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Morphometric Analysis of Kalal Badra Basin Using Remote Sensing Techniques and Geographic Information Systems (GIS)

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ABSTRACT

Natural water resources face many challenges due to changes in global climate conditions, such as scarcity of rainfall, high evaporation rates, rising temperatures, drought, and desertification. Morphometric analysis of a drainage basin is crucial for understanding its hydrological behavior, including flood risks, water resource management, and landscape evolution. Currently, there is a need for more detailed flood and drought risk assessments using modern remote techniques, including morphometric and hydrological data analysis. The present research aims to construct a hydrological model that can explain the effect of hydrological characteristics on water flow in the Kalal Badra basin in Iraq, and to determine its morphological and spatial characteristics. The methodology used herein involves the integration of satellite imagery, digital elevation models (DEM) of SRTM type with a spatial accuracy of 30 meters, automated GIS tools, and temporal analysis to provide essential data for effective environmental and water resource management. In the case of the Badra Basin, the results show that the utilization of Remote Sensing (RS) and Geographic Information Systems (GIS) offers an advanced method for analyzing its topographical, geological, and hydrological characteristics.

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التحليل المورفومتري لحوض كلال بدرة باستخدام تقنيات الاستشعار عن بعد ونظم المعلومات الجغرافية

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الملخص

تواجه الموارد المائية الطبيعية العديد من التحديات بسبب تغير الظروف المناخية العالمية مثل ندرة الأمطار ومعدلات التبخر العالية وارتفاع درجات الحرارة والجفاف والتصحر . يُعَدّ التحليل المورفومتري لحوض الصرف أمرًا بالغ الأهمية لفهم سلوكه الهيدرولوجي، بما في ذلك مخاطر الفيضانات وإدارة موارد المياه وتطور المناظر الطبيعية. هناك حاجة حاليًا إلى تقييمات أكثر تفصيلاً لمخاطر الفيضانات والجفاف باستخدام تقنيات حديثة عن بعد بما في ذلك تحليل البيانات المورفومترية والهيدرولوجية. يهدف البحث الحالي إلى بناء نموذج هيدرولوجي يمكنه تفسير تأثير الخصائص الهيدرولوجية على تدفق المياه في حوض كلال بدرة في العراق، ومعرفة خصائصه المورفولوجية والمكانية. استخدمت المنهجية الواردة هنا التكامل بين صور الأقمار الصناعية ونماذج الارتفاع الرقمية (DEM) من نوع SRTM بدقة مكانية تبلغ 30 مترًا وأدوات نظم المعلومات الجغرافية (GIS) الآلية والتحليل الزمني لتوفير بيانات أساسية لإدارة فعالة للبيئة والموارد المائية. وفي حالة حوض بدرة، تظهر النتائج أن استخدام الاستشعار عن بعد ونظم المعلومات الجغرافية يوفر طريقة متقدمة لتحليل خصائصه الطبوغرافية والجيولوجية والهيدرولوجية.

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Introduction

Water resources are considered the main artery for the environment of arid and semi-arid regions, as Iraq is located within these regions. Natural water resources are confronting, globally and particularly in Iraq, numerous challenges largely driven by changing global climate conditions, especially in the second half of the last century (Al-Ansari et al., 2021). These issues threaten water availability, quality, and sustainability, putting ecosystems and human communities at risk. It is well documented that the topography of the landforms that make up the drainage basin, as well as the structure and size of the stream system or drainage net, determine the morphology factors (Horton, 1945). Many works have been carried out on morphometric analysis using remote sensing RS and GIS. Analysis of the drainage morphometric parameter can be greatly aided by the synoptic picture over a vast area that can be obtained by RS and GIS (Alhadithi and Alaraji, 2024; Prabu and Baskaran, 2013). The world nowadays is witnessing great progress in science as statistical methods have been introduced for engineering analysis (Al-Heety et al., 2023). The main goal of such technical developments is to achieve greater objectivity in describing and interpreting the Earth's surface. This became essential after these techniques were widely used in all scientific and natural investigations. These techniques also tried to enhance the relationship between the elements of the earth's surface in mathematical equations that represent theoretical and field studies. Remote sensing and GIS have been widely used to conduct hydrological and morphometric analyses (Thamer et al., 2024).

In the identification of hydrological behavior, morphometric analysis helps in understanding the nature of water flow, stream patterns, and water retention capabilities within the basin (Hason et al., 2022). By using RS and GIS, large-scale and accurate data about the drainage network can be collected efficiently, aiding in the prediction of hydrological events such as flash floods, especially in arid or semi-arid regions like the Badra Basin. The assessment of erosion and sediment transport can be easily conducted by understanding the morphometric parameters such as basin relief, slope, stream order, the erosion potential, and sediment transportation patterns that can be assessed (Raja Shekar and Mathew, 2024). This is crucial for managing the soil and maintaining the fertility of agricultural areas around the Badra Basin. RS techniques in combination with GIS enable real-time monitoring of land degradation processes. Badra Basin is a potential site for water harvesting and storage, especially in regions with erratic rainfall. Morphometric analysis helps in identifying suitable sites for constructing dams or reservoirs (Kumari et al., 2023) and, thus, sustainable water resource management processes. The use of RS data, like satellite imagery and Digital Elevation Models (DEMs), combined with GIS, provides detailed spatial analysis, improving the decision-making process in water management. Moreover, flood risk assessment is a significant concern in many river basins (Yu et al., 2023). The morphometric analysis, such as the calculation of basin shape, drainage density, and bifurcation ratios, helps in understanding flood-prone areas. GIS tools facilitate mapping vulnerable areas based on these parameters. RS provides continuous monitoring, which is critical for flood forecasting and mitigation. Environmental and ecological conservation is another goal that can be achieved by mapping and analyzing the basin's terrain using morphometric techniques. Planners can assess the environmental impact of development projects (Musa et al., 2022). RS and GIS offer a non-invasive means to study changes over time, enabling the conservation of ecosystems within the basin.

