2025 نيسان مجلة دراسات في الإنسانيات والعلوم التربوية العدد 9
April 2025 Journal of Studies in Humanities and Educational Sciences No. 9
Print ISSN 3006-3256 Online ISSN 3006-3264

Morphometric Analysis for the Greater Zab Basin by Using GIS and RS Techniques

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Abstract

The Greater Zab basin supports has been considered as an important water source for industry, domestic use, and agriculture in both Turkey and the Kurdistan region - Iraq. This study aims at quantifying the surface water flow within the Greater Zab basin Remote Sensing (RS) techniques using Geographic Information System (GIS). Additionally, it analyzes the morphometric parameters of the drainage basin, the study focused on three primary components: linear, areal, and relief parameters. Concerning the data collection, the DEM 30M from earthexplorer.usgs.gov were considered. The study area encompasses 26,323 km², containing 8 stream orders and 28,590 stream numbers. The main land cover type results were displayed that the vegetation of the Greater Zab Basin is covering 35.6%, while water bodies accounted for a smaller proportion, with 0.4. The study area features an elevation range from 182 to 4,066 meters, with annual rainfall varying between 380 and 1,100 mm. The study demonstrates the effectiveness of using remotely sensed satellite imagery combined with GIS for morphometric analysis of a specific region. This approach proves valuable for watershed management, identifying critical zones, and implementing soil and water conservation practices within the watershed or region.

Keywords: Geographical Information System, Greater Zab Basin, Remote Sensing and Morphometric.

التحليل المورفومتري لحوض الزاب الكبير باستخدام تقنيات نظم المعلومات الجغرافية(GIS) والاستشعار عن بعد(RS)

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الملخص

يعتبر حوض الزاب الكبير مصدراً مهماً للمياه للصناعة والاستخدام المنزلي والزراعة في كل من تركيا ومنطقة كردستان - العراق. تهدف هذه الدراسة إلى قياس تدفق المياه السطحية في حوض الزاب الكبير باستخدام تقنيات الاستشعار عن بعد (RS) ونظم المعلومات الجغرافية (GIS). بالإضافة إلى ذلك، تحلل المعايير المورفومترية لحوض الصرف، وركزت الدراسة على ثلاثة مكونات رئيسية: المعايير الخطية، والمساحية، والتضاريسية. فيما يتعلق بجمع البيانات، تم اعتماد نموذج الارتفاع الرقمي 30 متر من earthexplorer.usgs.gov. تبلغ مساحة منطقة الدراسة 26,323 كم^2، وتحتوي على 8 رتب مجرى و28,590 مجرى مائي. تتميز منطقة الدراسة بنطاق ارتفاع يتراوح من 182 إلى 4,066 متر، مع هطول أمطار سنوي يتراوح بين 380 و1,100 ملم. توضح الدراسة فعالية استخدام صور الأقمار الصناعية عن بعد مع نظم المعلومات الجغرافية للتحليل المورفومتري لمنطقة محددة. يثبت هذا النهج قيمته في إدارة مستجمعات المياه، وتحديد المناطق الحرجة، وتنفيذ ممارسات الحفاظ على التربة والمياه داخل مستجمع المياه أو المنطقة.

الكلمات المفتاحية: نظم المعلومات الجغرافية، حوض الزاب الكبير، الاستشعار عن بعد والمورفومتري.

1. introduction

The Remote Sensing (RS) and Geographic Information Systems (GIS) combination takes significantly advanced hydrological research and applications. These technologies have been generally utilized for improve Morphometric Predictions by utilizing GIS and RS, researchers have been able to integrate spatial analysis, digital terrain modeling, with thematic layers derived from remote sensing data to enhance the understanding of Morphometric processes. Morphometric studies constitute one of the most important modern directions in the study of basins, as the shape of the river network through which the basin is formed is a reflection of the relationships between the characteristics of the rocks of the region in terms of the degree of permeability, hardness, structural shapes, areas of rock weakness, and climate conditions, as well as the general slope of the surface, the amount of rainfall, and vegetation. So the influence of these natural reasons is determined by the spatial correlation of these natural variables, which differ from region to region. In 1945, Horton pioneered the invention of a methodology for calculating several morphometric features related to drainage basins, which Strahler later improved in 1964 (Al-Hussein and Yahyaa, 2019).

The methodology demonstrated significant value by revealing strong relationships between the watershed's morphometric qualities and hydrological attributes. Since then, these discoveries have been crucial for thoroughly planning and developing watershed basins. The morphometric method is used to interpret the complex relationships between terrain features and basin attributes, such as relief, topography, infiltration rates, and subsurface characteristics (Al-Hussein and Yahyaa, 2019). The circulator ratio is intricately linked to several aspects, including the length and frequency of streams, the slope of the basin, structures of geological, land cover- land use types, relief, with climate. It is crucial in determining the developmental stage of a tributary watershed, where low, medium, and high circularity ratio (Rc) values correspond to the young, mature, and old stages of the watershed's life cycle, respectively (Rai *et al.*, 2017). The existence of stream frequency is affected by several variables, including soil composition, vegetation cover, rainfall patterns, and physiography. This characteristic functions as an indicator of different stages in the evolution of the landscape. cannot be directly compared between drainage basins of different sizes because their values change with drainage area size. Nonetheless, it's crucial to remember that stream frequency usually positively correlates with drainage density, meaning that the number of streams within a drainage area grows in tandem with an increase in drainage density (Jahan *et al.*, 2018). Morphometric features are standard for analyzing drainage and water resources, as well as for figuring out the hydrological behaviors of a basin. They are crucial to hydrological research. Because of their ability to clarify and focus the relationship between shape and other morphological processes, morphometric characteristics have drawn the attention of many scientists, including Horton, Strahler, and Miller. When studying river hydrology, understanding the characteristics of the river's flood and the amount of river discharge, both of which are influenced by the shape, size, and composition of the basin, combine to determine the characteristics of river flow in seasonal variations. This investigation employs a morphometric analysis to characterize seasonal and permanent water basins within the study area. By integrating digital data with statistical equations, the research seeks to achieve an objective. This study will contribute to watershed management by identifying critical areas and supporting the implementation of water conservation practices and various soil within this watershed. In order to conduct a thorough morphometric analysis of a crucial but little-studied basin in the Tigris-Euphrates River system, the title "Morphometric Analysis for the Greater Zab Basin by Using GIS and RS Techniques" is novel because it combines cutting-edge Geographic Information Systems (GIS) and Remote Sensing (RS) technologies. Using digital elevation models (DEMs) and high-resolution satellite data, this work presents a contemporary, data-driven method for quantifying and assessing important morphometric features. This study

Print ISSN 3006-3256 Online ISSN 3006-3264

closes a large knowledge gap by concentrating on the Greater Zab Basin and offering insights into its hydrological behavior, geomorphological features, and possible uses in flood control, water resource planning, and environmental sustainability—all of which are critical given the effects of climate change and human activity.

2. The Study Area

The Greater Zab (GZ) River begins in the Ararat mountains of Turkey, passes through the Kurdistan Region of Iraq, and finally joins the Tigris River 372 km south of Mosul. when the GZB is located between latitudes 36°-38° North and longitudes 43°-45° East. Based on Figure (3.1) the study catchment exhibits significant elevation variation, and the peak point is 4,0098 m while the lowest point is 183 meters above sea level. It also starts in the mountainous areas of northern Kurdistan, Iraq, bordering neighboring Turkish territory. It flows southward, traversing the Erbil Plains area in the southwest, before ultimately meeting the Tigris River. The GZ is the most important river after Euphrates and the Tigris of Iraq. The GZ is a major part of the Tigris River. In addition, this catchment is a huge and considerable area located in the Turkish territory and most of the GZB inside the Kurdistan region of Iraq. This basin is among the most critical in the Kurdistan Region, accounting for approximately 33% (50,330 km²) of the region's total area. It also contains the capital Erbil in Kurdistan (Omar, Rasul and Ali, 2023). While GZB spans 26,323 km², with 65% of this area located within Iraq, and the remaining 35% in Turkey. In basins with multiple springs, the primary source of irrigation often originates from this region.

The GZB experiences an average annual rainfall of 570 mm, which will range from 350 mm to approximately 1,000 mm. While the average annual temperature is 14.3°C. The distribution of rainfall throughout the year was uneven, and the highest levels occurring during winter and spring. Winter received the largest portion of total precipitation, including snowfall, accounting for 48.9%. This was followed by spring, which contributed 37.5% of the annual total. In contrast, autumn and summer experienced significantly lower precipitation, at 12.9% and 0.57%, respectively (Abdulla and Al-Badranih, 2000).

Figures (1) is presents detailed information regarding the boundaries of the GZB, highlighting the study area and various characteristics of the region.

