Morphometric Analysis Using Geospatial Tools In A Part of Upper Betwa River Basin of Madhya Pradesh, India

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Abstract- *The most essential characteristic of a river is the morphological analysis of its basin. This is the numerical analysis of the shape and morphology of the basin. It examines the fundamental characteristics of river basins, such as the linear, aerial, and relief features. Remote sensing provides a clear view of large areas which is useful for watershed morphology study. In the present study, the different morphometric parameters of the Betwa sub watershed have been evaluated using ASTER GDEM elevation product and ARC GIS. The Betwa sub-watershed, with a perimeter of 326.53 km, has three sub-Basins and covers an area of 4274.58 sq.km. The area s little affected by structural disturbances and subsoil materials are permeable in a low relief zone. Drainage density for the entire basin is 0.37 km per sq. km. resulting in lower basin runoff and stream frequency, therefore less flooding occurs in the present study area. The Melton Roughness Index (Mrn) of the Betwa river sub-watershed is 4.05 which indicates that there are no abnormal conditions like debris flow in the mainstream. Soil transport, rainfall water runoff, and infiltration rates are all influenced by the slope. In general, the study area shows a dendritic pattern of drainage, characterized by low regional slopes adapted to different geological structures. The results of the study will help in watershed management, and in the implementation of different practices for soil and water conservation.*

Keywords- ASTER GDEM, Betwa river, GIS, Morphometric, Watershed management

I. INTRODUCTION

Morphometric analysis of a river basin is very crucial to understand the groundwater potential and addressing the problems related to watershed management and soil erosion of the concerned area. The geomorphological features of watershed include linear undulations, hill undulations, and aerial undulations (Nag and Chakraborthy 2003). Watershed prioritization and morphological study can be carried out over vast areas using remote sensing and GIS with more accurate results. GIS-based watershed assessment using digital elevation data from the Shuttle Radar Topographic Mission (SRTM) has provided an accurate, rapid, and inexpensive method for analyzing hydrological systems (Farr and Kobrick, 2000; Grohmann et al., 2007; Panhalkar, 2014). Recently Bastawesy et al. (2013) uses remote sensing data and digital elevation models to derive watershed hydrological parameters for determining storage capacity for the Equatorial Lakes Region of Uganda. They concluded that Digital Terrain Models (DTMs) are a highly accurate tool for estimating morphological parameters and defining watersheds for watershed management.

The morphometric analysis was implemented in the Indian context in order to find solutions to problems pertaining to watershed management and analysis (Vijith and Satheesh, 2006; Thomas et al., 2010; Mishra et al., 2011; Singh, 2014; Prabu and Baskaran, 2013; Withanage et al., 2014; Prakash et al., 2016) and prioritization of micro-watersheds (Pankaj and Kumar, 2009; Vandana, 2013).

It is common practice to analyze morphological and hypsometric data to evaluate the drainage features of river basins (Rao and Babu, 1995; Pakhmode et al., 2003; Sreedevi et al., 2005; John et al., 2006; Manu and Anirudhan, 2008; Magesh et al., 2011).

To better comprehend the spatial variations in morphometric parameters and assess hydrological, geological, and topographical characteristics of the Betwa River basin in Central India, a morphometric characterization was conducted by analyzing SRTM DEM and topographical maps with a geographic information system (Madavi Venkatesh and Anshumali, 2018).

The present study utilizes the remote sensing data product that is ASTER digital elevation model has been used in the GIS platform to study a watershed in a dry sub-humid region located in the Bhopal, Raisen, Vidisha, and Sehore districts of Madhya Pradesh, India.