A study that estimated the morphometric parameters and runoff of the 559.493 km^2 Yagachi catchment—which is divided into 20 micro-watersheds—also used RS and GIS (Shrudha, 2013). The catchment is structurally controlled as indicated by the bifurcation ratio of less than 5. The low drainage density indicates that the subsoil is extremely permeable, and the drainage density is moderate to coarse. Another study identified artificial recharge sites in the 1,166 km^2 Loni watershed using RS and GIS (Agarwal et al., 2013). They conducted the morphometric analysis by measuring many factors, such as the parameters of bifurcation ratio, elongation ratio, drainage density, ruggedness number, relief ratio, and circulatory ratio. A morphometric analysis for the erosion-prone area district of Madhya Pradesh resulted in measuring the length of the River Narmada 269 km and drainage area of 4,884 km^2 (Meshram et al., 2023).

The Badra Basin, like many regions, may experience significant human impact, and studies need to incorporate land use/land cover (LULC) changes to evaluate how anthropogenic factors influence morphometric characteristics and hydrological processes. The eastern region of Iraq, including the study area, is a significant water harvesting and storage source. The morphometric data, with morphometric parameters derived from GIS, to hydrological models in this research could provide better predictive insights for water resource management and flood prevention. The used techniques can also help automate the extraction of drainage networks and improve the precision of geomorphological mapping.

Explaining the importance of spatial analysis tools is vital, especially hydrological analysis, for GISs in studying water basins and determining their properties. Building a hydrological model with morphometric analysis is crucial for understanding how hydrological characteristics, such as rainfall, soil properties, and land use, influence water flow. These models help simulate water flow within a watershed, allowing for the prediction of streamflow, flood events, and the overall water balance. By accurately representing the interactions between various hydrological processes, these models provide valuable insights for water resource management, flood risk assessment, and planning sustainable water use. They enable decisionmakers to anticipate changes in water flow due to natural or anthropogenic factors, ultimately supporting more effective and informed water management strategies.

Materials and Methods

Study area

The Kalal Badra basin is a water basin located in the eastern part of central Iraq within Wasit Governorate and on the Iraqi-Iranian border between latitudes 44" 47' 32° to 44" 38' 33° N and longitudes 42" 48' 45° to 18" 41' 46° E as shown in Figure 1. The total area of about 2616 km^2, extending inside Iranian territory for a distance of approximately 81 km with an approximate area of 2319 km^2 (88% of the basin area), while it extends inside Iraqi territory for an approximate distance of 48 km and covers an area of 296 km^2 (12% of the basin area) until it meets Al-Shuwaijah Marsh. On the Iraqi side, the waters of Badra Basin flow from the drainage of the basins and mountains located on the northern and northeastern sides, including the slopes of the Pashtako Mountains. The surface runoff waters of Badra Basin follow the original paths towards the south and southwest, reaching the Shuwaijah Marsh.

There are two distinct seasons in the research area's climate: summer and winter. Summer begins from the beginning of April until the end of October and is characterized by scarce rainfall and high temperatures. As for winter, it begins from the beginning of November until the end of March, where it is characterized by increased rainfall and low temperatures. The climate data of Badra Station are used to study and analyze the climatic elements and their changes in the study area and for the years from 1990 to 2022, based on the Iraqi Meteorological Authority, Ministry of Transport and Communications. The annual average rainfall was about 106 mm, while the monthly average relative humidity was 44.2%. The average monthly values for each of the temperatures were 24.6 °C (the max. and min. temperatures were 32 °C and 17.5 °C, respectively). The wind speed was 3.9 m/s, and the evaporation was 184.6 mm. The rainy season was from October to April, and hence the study area is characterized by a long dry period due to the interruption of rainfall from May to October, accompanied by high evaporation due to high temperatures, which contributes to the drying and disintegration of the soil.

Table 1: Climate details for the study area.

Month	Precipitation (mm)	Temperature (◦C)			Solar radiation (hr/d)	Wind speed (m/s)	Relative humidity (%)	Evaporation (mm)
		Max.	Min.	Av.				
Jan.	19.46	16.70	6.38	11.53	6.25	3.08	71.63	53.25
Feb.	15.61	19.55	7.96	13.47	7.08	3.38	62.35	77.00
Mar.	11.20	23.94	11.86	17.43	7.64	3.75	55.22	132.01
Apr.	12.59	31.55	17.36	24.42	8.36	3.70	43.57	181.53
May	2.86	38.25	22.47	30.83	9.38	3.83	31.13	258.73
Jun.	0.01	42.92	25.73	35.03	10.93	5.35	23.58	322.26
Jul.	0.00	45.27	27.80	37.02	11.48	5.67	23.22	344.33
Aug.	0.00	45.23	27.26	36.22	11.21	5.04	24.57	312.18
Sep.	0.12	41.47	23.24	32.45	9.92	4.17	27.83	242.70
Oct.	4.30	34.77	18.57	26.21	8.12	3.27	38.78	159.28
Nov.	21.04	25.51	12.43	18.13	6.55	3.15	57.65	78.95
Dec.	18.64	19.08	8.47	12.92	6.29	3.08	70.91	55.93
Av.	8.82	32.02	17.46	24.64	8.60	3.96	44.20	184.85
SD	8.11	10.29	7.54	9.24	1.86	0.88	17.83	103.91
CoV	0.92	0.32	0.43	0.38	0.22	0.22	0.40	0.56