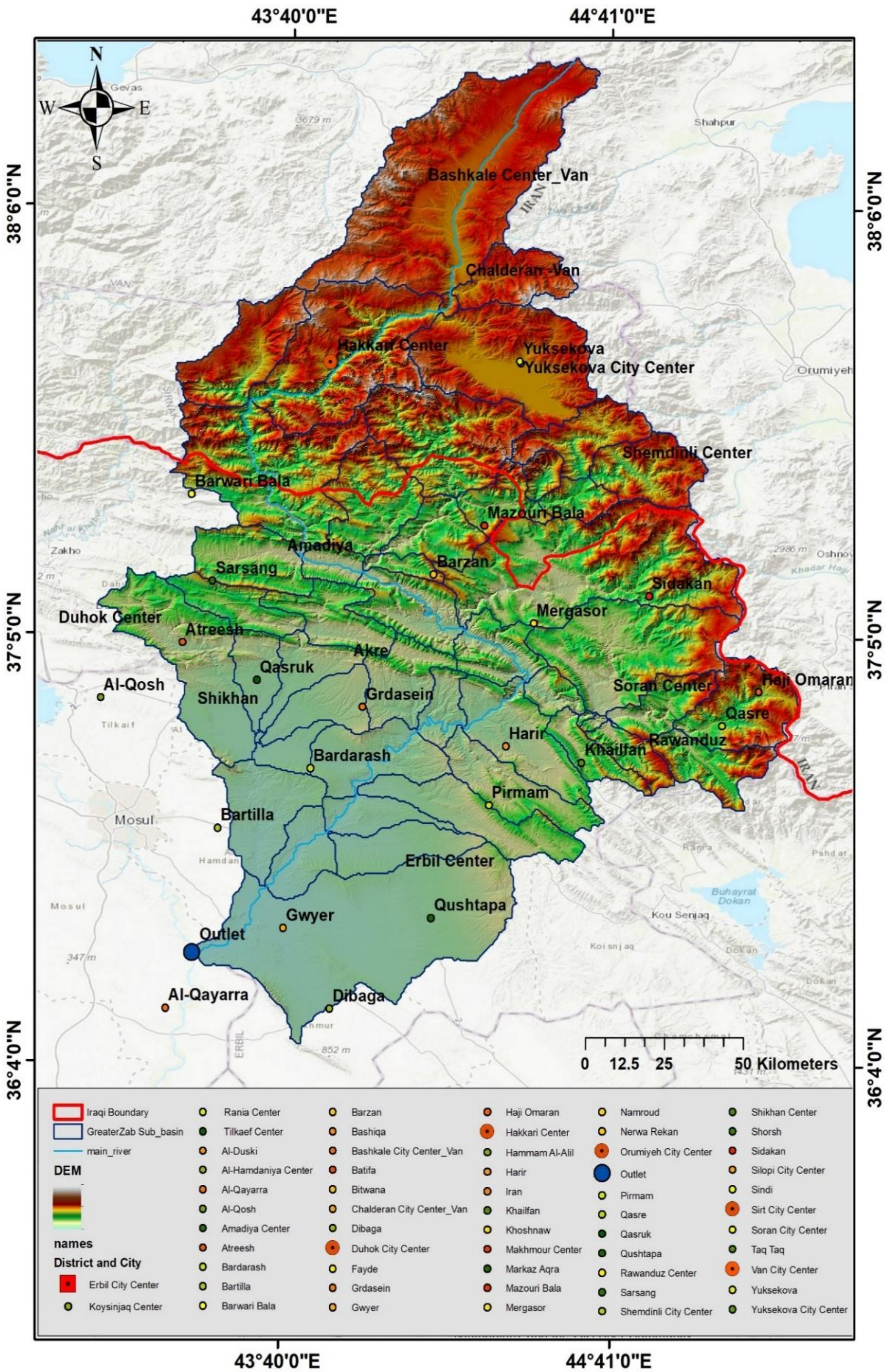

Figure 1 The Greater Zab Basin

3. Morphometric Analyses Methodology

This section utilizes a 30-meter resolution DEM obtained by USGS Earth Explorer as the primary data source. The main objective of this chapter is to identify and extract the key numerical morphometric characteristics. These characteristics are categorized into three groups: relief, areal, and linear. ArcGIS 10.8 software was employed to automate the extraction of stream networks with the calculate morphometric parameters within the GZB the Figure (2) was displayed Flowchart of Morphometric Analyses of GZB. The extracted morphometric data was subsequently used for both morphological and hydrological analyses. Table (1) provides a comprehensive list standard equations for calculating to morphometric parameters of the GZB, drawing upon the pioneering work of researchers such as (Horton, 1932, 1945, 1955; Miller, 1953; Schumm, 1956; Strahler, 1957) and (Horton, 1955). This study builds upon their contributions to the field of morphometry.

According Figure (2) the process involved extracting essential data, including flow direction, flow accumulation, and watershed delineation from the DEM. The analysis was divided into three key aspects: Linear, Areal, and Relief. In the Linear Aspect, parameters such as stream order, stream length, and stream number were used to evaluate the stream network structure. The Areal Aspect focused on metrics such as drainage density, basin area, and form factor to assess water distribution across the basin. The relief aspect examined elevation-related factors such as basin relief and slope to determine their influence on water flow and erosion.

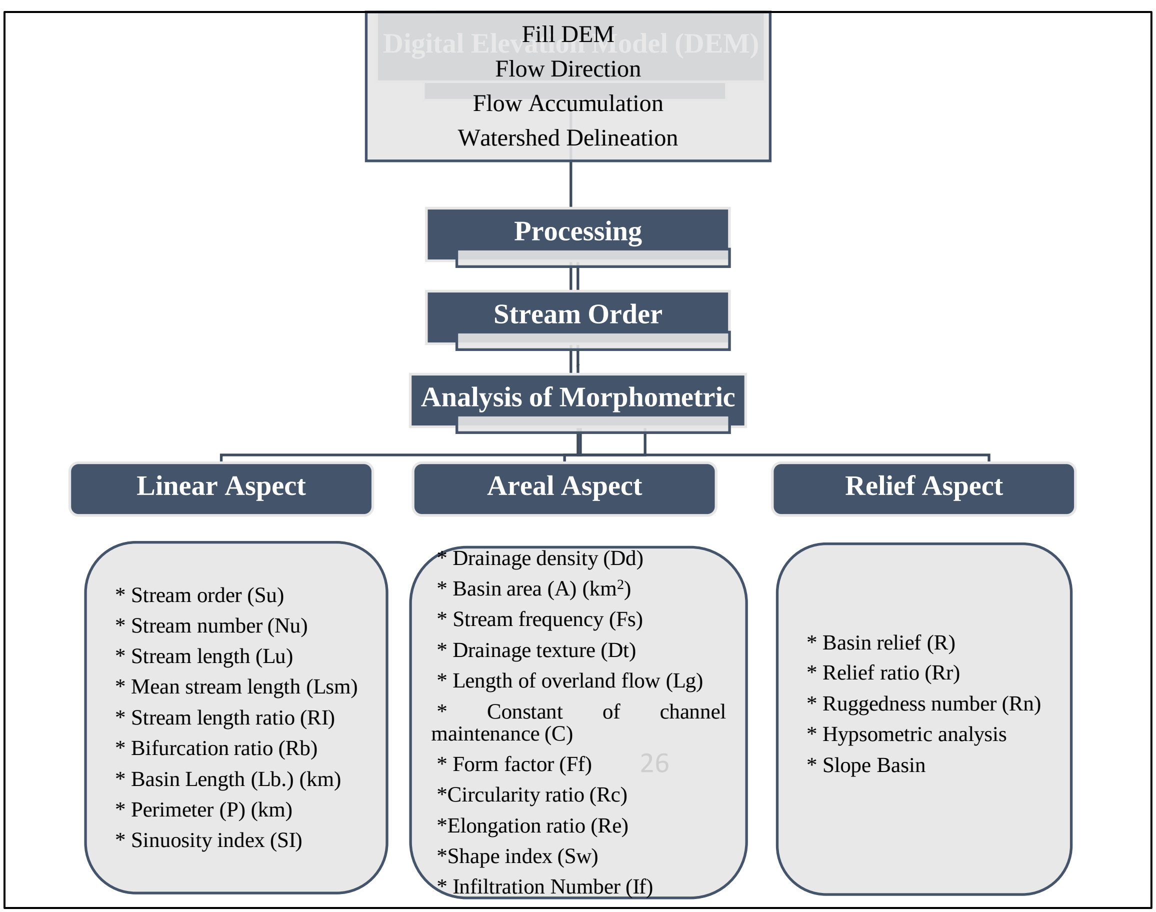

Figure 1 Flowchart of Morphometric Analyses of GZB

Table 1 Equations for Morphometric Parameters Calculation.

	Morphometric Parameters	Formula	References
Linear	Stream order (Su)	Hierarchical ordering	(Strahler, 1957)
	Stream number (Nu)	Number of streams order	(Horton, 1945)
	Stream length (Lu)	Length of the stream order	(Horton, 1945)
	Mean stream length (Lsm)	Lsm = Lu/Nu Where the Lu =Total length of stream order and Nu = Total number of stream orders.	(Horton, 1945)
	Stream length ratio (RI)	RI = Lu/L(u-1); where the Lu = total stream length of order u and L(u-1) = total stream of the next lower order	(Horton, 1945)
	Bifurcation ratio (Rb)	Rb = Nu/N(u+1); Nu = number of streams of any given order and N (u+1) = the next higher order	(Horton, 1945)
	Basin Length (Lb.) (km)	ArcMap 10.8 software	
	Perimeter (P) (km)	ArcMap 10.8 software	
	Sinuosity index (SI)	SI=AL/EL:SI= AL= Actual length of main stream line, EL= Expected straight line to the main stream order	(Schumm, 1956)
Areal	Drainage density (Dd)	Dd = L/A: where L = total stream length, A =Perimeter of area of basin(km2)	(Horton, 1945)
	Basin area (A) (km2)	ArcMap 10.8 software	
	Stream frequency (Fs)	Fs = N/A: N = total number of streams, and A = Basin Area(km2)	(Horton, 1945)
	Drainage texture (Dt)	T= Dd*Fs: where Dd = Drainage density, and Fs = Stream Frequency	(Smith, 1950)
	Length of overland flow (Lg)	Lg = ½*Dd: where Dd = Drainage density	(Horton, 1945)

