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IDENTIFICATION OF HYPSOMETRIC AND MORPHOMETRIC FEATURES OF THE INDUS BASIN THROUGH GIS TECHNIQUES

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ABSTRACT

Using cutting-edge geospatial tools, this study examines the hydrological and geomorphological features of a defined section of the Indus drainage basin located in the Union Territory of Jammu and Kashmir. Using a Digital Elevation Model (DEM) created from ALOS PALSAR data, the study performs morphometric and hypsometric studies. With a hypsometric integral value of 0.48, which indicates a balanced distribution of elevations over the basin, the hypsometric curve displays a varied elevation distribution. A hierarchical stream network dominated by first-order streams—which are distinguished by longer stream lengths and lower bifurcation ratios in higher orders—is also revealed by the morphometric study. Key traits identified by the study include a well-dissected basin reflected in drainage density, a low relief ratio implying gentle slopes, and a low form factor showing shaped like a little basin. Together, these findings improve our knowledge of the hydrological behavior and landscape dynamics of the Indus Basin and provide important new information for land use planning and efficient watershed management in the area. The findings highlight how crucial it is to incorporate geomorphological assessments into sustainable development environmental management plans.

Keywords: Indus Basin, Geomorphology, Hydrology, Hypsometric Analysis, Morphometric Analysis, Digital Elevation Model (DEM), Stream Network, Watershed Management, Bifurcation Ratio, Drainage Density, Relief Ratio

INTRODUCTION

The parameters of morphometry and hypsometry offer crucial information on the topography and geomorphology of a drainage basin. The hypsometric curve, which depicts the relationship between the height and the cumulative area at or below that elevation, is frequently used to highlight the hypsometric features, which are related to the quantitative study of the elevation distribution of the basin. This curve's shape indicates the geomorphic stage of development, providing crucial information on the topography of the basin. A more gradual curve indicates a more mature stage, whereas a steeper curve indicates a younger basin (Strahler, 1952). Furthermore, the curve's concavity or convexity can reveal information regarding tectonic activity and erosion; concave curves suggest a higher propensity for erosion, whereas convex curves suggest tectonic activity (Singh, 1998). The essential hypsometric integral The ratio of the area under the curve to the basin's overall area is a crucial statistic in this research that provides insight into the processes of erosion and deposition in the landscape (Ohmori, 1993).

In addition, knowledge of a drainage basin's morphometric features is essential for comprehending its landform features and hydrological behavior. Morphometric analysis involves using quantitative parameters to define and understand the physical aspects of landforms, particularly within drainage basins and watersheds. This method employs various measurements such as drainage density, stream order, basin shape parameters, relief characteristics, and slope analysis to assess landform shapes, sizes, relief, and the overall landscape configuration. A thorough understanding of how a basin reacts to both natural and man-made processes can be gained by the examination of morphometric parameters, such as drainage density, stream order, basin form, and relief features (Horton, 1945). This study looks at the morphometric characteristics of a particular demarcated section in the Union Territory of Jammu and Kashmir's Indus drainage basin. The study intends to enhance sustainable watershed management and land use planning by studying these attributes and comprehending the hydrological processes and terrain change of the basin (Sharma & Sinha, 2008). In conjunction, the morphometric and hypsometric investigations offer a thorough comprehension of the topography, geomorphic stage, erosion processes, and tectonic activity, which is necessary to forecast runoff patterns, sediment output, and the dynamics of the entire terrain (Bishop, 2007).

STUDY AREA

The study area encompasses a delineated segment within the larger hydrological framework of the Indus Basin, situated within the territorial boundaries of the Jammu and Kashmir Union Territory. Spanning a region with distinctive topographic features and varied geomorphological characteristics, this specific segment holds significance in the broader context of the Indus Basin's hydrological dynamics. Geographically, the segment is positioned within the mountainous terrain of the Himalayas, characterized by steep slopes, rugged landscapes, and diverse landforms. The area's elevation gradient ranges from relatively lower elevations to towering peaks, contributing to the intricate drainage network and water flow dynamics within the basin. The region's morphometric analysis focuses on understanding the basin's shape, relief, drainage patterns, and other quantitative landform characteristics. the study area's morphometric attributes contribute significantly to comprehending the basin's landscape evolution, hydrological behaviour, and inform strategies for effective watershed management and land use planning within the Indus Basin framework.

