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Geomorphological Assessment of the Barakar River Basin: A Hypsometric and Morphometric Approach Using GIS

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Abstract

The Barakar River Basin, originating near Padma in Hazaribagh, Jharkhand, is a key tributary of the Damodar River. Covering an area of about 7077 sq km with a perimeter of 686.38 km, this basin plays a critical role in the hydrology of the region, influencing water availability, sediment transport, and flood dynamics. This study focuses on a detailed geomorphological evaluation, utilizing high-resolution DEM data (12.5 m) from ALOS PALSAR, to assess the erosional processes and landscape development of the basin. A series of hypsometric and morphometric analyses were conducted to derive critical parameters such as slope, relief, drainage density, and stream order. The elevation of the basin was categorized into 10 distinct classes, ranging from 36.1 meters to 1319 meters, allowing for a comprehensive assessment of its relief structure. A hillshade map was also generated to visualize terrain and slope more effectively. Stream ordering, based on Strahler's method, revealed a maximum stream order of 5, signifying a well-established drainage network crucial for sediment transport and flow regulation. Using ArcGIS Pro 3.0.1, additional morphometric indices such as the basin shape, elongation ratio, and bifurcation ratio were calculated, offering valuable insights into the basin's susceptibility to erosion and flooding. The hypsometric integral (HI) of 0.50 for the Barakar River Basin indicates a mature stage of geomorphic development, where erosion and upliftment are balanced. Around half of the basin's original landscape has been eroded, with substantial areas leveled but retaining some relief. This reflects significant erosional shaping over time, with further flattening expected as the basin continues evolving towards a more stable topography. This mature stage of development calls for careful basin management to mitigate erosion, control sediment load, and preserve water resources. This study provides critical insights into the geomorphological evolution of the Barakar Basin, offering practical implications for flood control and sediment management in the broader Damodar River system.

Keywords: Hypsometric curve; Morphometric Analysis; Barakar Basin; Stream Order

Introduction

River basins play a pivotal role in the hydrological and geomorphological systems of a region, influencing water availability, sediment transport, and the overall landscape evolution. The Barakar River, a significant tributary of the Damodar River, contributes to the water dynamics of Jharkhand and West Bengal. The region surrounding the Barakar River is characterized by varying topography, including hills, plains, and lowlands, making it essential to study its geomorphological features for effective basin management and flood mitigation.

River basin studies using hypsometric and morphometric analysis provide insights into the terrain's evolutionary status and erosion potential. As human activities and climate change continue to impact river systems, understanding their current geomorphic stages becomes increasingly critical. In particular, the Barakar River Basin has not been extensively studied in terms of its geomorphological evolution, despite its hydrological significance. This study aims to bridge this gap by employing modern geospatial techniques to comprehensively evaluate the basin's characteristics and stage of development. Hypsometric and morphometric analyses have long been used to assess the geomorphic development and erosional status of river basins. According to Strahler[(1)], the hypsometric integral is a valuable tool for evaluating the geomorphic maturity of a basin, where higher HI values indicate youthfulness, and lower values suggest an older, more eroded landscape. Strahler's stream order classification method has also been extensively applied in morphometric studies, helping to identify the complexity of drainage networks[(2)]. These analytical tools, when integrated with modern GIS technology, have provided researchers with the ability to model and quantify various geomorphological parameters.

Several recent studies have focused on using GIS to assess river basins. For instance, Singh et al.[(3)] used morphometric analysis to evaluate the hydrological response of the Gomti River Basin, revealing significant variations in basin shape and drainage characteristics that were linked to flood potential. Similarly, Patel et al.[(4)] applied hypsometric analysis in the Tapi River Basin to understand its geomorphic development, concluding that the basin was in a mature stage with moderate erosion.

Despite these advancements, the Barakar River Basin has received limited attention in scientific literature. Previous studies have largely focused on the Damodar River as a whole, neglecting the individual contributions and characteristics of its tributaries, particularly the Barakar. The few existing studies on the Barakar have primarily concentrated on water quality and sediment load[(5)], leaving a significant gap in understanding its geomorphological status and erosion dynamics. This lack of detailed morphometric and hypsometric analysis underscores the need for further research.

While morphometric and hypsometric analyses have been applied to various river systems globally, the Barakar River Basin remains understudied, especially in terms of its geomorphological and erosional status. Existing research has primarily focused on broader hydrological assessments, but the specific geomorphic evolution and morphometric characteristics of the Barakar remain largely unexplored. This study aims to fill this gap by applying high-resolution DEM data and GIS techniques to derive crucial geomorphological parameters. By doing so, it provides a comprehensive understanding of the Barakar River Basin's developmental stage and erosion potential, offering valuable insights for basin management and regional planning.

