



"Morphometric Analysis Of The Birma River Basin Using Advanced Geospatial Technologies: Implications For Watershed Management And Hydrological Modelling"

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Abstract

The study area, located in the Hamirpur District of Uttar Pradesh, India, forms part of the Yamuna River Basin and covers an area of 859.185 km². The drainage pattern of the watershed was delineated using Geo-coded FCC bands 8, 4, and 3 of Sentinel-2A (dated 02 February 2025) on a 1:50,000 scale, with Survey of India toposheets serving as reference. Morphometric parameters were computed using ArcGIS 10.8 software. The drainage pattern of the study area is predominantly dendritic, with some regions exhibiting a trellis pattern, and stream orders ranging from I to V. The drainage density of 2.87326 km/km² suggests moderate density and coarse to moderate drainage texture. Variations in stream length ratio values indicate a late youth stage of geomorphic development. Bifurcation ratio values ranging from 1.181 to 2.192 classify the Birma watershed as a normal basin. Additionally, form factor and circulatory ratio values suggest an elongated shape for the watershed. The study concludes that remote sensing and GIS are highly effective tools for drainage delineation and updating. These updated drainage networks were utilized for morphometric analysis, demonstrating the utility of geospatial technologies in watershed characterization and management.

Introduction

Water, one of the most vital natural resources for agriculture, is increasingly becoming scarce due to over-exploitation, poor groundwater recharge, and excessive usage. This scarcity underscores the importance of studying morphometric characteristics, particularly in regions like Central India, where the development of surface and groundwater resources is critical for sustainable water management (Sahu et al., 2017). The development of a drainage system and its spatial and temporal flow patterns are influenced by a variety of factors, including geological, climatic, and topographic conditions (Horton, 1945; Leopold and Maddock, 1953; Abrahams, 1984).

Morphometry, defined as the measurement and mathematical analysis of the Earth's surface configuration, including the shape and dimensions of its landforms (Agarwal, 1998; Obi Reddy et al., 2002), plays a crucial role in understanding drainage systems. Morphometric analysis involves the measurement of linear, aerial, and relief aspects, as well as the gradient of the channel network

and the contributing ground slope of the basin (Nautiyal, 1994; Nag and Chakraborty, 2003; Magesh et al., 2012).

A fundamental principle of morphometry is that the morphology of a drainage basin reflects the geological and geomorphological processes that have shaped it over time. This principle has been supported by numerous studies (Horton, 1945; Strahler, 1952, 1964; Muller, 1968; Shreve, 1969; Evans, 1972, 1984; Ohmori, 1993; Cox, 1994; Oguchi, 1997; Hurtrez et al., 1999). The morphometric characteristics of a drainage basin are essential for understanding landform processes, soil properties, and erosional features, which are critical for hydrological investigations, groundwater potential assessment, watershed management, and environmental evaluation (Tiwari and Tripathi, 2018).

Drainage patterns provide insights into the initial gradient, variations in rock resistance, structural controls, and the geological and geomorphological history of a basin or watershed. The evaluation of morphometric parameters involves analyzing various drainage characteristics, such as stream ordering, basin area and perimeter, channel lengths, drainage density (Dd), bifurcation ratio (Rb), stream length ratio (RL), and relief ratio (Rh) (Rai et al., 2017).

Given the significance of these parameters, the present study focuses on the morphometric analysis of a watershed using Remote Sensing (RS) and Geographic Information Systems (GIS). These technologies have proven to be powerful tools for delineating drainage patterns, updating drainage networks, and conducting detailed morphometric analyses. By leveraging RS and GIS, this study aims to contribute to a better understanding of the geomorphic and hydrological characteristics of the study area, ultimately aiding in sustainable water resource management and watershed development.

Remote Sensing (RS) and Geographic Information Systems (GIS) have emerged as indispensable tools for morphometric analysis in regions like Hamirpur. These technologies enable the accurate delineation of drainage networks, computation of morphometric parameters, and visualization of spatial patterns, even in areas with limited ground data. By leveraging RS and GIS, this study aims to provide a comprehensive understanding of the morphometric characteristics of the Birma River Basin in Hamirpur, contributing to informed decision-making for watershed management, groundwater recharge, and sustainable agricultural practices in this water-stressed region.

The findings of this study are expected to aid policymakers, hydrologists, and environmental planners in developing strategies to mitigate water scarcity, reduce soil erosion, and enhance the resilience of the region's ecosystems and communities.