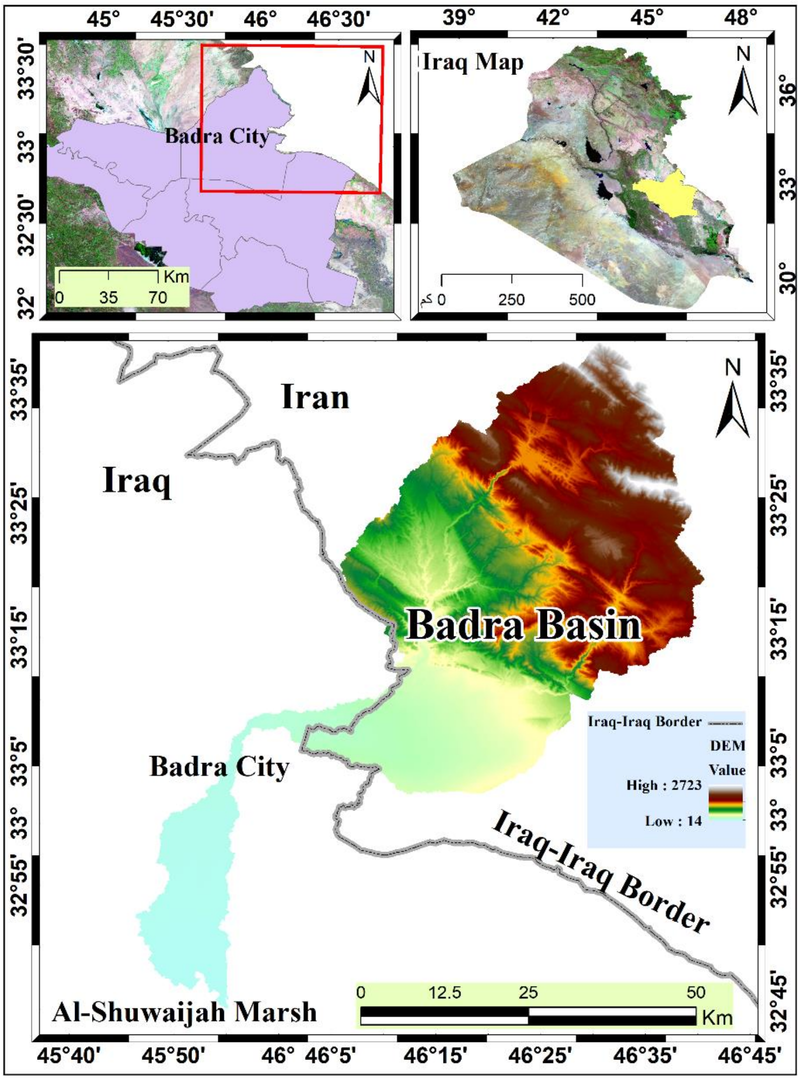


Fig. 1. Study area.

Data Collection

Remote sensing provides important spatial data, through which the hydrological and morphometric properties of water basins can be studied and water resources mapped (Hason et al., 2022). This study has relied on digital elevation model (DEM) data and used a digital elevation model of type SRTM (Shuttle Radar Topography Mission) version 3 with a 30m resolution (https://srtm.csi.cgiar.org). The goal of this project is to produce digital topographic data for 80% of the Earth's surface.

To conduct the hydrological and morphometric analyses of the Kalal Badra basin, the number of DEM scenes used is four scenes as shown in Figure 2. DEM is a digital layer consisting of a set of cells, each cell carries three numerical values: two of which describe the cell's location on the axial coordinates (x,y), and the third value (Z) represents the height above sea level. DEMs are frequently utilized in hazard observation, natural resource discovery, agricultural management, hydrological and geological assessments, and terrain characterization.