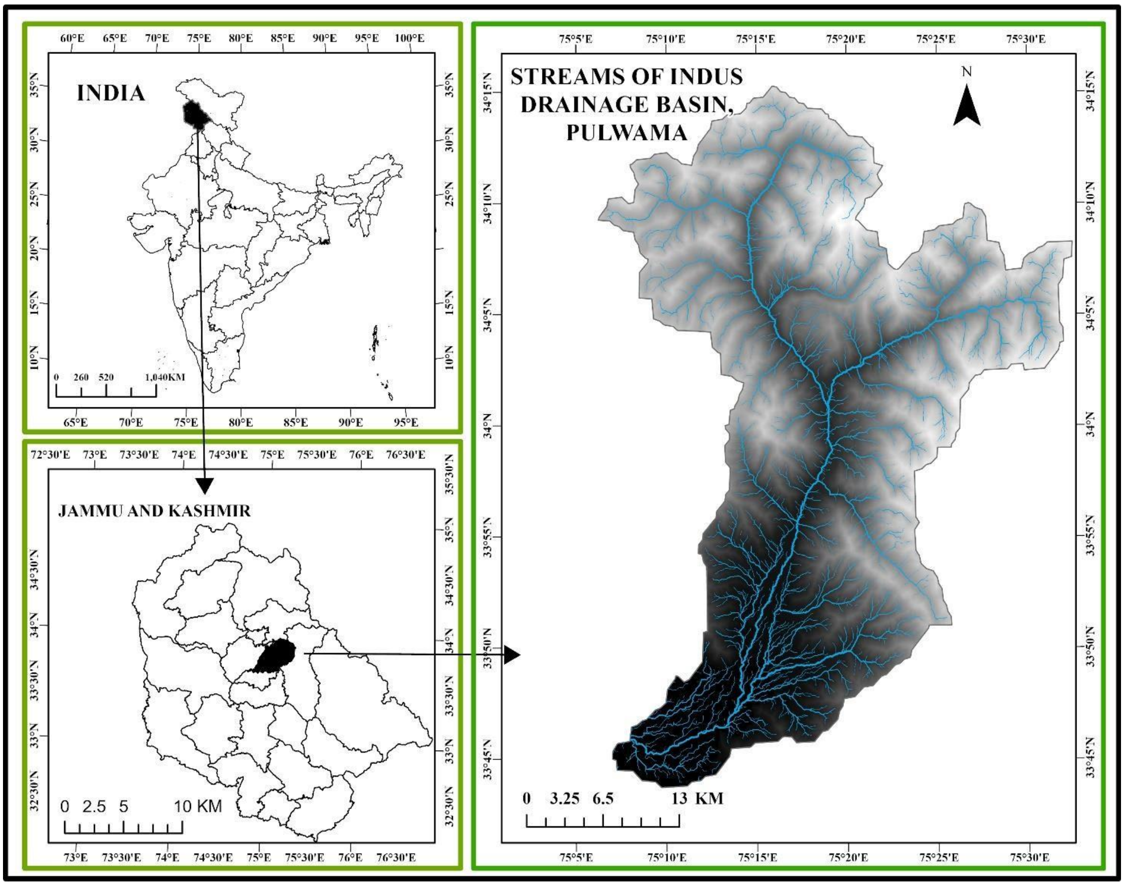

Figure 1: Study area showing Delineated Indus Drainage Basin

DATASETS AND METHODOLOGY

Hypsometric Properties: Utilizing a 30-meter resolution Digital Elevation Model (DEM) from ALOS PALSAR, a portion of the Indus drainage basin in the Union Territory of Jammu and Kashmir was examined. In order to guarantee the accuracy of elevation data, sinkholes and peak mistakes have to be fixed during the preprocessing step using the Fill tool. The values were classed from 1 to 32 for additional analysis after the DEM was split into 32 elevation classes using the Symbology tab. Each class's relative height and area were calculated, enabling the creation of a hypsometric curve in Microsoft Excel. The hypsometric integral and other relevant computations were obtained from this curve, which showed the cumulative area in relation to elevation ranges, in order to further evaluate the basin's topography (Jasrotia et al., 2020; Thakur et al., 2018).

