in the Hasab basin

Drainage density (Dd), drainage intensity: Reflecting the drainage network's prevalence and fragmentation within the watershed area. Natural elements, including geological composition and rock type, control the river system's discharge intensity. [45] classified the Dd into three types: poor 0.5, medium 0.5–1.5, and excellent 1.5. The drainage density of its subbasin is slightly larger than the two values, which were classified as excellent type according to [45].
Drainage texture (Dt) expresses the extent to which the basin's surface is interspersed with water streams, that is, the extent to which these streams are close or far apart. It also represents the total number of streams at the basin levels without considering their lengths in the calculation. The drainage texture is affected by several factors, the most important of which

are the geological structure, surface, and climatic factors, in addition to the nature of the vegetation [32, 46]. The drainage texture is classified into five categories: very coarse less than 2, coarse 2-4, medium 4-6, fine 6-8, and very fine more than 8. Fine texture means high drainage density, unlike rough texture, which means low drainage density. The Dt of the basin is equal to 11.6, which is considered very fine, while subbasin values vary from coarse to very fine Table 5.

Stream frequency (Fs), the water discharge volume, is reflected in the large number of wadis per square kilometer. It is expressed as the total number of valleys in the basin divided by its area. Fs for the main basin and subbasin vary from 1.76-2.06 Table 5. The type of rock and soil, the shape of the land, the amount of rainfall, and the type of vegetation determine a river's shape, size, and flow. The given value indicates that lithology rainfall and topography are primary factors that influence the formation and growth of streams in the subbasins, whereas the vegetation cover is rare and mainly of shrubs and herbaceous. The low stream frequency value within the drainage basin implies that fewer structural interruptions lead to a heightened rate of surface runoff and rapid stream flow from the streams of higher orders, as mentioned by [47].

Drainage intensity (Di), the ratio of Fs to Dd, is known as Di [41]. The findings indicate minimal Di variation across the main basin and subbasins, with generally low values throughout. The low topography in the area with low Di value reflects high infiltration and low runoff.

Form factor (Rf), a morphometric scale, helps demonstrate the relationship between the length and area of the pelvis. The shape coefficient refers to the regularity of the basin's overall shape along its upstream-to-downstream stretch. The pelvic shape parameter indicates how close or after the pelvic shape is to the triangle shape. Their value ranges from 1 to 0, with low values indicating that the pelvic shape is close to the triangle, and if its value is close to the right, it indicates an increase in the area-to-length ratio. The form factor (Rf) is the ratio of the watershed area to the square of the length of the watershed. A form factor < 0.78 indicates an elongated shape, and > 0.78 indicates a circular shape. The form factor (Rf) values for the main basin and subbasins range from 0.12-0.38; consequently, the studied basin and subbasins are elongated or fern-like shapes, Table 5.

The elongation ratio (Re) measures the shape of basins. It compares the maximum length of the basin to the diameter of a circle with the same area. The ratio ranges from 0 to 1, with a value below 0.5 indicating severe elongation of the pelvis, while a value above 0.5 indicates that the pelvis was moving away from a rectangular shape and approaching a circular shape. The Re value for the basin is equal to 0.5, while for subbasins ranges from 0.39 – 0.7, which is classified as elongated and more elongated Table 5.

The circularity ratio (Rc), the roundness ratio, is a geometric characteristic that expresses the proximity of a basin to a regular circular shape. [42] developed the rotation rate equation for the area of a circle with equal circumference. The values range from 0 to 1, with values close to zero indicating a rectangular shape and values close to one indicating a circular shape. Elongation is the longitudinal extension of the basin in the direction of surface flow. This ratio indicates how close or far the shape of the basin is from the regular circular shape. If the rotation ratio approaches 1, the basin tends towards the circular shape, while if it moves away from 1, the shape of the basin moves away from the circular shape and indicates a zigzag and irregular dividing line of water. This parameter confirms the elongated shape of the basin and subbasin.