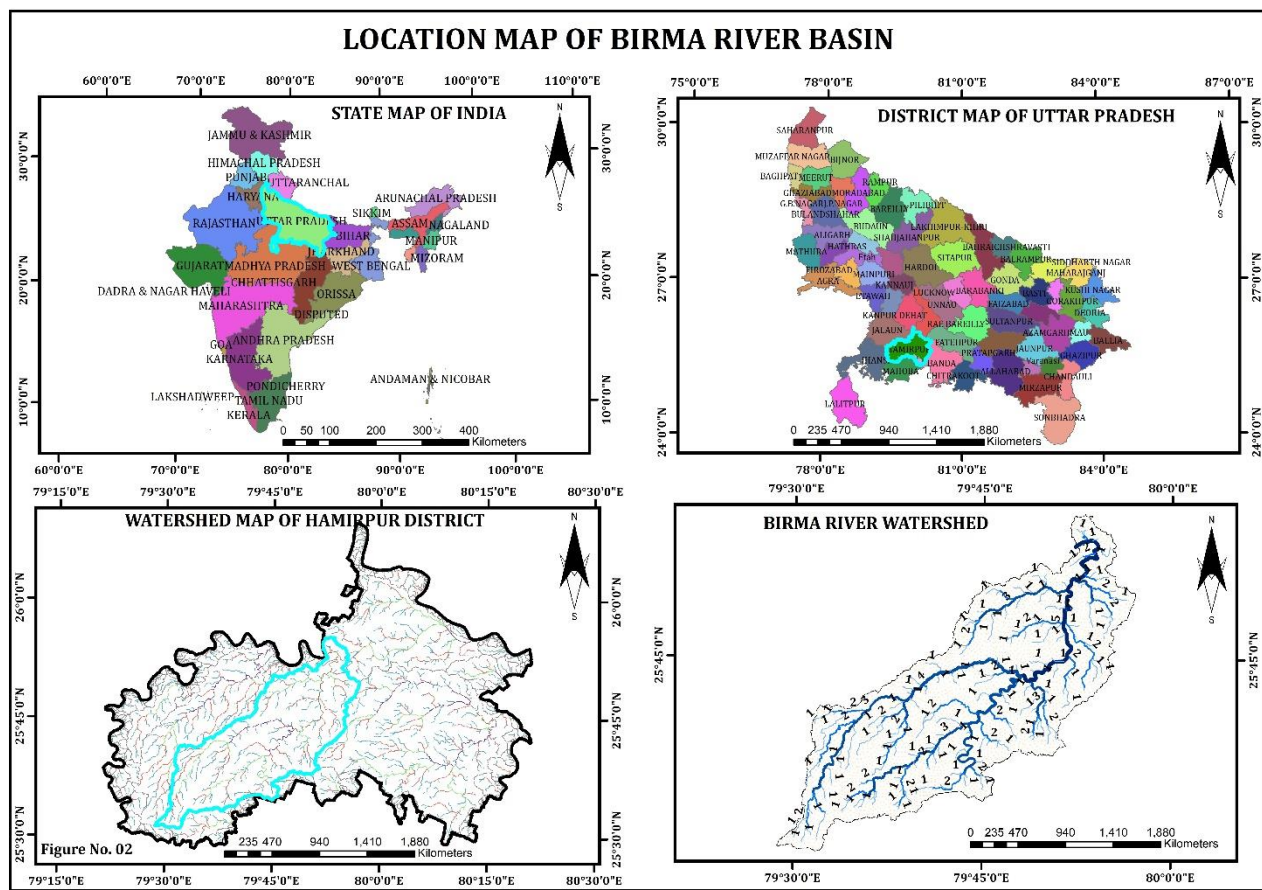
Study Area

Hamirpur district, located in the Bundelkhand region of Uttar Pradesh, India, is characterized by its semi-arid climate, undulating terrain, and limited water resources. The region faces significant challenges related to water scarcity, soil erosion, and erratic rainfall patterns, making it highly susceptible to droughts and land degradation. These factors underscore the importance of understanding the geomorphic and hydrological characteristics of the area for effective watershed management and sustainable resource utilization.

Morphometric analysis, which involves the quantitative evaluation of the Earth's surface features, is particularly relevant in Hamirpur due to its complex drainage patterns and varied topography. The district lies within the Yamuna River Basin, which plays a crucial role in the region's hydrology. The study of morphometric parameters such as drainage density, stream order, bifurcation ratio, and relief ratio provides valuable insights into the basin's geomorphic evolution, hydrological behaviour, and susceptibility to erosion.