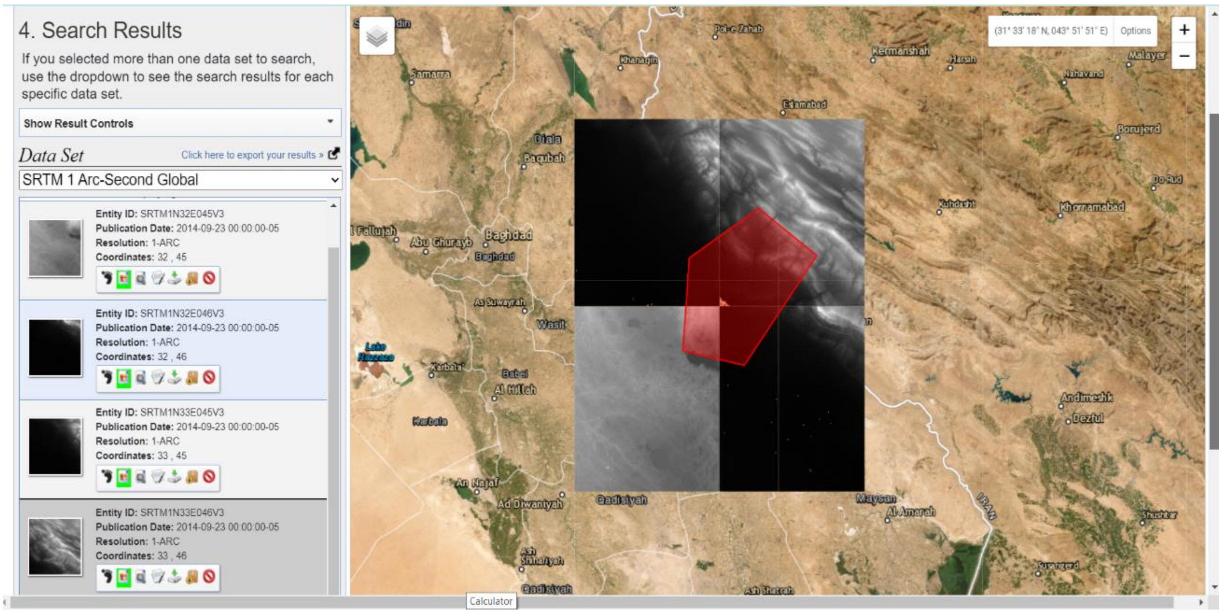


Fig. 2. Number of views of DEM.

Methodology

The research methodology herein (as shown in Figure 3) is according to, firstly, collecting the required data for the study area represented by the DEM of the SRTM type. An initial processing was conducted before the data digital analysis. It is worth mentioning that the initial processing has included geometric correction operations and converting the geographical projection from geographical coordinates to metric coordinates, which is considered a basic condition for conducting hydrological and morphometric analysis operations. Image assembling proceeded through the mosaic process using the ERDAS program, after which the study area was cut off as shown in Figure 4.

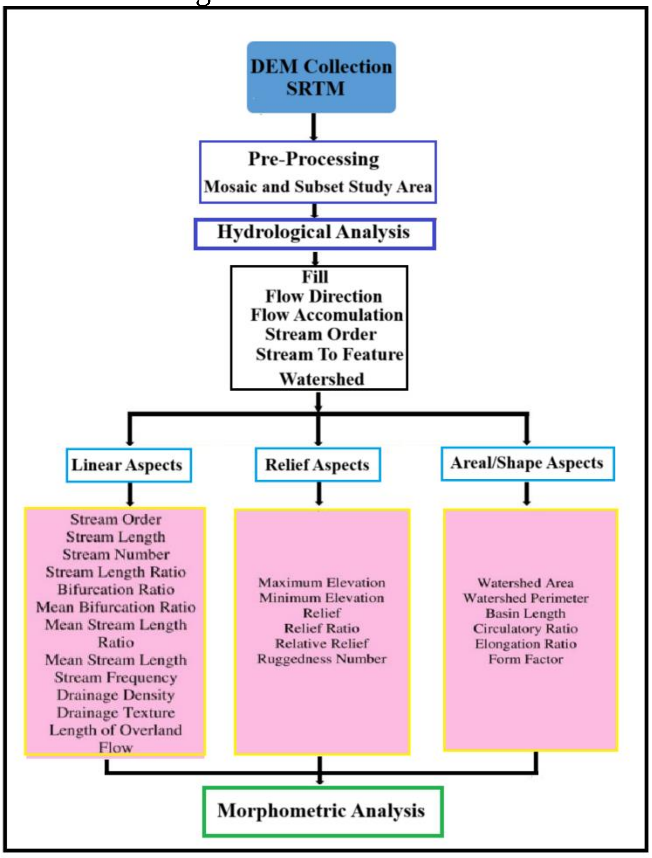
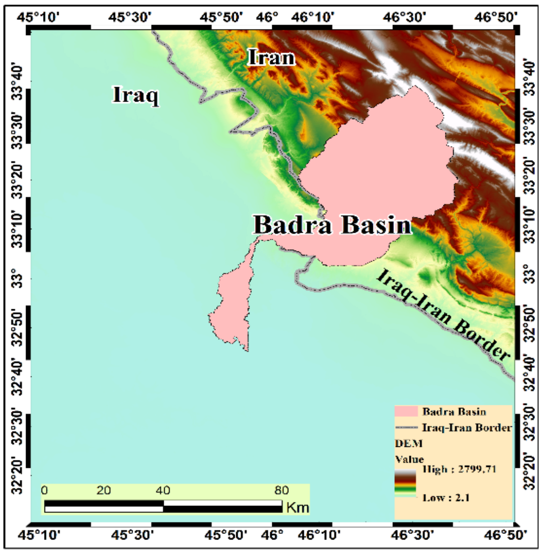
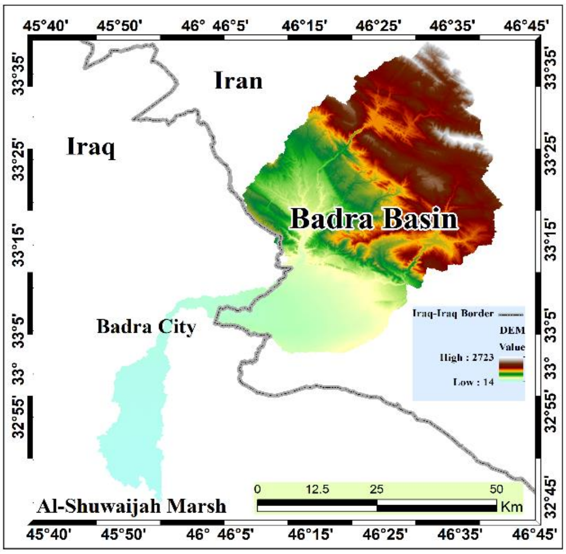


Fig. 3. Research methodology flow chart.