Lemniscate shape ratio (Ls), after one of the indicators indicating the shape of the pelvis, Chorley proposed this parameter. To express the geometric shape of watersheds, if the values are equal to the correct value, this indicates the ideal circular shape of the basin. However, if the values exceed 1.27, the basin will move away from the circular shape and approach the rectangular shape, and it will have a very long shape if the values range between 10-15. The basin and its subbasin, with a value of Ls larger than 2, confirm the elongated shape, Table 5.
The compactness coefficient (Cc) is a time scale that expresses the stage of development that water basins are going through. It also indicates the amount of rock resources still waiting for their role in development. Topographical characteristics gain their importance through some prevailing or previous environmental factors of the basin and their mutual relationship with other characteristics. The Cc value for the basin is 2.9, while for the sub-basins, it ranges from 1.61 (SB 6) to 2.61 (SB 1). This suggests that water takes longer to reach its peak flow in the basin than in the sub-basins as suggested by this parameter.

Length of overland flow (Lg), the length of the water stream that sometimes arrives recently concentrated in forever-introduced seepage channels or chiseled stream channels, is known as the length of the overland stream (Lg) [48]. Most of the time, the Lg normal is around half the normal of the stream channel dispersing. Subsequently, it is comparable to half of the Dd's corresponding [37]. The Lg values of both the bowl and its subbasins are around 0.22. This likeness in Lg values can be ascribed to comparable components such as slope, lithology, vegetation cover, precipitation concentration, and infiltration capacity. Within the upper portion of the Hasab, which incorporates the basin, the terrain is hilly and secured by bushes with inadequate to thick forest. In contrast, the lower section consists of flatter areas, including sloping and undulating fields with loose and loamy soil land-cover classes. The consistent Lg value across the basin and its subbasins indicate gentle slopes and longer flow paths for water within the drainage network.

The constant of channel maintenance (C), the C value signifies a level of surface susceptibility to erosion and infiltration depth, serving as a valuable indicator for assessing surface erodibility and the factors influencing surface degradation and drainage system evolution. Consequently, it can be applied to undeveloped sections of a drainage system to assist in predicting areas prone to future sediment loss [38]. The C values for both the basin and its subbasins are around 0.45. These values show that most bowls and sub-basins display low C values, suggesting a low penetration rate, tall erodibility, penetrability, and elevated surface runoff.