The primary objective of this research is to conduct a comprehensive geomorphological assessment of the Barakar River Basin through hypsometric and morphometric analyses using high-resolution DEM data.

The study aims

1. To evaluate the erosional processes and landscape development of the basin by categorizing elevation zones, slope, and relief structure;
2. To analyze the drainage network and stream ordering to determine the basin's hydrological dynamics, focusing on its influence on sediment transport and flooding;
3. To Calculate critical morphometric indices such as drainage density, bifurcation ratio, elongation ratio, and the hypsometric integral to assess the basin's geomorphic maturity and susceptibility to erosion.

Study Area

The Barakar River Basin (Figure 1) was chosen as the focus of this research due to its significant role in shaping the geomorphology of the Damodar River basin and its vulnerability to fluvial hazards, such as floods and sedimentation. Its mature geomorphic characteristics provide a rich source of data for conducting a hypsometric and morphometric analysis, while the basin's environmental and socio-economic importance underscores the need for a

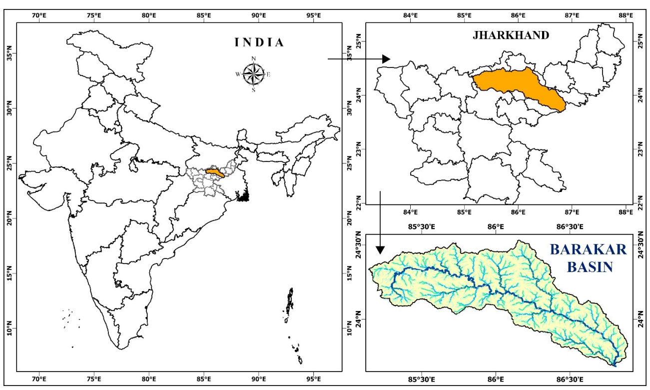

Fig. 1. Barakar Basin Study Area Map

detailed study to aid sustainable management and disaster mitigation efforts. Barakar Basin covers a large region in the northeastern part of Jharkhand, India, extending into parts of West Bengal. It is an important tributary of the Damodar River, which flows through a significant portion of the Chota Nagpur Plateau. The Damodar River is historically referred to as the "Sorrow of Bengal" due to the devastating floods it causes, especially in the lower reaches of West Bengal[(6)]. The Barakar River, as its largest tributary, plays a vital role in this hydrological system.

The physiographic setting of the Barakar River basin is dominated by the rugged terrain of the Chota Nagpur Plateau, characterized by an undulating landscape and moderate to high relief. The topography includes a mix of upland plateaus, ridges, and deeply incised river valleys. Hypsometric analysis of the basin reveals its mature stage of development, while morphometric parameters indicate the dynamic nature of erosion and sediment transport within the basin. The climate of the Barakar River Basin is sub-tropical, marked by hot summers, monsoon rainfall, and mild winters. The region experiences significant rainfall during the monsoon season, between June and September, with an average annual rainfall ranging from 1200 mm to 1400 mm. These seasonal variations heavily influence river flow patterns, leading to high discharge during the monsoon and relatively dry conditions during the rest of the year.

The soil in the basin is primarily composed of laterite and alluvial deposits. The upper catchment areas, especially near the plateau regions, are dominated by lateritic soils, while the lower floodplains are enriched with fertile alluvial soils brought by the river's depositional activities. These soils support both agriculture and natural vegetation, though soil erosion is a prevalent issue due to deforestation and other land-use changes. The Barakar River Basin presents an ideal location for geomorphological studies due to its complex physiographic structure and the interplay of fluvial processes. The region is also characterized by numerous geological formations, including the Gondwana rock formations, which hold significant paleontological and geological importance. The Damodar Valley coalfields are also located nearby, indicating the region's economic importance.

Methodology

For the comprehensive geomorphological analysis of the Barakar River Basin, high-resolution digital elevation data (DEM) was necessary to accurately capture the intricate details of the terrain and its hydrological features. The methodology (Figure 2) employed in this study consisted of several key stages, starting with data acquisition and progressing to the derivation of essential geomorphometric properties. In the data acquisition phase, the ALOS PALSAR DEM with a resolution of 12.5 meters was chosen due to its capability to provide highly detailed topographic information, which is critical for capturing the subtle variations in landscape features[(7)]. This dataset was obtained from the Alaska Satellite Facility (ASF) DAAC, which offers open and free access to ALOS PALSAR data. The fine resolution of the DEM was instrumental in representing the terrain more accurately, thereby facilitating an in-depth and detailed study of the basin's geomorphological and hydrological characteristics.