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Print ISSN 3006-3256 Online ISSN 3006-3264

	Constant of channel maintenance (C)	C = 1/Dd: Dd = Drainage density	(Schumm,1956)
	Form factor (Ff)	Ff = A/Lb2: where A = Basin area (km2),and Lb2 = Basin length(km)	(Horton, 1945)
	Circularity ratio (Rc)	Rc = 4πA/P2: where A=Basin Area(km2) P = perimeter of basin	(Miller, 1953)
	Elongation ratio (Re)	Re=2/Lb* (A/ π)1/2: where A = Area of the Basin(km2) π = pi value i.e,3, Lb = Basin length	(Schumm,1956)
	Shape index (Sw)	Sw = 1/Fs: where Fs= Stream frequency	(Horton, 1932)
	Infiltration Number (If)	If = Dd*Fs: where Dd=Drainage density, and Fs=Stream frequency	(Zävoianu,1985)
Relief	Basin relief (R)	R=H-h: where H = maximum elevation (m), and h = minimum elevation (m)of the basin	(Schumm, 1956)
	Relief ratio (Rr)	Rr= R/Lb: where R= Basin relief and Lb = length of the basin (km)	(Schumm, 1956)
	Ruggedness number (Rn)	Rn = R*Dd/1000 where R= Basin relief and Dd= Drainage density	(Schumm, 1956)
	Gradient ratio (Rg)	Rg = Es-Em/Lb; where Es = elevation at the source, and Em = elevation at the mouth	(Sreedevi *et al.*, 2009; Kabite and Gessesse, 2018)
	Hypsometric curve (HC)	Relative High = h/H, Relative = Area a/A	(Strahler, 1957)

4. Results

Morphometry of Greater Zab Basin

Understanding the morphometric properties of a drainage basin is crucial for hydrologists, mainly in semi-arid area, wherever controlling surface runoff is required because of the small amount of water resources (Abdeta et al., 2020). One of the most crucial instruments for examining these attributes is ArcMap, which permits thorough examination of the physical traits and attributes of a drainage basin. The Greater Zab drainage basin serves as an illustration that highlights the significance of morphometric studies in understanding and managing water

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resources. During the morphometric examination of the basin, it has three primary components of the linear, areal, and relief parameters were examined. Each variable provides relevant information when drainage basin features and hydrological behavior are considered.

4.1 Linear Parameters

Variety of critical linear morphometric parameters were calculated for this basin, including the total stream length, mean stream length, stream length ratio, bifurcation ratio, and Rho coefficient ratio for each stream order. These results are detailed in Table (2) Notably, where the basin displays a dendritic drainage pattern, with streams reaching up to the 8th order, as illustrated in Figure (3).

Table 2: Linear aspects of Greater Zab River Basin

stream order	**Total number of streams**	**Total Stream Length in km (TLu)**	**Mean Stream Length in km**	**Stream Length Ratio (RI)**	**Bifurcation Ratio**	**Main Bifurcation**
1	14015	11126.5	0.8	1.5	3.8	
2	3647	5284.2	1.4	5.8	3.3	
3	1093	2385.5	2.2	19.5	3.2	
4	339	1192.3	3.5	62.9	3.2	
5	106	627.9	5.9	201.1	1.1	
6	100	436.6	4.4	213.2	25.0	
7	4	100.7	25.2	5330.1	4.0	
8	1	167.0	167.0	21320.5	0.0	
Total	**19305**	**21320.5**	210.4	**27154.8**	**43.7**	

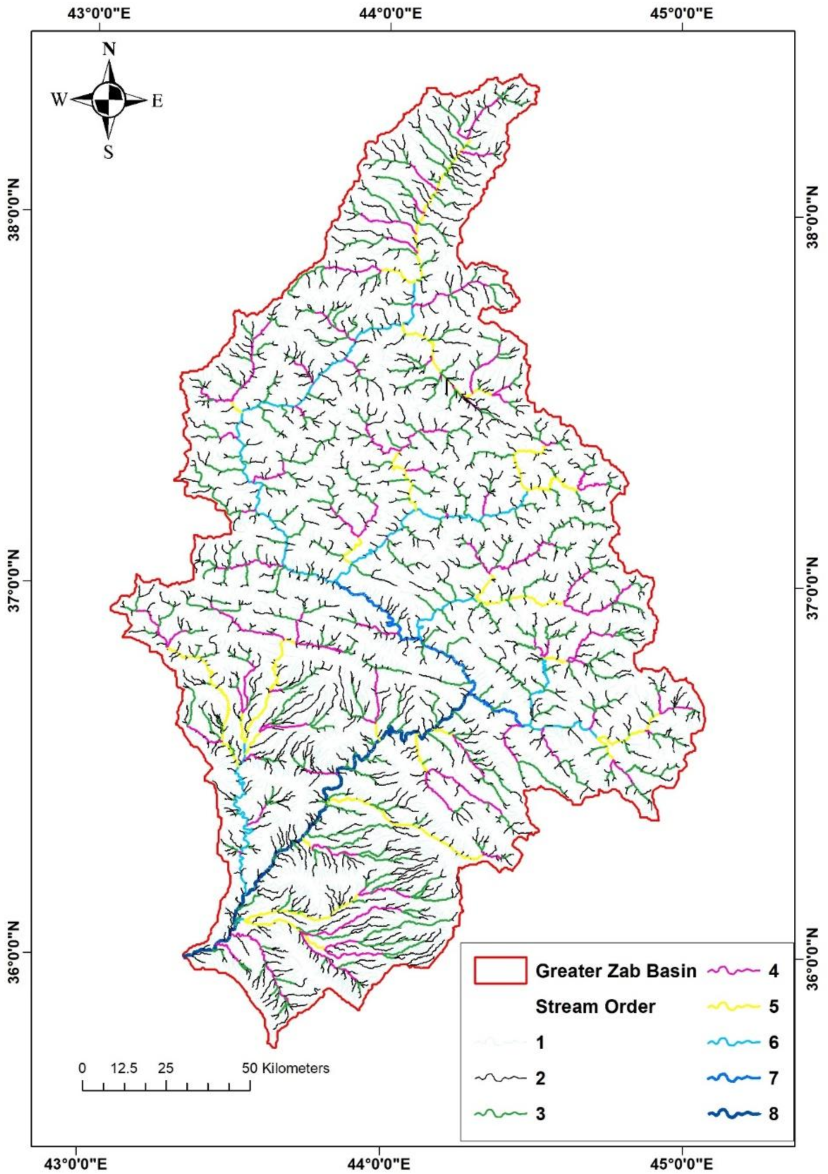

Figure 3 The Stream Order of the Study Area

4.1.1 Stream order (Su)

The methodical assignment of hierarchical rankings to the current streams, considering their various ranges and patterns, is called stream order. Stream classification in this study basin was performed using the method proposed by Strahler, (1957). As shown in Table (2), the classification results indicate that the study region contains an eight-order drainage basin.

4.1.2 Stream number (Nu)

The parameter under consideration exerted an important effect on the runoff process, specifically on the size and dimensions of the branches. Additionally, stream number is the impact of several factors, including topography, slope, climate, rock type, and geology. The overall number of streams within the GZB was determined to be 19305. The streams have been classified by stream order: 14,015 are 1st order, 3,647 are 2nd order, 1,093 are 3rd order, 339 are 4th order, 106 are 5th order, 100 are 6th order, 4 are 7th order, and 1 is 8th order. These details are summarized in Table (2) which provides information on the Linear Aspect of GZB. The total count of streams within the GZB and their categorization based on their order indicate that the basin has a well-developed and relatively efficient drainage network. This information is important for understanding the basin's hydrology and for developing management plans to protect its water resources.

4.1.3 Stream length (Lu)

The geometric similarity principle in basins is represented by stream length, which normally decreases from the highest stream order to the lowest stream order. Accordingly, streams with higher orders are usually shorter than those with lower orders.

The relationship between stream length and stream order is inverted (Horton, 1945; Goran and Khattab, 2023) . The stream length results of the GZB were 21320.5 km to the overall length of the stream, with the 1st order being 11126.5 km, 2nd 5284.2 km, 3rd 2385.5 km, 4th 1192.3 km, 5th 627.9 km, 6th 436.6 km,7th 100.7 km and 8th 167 km. Table (2) contains the stream length of the Linear Aspect of Greater Zab. The stream length results for the GZB indicate that the basin has a difficult with the well-built drainage network. First-order streams comprise most of the total stream length, with higher-order streams decreased as the stream order increased. This is a typical pattern for drainage networks in which streams are actively eroding and forming new tributaries.

All eight stream orders in the basin indicate that the drainage network was mature. Mature drainage networks are characterized by a hierarchy of streams of different orders, with higher-order streams draining larger areas and having more tributaries. The relatively high stream length ratios, which indicate that higher-order streams are longer than lower-order streams, suggest that the drainage network is efficient in collecting and transporting water. This is important for flood control and for water quality.

4.1.4 The Mean stream length (Lsm)

The given parameter reflects the basin's surface characteristics and the typical scale of the drainage network components that it by demonstrating the value of this parameter. The analysis of stream networks within the study area revealed

variations in mean stream length based on stream order, as presented in Table (2). First-order streams, which are the smallest streams in the network, exhibit a mean length of 0.8 kilometers. This length remains consistent for the second-order streams. As that move up in stream order, the mean lengths begin to decrease slightly. Third-order streams have a mean length of 2.2 kilometers, followed by 3.5 kilometers to fourth and fifth-order streams include 5.9. Sixth is 4.4 and seventh-order streams have a further increase in mean length, getting 25.2 kilometers. Finally, the largest streams in the network, classified as eighth-order, had a mean length of 167 kilometers. This suggests that as streams combine and progress to higher orders, they tend to be considerably longer, likely due to the accumulation of water and joining of tributaries.
The total mean stream length across all stream orders amounts to 210.4 km. This value represents the cumulative average length of streams across the studied orders, highlighting the extended reach of higher-order streams. Mean stream length provides insight into river network characteristics and can reflect underlying geomorphology and hydrological processes. The substantial increase at higher orders underscores the typical structure of river systems, where major rivers comprise extensive networks of smaller tributaries that contribute to their total length and flow. Figure (4) shows the mean stream plot of the GZB.