Calculation of Hypsometric Integral and Hypsometric Curve: An essential tool for determining the geomorphic features and evolutionary stage of a landform is the hypsometric integral, which has a range of 0 to 1. These metric captures, beyond its numerical representation, the link between elevation ranges and their respective regions, defining the distribution of surface characteristics across the environment. A hypsometric integral value in the range of 0.6 to 1.0 suggests a young terrain characterized by large dissection, high gradients, and large relief fluctuations. This stage is frequently associated with areas undergoing dynamic geomorphic processes, like tectonic activity and erosion, which determine the unique features of the landform. On the other hand, a hypsometric integral between 0.35 and 0.60 indicates a more developed and fractured terrain, indicating stabilized ground with less erosion and smoother relief. This stage, which marks an intermediary stage in the evolution of the landscape, shows a balance between erosional forces and landmass stability. When the hypsometric integral falls below 0.35, it indicates that the landform has achieved an equilibrium or ancient state of dissection, wherein it has undergone restricted geomorphic alterations and reduced relief. Determining these hypsometric integral values helps interpret the geological processes that have sculpted the landscape over time and provide important insights into the landform's historical history (Ritter et al., 2016; Sreedevi et al., 2009).

From the lowest to the highest elevation class, the areas represented by each elevation class are gradually added to determine area accumulation (a). A represents the maximum value of the accumulated area. Then, the area ratio (a/A), also known as relative area, is calculated. Simultaneously, the highest height is represented by H, and relative height (h) is computed by adding up the elevation ranges of the classes from top to bottom. The relative height is then calculated using the height-to-height ratio (h/H). Microsoft Excel's scatter diagram is used to depict a hypsometric curve, producing a smooth curve with relative area on the x- and relative height on the y-axes (Hare et al., 2020; Kumar et al., 2021).

Hypsometric Integral can be calculated by using following equation:

$$\frac{Mean\ Elevation - Minimum\ Elevation}{Maximum\ Elevation - Minimum\ Elevation}$$

Table 1: Representation of hypsometric integral, relative area and relative height

Value	Area (in sq km)	MIN	MAX	RANGE	MEAN	Mean-Min	HI	Area Accumulation (a)	a/A	h	h/H
1	67.73	1553	1660	107	1604.16	51.16	0.48	1144.83	1	107	0.03
2	52.64	1661	1768	107	1714.69	53.69	0.5	1077.1	0.94	214	0.06
3	42.81	1769	1876	107	1818.8	49.8	0.47	1024.46	0.89	321	0.09
4	29.55	1877	1983	106	1928.16	51.16	0.48	981.65	0.86	427	0.13
5	27.05	1984	2091	107	2038.65	54.65	0.51	952.1	0.83	534	0.16
6	30.22	2092	2199	107	2145.6	53.6	0.5	925.04	0.81	641	0.19
7	29.15	2200	2306	106	2252.4	52.4	0.49	894.83	0.78	747	0.22
8	29.92	2307	2414	107	2361.76	54.76	0.51	865.68	0.76	854	0.25
9	31	2415	2522	107	2468.69	53.69	0.5	835.76	0.73	961	0.28
10	30.01	2523	2629	106	2576.08	53.08	0.5	804.76	0.7	1067	0.31
11	32.57	2630	2737	107	2684.1	54.1	0.51	774.75	0.68	1174	0.34
12	33.77	2738	2845	107	2791.46	53.46	0.5	742.18	0.65	1281	0.38
13	31.67	2846	2952	106	2898.05	52.05	0.49	708.41	0.62	1387	0.41
14	32.44	2953	3060	107	3007.38	54.38	0.51	676.74	0.59	1494	0.44
15	33.2	3061	3168	107	3115.29	54.29	0.51	644.29	0.56	1601	0.47
16	35.87	3169	3276	107	3223.57	54.57	0.51	611.09	0.53	1708	0.5
17	39.11	3277	3383	106	3330.52	53.52	0.5	575.22	0.5	1814	0.53
18	44.3	3384	3491	107	3438.26	54.26	0.51	536.11	0.47	1921	0.56
19	50.39	3492	3599	107	3547.27	55.27	0.52	491.81	0.43	2028	0.59
20	57.19	3600	3706	106	3654.28	54.28	0.51	441.42	0.39	2134	0.62
21	65.76	3707	3814	107	3761.14	54.14	0.51	384.22	0.34	2241	0.66
22	65.44	3815	3922	107	3868.37	53.37	0.5	318.46	0.28	2348	0.69
23	59.34	3923	4029	106	3974.72	51.72	0.49	253.02	0.22	2454	0.72
24	53.57	4030	4137	107	4082.21	52.21	0.49	193.68	0.17	2561	0.75
25	42.74	4138	4245	107	4189.53	51.53	0.48	140.11	0.12	2668	0.78
26	34.52	4246	4352	106	4297.2	51.2	0.48	97.37	0.09	2774	0.81
27	27.45	4353	4460	107	4403.69	50.69	0.47	62.85	0.05	2881	0.84
28	18.9	4461	4568	107	4509.05	48.05	0.45	35.4	0.03	2988	0.87
29	9.92	4569	4675	106	4615.25	46.25	0.44	16.51	0.01	3094	0.91
30	4.32	4676	4783	107	4720.82	44.82	0.42	6.59	0.01	3201	0.94
31	1.81	4784	4891	107	4829.32	45.32	0.42	2.27	0	3308	0.97
33.46	0.46	4892	4999	107	4925.46	33.46	0.31	0.46	0	3415	1