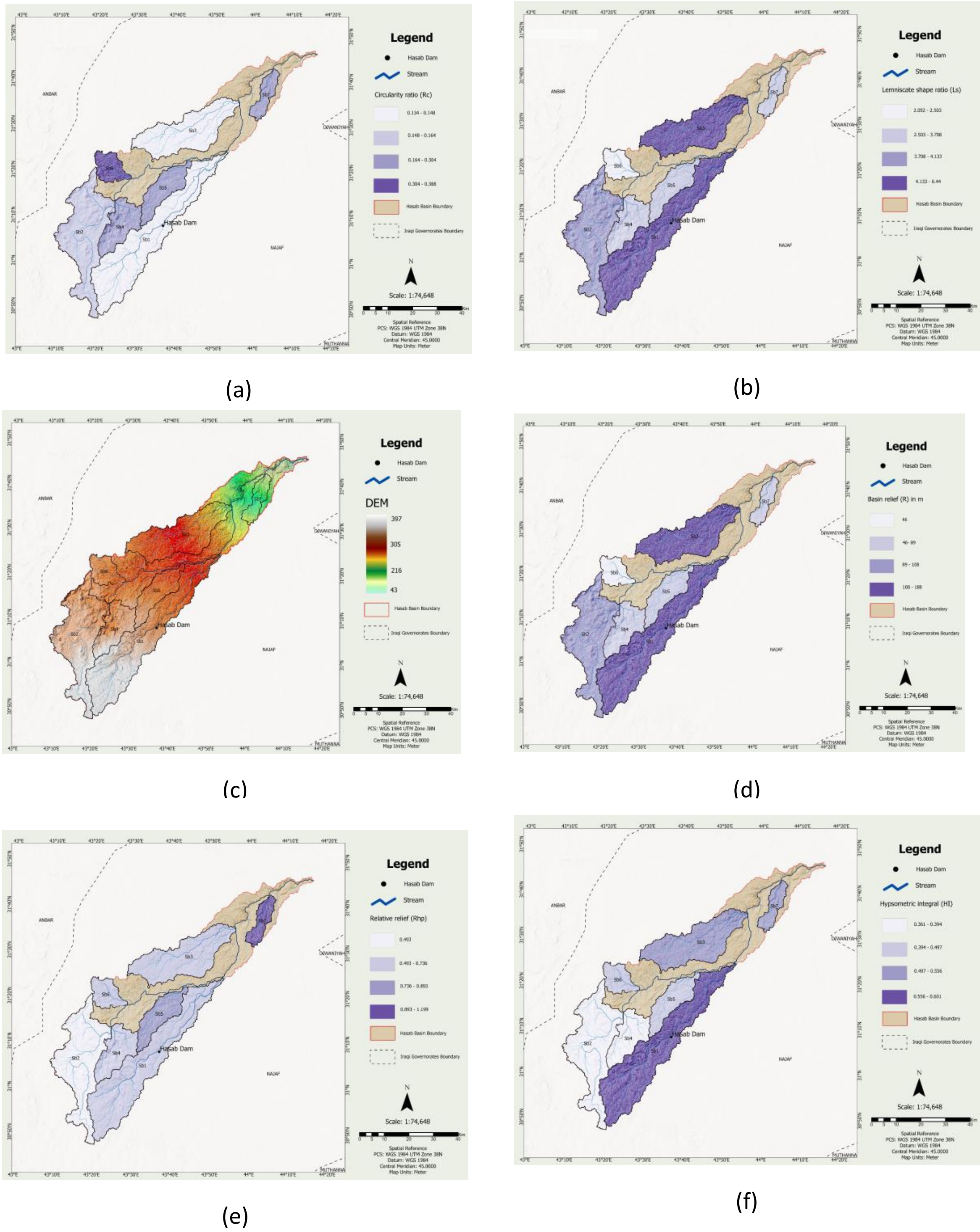


Figure 6: Spatial distribution of (a) Rc, (b) Ls, (c) elevation, (d) R, (e) Rhp, (f) HI in the Hasab basin

4.1.3 Relief aspect

Basin relief (R) The slope ratio means the difference in elevation between the highest point and the lowest point, and it is a measure of knowledge of the topographic nature, drainage density, water depth, and structural strength, in addition to the qualitative amount of sediment transported, and the rate of erosion. Erosion increases with the rate of bifurcation and river grades. It also appears from its effect on flow speed and drainage volume. The speed of flow increases with the steepness of the slope while the chances of underground leakage decrease, and the opposite lies in the decrease of the slope. The relationship between the extent of crushing and the intensity of the effectiveness of erosion agents is directly related. It increases with its increase and decreases with its decrease. The key parameters of both the main basin and sub-basins, such as the elevation of the highest and lowest points, basin relief, relief ratio, relative relief, ruggedness index, and hypsometric integral (HI), were calculated and assessed, Table 6.

Table 6: Calculated values of the maximum height of the basin, height of the basin mouth, and basin relief

Basin	Max. Height	Height of mouth	Mean elevation	Basin relief (R)	Relief ratio (Rh)	Relative relief (Rhp)	Ruggedness index (N)	Hypsometric Int. (HI)
Hasab Basin	397	43	271.19	354	2.90	0.58	0.60	0.64
SB1	396	208	321.02	188	4.81	0.71	0.70	0.60
SB2	397	289	328.09	108	7.31	0.49	0.71	0.36
SB3	308	147	236.61	161	6.48	0.74	0.53	0.56
SB4	359	289	316.64	70	13.34	0.72	0.69	0.39
SB5	331	242	286.27	89	9.96	0.89	0.64	0.50
SB6	323	277	299.01	46	18.02	0.73	0.65	0.48
SB7	179	91	138.69	88	8.01	1.20	0.32	0.54

The relief ratio (Rh), the proportion between R and the longest measurement of the bowl parallel to the vital seepage line, is called Rh [38]. The Rh value varies widely across the Hasab due to geomorphologic and topographic differences.

Relative relief (Rhp) is another measure between the intensity of erosion of the basin from the side and the degree of resistance of its rocks to erosion from the side, and the other is a quantitative representation of the mutual relationship between the value of relative erosion (the difference between the highest level and the lowest point in the basin) and the amount of the basin's circumference. It indicates the relationship between the topography of the basin and the basin's surroundings and the relationship between the relative topography and the degree of resistance of rocks to erosion processes when the climatic conditions are similar, a negative correlation. Low values indicate weak resistance of rocks, active erosion agents, and the activity of erosion agents. Thus, they reflect the ability of waterways to erode high areas of the basin, and high values indicate the resistance of the rocks and the weakness of erosion factors. The Rhp of the basin and subbasin are less than 1.2 Table 6. The data of the Rhp are categorized into four groups: low, moderate, high, and very high. The main basin and all subbasins are characterized by relatively low values within this classification scheme.