(a) (b)

Fig. 4. (a) Extraction and (b) Mosaic cut off of the study area.

In this research, hydrological indicators are used to determine the basin drainage and flow direction (Fig. 5), identifying watersheds (Fig. 6), and creating drainage networks (Fig. 7). Point elevation model or DEM is adopted as a basic input, through which the drainage system of the basin and its quantitative characteristics can be automatically determined. Morphometric analyses are a basic means of measuring terrain and linking numerous essential features for geomorphological, hydrological, and climatic processes, in addition to geological processes that reveal river drainage basins and other geological structures. Thus, this research also includes conducting morphometric analyses, which are considered significant processes related to water basins, water resources, terrain types; and the interrelationships between climate, plants and soil.

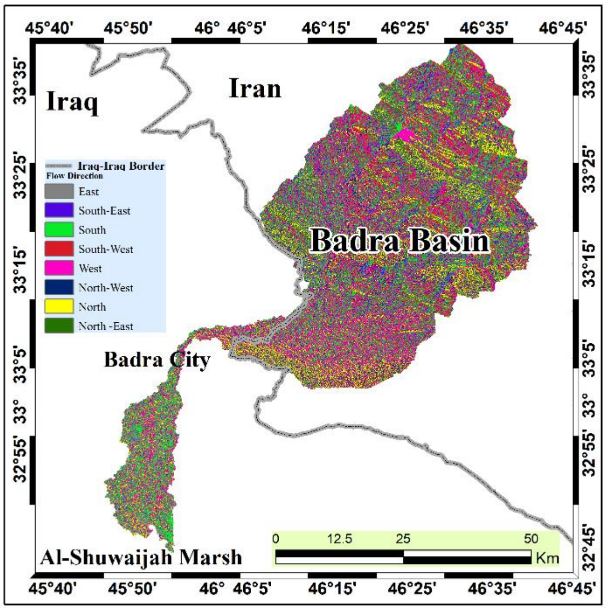


Fig. 5. Visualization of watershed direction within the Kalal Badra basin.

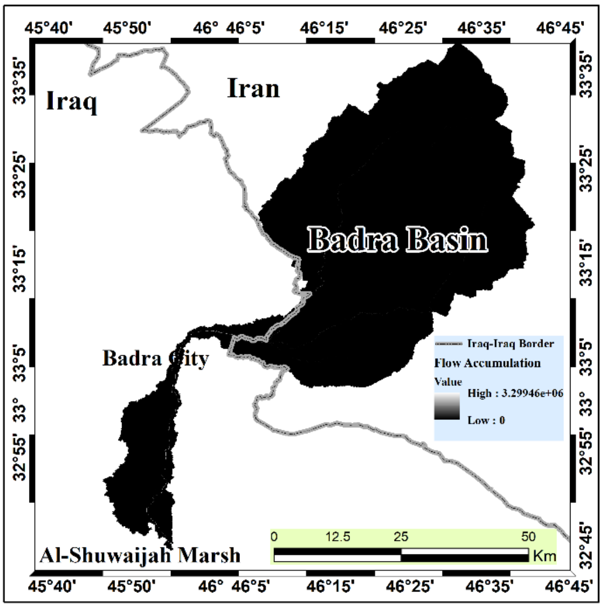


Fig. 6. Visual identification of watershed areas within the Kalal Badra basin.

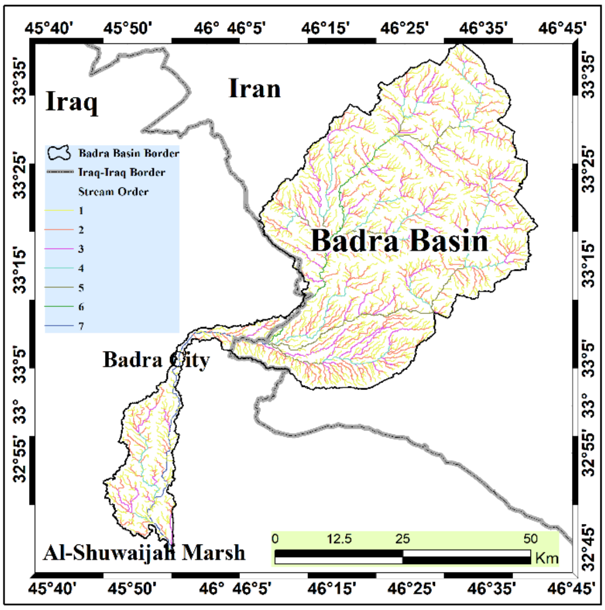


Fig. 7. Watershed visual identification for the Kalal Badra basin.

Results and Discussion

Hydrological and morphometric analysis of water basins helps to identify the characteristics of the drainage network and the effect factors. It also helps to determine the morphological characteristics of the water network and the amount of changes that have occurred, and thereby, to know the amount of water and sediments transported to the estuaries of these basins. The morphometric characteristics are directly affected by the geological and topographical structure of the region, as well as the cover of vegetation and climate. The change in the mentioned variables resulted in obvious variations in the morphometric characteristics of the water network. Hydrological and morphometric characteristics of water basins include both morphological and network characteristics; the accuracy essentially depends on the accuracy of defining and drawing the watershed network of the water basin.