It is found that the average Hypsometric Integral (HI) is 0.48 based on the values computed in the table. According to this score, the basin is a mature, dissected landform. This kind of HI indicates a balance between erosional forces and landform stability, indicating extensive erosion and stabilization processes throughout the landscape (Rao et al., 2018; Gupta et al., 2015).

Morphometric Properties: One of the datasets used in this analysis was a 30-meter-resolution ALOS PALSAR Digital Elevation Model (DEM). The Fill tool was used in the first preprocessing steps to fix sink and peak issues in the DEM. Subsequently, the stream network was demarcated using the Flow Direction and Flow Accumulation tools, with a threshold value of 250 being established for more distinct stream identification. To ascertain the stream order, the Stream Order tool was utilized in conjunction with the Strahler approach. The Stream to Feature tool was then used to turn the streams that had been discovered into vector files. A number of procedures were carried out in order to precisely count the number of streams: the vector streams were first dissolved, and then the separate intersecting features for subsequent streams—more precisely, for the first and second order, the second and third order, and finally for all orders—the PLANARIZE tool was employed. Following the accurate segmentation of the streams, the delineated stream network was used to calculate a number of morphometric aspects of the drainage basin, such as drainage density, stream order, basin form parameters, and terrain characteristics. The systematic extraction and analysis of morphometric features inside the study area was made easier by this thorough methodology (Ravi et al., 2019; Jain et al., 2020; Kumar & Rao, 2017).

Table 2: Methods of Calculating Morphometric Parameters of Drainage Basin

	Morphometric parameters	**Methods**	**References**
L I N E A R	Stream order (U)	Hierarchical order	Strahler,1964
	Stream length (Lu)	Length of the stream	Horton,1945
	Mean stream length (Lsm)	Lsm=Lu/Nu, where Lu =stream length of order 'U' Nu=Total number of stream segments of order 'U'	Horton,1945
	Stream length ratio (RL)	RL=Lu/Lu-1; where Lu=Total stream length of order 'U', Lu- 1=Stream length of next lower order.	Horton, 1945
	Bifurcation ratio (Rb)	Rb = Nu/ Nu+1; where, Nu=Total number of stream segment of order 'u'; Nu+1=Number of segments of next higher	Schumn,1956