The dendritic and trellis drainage patterns observed in parts of Hamirpur reflect the underlying geological structures and lithological variations. These patterns, combined with the region's

moderate drainage density and elongated basin shape, indicate a landscape in the late youth stage of geomorphic development. Such characteristics have direct implications for groundwater recharge, surface runoff, and soil conservation efforts.



Methods of Investigation

The morphometric analysis of the Birma watershed, a part of the Yamuna River Basin, was conducted using a combination of remote sensing data, topographic maps, and Geographic Information Systems (GIS) tools. The following steps outline the methodology employed in this study:

1. Preparation of Base Map and Data Collection

- The base map of the Birma watershed was prepared using **Survey of India (SOI) Topographic Maps** on a **1:50,000** scale.
- **Sentinel-2A** satellite imagery (dated 02 February 2025) and **Shuttle Radar Topographic Mission (SRTM)** data from the United States Geological Survey (USGS) were used to supplement the topographic maps.
- **Global Mapper 15** software was utilized to delineate the study area and export the data into Digital Elevation Model (DEM) format.

2. Digital Elevation Model (DEM) Processing

- The SRTM DEM data was imported into **ArcGIS 10.8** for further analysis.
- Using the DEM, **slope**, **aspect**, and **contour** maps of the watershed were generated to understand the topographic characteristics of the study area.

3. Drainage Network Delineation

- The drainage network of the watershed was extracted from the **Survey of India toposheets** using **ArcGIS 10.8**.
- The streams were classified according to their **drainage order** following the **Strahler (1964)** method, which categorizes streams from **Order I** (smallest) to **Order V** (largest) based on their hierarchy.

4. Calculation of Morphometric Parameters

- Key watershed parameters, such as **area, perimeter, stream length, and stream order**, were calculated using GIS tools.
- These parameters were further used to compute additional morphometric indices, including:
 - Bifurcation Ratio (Rb), Stream Length Ratio (RL), Stream Frequency (Fs), Drainage Density (Dd), Elongation Ratio (Re), Circulatory Ratio (Rc), Form Factor (Rf)

5. Data Analysis and Interpretation

- The calculated morphometric parameters were analysed to understand the geomorphic and hydrological characteristics of the Birma watershed.
- The results were interpreted in the context of the watershed's geological structure, drainage patterns, and potential for water resource management.

6. Documentation and Visualization

- All morphometric parameters and their calculations were documented in **Table 1**, which includes the formulae used for each parameter.
- Maps and diagrams were generated to visualize the drainage network, slope, aspect, and other topographic features of the watershed.

This systematic approach, combining remote sensing, GIS, and morphometric analysis, provides a comprehensive understanding of the Birma watershed's characteristics, aiding in effective watershed management and sustainable resource planning.

Table No. 1 Formulae adopted for Computation of Morphometric Parameters

S.N.	Morphometric Parameters	Formula	Reference
1	Stream order	Hierarchical rank	Strahler (1964)
2	Stream length (Lu)	Length of the stream	Horton (1945)
3	Mean stream length (Lsm)	$Lsm = \frac{Lu}{Nu}$ Where, Lsm = Mean stream length Lu = Total stream length of order 'u' Nu = Total no. of stream segments of order 'u'	Strahler (1964)
4	Stream length ratio (RL)	$RL = \frac{Lu}{Lu - 1}$ Where, RL = Stream length ratio Lu = The total stream length of the order 'u' Lu - 1 = The total stream length of its next lower order	Horton (1945)
5	Bifurcation ratio (Rb)	$Rb = \frac{Nu}{Nu + 1}$ Where, Rb = Bifurcation ratio Nu = Total no. of stream segments of order 'u' Nu + 1 = Number of segments of the next higher order	Schumn (1956)
6	Mean bifurcation ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	Strahler (1957)
7	Total Reliefs (in Meter)	Maximum Height-minimum Height	
8	Relief ratio (Rh)	$Rh = \frac{H}{Lb}$ Where, Rh = Relief ratio H = Total relief (Relative relief) of the basin (km), Lb = Basin length	Schumm (1956)
9		$Re = \frac{2}{Lb}$ Where, Re = Elongation ratio	Schumn (1956)