In geomorphometric research, morphometric analysis is a quantitative technique. It is the process of digitally analyzing occurrences on the Earth's surface using information from field studies, satellite images, aerial photos, and topographic maps (Thamer et al., 2024). The current study has measured the drainage basin dimensions. Moreover, it determines a wide range of morphometric properties associated with the drainage basin's and the research area's network of basins' morphological features.

Basin geometry characteristics

The importance of studying the drainage basin area is evident from its direct effect on the volume of water flow and its relationship with the numbers and lengths of the river network. In other words, the larger the basin area, the larger the number and length of the river network, and thereby leads to a direct relationship between the basin area and the volume of water flow. The area of the Kalal Badra drainage basin reached (2699.48 km^2) as shown in Figure (8). It is worth mentioning that several structural factors contributed to determining the area of the basin, including climatic factors and rock formation, in addition to tectonic movements and the effect of faults and their location in the basin within Iranian territory. Besides, according to the rule of Schumm (1956), the basin area also affects the amount of water lost by either evaporation and/or seepage into the Earth's subsurface (inner layers of the Earth), proving the fact that the higher loss in water amount is based on a higher basin area.

The basin perimeter (ρ) is the outer boundary of a drainage basin that surrounds its area (Prabu and Baskaran, 2013), which can be used to determine the size and basin shape. Basin perimeter is one of the most important morphometric elements because it is related to many other morphometric variables, such as basin area, basin shape, basin length, and other properties. The relationship between basin perimeter and basin area is proportional, as the basin perimeter increases according to the basin width, and vice versa. The perimeter of the Kalal Badra Basin in the study area was measured using ArcGIS at about 440.6 km (Fig. 8).

The length (l) and width (w) of the drainage basin are considered the most significant morphometric variable that are related to many other properties, due to their effect on the surface runoff in the basin and the time it takes to remove water and sediments. These two dimensions help in determining the basin shape through the ratio between the length and width of the basin. The rate of watershed expansion, regressive erosion, and the area of the basin are also active variables that affect the length of the basin. The length of the water basin is calculated by measuring the longitudinal line that extends from the lowest point in the water basin (estuary point) to the highest point in the basin (basin’s source point). While the width of the basin is determined by drawing parallel lines as shown in Figure 8, accordingly, the length and width of the Badra Basin are 115.48 km and 49.72 km respectively.

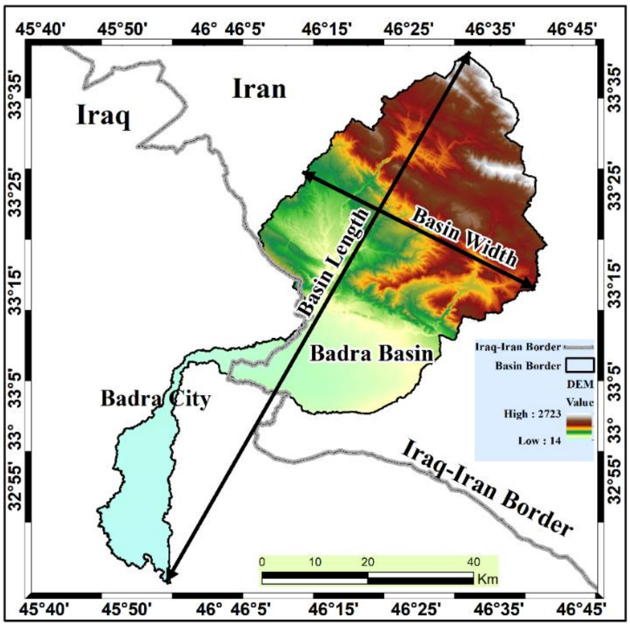


Fig. 8. Kalal Badra drainage basin (geometric characteristic).

Morphological characteristics

The elongation ratio (R_e) is the ratio of the basin's maximum length to the circle's diameter, which represents the same area of the basin (Eq. 1).

$$\boldsymbol{R_e = 1.28\ \sqrt{D_c}/L_b} \qquad (1)$$

The D_c is calculated as $\sqrt{4A_b/\pi}$. The R_e mainly indicates how close the water surface is to a rectangular shape. The R_e is the coefficient value shows that the basin shape and the elongation ratio value are inversely related. The smaller the result is from one, the closer it is to the rectangular shape. However, if the result is far from one, the shape becomes close to a circular shape. The R_e of the Kalal Badra basin reached 0.58. It is observed that the values of the R_e are close to zero, which indicates that the basin is more inclined to elongation, and this resulted in increasing the peak flow of floods due to rainfall intensity.

Another significant factor is the circularity ratio (R_c):

$$\boldsymbol{R_c = \frac{A_b}{A_p} = \frac{4\pi A_b}{L_p^2}} \qquad (2)$$

Where A_p is calculated as $(L_p^2/4\pi)$ Since the morphological inverse of the elongation ratio is the R_c, the drainage basin's shape is comparable to a circle. The basin shape and the R_c value are directly correlated, according to the geomorphological expression of the R_c. The basin tends to be more circular as the value gets closer to one, and vice versa. The R_c is value of Kalal Badra is about 0.17. This low value indicates that the basin shape is far from the shape of a circle, because of the basin's extreme curve and the irregularity of the water division lines surrounding it.