		order	
	Drainage density (Dd)	Dd = Lb/A where, L=Total length of streams; A=Area of watershed	Horton, 1945
A R E A L	Stream frequency (Fs)	Fs = N/A where, N=Total number of streams; A=Area of watershed	Horton, 1945
	Texture ratio (T)	T = N1/P where, N1=Total number of first order streams; P=Perimeter of watershed	Horton, 1945
	Form factor (Rf)	Rf=A/(Lb) 2; where, A=Area of watershed, Lb=Basin length	Horton, 1932
	Circulatory ratio (Rc)	Rc=4Πa/P2; where, A=Area of watershed, π=3.14, P=Perimeter of watershed	Miller, 1953
	Elongation ratio (Re)	Re=2√(A/π)/Lb; where, A=Area of watershed, π=3.14, Lb=Basin length	Schumn,1956
	Length of overland flow (Lg)	= ½ Dd where, Dd = Drainage density	Horton,1945
	Constant channel maintenance (C)	Lof = 1/Dd where, Dd=Drainage density	Horton, 1945
R E L I E F	Basin relief (Bh)	Vertical distance between the lowest and highest points of watershed.	Schumn, 1956
	Relative relief (Rr)	Rr=Bh/p, where, Bh=Basin relief, p= perimeter of the basin	Melton (1957)
	Relief ratio (Rh)	Rh=Bh/Lb; Where, Bh=Basin relief; Lb=Basin length	Schumn, 1956
	Ruggedness number (Rn)	Rn= Bh × Dd, where Bh =Basin relief; Dd=Drainage density	Schumn, 1956

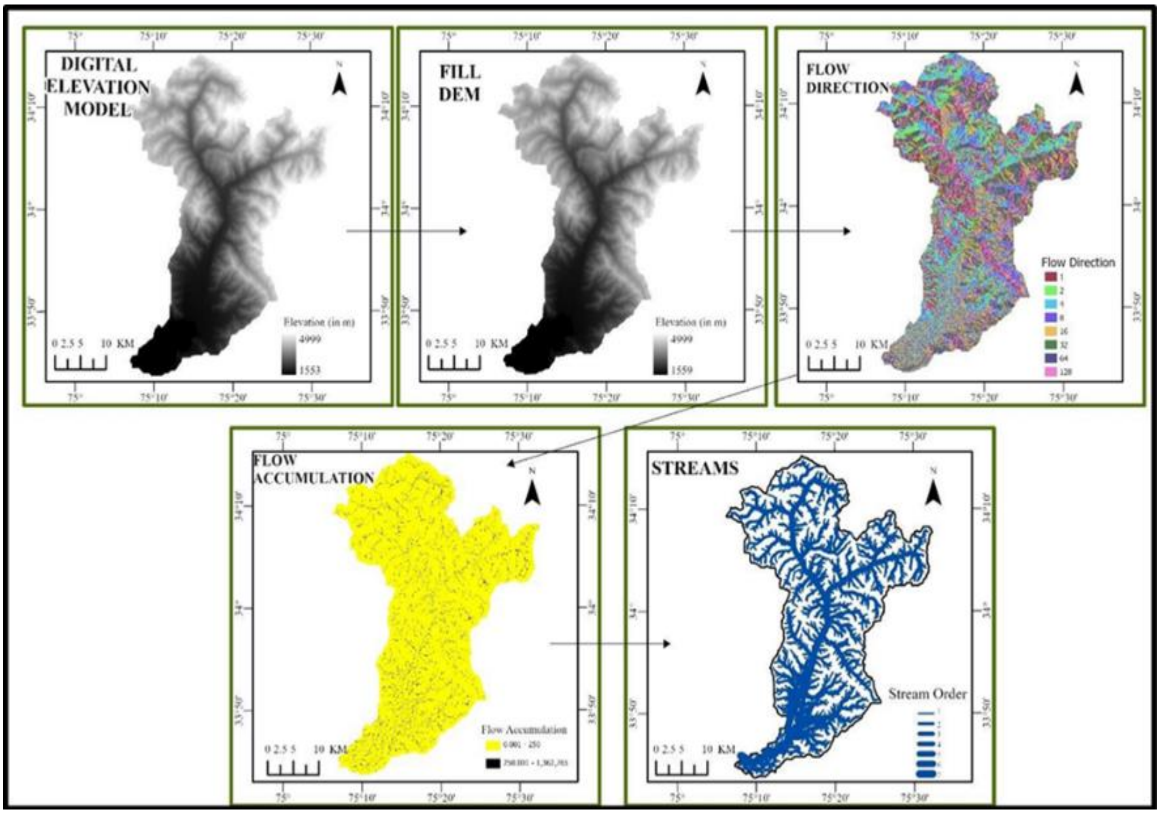

Figure 2: Datasets used for studying the morphometric properties of drainage basin

RESULTS AND DISCUSSIONS

Within the designated portion of the Indus drainage basin in the Union Territory of Jammu and Kashmir, the hypsometric curve created from the relative height and relative area data shows a consistent pattern that depicts the relationship between elevation and cumulative area.