Once the DEM was acquired, several GIS-based processing and spatial analyses were conducted using ArcGIS Pro 3.0.1 and its advanced spatial tools:

Digital Elevation Model

The Digital Elevation Model (DEM) of the Barkar River Basin generated from ALOS PALSAR with a resolution of 12.5 meters (Figure 3) provides detailed topographical data that

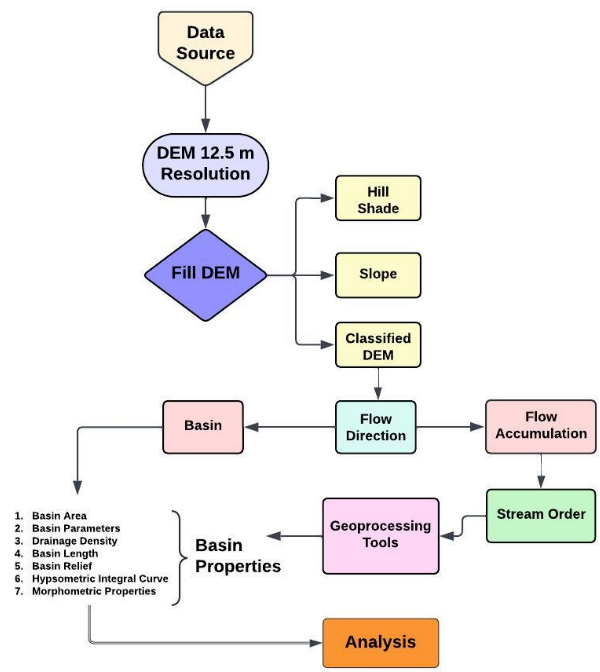

Fig. 2. Methodology Flow Chart

is critical for understanding the basin's terrain. In the image, the elevation ranges from 36 meters (low-lying areas) to 1310 meters (higher elevations), represented by a color gradient where green indicates lower elevations and red denotes higher elevations. The steep elevational gradient observed, especially in the northern and western regions of the basin, points to rugged and elevated terrain, suggesting more active erosional processes and possibly steep slopes. The lower elevation areas in the southeast are likely alluvial plains or valleys, contributing to sediment deposition zones. This variation in elevation is essential for analyzing water flow patterns, potential flood-prone areas, and the overall basin behavior of the river basin.

The DEM data can be utilized to delineate drainage networks and understand runoff dynamics, where higher areas likely contribute to faster surface runoff, while lower, flatter regions may indicate areas of water accumulation or flood plains. The precise elevation data from this DEM also enables slope and aspect analysis, crucial for assessing erosion potential, land stability, and the feasibility of various conservation and development projects within the basin.

Hillshade

The hillshade map (Figure 4) of the Barakar River Basin, as shown in the image, provides a visual representation of the terrain by simulating the effect of sunlight on the landscape. This helps in highlighting the relief features like ridges, valleys, and slopes, which are visible as variations in shading from light to dark.The darker areas in the map represent steeper slopes or regions with less sunlight exposure, while the lighter areas correspond to gentler slopes or areas that would receive more sunlight. This contrast allows for easy identification of significant landforms, aiding in the interpretation of the basin's topography. In terms of morphometric and hypsometric analysis, this visualization helps reveal important geomorphological features that influence water movement and erosion patterns. For instance, the ridges define basin boundaries, while the slopes determine flow accumulation and drainage patterns. By providing insight into the terrain's elevation variations, the hillshade map supports calculations of parameters such as relative relief and slope gradients, which are critical for assessing the erosional processes and the overall geomorphic evolution of the basin. This image helps guide researchers in identifying areas of potential erosion and sediment transport, contributing to a more detailed and practical understanding of the Barakar River Basin's landscape development.

Classified Elevation

The Classified Elevation Map (Figure 5) of the Barkar River Basin categorizes the basin's topography into distinct elevation classes. The map highlights eight elevation ranges, from 36 meters to 1310 meters, using different colors to represent each class. The lowest elevations (36 to 132 meters), shown in light blue, dominate the southeastern region of the basin, which likely corresponds to floodplains or valley areas, important for agriculture and water storage. Conversely, the highest elevations (933 to 1310 meters), marked in brown, are concentrated in the northern and northwestern sections, indicating mountainous terrain or high ridges, potentially prone to erosion and rapid runoff.