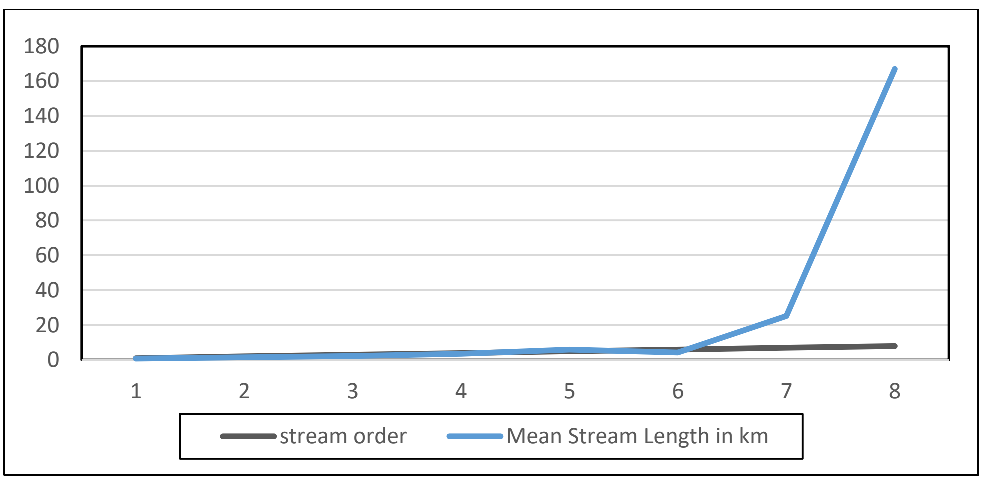

Figure 4 The mean Stream Order Plot and Stream Length of the study area

4.1.5 Stream Order and Stream Length

Today ArcGIS 10.8 an important role in morphometric studies. This was employed to calculate the lengths of the various stream segments. Hence, the stream length of an order serves as a signature for the contributing region of the watershed. The mean stream length was calculated by dividing the total length of the stream by the number of segments within that sequence. Starting the watershed's total estimated stream length is 21320.5 km. The computed mean and cumulative stream lengths for the various orders are listed in Table (2). First-order streams are 11126.4 km lengthy, or around 52% of the total stream length, indicating that the drainage network is relatively young. In this study, Figures (5) and (6) illustrate an inverse relationship between stream order, stream number and stream length.

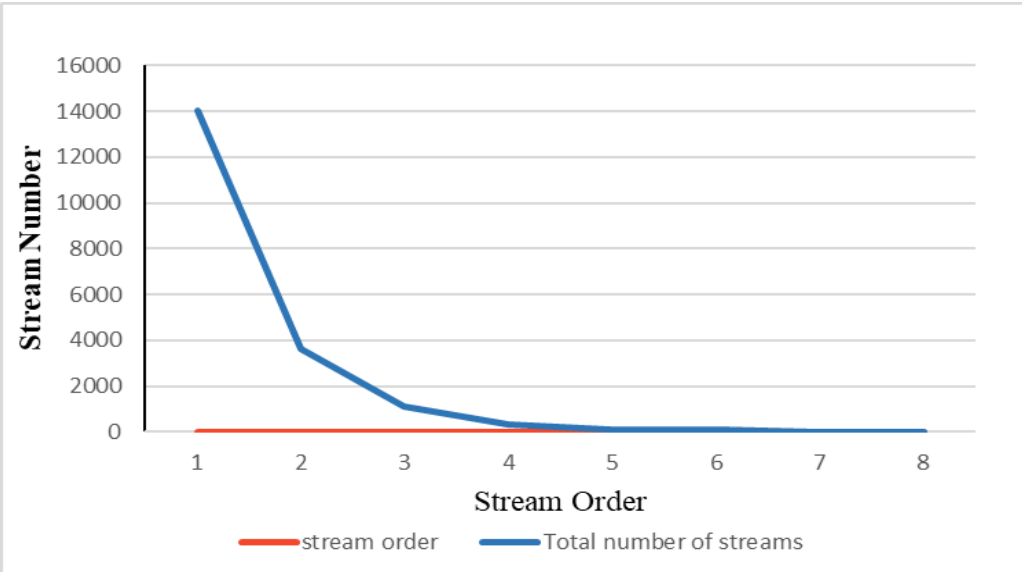

Figure 5 The Stream Order Plot and Stream Number

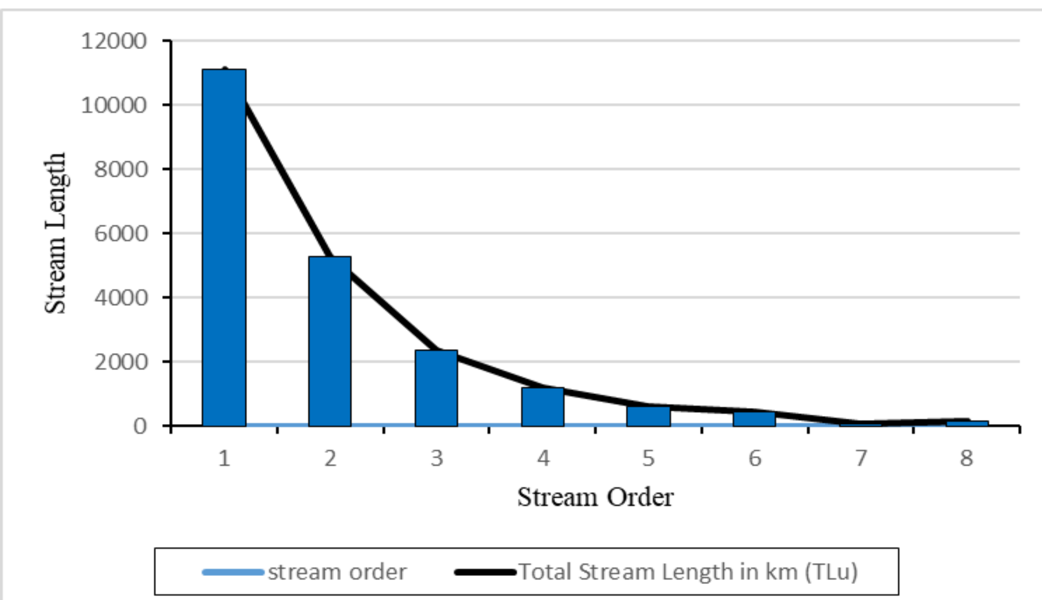

Figure 6 The Stream Order Plot and Stream Length

4.1.6 Stream length ratio (RL)

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The Stream Length Ratios to stream orders within the study area are presented as follows: the 1st order is1.5, the 2nd order is5.8, the 3rd order is 19.5, the 4th order is 62.9, the 5th order is 201.1, the 6th order is 203.2, the 7th order is 5330.1, and the 8th order is 21320.5 stream order, as presented in Table (2). The branching and hierarchical structure of a river network can only be adequately described using these stream length ratios. They specifically show how successive stream lengths in the drainage system are related. To manage watersheds and evaluate the environment, a complete understanding of the morphological and hydrological behavior of the GZB was facilitated by analyzing these ratios. Table (3) presents the stream length ratios across various stream orders and their implications on stream efficiency.

Table 3 The Stream Length Ratios and their impact to The Greater Zab

Stream order	Stream Length Ratio	Implication
1	1.8	Relatively inefficient
2	1.5	Becoming more efficient
3	1.6	Becoming more efficient
4	1.7	More efficient
5	0.7	More efficient
6	5.8	More efficient
7	6.6	Very efficient
8	1.3	Very efficient

Depending on table (3) that is show Stream length ratio is a measure of how the length of streams changes between successive orders, providing insight into the efficiency of water and sediment transport within the stream network. For lower orders (1 to 3), the stream length ratios vary between 1.5 and 1.8, suggesting a gradual increase in efficiency as streams become more interconnected. By order 4, the ratio remains consistent at 1.7, which indicates a more efficient system as tributaries begin to combine and streamline water flow.

As the stream order increases, stream length ratios fluctuate. Notably, at order 5, the ratio decreases to 0.7, but the system remains efficient, potentially due to the simplification or alignment of tributaries. Stream orders 6 and 7 show the highest ratios, 5.8 and 6.6, respectively, which reflect a substantial increase in efficiency, likely due to fewer branching tributaries and more direct flow paths in larger channels. By stream order 8, the ratio drops back to 1.3, still classified as "very efficient," which indicates a highly streamlined and established main river course. These variations demonstrate how the river system achieves increasing efficiency as it progresses from smaller, branching tributaries to a more centralized and direct flow path in higher orders. This could be due to several factors, such as a gentle slope, soft rocks, or a humid climate. In summary, stream length ratios across orders indicate a trend toward greater efficiency as streams progress. Lower orders (1 to 4) show gradual efficiency gains, while higher orders (6 and 7) practice significant jumps, reflecting fewer branches and more direct flow paths. By the highest order (8), the system achieves peak efficiency with a stable main river course. This pattern highlights how river networks naturally organize from smaller tributaries into larger, efficient channels for effective water and sediment transport.