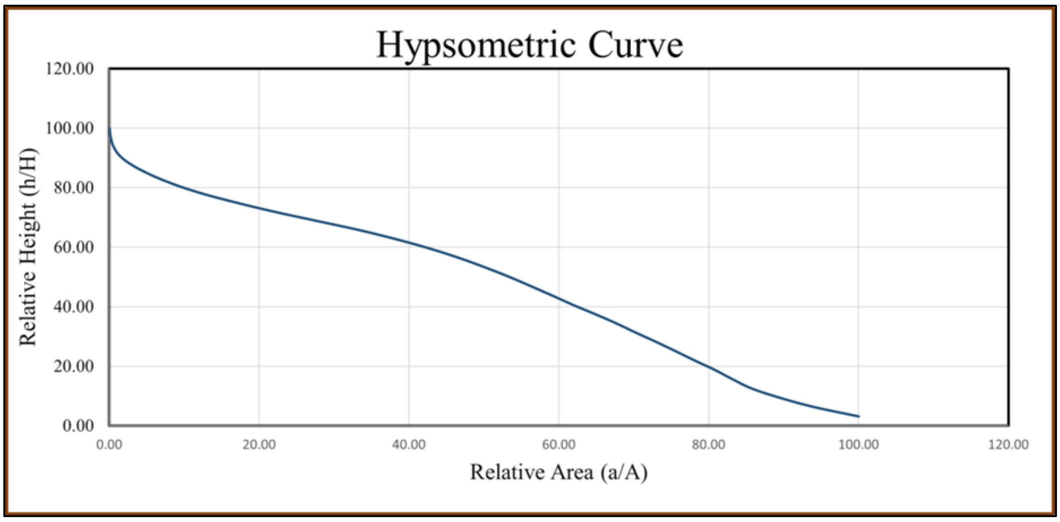

Fig 3 Hypsometric curve of Indus Drainage Basin

The curve begins with a slow ascent, suggesting that a tiny cumulative area is composed of a wide range of altitudes. The curve steepens with elevation, indicating that higher elevations cover bigger cumulative areas. This association suggests that the region under examination has a diversified topographic distribution. Given that the hypsometric integral value is 0.48, it can be inferred that 48% of the total area is located below the median elevation and 52% is located above it. This demonstrates the basin's evenly distributed elevation. A study like this provides important information about the elevation distribution and geomorphological characteristics of the studied area of the Indus drainage basin (Rao et al., 2018; Kumar & Rao, 2017).

A noteworthy pattern that highlights the hierarchical structure of the stream network within the basin can be seen in the stream order characteristics in the designated portion of the Indus Basin. The analysis includes multiple stream orders, starting with a large number of first-order streams whose quantity decreases with increasing stream order. This ordered configuration shows how stream lengths and bifurcation ratios change between orders. The information shows that the streams in this area of the Indus Basin are arranged in an ordered network, providing information about the historical development and spatial arrangement of the streams based on their individual orders. The conclusions on the delimited Indus River's linear, relief, and aerial characteristics are shown below.

Table 3: Result of Morphometric Analysis in Linear Aspects

Stream Order	**No. of Streams (Nu)**	**Minimum stream Length (in m)**	**Maximum stream Length (in m)**	**Mean stream Length (in m)**	**Stream Length (in Km)**	**Stream Length Ratio (Rl)**	**Bifurcation Ratio (Rb)**	**Mean Bifurcation Ratio**
				(Lsm)	**(Lu)**			
1	1508	4.2	3848.7	576.7	869.71	-	4.86	
2	310	28.3	7177.6	1307.9	405.46	2.27	4.92	
3	63	80.1	10293	3312	208.66	2.53	3.94	
4	16	429.2	10036	4542.3	72.676	1.37	4	
5	4	1400.5	25167	13530	54.121	2.98	2	
6	2	4341.8	30190	17266	34.532	1.28	2	**3.62**
7	1	12017	12017	12017	12.017	0.7	-	