The central portion of the map, represented by red and green, shows intermediate elevations (240 to 465 meters), likely reflecting moderately sloping terrain with a mix of forested areas and agricultural zones. These elevations form a transition zone between the highlands and lowlands, crucial for drainage pattern development and controlling water flow across the basin. This classified elevation data helps in identifying the spatial distribution of terrain features, which is vital for managing land use, water resources, and flood risk across different elevation zones.

Slope

The Classified Elevation Map (Figure 6) of the Barkar River Basin divides the terrain into ten elevation classes, ranging from 36 meters to 1319 meters, allowing for a detailed understanding of the region's topography. The lowest elevations (36.01 to 132 meters), represented in light blue, dominate the southeastern region, typically indicating lowland areas, likely

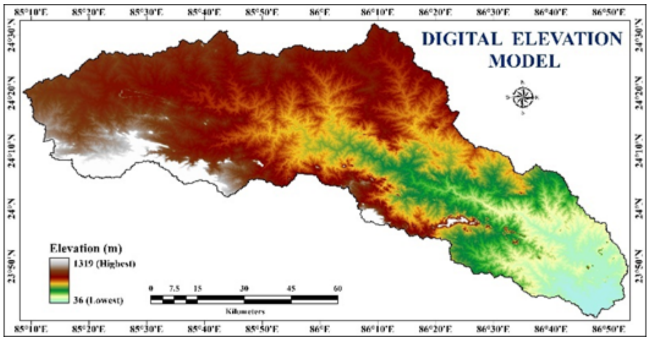

Fig. 3. Digital Elevation Model

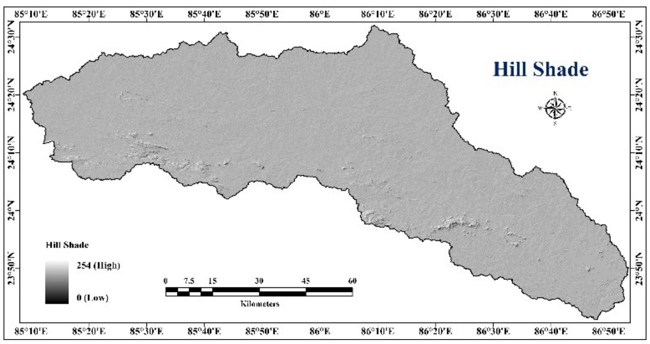

Fig. 4. Hillshade

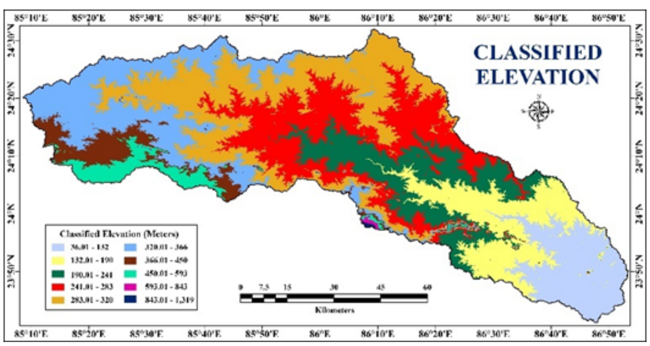

Fig. 5. Classified Elevation

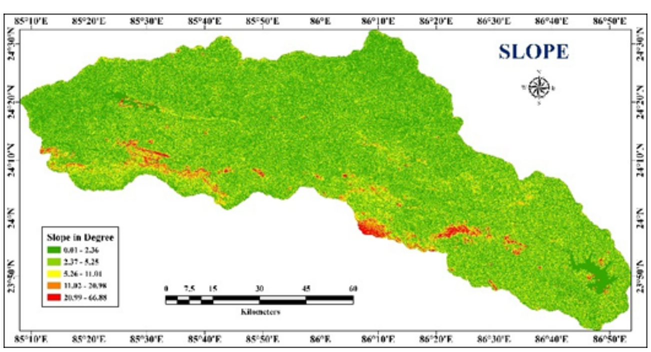

Fig. 6. Slope

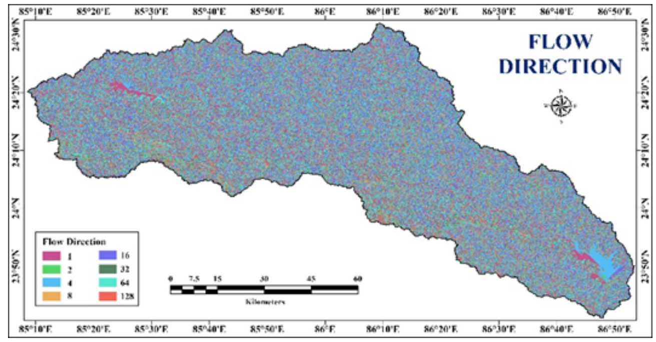

Fig. 7. Digital Elevation Model

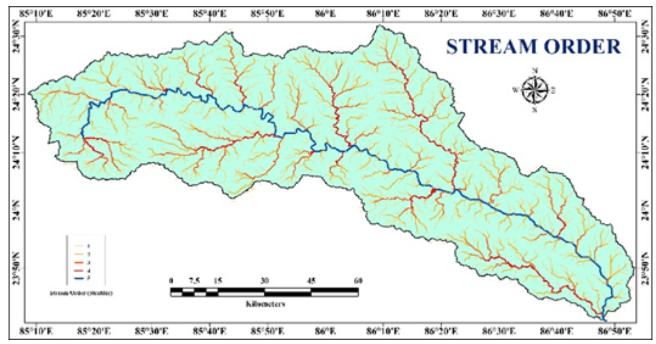

Fig. 8. Stream Order

floodplains or agricultural zones. These lower elevations are crucial for water retention and may be prone to seasonal flooding. The second through fifth classes (132.01 to 320 meters) represent moderate elevation zones, seen in green and yellow shades, covering a substantial portion of the basin. These areas are likely gently sloping terrains, where agricultural activities and settlements are common, due to their relative stability and lower flood risk. The sixth to eighth classes (320.01 to 593 meters) encompass mid-level elevations in brown and red shades, representing more rugged and sloping terrain. This elevation range indicates areas where drainage patterns become more defined, and erosion processes are more active, contributing to soil loss and influencing runoff dynamics.

The highest elevations (593.01 to 1319 meters), shown in darker shades, are concentrated in the northern and northwestern parts of the basin, indicating mountainous or hilly regions. These areas are characterized by steep slopes, faster runoff, and higher erosion potential. The steep gradient in these regions can also significantly impact water flow patterns and flood control strategies within the basin. This classification allows for effective analysis of landform characteristics, informing basin management, soil conservation, and land-use planning.

Flow Direction