II. STUDY AREA

The Betwa river starts its journey from 475 MSL. and flows through Dehgaon Bamori Forest Range in the Raisen District forest range which is ecologically fragile. The sub-watershed of the upper Betwa river of Madhya Pradesh which comprises three watersheds having WRIS codes C2AYAL01, C2AYAL02, and C2AYAL03 were considered for the present morphometric analysis. The basin area is 4280.91 sq. km. and falls between latitudes ranging from 22°51'46.64" N to 23°37'56.12 N, and longitudes ranging from 77°7'36.69" E to 77°54'8.56 E. The larger portion of the watershed area falls in the Raisen district (49.02 %), Bhopal district (36.37%) and the rest of the area i.e 14.6 % covers the Sehore and Vidisha districts of Madhya Pradesh (Figure 1).

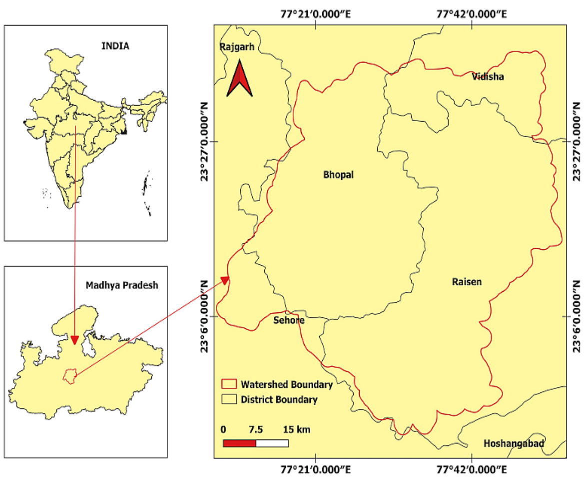

Figure 1: Location of Study Area.

Year-round heat and clear skies characterize the study area's climate, even during the rainy season. The temperature varies from 12 to 40 degrees Celsius throughout the year and it is extremely rare that the temperature goes down below 8 degrees Celsius or above 43 degrees Celsius shown in figure 2. At least 13 millimeters of rainfall falls on a 31-day moving average during the rainy season are observed from May to November for the last ten years. The wettest month is July, which receives an average of 346 millimeters of rain. A total of 6.1 months of the year are completely dry.

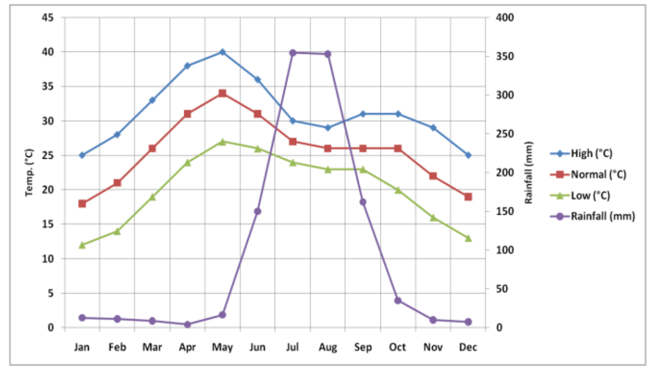

Figure 2: Average monthly precipitation and temperatures totals in the study area.

III. MATERIALS AND METHODOLOGY

Extracting the drainage network and assigning the order number to the streams from a published topographic map is a long and tedious task. Automated delineation of drainage networks and stream order numbers from an ASTER DEM in a GIS environment is more convenient, faster, and more accurate than the manual delineation of drainage networks. Table 1 shows the formula adopted for the calculation of various morphometric parameters.

Table 1: Morphometric Parameters derivation for the Betwa river sub-watershed.

S.No.	Parameters	Formula	References
Linear Morphometric Parameters			
1.	Number of Stream Order (Nu)	Nu=N1+N2+...+ Nn	Horton (1945)
2.	Length of stream orders (Lu)	Lu=L1+L2+…+ Ln	Horton (1945); Strahler (1964)
3.	Bifurcation Ratio (Rb)	Rb=Nu/Nu+1	Schumm (1956); Strahler (1964)
4.	Mean bifurcation ratio (Rbm)	All-order average bifurcation ratio	Strahler AN and Chow VT (1964)
Geometric Areal Parameters			
5.	Basin Length (Lb)	The distance from the basin's outlet to the basin's farthest point.	Schumm (1956)
6.	Total Basin	Length of outer	Schumm