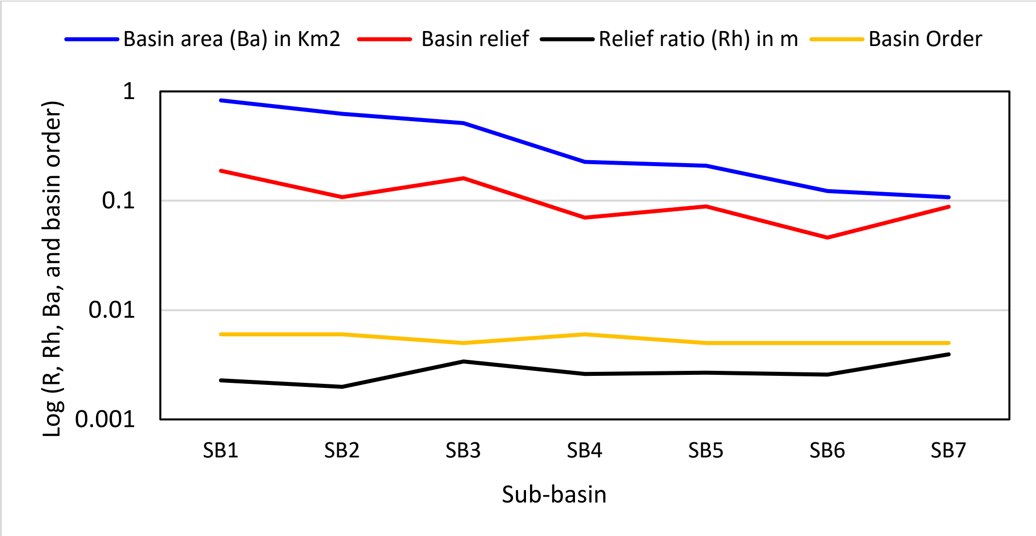
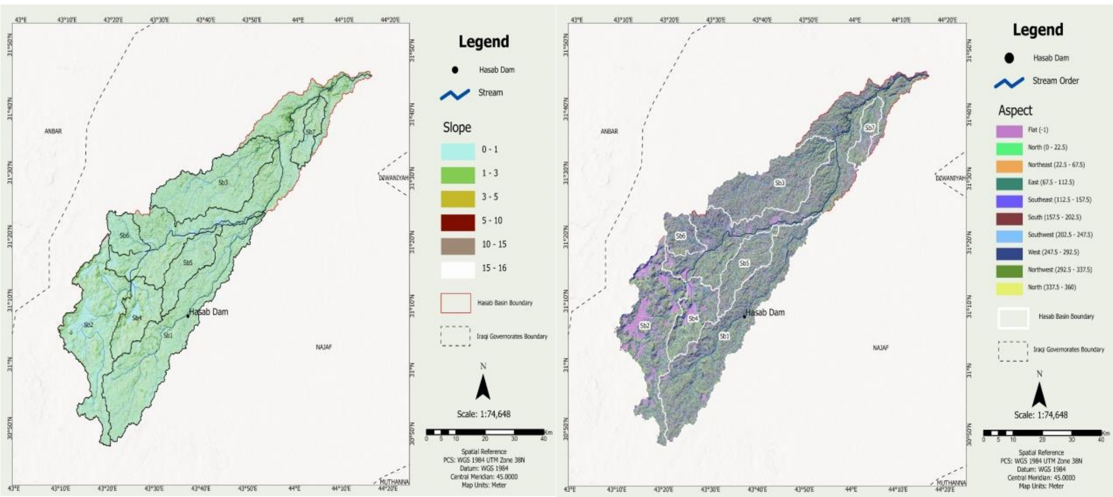


Figure 7: Relation between R, Rh, Ba, and basin order

The slope, the main basin, and the subbasin have slopes that range from almost flat to very flat. Most of the slope ranges fall under low-sloping categories. The slope of the main basin is affected by the structural setting and the type of rock or soil in the area. Basin areas with low slopes are more likely to infiltrate precipitation into the subsurface areas Figure 8.