The flow direction map (Figure 7) of the Barakar River Basin is a key component in understanding the basin's hydrology and geomorphology. Derived from DEM data, it shows the direction of water movement across the landscape, with each pixel representing the steepest descent from one cell to another. This information is vital for conducting morphometric analysis, helping to define the drainage network, stream order, and drainage density, which are critical for assessing the basin's hydrological structure and erosion potential [2]. Furthermore, flow direction data aids in basin delineation, enabling the identification of sub-basins and the analysis of water accumulation patterns. In hypsometric studies, this flow data helps correlate water distribution with different elevations, contributing to a better understanding of the basin's geomorphic evolution and erosion stages [1]. Thus, the flow direction map is fundamental for both morphometric and hypsometric analyses in the assessment of the Barakar River Basin.

Stream Order

Further hydrological and geomorphological assessments were performed (Figure 8), including stream ordering based on the Strahler method [8], which revealed a maximum stream order of 5. This indicated a well-established drainage network, essential for understanding the basin's capacity for sediment transport and flood regulation. In addition, several morphometric properties were calculated, such as drainage density, elongation ratio, and bifurcation ratio, to analyze the shape and structure of the basin [9].

Moreover, hypsometric analysis and Morphometric analysis (Table 1) was carried out to evaluate the erosional development of the basin. The hypsometric curve and hypsometric integral were derived, with an HI value of 0.50 for the Barakar River Basin indicates a mature stage of geomorphic development, where erosion and uplift are balanced. These comprehensive analyses with Morphometric analysis, supported by the high-resolution DEM and advanced GIS techniques, provided valuable insights into the basin's geomorphological characteristics (Table 2), contributing to a deeper understanding of the landscape's evolution and hydrological dynamics.

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Result Discussion

The hypsometric analysis of the Barakar River Basin, as depicted in the provided table (Table 3), allows for an in-depth understanding of the geomorphological evolution of the basin. Hypsometric Integral (H.I.), relative area (a/A), and relative height (h/H) are important parameters to assess the erosional stage of a basin, reflecting how much of the land surface remains elevated relative to its original elevation. The hypsometric analysis of the Barakar River Basin reveals its geomorphological maturity, with elevation ranging from 36.01 m to