Table 4: Result of Morphometric Analysis in Aerial and Relief aspects	
Basin Area (sq. km)	1092.3
Number of streams (Nu)	1904
Perimeter (km)	233.29
Basin Length (km)	79.9
Basin Relief (m)	3446
Relief Ratio	0.0431
Relative relief	0.0148
Drainage density	1.5172
Texture ratio	6.4641
Form Factor	0.1711
Circulatory ratio	0.2525
Elongated Ratio	0.0679
Length of overland Flow	0.3296
Constant Channel Maintenance	0.6591
Ruggedness number	5.2282

The Union Territory of Jammu and Kashmir's demarcated part of the Indus drainage basin yielded important results about its hypsometric and morphometric properties. Plotting relative height and relative area data resulted in a hypsometric curve that showed a consistent pattern that shows the link between elevation and cumulative area. The curve first showed a slow increase, suggesting that a tiny cumulative area is influenced by a wide range of heights. The curve steepens with elevation, indicating that bigger cumulative areas are explained by higher elevations. The pattern draws attention to the region's varied topography distribution. A balanced distribution of heights within the basin is reflected by the computed hypsometric integral value of 0.48, which shows that around 48% of the total area is below the median elevation and 52% is above it. The evolution and geomorphological characteristics of the landform are better understood thanks to these insights into the hypsometric features.

The study found a hierarchical stream network with different stream orders based on morphometric analysis. First-order streams dominated the analysis, with the number of streams gradually decreasing as the order increased. Understanding the hydrological dynamics of the basin requires an understanding of the fluctuations in stream lengths and bifurcation ratios, which are indicated by this layered design. The results point to a well-organized network of streams that show how the morphological elements of the environment have changed throughout time. In general, the amalgamation of hypsometric and morphometric findings amplifies our comprehension of the geomorphological mechanisms molding the Indus drainage basin, hence aiding in efficient watershed administration and further investigations.

CONCLUSION

Important new information on the hydrological and geomorphological features of the delimited segment of the Indus Basin has been provided by morphometric analysis. The ordered growth of the drainage system of the basin is reflected in the hierarchical stream network, which is typified by a preponderance of first-order streams and gradually longer lengths with increasing stream order. The basin's diverse terrain is highlighted by key morphometric properties such as a low relief ratio, which indicates gradual slopes, and a drainage density that indicates a well-dissected basin. Moreover, a balanced height distribution is shown by the hypsometric curve analysis, which shows a varied elevation distribution with a hypsometric integral value of 0.48, indicating that about half of the region is below the median elevation. Taken together, these results improve our comprehension of the landscape dynamics of the Indus Basin and hydrological behavior, offering crucial data that is required for knowledgeable watershed management and regional environmental planning.

APPENDICES

The details for each morphometric parameter:

1. *Stream Order (U):* A hierarchical classification of streams based on their branching pattern within a watershed.
2. *Stream Length (Lu):* The total length of all stream segments within a particular stream order.
3. *Mean Stream Length (Lsm):* The average length of stream segments for a specific stream order.
4. *Stream Length Ratio (RL):* The ratio of the lengths of streams between consecutive stream orders.
5. *Bifurcation Ratio (Rb):* The ratio of the number of streams in one order to the number in the next higher order, indicating the degree of branching.

6. *Drainage Density (Dd):* The total length of streams per unit area of the drainage basin.
7. *Stream Frequency (Fs):* The number of stream segments per unit area of the drainage basin.
8. *Texture Ratio (T):* The density of first-order streams relative to the perimeter of the basin.
9. *Form Factor (Rf):* A ratio that indicates the shape of the basin, comparing area to basin length.
10. *Circulatory Ratio (Rc):* A measure of the circularity of the basin, indicating how close the basin shape is to a perfect circle.
11. *Elongation Ratio (Re):* A ratio describing the elongation of the basin relative to a circular shape.
12. *Length of Overland Flow (Lg):* The average distance water travels over land before entering a stream.
13. *Constant Channel Maintenance (C):* The required basin area to maintain a unit length of stream channel.
14. *Basin Relief (Bh):* The difference in elevation between the highest and lowest points of the basin.
15. *Relative Relief (Rr):* The ratio of basin relief to the perimeter of the drainage basin.
16. *Relief Ratio (Rh):* The ratio of the vertical relief of a basin to its horizontal distance.
17. *Ruggedness Number (Rn):* A combined measure of basin relief and drainage density, indicating the roughness of the terrain.

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