Aspect Angle, the point of view alludes to the compass's introduction of the steepest downhill slope or azimuth of inclination from the north [49]. Viewpoints are critical in microclimates, especially in dry and semiarid locales. This is often because vegetation patterns differ between slopes confronting the sun and shaded inclines in such environments, as they encounter distinctive micro meteorological conditions. Mostly, the vegetation cover tends to be denser on shaded slopes compared to sun-facing slopes, as moisture substance is held longer on the shaded side.[50]. Microclimatic varieties inside a given region depend on the direction of slope introduction or angle, impacting hillslope and drainage basin improvement [51]. For example, slopes facing northeast, east, and southeast, exposed to the sun during the hottest time of day, tend to be warmer than slopes facing the opposite direction.



(a) (b)

Figure 8: (a) slope and (b) aspect maps in the Hasab basin

Hypsometric analysis

Hypsometric analysis is a time scale that expresses the stage of development that water basins are going through. It also indicates the amount of rock resources still waiting for their role in development. Topographical characteristics gain their importance through some prevailing or previous environmental factors of the basin and their mutual relationship with other characteristics.

Hypsometric integration (HI) indicates the length of time that the erosion cycle took in watersheds. It also expresses the relationship between the basin and the basin's topography and explains the morphological stages that the basin has reached. [37] classified into three categories, as the basin is in an early stage, while the largest part is still in the erosion cycle 35, where the induction process is superior to precipitation. It is in the mature stage if 45 of its area is removed, as erosion is balanced by water deposition, while it is in the aging stage if 55 of its area or more is removed. This scale is used to determine the length of time that watersheds have gone through in their cycle of terrain erosion, and it is extracted according to the equation in Table 1 [23, 31].

HI values give experiences not only in the basin's erosional organization but also in its tectonic, climatic, and lithological conditions. As depicted by [23], the erosion cycle can be classified into three stages: monadnock (old) arrange (HI < 0> 0.6), meaning a high susceptibility to disintegration. Based on the HI values for the basin and its sub-basins, it can be induced that the Hasab basin and most sub-basins are within the late youthful or mature stage, and only SB2 and SB4 are within the old stage Table 6.

5. Conclusions

The study zone, for the most part, shows a delicate slope from the southwest to the northeast. The drainage network and geographical composition of the zone essentially impact the rate of groundwater penetration into the subsurface. In certain occasions, morphological features like lineaments, flaws, and fractures can improve the infiltration rate inside the basin. Morphometric analysis, encouraged by remote sensing and GIS technology, is an effective tool for hydrological analysis of drainage networks and basin delineation. It offers quantitative morphometric experiences into different characteristics of the study region, such as stream length, basin width, area, perimeter, and more. The shape parameters of both most basins and subbasins recommend an elongated form, demonstrating that these basins typically encounter smaller flood peaks and have longer flowways. In differentiation, circular basins tend to quicker floods and expanded dregs transport load. By measuring straight, areal, and relief characteristics, has been able to watch the interaction between hydrological systems and their related landforms. The study area has a dendritic drainage pattern, and the nearly flat to moderate slope terrain consists of streams with long flow lengths. Geological formations influence the drainage pattern. The hypsometric evaluation of the main basin and subbasin indicates the equilibrium or mature stage of landscapes.

Reference

[1] T. S. Khayyun, I. A. Alwan, and A. M. Hayder, "Hydrological Model for Derbendi-Khan Dam Reservoir Watershed Using SWAT Model," Engineering and Technology Journal, vol. 38, pp. 896-909, 2020. [Online]. Available: https://api.semanticscholar.org/CorpusID:225713158.

[2] V. M. Chowdary, D. Chakraborthy, A. Jeyaram, Y. V. N. K. Murthy, J. R. Sharma, and V. K. Dadhwal, "Multi-Criteria Decision Making Approach for Watershed Prioritization Using Analytic Hierarchy Process Technique and GIS," Water Resources Management, vol. 27, no. 10, pp. 3555-3571, 2013, doi: 10.1007/s11269-013-0364-6.