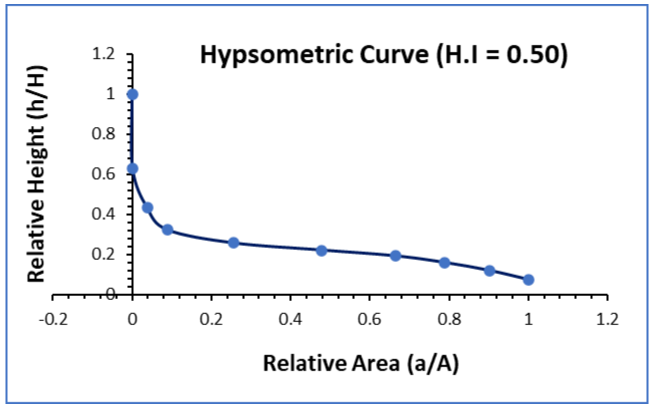

Fig. 9. Hypsometric Curve

1,319 m. The variation in elevation across bands, from 36.99 m to 475.99 m, indicates significant relief changes, particularly at higher elevations, reflecting increased terrain ruggedness [1].

The total basin area (Table 4) of 7,077 km^2 is predominantly distributed in mid-elevation zones, as seen between 241.01 m and 283.00 m, a typical feature of semi-mature to mature basins. The relative area (a/A) decreases with elevation, highlighting an advanced erosional stage where minimal area remains at higher altitudes [10]. The mean elevation across bands ranges from 84.01 m to 1,081.01 m, with a consistent hypsometric integral (H.I.) of 0.50, reflecting a uniform erosion process. The H.I. indicates that 50% of the basin's original volume has been eroded, signaling a balanced denudation and deposition state [1]. Relative height (h/H) increases from 0.07 at lower elevations to 1.00 at the highest, with significant height distributed in the upper elevations, pointing to steep valleys and uneroded portions of the landscape [9].

The overall relief of 1,282.9 m suggests substantial erosional activity, particularly in the lower and mid-elevation zones, with remnants of the original topography preserved at higher elevations. This mature stage of development provides insights into future geomorphological trends [1].

$$\text{H.I.} = \frac{\text{Mean Elevation-Minimum Elevation}}{\text{Maximum Elevation-Minimum Elevtion}} \qquad (1)$$

The hypsometric curve shown in the figure (Figure 9) highlights the relationship between the relative height (h/H) and the relative area (a/A) of the Barakar River Basin, with a Hypsometric Integral (H.I.) we get by implementing eqn(1)

Table 1. Methods of CalculatingMorphometric Parameters of Drainage Basin

	Morphometric Parameters	Methods	References
LINEAR	Stream order (U)	Hierarchical order	Strahler, 1964
	Stream length (L_u)	Length of the stream	Horton, 1945
	Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$ where, L_u = Stream length of order 'U', Nu = Total number of stream segments of order 'U'	Horton, 1945
	Stream length ratio (R_L)	RL = L_u/L_{u-1}; where, L_u = Stream length of order 'U', L_{u-1} = Stream length of next lower order.	Horton, 1945
	Bifurcation ratio (R_b)	Rb = N_u/N_{u+1}; where, N_u = Total number of stream segments of order 'U'; N_{u+1} = Number of segment of next higher order	Schumm, 1956
AREAL	Drainage density (D_d)	Dd = L_b/A where, L_b = Total length of streams; A = Area of basin	Horton, 1932
	Stream frequency (F_s)	F_s = N/A where, N = Total number of streams; A = Area of basin	Horton, 1932
	Texture ratio (T)	T = N_1/P where, N_1 = Total number of first-order streams; P = Perimeter of basin	Horton, 1945
	Form factor (R_f)	Rf = A/L_{b^2} where, A = Area of basin, Lb = Basin length	Horton, 1932
	Circulatory ratio (R_c)	$R_c = 4\pi A/p^2$ where, A = Area of basin, π = 3.14, P = Perimeter of basin	Miller, 1953
	Elongation ratio (R_e)	R_e = 2P$(A/\pi)/L_b$ where, A = Area of basin, π = 3.14, L_b = Basin length	Schumm, 1956
	Length of overland flow (L_g)	$L_g = 1/2D_d$ where, D_d = Drainage density	Horton, 1945
	Constant channel maintenance (C)	C = $1/D_d$ where, D_d = Drainage density	Schumm, 1956
RELIEF	Basin relief (B_h)	Vertical distance between the lowest and highest points of basin	Schumm, 1956
	Relative Relief (R_r)	Rr= B_h/p; Where B_h= Basin Relief, p= Perimeter of the Basin	Melton 1957
	Relief ratio (R_h)	$R_h = B_h/L_b$; where, B_h = Basin relief, L_b = Basin length	Schumm, 1956
	Ruggedness number (R_n)	$R_n = B_h \times D_d$ where, B_h = Basin relief; D_d = Drainage density	Schumm, 1956