4.1.7 Bifurcation Ratios (Rb)

In hydrology and geomorphology, the Bifurcation Ratio (Rb) is a crucial morphometric measure for evaluating the branching and hierarchical structure of a river channel network within a drainage basin. This ratio provides insights into the structure of the river network by quantifying the relationships between streams of several orders within the basin. This is the basic measure used to describe stream patterns in a basin and is closely related to the structure of the watershed and weather patterns. According to Goran and Khattab (2023), this ratio provides information about the geometric features of the basin as well as the watershed discharge pattern. Therefore, the Bifurcation Ratio (Rb) values for the GZB that fall under the previous study are listed in Table (2).

The table showed bifurcation ratios across stream orders from 1 to 8, with an additional main bifurcation ratio of 5.5, providing insight into the branching structure of a river network. The bifurcation ratio quantifies the frequency of branching between consecutive stream orders, with higher values indicating more complex branching patterns. For lower stream orders (1 through 4), the bifurcation ratios are relatively consistent, ranging from 3.2 to 3.8, suggesting moderate branching that enables water distribution across various tributaries. At order 5, the bifurcation ratio drops significantly to 1.1, likely indicating a reduction in branching as streams begin to converge. At stream order 6, there is a dramatic increase to a ratio of 25.0, implying extensive branching or a highly complex network at this level. The main bifurcation ratio of 5.5 likely represents an average across the entire network, showing a general trend of moderate branching across orders. However, by stream order 8, the bifurcation ratio falls to 0.0, indicating no further branched at the highest order, as these streams likely form the main river channel or reach their final discharge point. This variation in bifurcation ratios, alongside the main bifurcation ratio, highlights the natural progression from numerous small tributaries in lower orders to a consolidated, efficient flow path in higher orders. Higher bifurcation ratios values indicate a more intricate and extensively branching river network, whereas lower values suggest a simpler and less interconnected system. Finally, these findings significantly affect understanding of the morphological characteristics of the study area, which in turn influences hydrological dynamics, erosion phenomena, and environmental management strategies.

4.2 Areal Aspects Parameter’s

Multiple region-related factors were examined to better understand the features of the research area. These attributes include basic calculation such as the circularity ratio, area, perimeter, drainage texture, shape index, form factor, infiltration number, length of overland flow, channel constant, elongation ratio, drainage density, and stream frequency (Sofi, 2017). Together, these factors provide thorough evaluation of the physical and hydrological characteristics of the study area, supporting initiatives for the planning and management of watersheds. Table (4) displays information about all parameters on the areal aspect.

Table 4 Areal Parameters of Greater Zab Basin

No	Basin Name	Greater Zab
1	Area (A) in km^2	26323
2	Perimeter (P) in km	1087.47
3	Drainage density (Dd) in km/km^2	0.81
4	Stream frequency (Fs) in km^2	0.73
5	Drainage texture (Dt)	0.87
6	Shape index (Sw)	1.36
7	Infiltration Number (If)	0.87
8	Length of overland flow (Lg)	0.41
9	Constant of channel maintenance (C) km^2 /km	1.23
10	Form factor (Ff)	0.11
11	Circularity ratio (Rc)	0.28
12	Elongation ratio (Re)	0.34
13	Sinuosity index (Si)	1.77

4.2.1 Basin area (A)

The designated region where precipitation is collected and drained is called the basin area. In addition, the watershed area has a direct effect on the runoff volume within a basin. An interesting connection was found between the whole basin area and the overall stream length, which was supported by the surface area where the runoff drains. A significant association exists between the basin area and other the basin factor (Schumm, 1956). Therefore, a drainage region is where water is collected before it flows into a stream. In the Greater Zab Basin the entire drainage area measured with a GIS tool was 26323 km^2, as shown in Table (4).

4.2.2 Basin Perimeter of Greater Zab (P)

Basin perimeters, also known as basin boundaries, calculated all the borders around the watershed could be employed for determine the form and size of the basin (Schumm, 1956). While the perimeter of a stream watershed is often referred to as its length, it is a distinct measurement that encompasses the total distance around the edge (Benshlomo, 2023). Notably, the basin perimeter influences two key morphometric parameters the elongation ratio and circularity ratio. However, depending on Table (4), the Perimeter of the GZB was 1087.47 km.

The length with drainage area of the Greater Zab watershed indicate a large with well-developed river basin. The large drainage area means that the basin collects a significant amount of water from its surrounding watershed. The long length of the basin means that the river has a lot of time and distance to erode its bed and form a complex network of tributaries.

4.2.3 Drainage texture (T) with Drainage Density (Dd)

According to Horton, (1932),the drainage density is defined as the surface area of the watershed divided by the overall length of all channel segments in different stream orders. Drainage density measures the proximity of the channels within the drainage basin. The structure and properties of a drainage basin are greatly influenced by its drainage density, and the distinctive characteristics of the drainage system are determined by a variety of elements such as lithology, topography, and vegetation, all dependent on one another (Hamad, 2020). A fine drainage texture results from a high drainage density, whereas a coarse drainage texture is associated with low drainage density. These patterns arise from factors such as excessive drainage, mountainous topography, and weak underlying materials or impermeable. Table (4) was displayed information about the areal aspect of the study area and measured the drainage density was measured at 0.81 km/km². According to Horton's classification, this low drainage density value for the Greater Zab River Basin indicates a drainage texture that is characterized as very coarse. This means that fewer streams per square kilometer exist than in a drainage network with a higher drainage density. The Drainage texture is the ratio of the overall number of streams inside a catchment to the perimeter (Horton, 1945). Table (5) was presents the classification of the drainage texture Based on the Drainage Density values, following the criteria established by Smith (1950).

Table 5 The Drainage texture

No	Drainage Density (Dd)	Drainage texture
1	Less than 2	"Very coarse"
2	2 to 4	"Coarse"

3	4 to 6	" Moderate "
4	6 to 8	"Fine"
5	Over than 8	"Very fine"

In the case of the Greater Zab River, the computed drainage texture stands at 0.87 per km, as illustrated in Table (4) of areal aspect parameters, which means the spacing between streams is relatively large. Smith's classification categorizes drainage density (Dd) and has been categorized into five drainage texture groups: values below 2 is classified as very coarse, 2–4 as coarse, 4–6 as moderately, 6–8 as fine, and values above 8 as very fine. (Smith_1950). The assessment of drainage texture is subject to the influence of numerous factors, including the rainfall forms, slope characteristics, capacity of infiltration, and presence of vegetation. Additionally, it's worth noting that an increase in drainage texture often corresponds to heightened erosion and dissection within the catchment. Finally, Figure (7) was showed the drainage density of the GZB.