	perimeter (P)	boundary of drainage basin	(1956)
7.	Total Basin Area (A)	Area enclosed by basin boundary	Schumm (1956)
8.	Form factor (Ff)	$Ff = A/Lb^2$	Horton (1932)
9.	Drainage Texture (Dt)	$Dt = Nu/P$	Horton (1945)
10.	Elongation ratio (Re)	$Re = 1.129 \times \sqrt{A/Lb}$	Schumm (1956); Seyhan (1977)
11.	Circularity Ratio (Rc)	$Rc = 4\pi A/P^2$	Miller (1953)
Analysis of the Drainage's Texture			
12.	Drainage density (Dd)	$Dd = Lu/A$	Strahler (1964)
13.	Stream frequency (F)	$F = Nu/A$	Horton (1932)
14.	Infiltration Number (Ifn)	$Ifn = F \times Dd$	Faniran (1968); Pareta and Pareta (2011)
15.	Average Length of Overland Flow (Lg)	$Lg = 1/2 \times Dd$	Horton (1945)
Relief Parameters of Basin			
16.	Total Basin Relief (H)	$H = Z - z$ Where, Z = Maximum elevation of the basin (m) and z = Minimum elevation of the basin (m)	Strahler (1952)
17.	Relief Ratio (Rr)	$Rr = H / Lb$	Schumn SA (1956)
18.	Gradient Ratio (Rg)	$Rg = (Z-z) / Lb$	Sreedevi, Subrahmanyam and Ahmed (2005); Pareta and Pareta (2011)
19.	Melton Ruggedness Number (MRn)	$MRn = H/A\ 0.5$	Melton (1956)

First, extract the river basin was first extracted followed by the extraction of the drainage networks. To begin, satellite data from the ASTER DEM were downloaded from the Earth Explorer website (http://earthexplorer.usgs.gov). The DEM data products from an ASTER were successfully mosaiced. The mosaiced image was used in Arc GIS's Arc Hydro tool to extract watershed boundaries. UTM zone 43N projection was used to project the extracted basin and stream networks.

The systematic depiction of the process through which the watershed basin and drainage networks were extracted is illustrated in Figure 3.

A slope map, drainage network, and density map were generated by using the Spatial Analyst tool of Arc GIS for the Betwa River sub-watershed. Morphometric parameters, such as the number of stream orders, the length of stream orders, bifurcation ratios, mean bifurcation ratios, the length of overflow land, the basin area and perimeter, Melton ruggedness number based on linear morphometric, geometric areal, drainage texture as well as relief parameters were assessed using equations as shown in table 1.

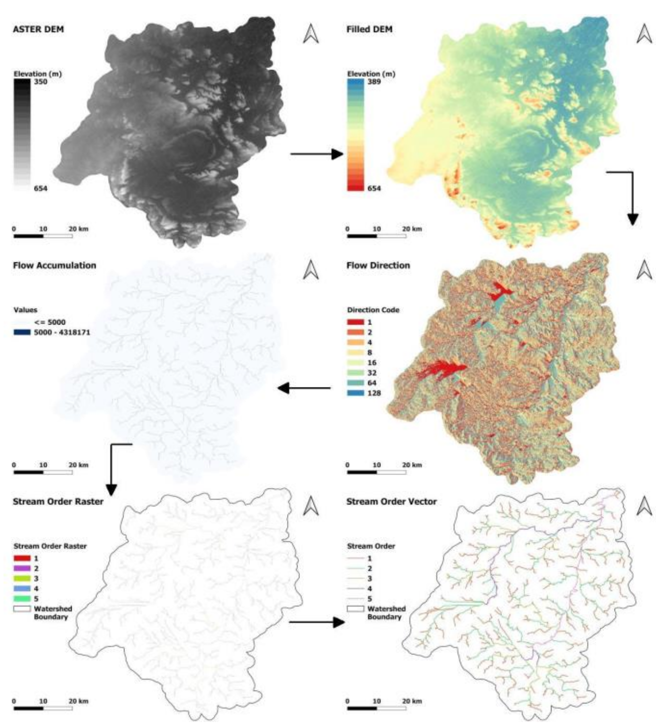

Figure 3: Process Illustration for Extraction of Stream Network and Watershed Boundary from ASTER DEM.