[3] S. A. Abdullah, K. H. Abbas, A. H. Harif, R. F. Alaa, and S. Hiba, "Sustainable Urban Distribution of Educational Institutions and Population Density in Baghdad City Using Remote Sensing Techniques," IOP Conference Series: Earth and Environmental Science, vol. 1202, no. 1, pp. 12015-12015, 2023, doi: 10.1088/1755-1315/1202/1/012015.
[4] C. A. J. Appelo and D. Postma, Geochemistry, Groundwater and Pollution. CRC Press, 2004.
[5] M. Ghosh and D. Gope, "Hydro-Morphometric Characterization And Prioritization Of Sub-Watersheds For Land And Water Resource Management Using Fuzzy Analytical Hierarchical Process (FAHP): A Case Study Of Upper Rihand Watershed Of Chhattisgarh State, India," Applied Water Science, vol. 11, no. 2, 2021, doi: 10.1007/s13201-020-01340-x.
[6] N. A. Aziz, Z. T. Abdulrazzaq, and M. N. Mansur, "Gis-Based Watershed Morphometric Analysis Using Dem Data In Diyala River, Iraq," Iraqi Geological Journal, vol. 53, no. 1, pp. 36-49, 2020, doi: 10.46717/igj.53.1c.3rx-2020.04.03.
[7] F. G. Mohammed, M. H. Ali, S. G. Mohammed, and H. S. Saeed, "Forest Change Detection in Mosul Province using RS and GIS Techniques," Iraqi Journal of Science, pp. 3779-3789, 2021, doi: 10.24996/ijs.2021.62.10.36.
[8] M. F. Rahaman, C. S. Jahan, and Q. Mazumder, "Rainwater Harvesting: Practiced Potential For Integrated Water Resource Management In Drought-Prone Barind Tract, Bangladesh," Groundwater for Sustainable Development, 2019. [Online]. Available: https://api.semanticscholar.org/CorpusID:202175766.
[9] P. D. Aher, J. Adinarayana, and S. D. Gorantiwar, "Quantification Of Morphometric Characterization And Prioritization For Management Planning In Semi-Arid Tropics Of India: A Remote Sensing And GIS Approach," Journal of Hydrology, vol. 511, pp. 850-860, 2014/4// 2014, doi: 10.1016/j.jhydrol.2014.02.028.
[10] A. A. M. Ali, H. A. Al-Thamiry, and S. Q. Alazawi, "Estimation Of Runoff For Goizha-Dabashan Watershed With Aid Of Remote Sensing Techniques," Journal of Engineering, vol. 17, no. 02, pp. 306-320, 2011, doi: 10.31026/j.eng.2011.02.08.
[11] H. G. Maarez, H. S. Jaber, and M. A. Shareef, "Utilization of Geographic Information System for hydrological analyses: A case study of Karbala province, Iraq," Iraqi Journal of Science, pp. 4118-4130, 2022, doi: 10.24996/ijs.2022.63.9.39.
[12] A. S. Mahdi, "The Land Use and Land Cover Classification on the Urban Area," Iraqi Journal of Science, pp. 4609-4619, 2022, doi: 10.24996/ijs.2022.63.10.42.
[13] P. K. Chaubey, A. Kundu, and R. K. Mall, "A Geo-Spatial Inter-Relationship With Drainage Morphometry, Landscapes And NDVI In The Context Of Climate Change: A Case Study Over The Varuna River Basin (India)," Spatial Information Research, vol. 27, no. 6, pp. 627-641, 2019, doi: 10.1007/s41324-019-00264-2.
[14] G. Godif and B. R. Manjunatha, "Prioritizing Sub-Watersheds For Soil And Water Conservation Via Morphometric Analysis And The Weighted Sum Approach: A Case Study Of The Geba River Basin In Tigray, Ethiopia," Heliyon, vol. 8, no. 12, 2022, doi: 10.1016/j.heliyon.2022.e12261.
[15] E. F. Khanger, B. A. A. Razaq, R. R. Ismail, and Z. Rasheed, "Using Spatial Analysis Techniques To Preparing Maps For Distribution Of Pollutant Concentrations In Shatt Al-Arab Waters In November 2015," IOP Conference Series: Materials Science and Engineering, vol. 757, 2020. [Online]. Available: https://api.semanticscholar.org/CorpusID:216262537.
[16] A. A. Al-Shammari and M. A. Al-Dabbas, "Extraction Drainage Network for Lesser Zab River Basin from DEM using Model Builder in GIS," Iraqi Journal of Science, vol. 56, no. 4A, pp. 2915-2926, 2015.
[17] M. J. Mohammed and L. A. Jawad, "The Quantitative Morphometric Analysis of the Biggest Basin in Western Plateau of Iraq," IOP Conference Series: Earth and Environmental Science, vol. 1202, 2023. [Online]. Available: https://api.semanticscholar.org/CorpusID:264600404.
[18] Q. Al-Kubaisi and M. Al-Kubaisi, "Using Water Balance To Assess The Groundwater Recharge In The Area Between Rutba And Dhabaa, Western Iraq." 2018.
[19] H. Chandrashekar, K. V. Lokesh, M. Sameena, J. roopa, and G. Ranganna, "GIS-Based Morphometric Analysis of Two Reservoir Catchments of Arkavati River, Ramanagaram District, Karnataka," Aquatic Procedia, vol. 4, pp. 1345-1353, 2015, doi: 10.1016/j.aqpro.2015.02.175.