The form factor ratio (R_{FF}) represents the ratio of the basin area to the square of the basin length (Eq. 3), which is considered a useful tool for describing the basin shape.

$$\boldsymbol{R_{FF} = A_b/L_b^2} \qquad (3)$$

The drainage basin's general shape, regularity, and degree of symmetry between its components are indicated by the R_{FF}. A larger amount alludes to the drainage basin's general closeness to the square shape and the symmetry among its components. The R_{FF} of Kalal Badra was recorded as a low value of about 0.2, indicating the wideness of the upper source basin and its mouth narrowness.

Morphometric Characteristics

Calculating the morphometric factors is a critical stage in formulating hypotheses and approaches for water resources development planning (Raja Shekar and Mathew, 2024). The study of the watershed network characteristics is also vital to understanding the characteristics of the water basin area by determining the relationship between the orders of the streams and their drainage region. As well as the relationship between the drainage network and the dimensions of the basin and its natural properties (geology, climate, slope, soil, etc.). The drainage network indicates the general shape of the river stream group, which is the correlation between the rock type, structural system, and prevailing climatic conditions (Saber et al., 2020).

The study of the stream number (Horton's Law) aims to classify the rivers based on the classification of river valleys according to the beginning of their sequence during the formation of the river course. The process of arranging the stream orders gives an approximate indication of the amount of drainage that may be in any particular river network. Stream orders are mainly extracted using the drainage network map in the river basin by dividing it into several sections based on orders and taking the main branches that create the river.

Classification of watersheds is based on the method of Strahler (1964) (Strahler, 1964) in studying stream orders and the branching ratio (Raja Shekar and Mathew, 2024). It is found that the Kalal Badra Basin consists of 7 stream orders, where order number 7 represents the peak order, and the total number of streams in the Kalal Badra Basin reached 2475 streams distributed among those orders. The total length reached 3584.82 km as shown in Figure 9. Besides, Table 2 shows the details of the stream orders. The number of watershed lengths is directly proportional to the area of the basin. It is observed that as the basin area increases, the number and length of watersheds increase. The total and each length of watersheds is shown in Table 2.

The bifurcation ratio (R_b) is a vital variable that controls the river drainage network system, and then the drainage system after sudden rains (Kant et al., 2023). The average R_b can be found, based on Horton (1945), by dividing the number of tributaries of a particular order to the next order (Horton, 1945).

$$\boldsymbol{R_b = \frac{N_{u-1}}{N_u}} \text{ or } \boldsymbol{R_b = \frac{N_u}{N_{u+1}}} \qquad (4)$$

Where N_u represents the total number of streams in a given order, and N_{u+1}' is the total number of streams in the next higher order. The R_b in Kalal Badra ranges between (2-5), and this ratio is somewhat close to the ratio determined by other researchers for basins that are similar in climate and geological structure (Thamer et al., 2024). The fourth order is found as the highest R_b of about 4.7 compared to the other ratios, as illustrated in Table 2. This difference in the R_b is properly due to the difference in topographical conditions and the low rainfall rate. Another reason is that the northeastern parts, which are characterized by their slope towards the mainstream, receive a higher share of rainfall in the Kalal Badra basin.

The average length ($\overline{L_u}$) of the drainage network represents the relationship between the sum of the lengths of the stream in a given order and the number of streams (N_u) in that order, and is derived according to the following equation (Strahler, 1964):

$$\boldsymbol{\overline{L_u} = \frac{1}{N_u}\sum_{i}^{u} L_{ui}} \qquad (5)$$

Where, $\boldsymbol{\overline{L_u}}$ is the length of the i-th stream of u-order streams. As shown in Table 2, the average total length of all its ranks reached (19.42 km), and the river ranks varied in their proximity or distance from this average.

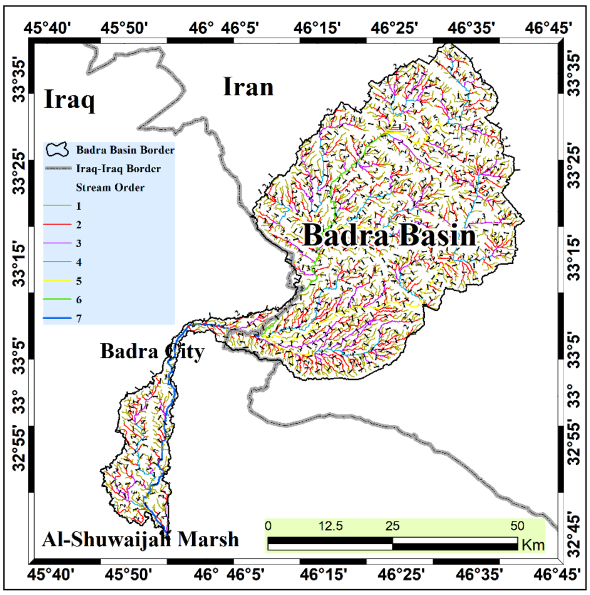


Fig. 9. Drainage network in Kalal Badra basin.