IV. RESULTS AND DISCUSSION

Linear Morphometric Parameters

Number of Stream Order (Nu)

It depends on the streams' position within the hydrological system to determine the order in which the streams flow. The most important stream is the higher order stream segment in the river. In this Betwa sub-watershed, the fifth-order stream segment is identified (Table 2). The spatial distribution of stream order in the hydrological system is shown in Figure 4.

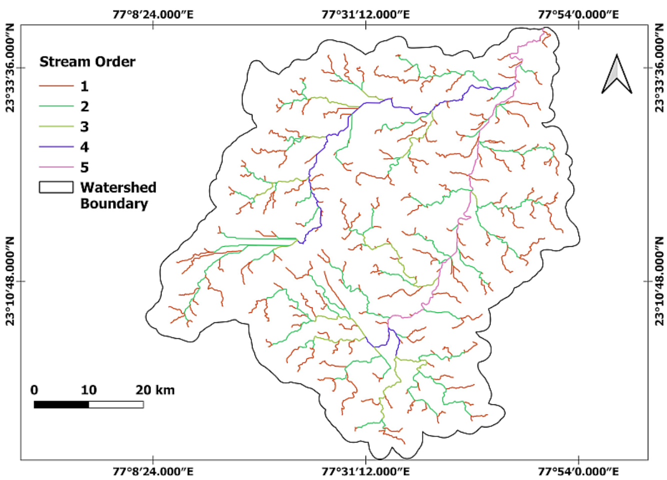

Figure 4: The stream orders in the Betwa river sub-watershed.

Table 2: The streams and lengths of Betwa sub-watershed

S.No.	Stream Order	Stream Number	Stream Order Length (km)
1.	Stream Order 1	N1 = 263	L1 = 769.28
2.	Stream Order 2	N2 = 62	L2 = 475.1
3.	Stream Order 3	N3 = 16	L3 = 142.07
4.	Stream Order 4	N4 = 3	L4 = 911.01
5.	Stream Order 5	N5 = 1	L5 = 889.78
Total		**Nu** = 345	**Lu** = 1566.51

Length of Stream Order (Lu)

To get a sense of how much area a stream contributes to a given basin. The span of the stream segment is relatively long for first-order streams, but this length gets shorter as the stream order gets higher. (Table 2).

Bifurcation Ratio (Rb)

The typical range of bifurcation ratio for a drainage basin without geological structures affecting the drainage pattern range between 3.0 and 5.0 Strahler (1964). The lithology and development of the basin are primarily responsible for the variations in the bifurcation ratio. The influence of the geological structures is negligible when the bifurcation ratio is in the range of 3.0 to 5.0. Betwa river sub-watersheds mean bifurcation ratio is 4.11.

Table 3: Bifurcation Ratios of Betwa river sub-watershed.

S.No.	Bifurcation Ratio (Rb)	Value
1.	Rb for 1:2	4.24
2.	Rb for 2:3	3.88
3.	Rb for 3:4	5.33
4.	Rb for 4:5	3.0
Mean Bifurcation Ratio (Rbm)		4.11

Geometric Areal Parameters

Basin Length (Lb)

The longest measure of the basin that is parallel to a principle drainage line is what's meant to be considered as the basin length. The sub-watershed's length has been calculated to be 90.2 km. for this study area.

Total Basin perimeter (P)

The perimeter of the basin or sub-watershed is the length of the outer border of the watershed that surrounds its area. The Betwa sub-basin, has a perimeter of 326.53 km (Table 4).