[20] R. H. Al-Suhaili and R. H. Hassan, "A Developed Model for Selecting Optimum Locations of Water Harvesting Dams Using GIS Techniques," Journal of Engineering, vol. 20, no. 1, pp. 98-113, 2014.
[21] B. Das, S. Pal, S. Malik, and R. Chakrabortty, "Modeling Groundwater Potential Zones Of Puruliya District, West Bengal, India Using Remote Sensing And GIS Techniques," Geology, Ecology, and Landscapes, vol. 3, pp. 1-15, 2018, doi: 10.1080/24749508.2018.1555740.
[22] M. A. R. Joy, S. Upaul, K. Fatema, and F. M. R. Amin, "Application Of GIS And Remote Sensing In Morphometric Analysis Of River Basin At The South-Western Part Of Great Ganges Delta, Bangladesh," Hydrology Research, vol. 54, no. 6, pp. 739-755, 2023, doi: 10.2166/nh.2023.087.
[23] A. N. Strahler, "Hypsometric (Area-Altitude) Analysis Of Erosional Topography," Geological Society of America Bulletin, vol. 63, no. 11, pp. 1117-1142, 1952.
[24] S. Wu, J. Li, and G. H. Huang, "A Study On DEM-Derived Primary Topographic Attributes For Hydrologic Applications: Sensitivity To Elevation Data Resolution," Applied Geography, vol. 28, no. 3, pp. 210-223, 2008.
[25] R. Zy Harifidy, R. Zy Misa Harivelo, I. Hiroshi, M. Jun, and S. Kazuyoshi, "A Systematic Review of Water Resources Assessment at a Large River Basin Scale: Case of the Major River Basins in Madagascar," Sustainability, vol. 14, no. 19, pp. 12237-12237, 2022.
[26] M. Falkenmark, P. Fox, G. Persson, and J. Rockström, "Water Harvesting For Upgrading Of Rainfed Agriculture," Problem Analysis and Research Needs, pp. 76-87, 2001.
[27] M. Y. A. Khan, M. ElKashouty, A. M. Subyani, and F. Tian, "Morphometric Determination and Digital Geological Mapping by RS and GIS Techniques in Aseer–Jazan Contact, Southwest Saudi Arabia," Water (Switzerland), vol. 15, no. 13, 2023, doi: 10.3390/w15132438.
[28] N. S. Al-Daghastania, K. J. Al-Maitahb, and B. aAl, "Water Harvesting Using Morphometric Analysis And Gis Techniques: A Case Study Of The Hrh Tasneem Bint Ghazi For Technology Research Station," 2006.
[29] U. Ali and S. Ali, "Analysis of Drainage Morphometry and Watershed Prioritization of Romushi-Sasar Catchment, Kashmir Valley, India using Remote Sensing and GIS Technology," International Journal of Advance Research, vol. 2, pp. 5-23, 2014.
[30] H. J. Alatta, L. E. George, S. F. Behadili, B. H. Sayyid, and M. H. Ali, "Geospatial Data Analysis of School Distribution in Baghdad City," Iraqi Journal of Science, pp. 6675-6685, 2023.
[31] R. Chakrabortty, S. Ghosh, S. C. Pal, B. Das, and S. Malik, "Morphometric Analysis for Hydrological Assessment using Remote Sensing and GIS Technique: A Case Study of Dwarkeswar River Basin of Bankura District, West Bengal," Asian Journal of Research in Social Sciences and Humanities, vol. 8, no. 4, pp. 113-113, 2018, doi: 10.5958/2249-7315.2018.00074.6.
[32] Y. I. Al-Saady, Q. A. Al-Suhail, B. S. Al-Tawash, and A. A. Othman, "Drainage Network Extraction And Morphometric Analysis Using Remote Sensing And GIS Mapping Techniques (Lesser Zab River Basin, Iraq And Iran)," Environmental Earth Sciences, vol. 75, pp. 1-23, 2016.
[33] S. F. A. Fouad, "Tectonic Map Of Iraq, Scale 1: 1000 000, 2012," Iraqi Bulletin of Geology and Mining, vol. 11, no. 1, pp. 1-7, 2015.
[34] V. Sissakian and S. Fouad, "GEOLOGICAL MAP OF IRAQ, SCALE 1: 1000 000, 4 Th EDITION, 2012," vol. 11, pp. 9-16, 07/14 2015.
[35] H. K. Al-Jiburi and N. H. Al-Basrawi, "Hydrogeology," IRAQI BULLETIN OF GEOLOGY AND MINING, no. 1, pp. 125-144, 2007.
[36] A. N. Strahler, "Quantitative Geomorphology Of Drainage Basin And Channel Networks," Handbook of applied hydrology, 1964.
[37] R. E. Horton, "Erosional Development Of Streams And Their Drainage Basins; Hydrophysical Approach To Quantitative Morphology," Geological Society of America Bulletin, vol. 56, no. 3, pp. 275-370, 1945.
[38] S. A. Schumm, "Evolution Of Drainage Systems And Slopes In Badlands At Perth Amboy, New Jersey," Geological Society of America Bulletin, vol. 67, no. 5, pp. 597-646, 1956.
[39] A. N. Strahler, "Quantitative Analysis Of Watershed Geomorphology," Eos, Transactions American Geophysical Union, vol. 38, no. 6, pp. 913-920, 1957.
[40] R. E. Horton, "Drainage-Basin Characteristics," Eos, Transactions American Geophysical Union, vol. 13, no. 1, pp. 350-361, 1932, doi: 10.1029/TR013i001p00350.