Table 2. Barkar River Basin Stream Details

S.No	Stream Order	No. of Streams (Lu)	Stream Length (Km)	Mean Stream Length (Lsm)	Stream Length Ratio (RL)	Bifurcation Ratio (Rb)
1	1st Order	1336	2131.77	1.60	4.59	4.59
2	2nd Order	291	1085.31	3.73	4.22	4.22
3	3rd Order	69	540.08	7.83	4.60	4.60
4	4th Order	15	270.43	18.03	15.0	15.0
5	5th Order	1	262.85	262.85	0.00	
	Total	**1712**	**4290.44**	**58.81**	Mean Rb=7.10	

as value of 0.50. This indicates that the basin is in a mature stage of geomorphological evolution, where approximately 50% of the original landmass volume has been eroded. The steep curve at the upper part of the graph, where (h/H) is closer to 1, suggests that a small portion of the basin occupies higher elevations, typically associated with steep slopes and preserved topography. As the curve flattens toward the lower values of (a/A), it implies that much of the basin is composed of mid to lower elevations, which have undergone significant erosion. The overall shape of the curve, with a sharp drop followed by a gradual slope, is characteristic of a basin transitioning from a youthful to a mature stage, with minimal area remaining at the highest elevations. This reinforces the inference that the Barakar River Basin has experienced extensive fluvial erosion, leaving steep residuals at higher elevations while most of the landscape has been reduced to lower levels. Such insights are critical in understanding the long-term evolution of the basin and the dominant erosional processes shaping its terrain [10].

The stream order analysis of the Barakar River Basin, as depicted in the table, shows significant insights into the drainage characteristics. The basin comprises a total of 1,712 streams, with the first-order streams being the most numerous (1,336), which gradually decrease as the stream order increases. This follows the typical pattern in river systems, where higher-order streams are fewer in number.

Table 3. Showing Hypsometric Integral (H.I) , Relative Area (a/A) and Relative Height (h/H)

S.No	Lower Elevation	Higher Elevation	Area Square Km	Range	Mean Elevation	Mean Elevetion - Lower Elevetion	H.I	a	a/A	(h)	(h/H)
1	36.01	132	695	95.99	84.01	48.00	0.50	**7,077**	1.00	95.99	0.07
2	132.01	190	799	57.99	161.01	29.00	0.50	6,382	0.90	153.98	0.12
3	190.01	241	881	50.99	215.51	25.50	0.50	5,583	0.79	204.97	0.16
4	241.01	283	1314	41.99	262.01	21.00	0.50	4,702	0.66	246.96	0.19
5	283.01	320	1585	36.99	301.51	18.50	0.50	3,388	0.48	283.95	0.22
6	320.01	366	1170	45.99	343.01	23.00	0.50	1,802	0.25	329.94	0.26
7	366.01	450	364	83.99	408.01	42.00	0.50	633	0.09	413.93	0.32
8	450.01	593	256	142.99	521.51	71.50	0.50	269	0.04	556.92	0.43
9	593.01	843	9	249.99	718.01	125.00	0.50	13	0.00	806.91	0.63
10	843.01	1,319	4	475.99	1081.01	238.00	0.50	4	0.00	1282.9	1.00
			A = 7077	**a** = Area Accumulation, **h** = Cumulative Height, **H** = Relief of Basin						**H = 1282.9**	

Table 4. Bhagirathi Basin Property

S.No	Details	Results
1	Basin area (A) (Sq.Km)	7077.00
2	Basin length (Lb) (Km)	188.01
3	Basin perimeter (P) (Km)	686.38
4	Basin relief (H) (Km)	1.28
5	Mean bifurcation ratio (Rbm)	7.10
6	Relief Ratio (Rh)	0.01
7	Drainage Density (D) (Sq.Km)	0.61
8	Stream Frequency (Fs) (Sq.Km)	0.24
9	Form Factor (Rf)	0.20
10	Circularity Ratio (Rc)	0.19
11	Elongation Ratio (Re)	0.51
12	Constant Channel of Maintenance (Km)	1.65

The total length of all streams in the basin is 4,290.44 km, and the average stream length increases with the stream order, indicating the progression of stream lengths as the drainage network becomes more organized. The mean stream length (Lsm) ranges from 1.60 km for first-order streams to 262.85 km for the fifth-order stream, showing an expected correlation between stream length and order.

The stream length ratio (RL), which measures the ratio of the stream lengths between successive orders, ranges from 4.22 to 15.00. This variability suggests that stream lengths increase at different rates between the orders, possibly due to variations in topography or geological influences within the basin. The high RL between the fourth and fifth orders is noteworthy, as it points to significant changes in stream length in the higher orders.