Total Basin Area (A)

It represents the combined area of all streams, rivers, and lakes in a watershed that make up the total basin area. This helps to determine the total volume of water flowing across a watershed. The result shows that the Betwa river sub-watershed has a basin area of 4274.58 sq. km.

Form Factor (Ff)

The ratio of the basin's surface area to its length squared is known as the form factor. The basin becomes longer as the form factor value decreases. Narrow and deep channels have a low form factor; shallow and broad channels don't. The study area has a form factor of 0.53 (Table 4).

Drainage Texture (Dt)

The relative spacing of the streams within a unit area across a linear direction is what is meant by the term "drainage texture" when referring to a basin. It is dependent on various factors such as the weather, rainfall, vegetation, infiltration rate, relief, and developmental stages of the basin. Drainage texture was defined by Horton (1945) as a sum of all its stream segments divided by the basin's perimeter, no matter what order they occur. As a fundamental principle of geomorphology, the infiltration capacity, soil characteristics, and relief of the terrain all influence how far drainage channels are spaced. There are five levels of coarseness for drainage textures, according to Smith (1950), ranging from extremely coarse (< two) through coarse (2 to 4), moderate (4 to 6) fine (6 to 8), and very fine (> eight). The value of 1.06 that was obtained for this sub-watershed reveals that its texture is extremely coarse, indicating that it has several rock formations.

Elongation Ratio (Re)

The elongation ratio (Re) is the circle's diameter to the basin's maximum length. Possible values of Re range anywhere between 0 and 1.0. For extremely long-shaped Re value is zero and one for a circular shaped basin. Areas with low relief tend to have values around 1.0, while areas with the values around 0.6 and 0.8 are typically reported to have the greatest relief and the steepest surface slope. The Betwa river sub-watershed was found to have a value of 0.82, which suggests that the basin has a relatively low relief terrain and that it is nearly circular in shape.

Circularity Ratio (Rc)

It is a measure of how close a shape is to a perfect circle. When the value is 0, the shape would be a straight line, and when value is 1, the shape would be a perfect circle. Values that are closer to one indicate a form that is more circular, whereas values that are closer to zero indicate a shape that is more elongated. Over time, the shape of every basin has a natural instinct to become progressively elongated. In this case, the value obtained is 0.5, which means the shape is closer to being elongated than it is to be a perfect circle.

Table 4: Geometric morphometric parameters of Betwa river sub-watershed.

S.No.	Geometric Areal Parameters	Value
1.	Basin Length (Lb) in km.	90.20
2.	Total Basin perimeter (P) in km.	326.53
3.	Total Basin Area (A) in s q.km.	4274.58
4.	Form Factor (Ff)	0.53
5.	Drainage Texture (Dt)	1.06
6.	Elongation Ratio (Re)	0.82
7.	Circularity Ratio (Rc)	0.5

Drainage Texture Parameters

Drainage Density (Dd)

An area's drainage density is calculated by dividing the combined length of all stream orders by the drainage area (Table 1). There are several factors that influence drainage density, including the annual rainfall, rock surface roughness and runoff contribution, infiltration ability and vegetation cover. In areas with low relief and subsoils that are resistant but permeable, drainage density is lower. Conversely, areas with impermeable rock formations and high relief support high drainage densities (Strahler 1964). Table 5 shows that the Betwa river sub-watershed has a drainage density of 0.37 km per sq. km. indicating that the underlying soil materials are impervious in lower relief zones. Figure 5 depicts the study area's drainage density map.

Stream Frequency (F)

It is the cumulative number of flow sections in the basin (Horton 1932). Within the scope of this investigation, the average stream density is approximately 0.08 sq km. across the basin (Table 5), which indicates low slopes, permeable underground material, and flat terrain. It mainly reveals the bedrock and the runoff of the basin. The lower the basin runoff density and the stream frequency, the slower the runoff and therefore less flooding.