[41] A. Faniran, "The Index Of Drainage Intensity—A Provisional New Drainage Factor," in Aust J Sci 31, ed, 1968, pp. 328-330.
[42] V. C. Miller, A Quantitative Geomorphic Study Of Drainage Basin Characteristics In The Clinch Mountain Area, Virginia, and Tennessee. Columbia University New York, 1953.
[43] J. T. Hack, "Studies of Longitudinal Stream Profiles in Virginia and Maryland," ed: U.S. Government Printing Office, 1957, pp. 294-B.
[44] S. Sukristiyanti, R. Maria, and H. Lestiana, "Watershed-based Morphometric Analysis: A Review," IOP Conference Series: Earth and Environmental Science, vol. 118, no. 1, p. 012028, 2018/02/01 2018, doi: 10.1088/1755-1315/118/1/012028.
[45] R. A. Deju, "Regional Hydrology Fundamentals," Hydrotechnical Construction, vol. 6, no. 10, pp. 1009-1009, 1972/10/01 1972, doi: 10.1007/BF02376895.
[46] K. G. Smith, "Standards For Grading Texture Of Erosional Topography," American Journal of Science, vol. 248, no. 9, pp. 655-668, 1950.
[47] M. V. Vincy, B. Rajan, and A. P. Pradeepkumar, "Geographic Information System–Based Morphometric Characterization Of Sub-Watersheds Of Meenachil River Basin, Kottayam District, Kerala, India," Geocarto International, vol. 27, no. 8, pp. 661-684, 2012.
[48] G. Prasad, Environmental geomorphology. Discovery Publishing House, 2008.
[49] R. Huggett and J. Cheesman, "Topography and the Environment," 2002.
[50] R. J. Warren II, "An Experimental Test Of Well-Described Vegetation Patterns Across Slope Aspects Using Woodland Herb Transplants And Manipulated Abiotic Drivers," New Phytologist, vol. 185, no. 4, pp. 1038-1049, 2010.
[51] S. A. Schumm and R. F. Hadley, Progress In The Application Of Landform Analysis In Studies Of Semiarid Erosion. United States Department of the Interior, Geological Survey, 1961.