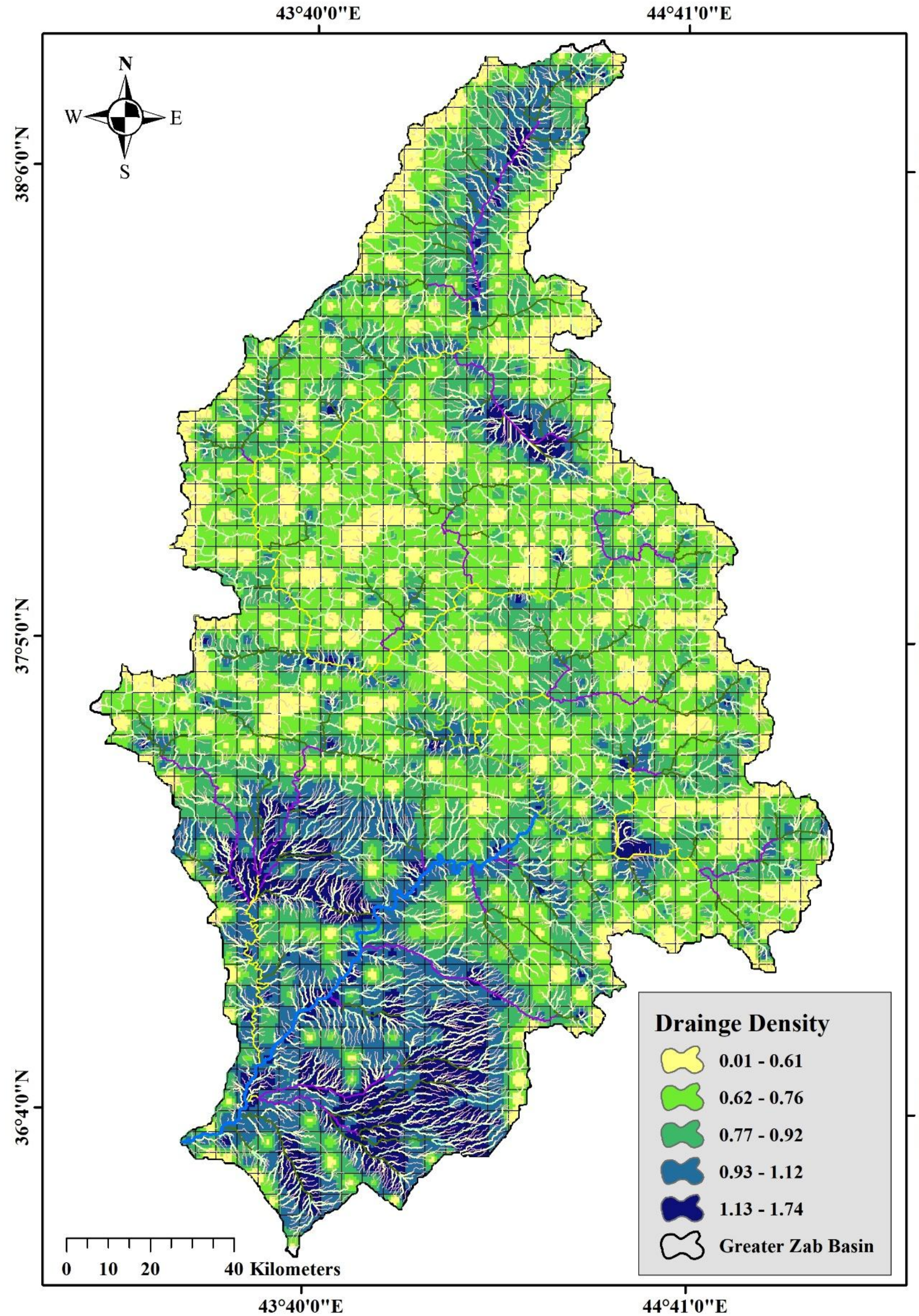

Figure 1 Drainage Density Map of Greater Zab Basin

4.2.4 Stream frequency (Fs)

Horton (1955) defined the channel frequency (Fs) as the ratio of the entire area of the river basin to the overall number of stream segments, which includes complete stream orders within the basin . The stream frequency (Fs) within the study area is measured at approximately 0.73 streams per km^2 depending on the result, categorizing it as a low value according to the classification in Table (4). A higher stream frequency typically signifies an increased surface runoff with relief within the basin. The low stream frequency in the study area may have several impacts on many fields, such as water quality, flood risk, and other aspects of watershed hydrology. For example, areas with low stream frequency are more likely to experience flooding during heavy rainfall events. This is because the sparse drainage network cannot efficiently collect and transport water from the surface.

4.2.5 Basin shape Parameters

Computation of the form factor (Rf), circularity ratio (Rc), and elongation ratio (Re) computation with analysis is crucial for comprehending the shape features of a drainage basin. These metrics are essential for assessing and understanding the behavior and patterns of the streamflow within a basin. In particular, the form factor is a useful computation of the general form and outline of a watershed. Through the evaluation of these form factors, scientists and hydrologists may better understand how the basin shape affects its hydrological features, which helps with flood forecasting and the management of water resources.

4.2.6 Elongation ratio (Re)

The elongation ratio is defined as the ratio of the diameter of a circle with an area equivalent to that of the drainage basin to the maximum length of the basin. (Schumm, 1956) GIS software that allows for the determination of the maximum basin length. Additionally, Table (6) highlights that Schumm's elongation ratio typically falls within the range Less than 0.5 to 1.0 across diverse climatic and geological settings.

Table 6 Categories of the elongation ratio based on Schumm, (1956).

No	Elongation ratio Range	Classes
1	0.9-1.0	Circular
2	0.8-0.9	Oval
3	0.7-0.8	Less elongated
4	0.5-0.7	Elongated
5	Less than 0.5	More elongated

A circular basin typically discharges runoff more efficiently than an elongated basin does. In areas with high relief, the elongation ratio typically ranges from 0.6 to 0.8, whereas values near 1.0 suggest basins with very low relief and a more circular shapes (Adhikari, 2020). The result of the elongation ratio is given us on the Table (4) on the areal aspects, that the Elongation ratio computed for GZB is 0.34 it is more Elongated, this shape characterized by a long and narrow configuration. This elongation has significant implications for the hydrology of the basin, particularly in terms of erosion susceptibility and sediment loading. The elongated shape suggests a heightened vulnerability to erosion due to an extended network of streams that can efficiently transport eroded sediments over the basin length. Consequently, this configuration can increase sediment loading, impacting downstream water quality and sediment deposition.

4.2.7 The circularity ratio (Rc)

The Rc, is the ratio of the basin's area to the area of a circle whose circumference is equal to the perimeter of the basin (Miller,1953). Miller emphasized that (Rc) helps as a crucial indicator of a basin's dendritic stage and is primarily influenced by factors such as the basin's diverse relief patterns and the slope. It is crucial in determining the developmental stage of a tributary watershed, where low, medium, and high circularity ratio (Rc) values correspond to the young, mature, and old stages of the watershed's life cycle, respectively (Rai *et al.*, 2017). According to Table (4), the circularity ratio of the GZB is 0.28, falling below the typical range of 0.3 to 0.6 for areal parameters. This low value indicates an elongated basin with a high relief ratio. The elongated shape and high relief can have several implications for water management in the basin, including an increased risk of erosion and flooding.

4.2.8 Form factor (Ff)

The form factor was defined by Horton, (1932) is a ratio that describes the shape a drainage basin, calculated by dividing the basin's area by the square of its maximum length . A form factor of 0.11 for the GZB indicates a highly elongated shape, leading to slower flood responses with delayed and prolonged peak flows. This elongated morphology affects flood wave travel time and sediment transport, offering key insights for effective water management. This result is shown in Table (4) as the related areal parameters, indicate an elongated shape. This lower form factor value signifies an elongated basin with extended discharge periods, making flood management more manageable than in circular basins.

4.2.9 Constant channel maintenance (C)

the definition, constant channel maintenance is calculated as the opposite of drainage density and is expressed in square feet per foot (Schumm,1956). This characteristic calculates the amount of surface area in the basin that must be covered to build a single linear foot of the stream channel. This constant size increases in proportion to the scale of landform unit. The constant channel maintenance of the study area was 1.23 km^2/km, indicating that the drainage network is relatively small. This outcome depends on Table (4), which shows the areal parameter.

4.2.10 Length of Overland Flow (Lg)

The length of the overland flow is the distance that the water travels before condensing into the mainstream, affecting the hydrologic and physiographic evolution of the drainage basin (Horton,1945). Rainwater must travel a greater distance before joining stream channels according to a higher Lg value. The (Lg) is significantly influenced by exfiltration, infiltration, and percolation through the soil, all of which exhibit temporal and spatial variations (Adhikari, 2020). The length of the overland flow is a main areal parameter analyzed in this study, as shown in Table (4). The calculated length of overland flow value for the basin area was computed 0.41 kilometers, signifying a relatively short distance that water travels over land before concentrating in stream channels. The shorter length of overland flow generally suggests more efficient drainage networks because water has less chance to evaporate or infiltrate before reaching streams.

4.2.11 Infiltration number (If)

The infiltration number was computed by multiplying the stream frequency by the drainage density. As mentioned by Faniran in 1968, a greater infiltration number denotes a lower infiltration rate and greater surface runoff (Farhan et al., 2018). The analysis of the infiltration numbers in the current study suggests a dominance of linear properties, potentially indicating a well-developed drainage network. As shown in Table (4), the infiltration number for the study area was 0.87. This value suggests a relatively low infiltration rate, potentially leading to higher surface runoff. Consequently, a well-developed drainage network may have formed to accommodate this runoff.

4.2.12 Sinuosity index (Si)

According to Schumm, (1956), this factor contributes to determining the deviation of a river from its expected straight path. The meander ratio, which is also known as the sinuosity index, quantifies the extent to which a river meanders. It is computed as the ratio of the actual length of the river channel along its meandering

2025 نيسان مجلة دراسات في الإنسانيات والعلوم التربوية العدد 9
April 2025 Journal of Studies in Humanities and Educational Sciences No. 9
Print ISSN 3006-3256 Online ISSN 3006-3264

path to the straight-line distance between the starting and ending points. In addition, the (Si) index of the 8th order stream, also known as the trunk stream segment with the highest order, was calculated in the research area. This stream segment is known as the highest-order stream segment. This ratio is identical to that in the case of a river flowing along a meandering line. Sinuous river courses are characterized by ratios between 1 and 1.5, while meandering river courses have ratios more than 1.5 (Kusratmoko, Wibowo and Ahmad Kurnia, 2019). as shown in Table (7), which is the Sinuosity Index Classification, and Figure (8) illustrates the Sinuosity of the study area. Finally, the sinuosity value in the Greater Zab area was.77. Therefore, a stream's path is sinuous, which places it in the middle of the meandering types of basins.

Table 7 Sinuosity Index Classification

Class Type	Sinuosity
Straight	Less than 1.1
Sinuous	1.1 to 1.5
Meandering	More than 1.5

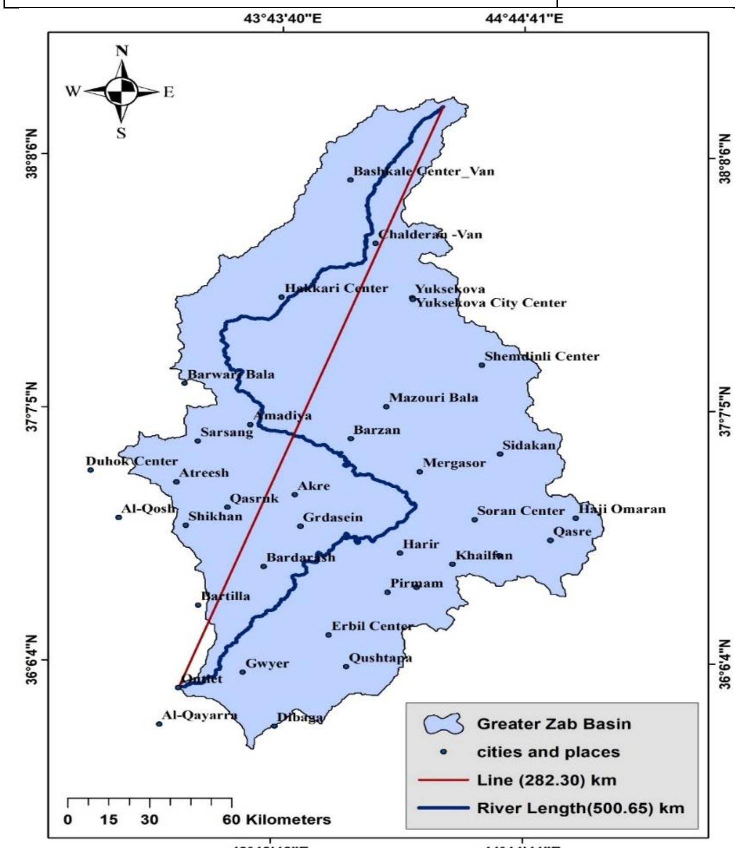

Figure 8 Sinuosity Index of GZB

4.3 Relief Morphometric Aspect

The Relief morphometric parameters encompass the three-dimensional characteristics of a drainage basin, including relief, relief ratio, ruggedness number, slope, gradient ratio and the hypsometric curve. These parameters collectively provide valuable insights into the topographical complexity, terrain steepness, and characteristics. These parameters are crucial for understanding how variations in elevation, slope, and landforms influence the water flow and sediment transport within the GZB landscape. Table (8) presents the calculated relief morphometric parameters.