Table 2: Stream order details in Kalal Badra basin.

u_i	N_u	$\frac{N_u}{\sum N_u} \times 100$	L_u (km)	$\frac{L_u}{\sum L_u} \times 100$	B_r
1	1820	73.54	1815.53	50.64	
2	502	20.28	930.58	25.96	3.6
3	118	4.77	379.3	10.58	4.3
4	25	1.01	202.38	5.65	4.7
5	7	0.28	121.16	3.38	3.6
6	2	0.08	62.81	1.75	3.5
7	1	0.04	73.06	2.04	2
$\sum$	2475	100.00	3584.82	100.00	21.7

Drainage density of the river network

The drainage density (D_d) can be defined as the branching degree and river network spread within a specific area (Dragičević et al., 2019).

$$D_d = \frac{\sum_{i=1}^{N_\omega} L_{\omega i}}{A_b} \qquad (6)$$

The importance of the flow density lies in that it affects the pattern of surface runoff and the volume of flow, and shows the extent of the basin surface's exposure to erosion and river erosion. The drainage density is an indicator that shows the extent of the impact of geological, topographic, climatic, soil, and vegetation conditions on the river basin. There is a direct relationship between the drainage density and the amount of rainfall and an inverse relationship with temperature. The flow density increases in areas characterized by abundant rainfall, hardness, and few joints and fractures in their rocks with a steep slope. While the flow density decreases in areas where limestone rocks are present, as well as areas of geological weakness and basins filled with Quaternary sediments.

The drainage density reached about (1.33 km /km^2), which is considered moderate due to the settlement processes, the steepness of the channels, the small area of the basin, and the difference in rock formations. The variation in rainfall from one place to another and from one season to another was one of the important reasons for the decrease in the flow density, which is in the form of seasonal waves. Figure 10 shows the watershed scattering of the drainage density of the Kalal Badra basin.

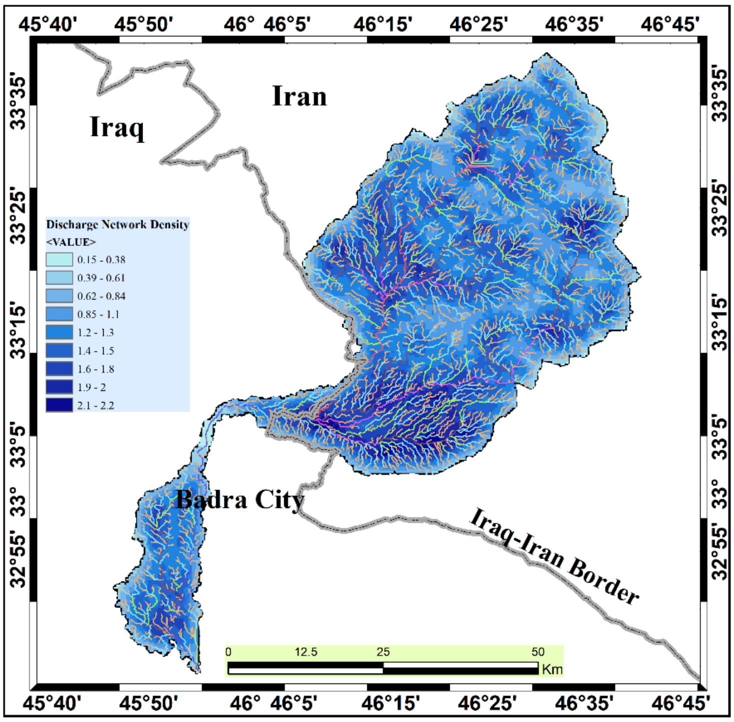


Fig. 10. River network drainage density of Kalal Badra basin.

Conclusions and Future Research Needs

The integration between GIS and RS techniques provides advanced spatial analyses to reach fast, accurate, and diverse results compared to traditional methods. This supports in predicting and anticipating the water basin measurements and affording new proposed solutions for future developments. The following conclusion can be drawn from the current research.

- The digital elevation model (DEM) analysis, after determining the Kalal Badra basin, shows that the largest part of the basin area is located in Iran, of about 88% of the total basin area, compared to the Kalal Badra basin in Iraq of about 12% of the total basin area. Besides, the morphometric analyses of the studied basin show that there is a discrepancy in the measurements, as the width of the basin becomes smaller compared to the area covered by the basin.
- Several structural factors contributed to determining the area of the basin (about 2699.48 km^2). In addition to other factors, including climatic factors, rock formation and tectonic movements.
- The elongation ratio value (0.51) indicates that the basin is closer to an elongated shape, which led to an increase in the peak flow of torrents resulting from the rainfall intensity.
- The circularity ratio for the Kalal Badra is very low, of about 0.17, which indicates that the overall geometry of the basin is far from the circular shape and leads to irregularity of the water division lines surrounding this basin and severe meandering. The analysis of the shape factor for the Kalal Badra shows the widening of the basin at the upstream and narrowing at the downstream.
- Morphometric analyses of the river network of the Kalal Badra basin show that the bifurcation ratio (R_b) ranges between (2-5), and this ratio is somewhat close to the ratio of other basins that are similar in their climate and geological structure. The difference in the bifurcation ratio of the river network streams is due to the difference in topographical conditions and the low rainfall rate, in addition to the fact that the northeastern parts are characterized by a slope towards the main channel, which also receives a higher share of rainfall in Kalal Badra Basin.
- The flow density of the river network is considered medium due to the settlement processes, steepness of the channels, relatively small area of the basin, and the difference in rock formations.

The study conclusions have shed light on the connection between river networks and basin morphology in Iraq's Kalal Badra basin.

Nevertheless, it is essential to record other factors that influence the complexity of river networks. Additional research is required to completely understand this issue and to study and investigate other factors that may contribute to additional accuracy of the morphometric analysis.

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Conflict of Interest

There is no conflict of interest according to the research authors.

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