The bifurcation ratio (Rb), which represents the ratio between the number of streams in successive orders, averages 7.10. The individual Rb values range from

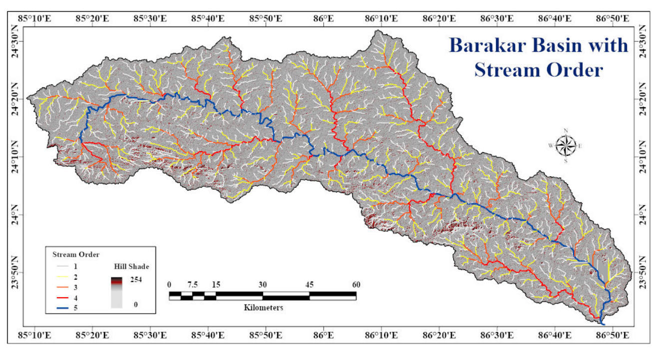

Fig. 10. Barakar Basin with Stream Order

4.22 to 15.00, with higher values suggesting greater structural control or rugged terrain, common in areas with complex drainage networks. This high bifurcation ratio implies that the Barakar River Basin experiences strong geological or topographical influences, which impact its stream network's development and organization.

In conclusion, the stream order and bifurcation ratio analysis of the Barakar River Basin highlight the basin's organized but complex drainage structure, influenced by both topography and geology, making it an example of a structurally controlled river system.

The Bhagirathi Basin (Table 4), covering an area of 7077 square kilometers, represents a large drainage system, which has a notable impact on water flow dynamics and sediment deposition. The basin length of 188.01 kilometers suggests the river extends over a considerable distance, influencing its discharge patterns and sediment transport capacity. With a basin perimeter of 686.38 kilometers, the basin boundary is highly irregular, affecting how runoff converges towards the river channels.

The basin relief of 1.28 kilometers indicates a moderate elevation difference between the highest and lowest points, contributing to the potential energy available for erosion and the movement of water and sediment through the basin. The mean bifurcation ratio (7.10) is relatively high, suggesting the presence of a structurally controlled drainage network, with less branching between stream orders and potentially steep slopes.

A relief ratio of 0.01 suggests a gentle slope across the basin, implying slower runoff, which could allow more infiltration, reduce soil erosion, and promote groundwater recharge. The drainage density (0.61 km/sq.km) is moderately low, indicating that the basin has fewer stream channels relative to its size, likely due to infiltration-dominated processes or impermeable bedrock. The stream frequency (0.24 streams/sq.km) supports this, showing that the number of streams is low for the area, which could influence flood response times during heavy rainfall events.

The form factor (0.20) and elongation ratio (0.51) suggest that the basin is elongated, contributing to a prolonged peak flow during storms, rather than rapid, short-duration floods. Similarly, the circularity ratio (0.19) further supports the elongated nature, indicating a shape that delays the time of concentration of runoff. Finally, the constant of channel maintenance (1.65 km) reflects the amount of area needed to sustain one kilometer of stream channel. This moderate value implies that the basin has a balanced interaction between its surface area and the stream network, reflecting moderate permeability and runoff generation.

These morphometric characteristics suggest that the Bhagirathi Basin is characterized by a combination of moderate relief, a structurally controlled drainage network, and slower runoff, which has implications for its hydrological behavior, sediment transport, and flood potential.

Conclusion

The hypsometric and morphometric analysis of the Barakar River Basin provides a detailed view of its geomorphological evolution and structural dynamics. The hypsometric integral (H.I.) of 0.50 suggests a mature stage of erosion, where about 50% of the original volume has been worn away, indicating balanced denudation and deposition processes. The steep hypsometric curve at higher elevations reflects preserved topography in the upper reaches, while the flatter curve at lower elevations indicates significant erosion, typical of semi-mature basins. This pattern reveals how the basin's landscape has evolved, with most of the area concentrated in mid-elevation zones, signifying advanced erosion stages.

Morphometric parameters such as a high bifurcation ratio (7.10) and low drainage density (0.61 km/km^2) highlight the structural control of the drainage system, with elongated basin characteristics delaying runoff concentration. The variability in stream length ratios, particularly the increase in higher stream orders, points to complex topographic influences on stream development. These factors suggest that the Barakar River Basin is largely shaped by geological structures and rugged terrain, with slower runoff and moderate sediment transport.

Together, these analyses present a comprehensive understanding of the basin's mature geomorphology, helping predict future erosion patterns and water flow dynamics.

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