Table 8 Relief Parameters of Greater Zab Basin

No	**Parameters**	**Greater Zab Basin**
1	Maximum height and mouth height of basin (z) (m)	4098_183
2	(R) = Basin relief in (m)	3915
3	(Lb) = Basin length in (km)	500.65
4	(Rr) = Relief ratio	7.82
5	(Rn) = Ruggedness number	3.17
6	Slope (m)	(0-2) to more than 30

4.3.1 Maximum height and mouth height of basin (z)

The maximum height of the basin, representing the highest elevation point in this study, was determined utilize ArcMap10.8 software which recorded at 4098 m. The height of the watershed mouth, signifying the lower elevation point or watershed outlet, was 183 m. Table (8) and Figure (9) show the height and low area of the GZB.

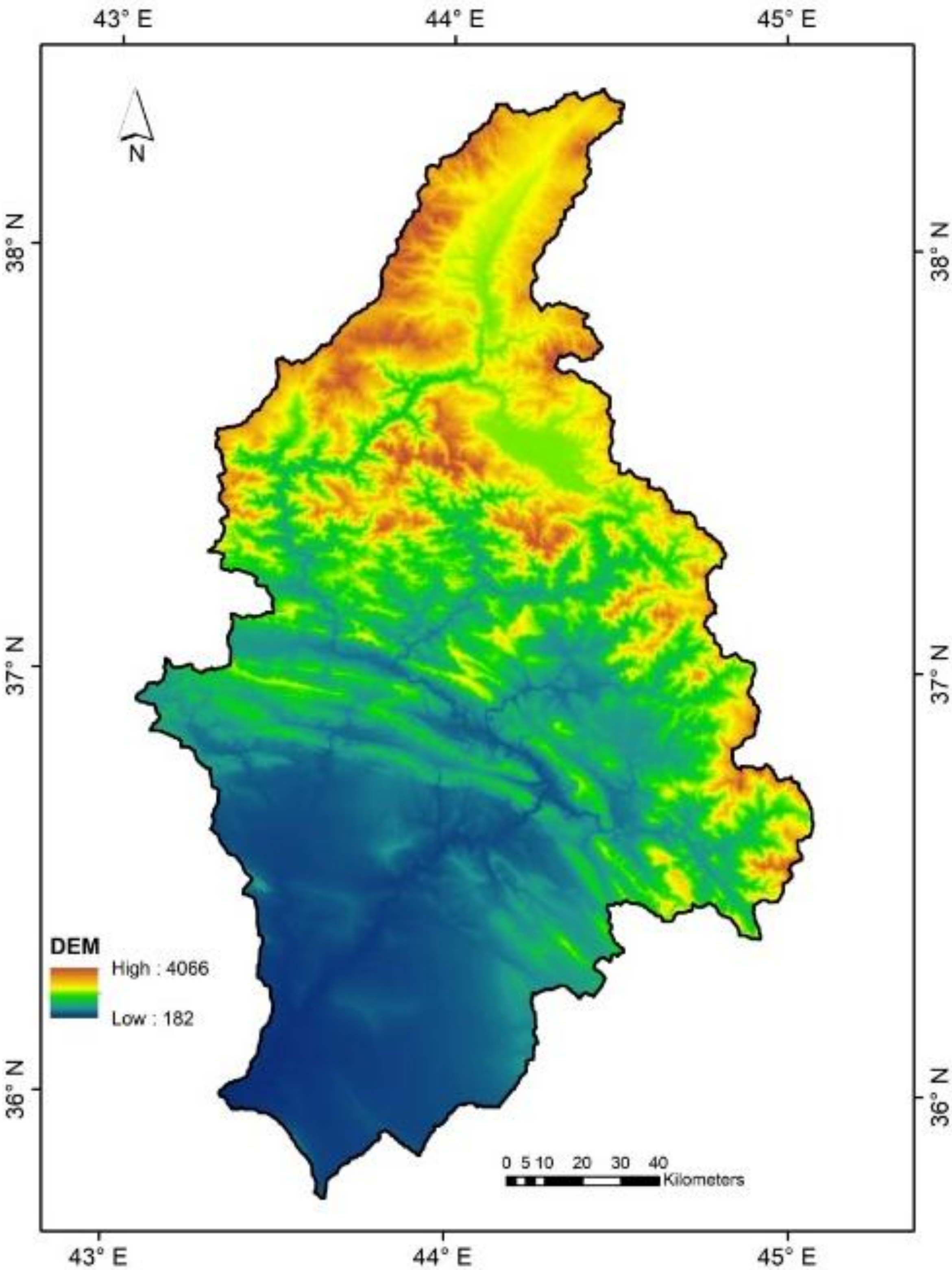

Figure 9 Lowest and Highest Elevations (M.A.S.L.) of the Study Area

4.3.2 Basin relief (R)

The total basin relief represents the elevation difference between the highest point within the watershed and the lowest point on the basin floor. This vertical difference, known as basin relief, is a key indicator of the topographic variation within the river basin. Table (5.7) shows that the total basin relief of the GZB is 3915 m. This significant elevation change, from its highest peak to its lowest point, highlights the diverse topography within the basin, which means that there are large differences in elevation between the highest and lowest points in the basin. This can have several implications for basin hydrology, geomorphology, and other studies. This parameter is essential for understanding the topographical diversity and physical characteristics of the GZB.

4.3.3 Relief ratio (Rr)

The relief ratio is the ratio of the total relief of a basin to its longest dimension aligned with the primary drainage line (Schumm,1956). Schumm also observed a potential strong correlation between the relief ratio and the hydrologic characteristics of the basin. particularly sediment loss per unit area. depending on the Table (8) as the result that is the calculated relief ratio stands at7.82, indicating that the drainage network in the study area has very high relief. This indicate that the basin has a large difference in elevation between the highest and lowest points. Steep slopes, narrow valleys, and fast-flowing streams typically characterize basins with high relief ratios. These basins are more susceptible to erosion and flooding than those with lower relief ratios area. Areas with a moderate slope and relief tended to display moderate relief ratio values. Conversely, low relief ratios are primarily attributed to the presence of resistant basement rocks within a basin with a relatively gentle slope (Kabite and Gessesse, 2018). This parameter is indicative of the topographic characteristics of the basin and its potential influence on the sediment dynamics.

4.3.4 Slope

In hydro-morphometric analysis, the slope is a crucial factor. Several factors influence the slope, including the climate, runoff patterns, geological structures, and lithology (rock types). Meteorological parameters also played important role. Notably, the slope had an inverse relationship with infiltration and a direct relationship with surface runoff. Steeper slopes promote faster runoff and less infiltration, whereas gentler slopes allow greater infiltration and less runoff (Goran and Khattab, 2023). DEM and ArcGIS 10.8 software to determine the slope of the study area. According to the FAO slope classification, five slope classes exist in the study area, Table (9) and the Figure (10) is illustrate the slope classification of the GZB.

Table 9 The Slope Classification on the Greater Zab Basin

No	**Range of Slope %**	**Area km^2**	**Area %**	**Suitability**
1	0 - 2	3692	14	Suitable
2	2.1 - 8	5565	21	Averagely suitable
3	8.1 - 15	4834	18	Moderate suitable
4	15.1 - 30	8345	32	Poorly suitable
5	More than 30	3912	15	unsuitable

Based on the Table (9) was displayed the slope was divided into five ranges. The largest class range of the area is 15.1-30% slope, which contains 32%, indicating a significant presence of moderately steep terrain, the second-largest category, with 21%, is within the 2.1-8% range, which suggests a fairly flat to gently rolling landscape, while areas with very gentle slopes (0-2%) constitute 14%, at the same time the steep slopes (more than 30%) cover 15%. Also The 8.1-15% slope range accounts for 18% of the total area. This distribution suggests that the region has a varied topography, with an important helping of the land having moderate to steep slopes, which could impact LULC, surface water and water management.