***Infiltration* Number (Ifn)**

Infiltration number is the product of the density of water flow and the frequency of appearance of streams and is an index showing the infiltration characteristics of hydrological areas of the basin (Table 1). Betwa's sub-watershed inflow index is very low (0.03) (Table 5), indicating a low amount of runoff and a high amount of infiltration.

Average Length of Overland Flow (Lg)

The average length of overland flow is the distance that rainwater flows over the ground, and indicates the length until it fits in an infinite small-diameter river. It is one of the most independent variables that have a significant impact on the hydrological and geographic development of the basin. (Schumm 1956). Horton considered overland flow to be half the reciprocal of the density of the basin. (Table 1). Here, Lg in the basin of the study area i.e. 1.36 km (Table 5) indicates that the outflow of the area is small.

Table 5: Drainage texture analysis parameters of Betwa river sub-watershed.

S.No.	Drainage Texture Parameters	Value
1.	Drainage density (Dd) in km per sq km.	0.37
2.	Stream frequency (F) in number of stream per sq.km.	0.08
3.	Infiltration Number (Ifn)	0.03
4.	Average Length of Overland Flow (Lg) in km.	1.36

Relief Parameters

Total Basin Relief (H)

When it relates to hydrology, Schumm (1956) defined a river basin's total relief as the difference between its highest point and its lowest point, as per the equation shown in Table 1. While trying to understand hydrological processes and topographical features, basin relief is an essential component to consider. The overall basin slope of the Betwa River sub-water source is 265 m. (Table 6). It has been observed that the correlation between relief, drainage frequency, and river slope is high.

Relief Ratio (Rr)

Basin relief ratio (Rr) is an effective metric of watershed alignment based on the dimensionless ratio of basin relief to basin length (Schumm 1956; Vitala et al., 2004). This ratio is a measurement of the total slope of the drainage basin and indicates the intensity of the erosion that is taking place on the slope of the basin. (Magesh, et al., 2012). The Rr value for the study area was 0.00294, as shown in Table 6. This value indicates the presence of gentle slopes and subdued terrain that is underlain by rock formations.

Gradient Ratio (Rg)

This ratio is helpful for determining the amount of runoff since it reveals the extent of the channel undulation (Sreedevi et al. 2004; Thomas et al. 2010; Prakash et al. 2016). The Betwa sub-watershed has Rg values of 0.00293, which suggest minimal surface runoff and a higher opportunity for rainwater penetration into groundwater. Significant Rg values imply steep terrain and high runoff.

Melton Ruggedness Number (MRn)

The Melton Roughness Index (Mrn) of the Betwa river sub-watershed is calculated from the ratio of combined basin relief to the basin area (Melton 1965). Mrn is an index that expresses the roughness of the ground slope of the entire basin. The Melton roughness index of the area is 4.05 (Table 6). This is a low value indicating that there are no abnormal conditions like debris flow in the mainstream.

Table 6: Relief parameters of Betwa river sub-watershed.

S.No.	Relief Parameters	Value
1.	Total Basin Relief (H) in meters	265.0
2.	Relief Ratio (Rr)	0.00294
3.	Gradient Ratio (Rg)	0.00293
4.	Melton Ruggedness Number (MRn)	4.05

Slope

Slopes have an influence on the distribution and transport of rainwater, as well as the land use including hydrological behaviour. The slope is an important factor to consider, with respect to runoff as well as infiltration and the rate of soil movement. The inclination of the land determines both the rate at which the outflow occurs and its overall scope. The higher the slope, the greater the rate at which the water is moving. The spatial distribution of the slope map of the Betwa river sub-watershed has showing slope in degree (Figure 6).