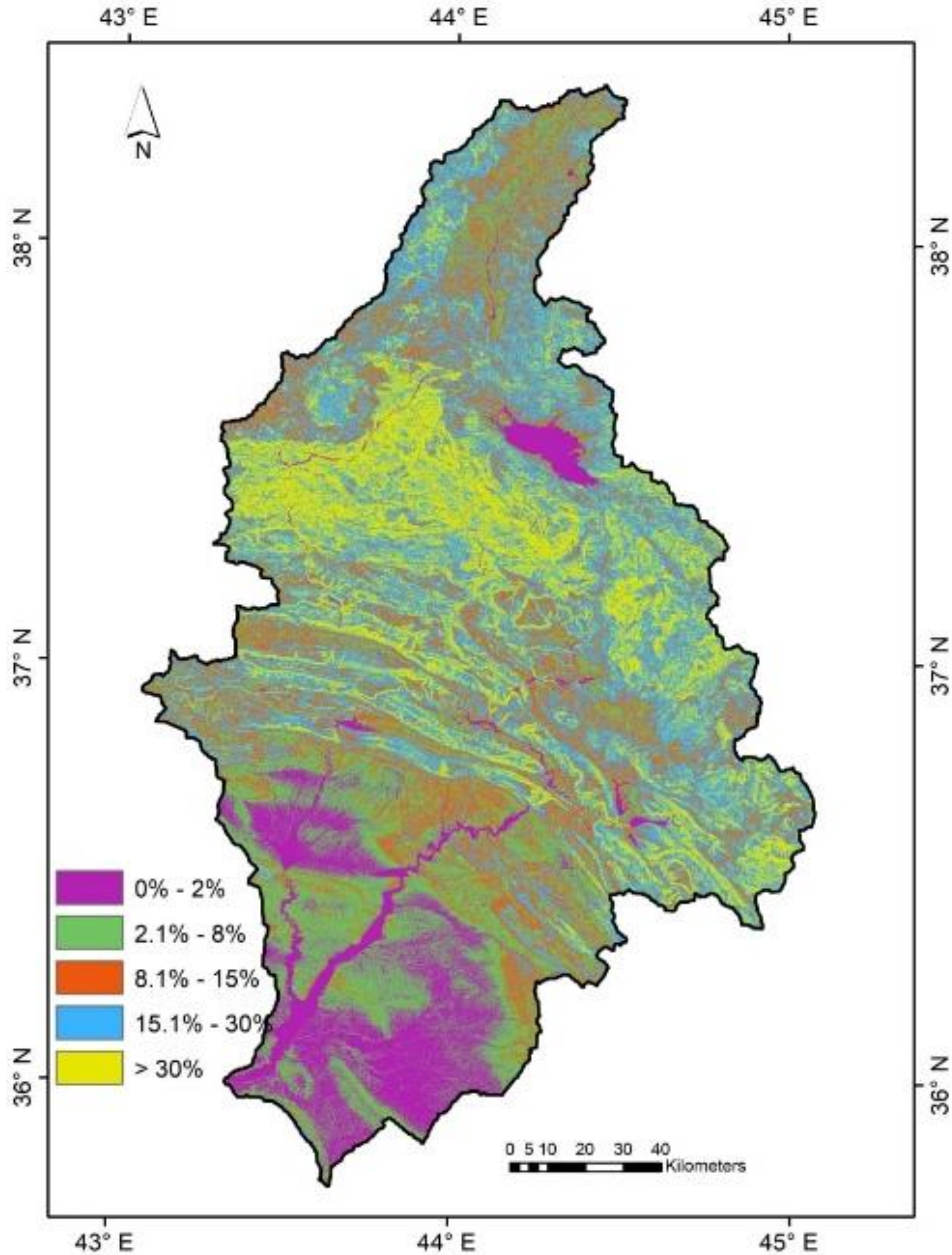

Figure 10 The Slope Classification of the Greater Zab Basin

4.3.5 Hypsometric Curve Analysis

In hypsometric analysis, the impact of the watershed shape and river system on hypsometry was considered. The hypsometric curve is significantly shaped by the aspect or catchment width to length ratio. The elevations are shown in relation to the relative surface area using hypsometric curves (Shekar and Mathew, 2022). These curves reveal information about the age and state of the basin. A mature basin has an S-shaped curve, an old or eroded basin has a concave curve and a young basin typically has a convex upward hypsometric curve. In the case of the Greater Zab Basin, the hypsometric curves exhibited a combination of convex and concave shapes, likely due to factors such as soil erosion and stream cutting. The calculation of the hypsometric integral, following Pike and Wilson's technique (Pike and Wilson, 1971), yielded a value of 0.87, signifying that the soil information within the study area was mature or in equilibrium. Figure (11) represents the hypsometric curve of the GZB.

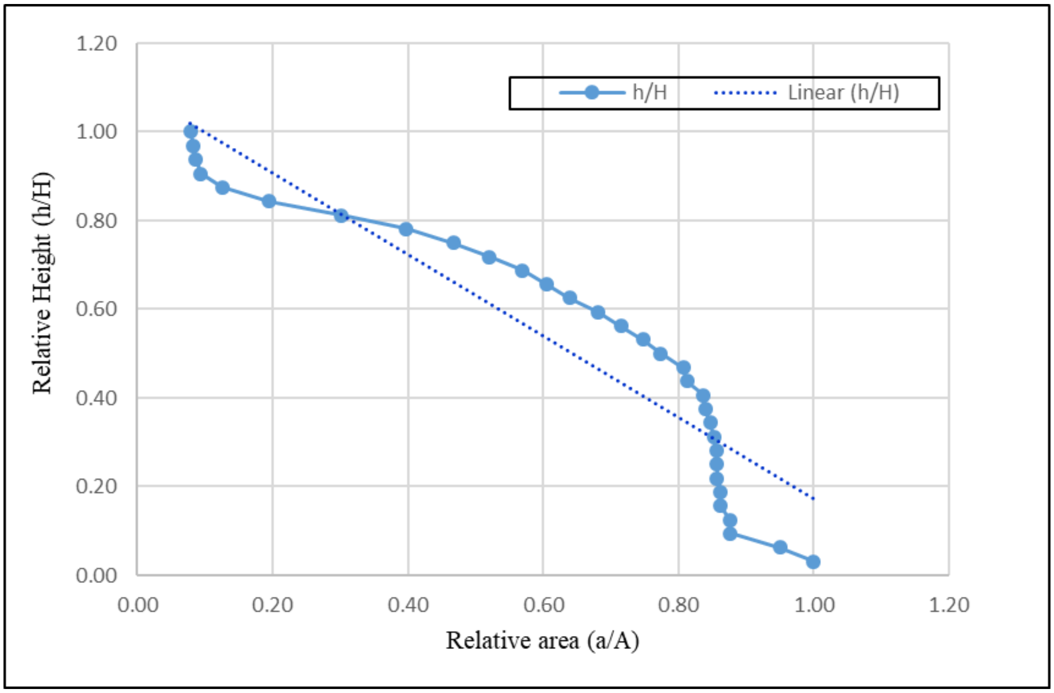

Figure 11 The Hypsometric Curve of the Greater Zab

5. Discussion

Analysis of river basins has emerged as a critical tool for understanding the interplay between, the hydrological, and climatic factors that shape a basin's physical characteristics. Owing to extensive and complex drainage network, the GZB provides an excellent case study for such an analysis. It employs a detailed numerical method to assess various morphometric parameters, offering insights into the hydrological behavior of the basin and its implications for the management of water resources and environmental sustainability.

This work supported The study of Hamad, (2020) to emphasizes the vital role of GIS and RS in preparing morphometric analysis and drainage maps. These techniques simplify the analysis of the linear, regional, and refractory morphometric factors related to hydrological processes, making them essential for effective watershed management and sustainability.

The slope analysis revealed that most of the basin has slopes between 15.1% and 30%, indicating a predominantly steep terrain. This steepness contributes to rapid surface runoff and increased erosion rates, impacting the basin's hydrological response during rainfall, depending of the study of Goran and Khattab, (2023) has moderate to low slope, low relief, low runoff, and high infiltration, with low erosion and sediment loading exposure. The ruggedness number of 3.17 reflects the roughness and complexity of the terrain, which can complicate water flow and sediment transport. The hypsometric analysis, which examines the elevation distribution within the basin, shows a combination of convex and concave shapes. This suggests a mature stage of soil development and equilibrium, with ongoing erosion and stream incision processes shaping the basin topography.

The morphometric analysis of the GZB depends on a detailed understanding of its physical and hydrological characteristics. The basin's complex and well-developed drainage network, substantial relief, and elongated shape highlight its potential for erosion and sediment transport. These insights are crucial for developing effective management strategies to ensure sustainable water resources, mitigate flood risks, and protect the environment. Morphometric analysis supports the analysis of landforms precisely for any planning and development purposes (Nadhim Al-neama, Yang and Muneer Yahya, 2022) , which implied the integration of morphometric parameters with hydrological data, and offers a comprehensive framework for understanding and managing river basins in semi-arid regions areas such as the Greater Zab.

6. Conclusion

Using Geographic Information Systems (GIS) greatly enhances the effectiveness of morphometric analyses. GIS facilitates the accurate mapping and analysis of the basin's topography, stream networks, and other critical parameters. It allows for the efficient processing of large datasets, providing detailed spatial analysis and visualization. This capability is essential for identifying patterns, assessing drainage characteristics, and pinpointing suitable dam sites.

GIS technology plays a crucial role in modern hydrology and resource management. It offers precise and comprehensive tools for understanding and managing river basins like the Greater Zab Basin. A morphometric analysis of the basin, using GIS, provides valuable insights for hydrology.

The basin's characteristics, including its complex drainage network, significant elevation variation, and elongated shape, suggest areas with high runoff potential – a key factor in hydrological studies. Additionally, the extensive stream network and high bifurcation ratios indicate areas with substantial water flow.

Ultimately, these GIS-based findings guide the improvement of sustainable and effective water management strategies to the Greater Zab Basin. This ensures long-term environmental protection and resource availability.

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