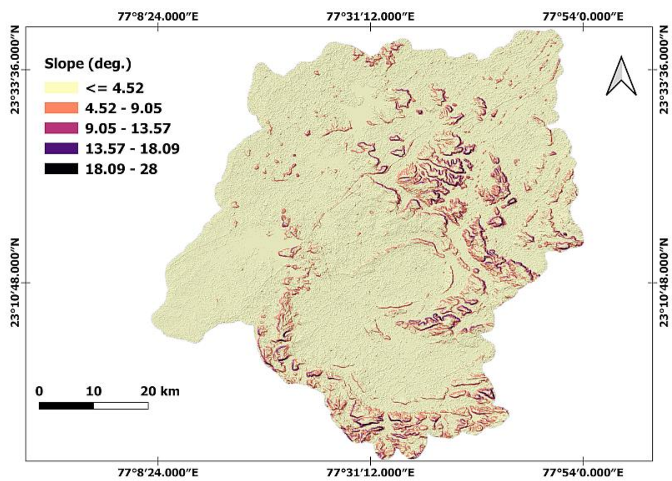

Figure 7: Slope map of Betwa river sub-watershed.

Hypsometric curve

Correlations between drainage basin area and elongation were calculated using a hypsometric curve. The hypsometric integral was calculated by using values of relative height and relative area. Relative area value (a / A) continuously fluctuates from 0 (h / H) to 1.0 (h / H) representing highest and lowest point respectively. According to Strahler (1952, 1964), the hypsometric curve can be used to identify three types of terrain i.e. youth, maturity, and old age.

In this study area, the hypsometric curve indicates old-growth terrain, which also reveals that the majority of the hills are located at relatively low elevations (Figure 8). The hypsometric integral data has been given in Table 8.

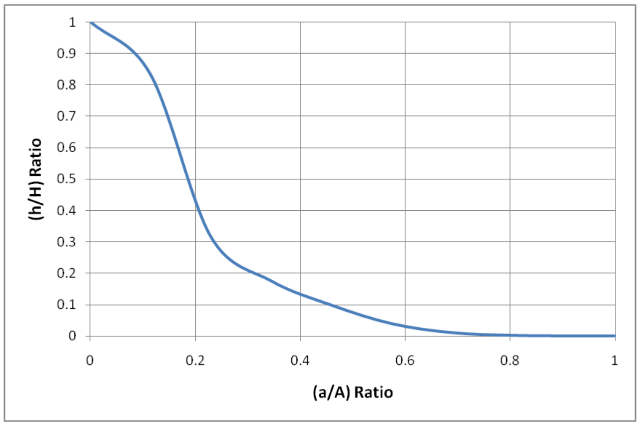

Figure 8: Hypsometric curve for Betwa river sub-watershed.

Table 7: Hypsometric integral data.

S.No.	Hypsometric Integral Data	Value
1.	Minimum Height in m	389.0
2.	Maximum Height in m	650.0
3.	Elevation increments interval in m	30.0
4.	Total Basin Height (H) in m	261.0
5.	Height Area Ratios	21.65
6.	Total Basin area (sq.km.)	1173.46

V. CONCLUSION

Studies have demonstrated that remote sensing data and GIS techniques are excellent tools for assessing drainage characteristics in the sub-watershed of the Betwa river basin. The findings of this study, which were obtained from ASTER-DEM, contained morphometric parameters that indicate how many streams there are, their topology, and the dissection of topography. The morphometric analysis of various linear, areal, and relief parameters was calculated for further studies on river development and in the consent of hydrological processes. The spatial variation of the morphometric indicators evaluated in this study is very significant. Some examples of these factors include the capacity for infiltration and surface flow, as well as the extent to which the river basin has been developed. In general, the study area exhibits a dendritic pattern of drainage, characterized by low regional slopes that are adapted to different geological structures. However, the dendritic pattern in the study area has horizontal uniform bedrock and varies slowly tilted bedrock. Numerous streams in the first and second orders show structural deformation mainly due to faults, linear objects, and folded rock strata. The values of the bifurcation ratio of this basin indicate high drainage integration in the basin and the nature of the carved mountainous area characterized by matured terrain. The high drainage density of the Betwa river sub-watershed is supposed to be due to the impermeable bedrock present in the area. It is concluded that the morphometric analysis of river basins provides a better understanding of river management and the development of groundwater potential in water scarcity areas.

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