	Elongation ratio (Re)	Lb = Basin length	
10	Drainage density (D)	$D = Lu / A$ Where, D = Drainage density Lu = Total stream length of all orders A = Area of the basin (km ²)	Horton (1932)
11	Length of overland flow (Lg)	$Lg = 1 / D * 2$ Where, Lg = Length of overland flow D = Drainage density	Horton (1945)
12	Stream frequency (Fs)	$Fs = Nu / A$ Where, Fs = Stream frequency Nu = Total no. of streams of all orders A = Area of the basin (km ²)	Horton (1932)
13	Texture Ratio (Rt)	$Rt = Nu / P$ Where, Rt = Drainage texture Nu = Total no. of streams of all orders P = Perimeter (km)	Horton (1945)
14	Form factor (Rf)	$Rf = A / Lb^2$ Where, Rf = Form factor A = Area of the basin (km ²) Lb ² = Square of basin length	Horton (1932)
15	Circularity ratio (Rc)	$Rc = 4 * Pi * A / P^2$ Where, Rc = Circularity ratio Pi = 'Pi' value i.e., 3.14 A = Area of the basin (km ²) P ² = Square of the perimeter (km)	Miller (1953)

Table No. 2 Stream Parameter of Birma Watershed

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Sr. No.	1	2	3	4	5
Stream Order	I	II	III	IV	V
Number of Stream (km.)	182	83	50	26	22
Length of Stream (km.)	304.917848	139.2996	84.830808	34.432561	34.23002

Table No.3 Calculation of different Morphometric Parameters of Birma Watershed

Watershed Name		Birma Watershed
Area (Sq. Km.)		859.185
Mean Stream Length in Km. (Lsm)	I	1.675
	II	1.678
	III	1.697
	IV	1.324
	V	1.556
Stream Length ratio (RL)	II/I	0.457
	III/II	0.609
	IV/III	0.406
	IV/V	0.994
Bifurcation Ratio (Rb)	I/II	2.193
	II/III	1.660
	III/IV	1.923
	VI/V	1.182
Mean Bifurcation Ratio (Rbm)		1.739
Perimeter (P) in Km.		204.800

Basin Length (Lb) (km.)	60.473
Total Reliefs (meters)	100.000
Relief Ratio (Rh)	0.002
Elongation Ratio (Re)	0.033
Drainage Density (D) (Km/Sq. Km.)	2.8732
Length of overland flow (Lg)	0.696
Stream Frequency (Fs)	0.422
Texture Ratio (Rt)	1.772
Form Factor (Rf)	0.234
Circulatory Ratio (Rc)	0.257

Morphometry

Morphometry, as defined by **Clarke (1966)**, refers to the measurement and mathematical analysis of the Earth's surface configuration, including the shape and dimensions of its landforms. Morphometric analysis involves the quantitative evaluation of a basin's **linear, areal, and relief** aspects, as well as the contribution of slope to the overall geomorphic characteristics (Nag and Chakraborty, 2003).

In this study, various morphometric parameters were calculated to understand the geomorphic and hydrological characteristics of the Birma watershed. These parameters include:

1. **Stream Order (u)**: The hierarchical ranking of streams based on the Strahler (1964) method.
2. **Stream Length (Lu)**: The total length of streams of a particular order.
3. **Mean Stream Length (Lsm)**: The average length of streams of a given order, calculated as the ratio of the total stream length to the number of streams.
4. **Stream Length Ratio (RL)**: The ratio of the mean length of streams of one order to the mean length of streams of the next lower order.
5. **Bifurcation Ratio (Rb)**: The ratio of the number of streams of one order to the number of streams of the next higher order.
6. **Mean Bifurcation Ratio (Rbm)**: The average of bifurcation ratios for all orders.
7. **Relief Ratio (Rh)**: The ratio of the total relief of the basin to its maximum length.
8. **Drainage Density (D)**: The total length of streams per unit area, indicating the efficiency of the drainage network.
9. **Stream Frequency (Fs)**: The total number of streams per unit area, reflecting the texture of the drainage network.
10. **Drainage Texture (Rt)**: The density of streams in relation to the basin's topography.
11. **Form Factor (Rf)**: The ratio of the basin area to the square of its maximum length, indicating the basin's shape.
12. **Circulatory Ratio (Rc)**: The ratio of the basin area to the area of a circle with the same perimeter, reflecting the basin's circularity.
13. **Elongation Ratio (Re)**: The ratio of the diameter of a circle with the same area as the basin to the maximum basin length, indicating the basin's elongation.
14. **Length of Overland Flow (Lg)**: The average length of flow of water over the land surface before it enters a stream.

The calculated values of these parameters are presented in **Table 3**, providing a comprehensive overview of the morphometric characteristics of the Birma watershed.

Use of Remote Sensing Data

In this study, **remote sensing data** was utilized to update the drainage network of the Birma watershed. The updated drainage maps, derived from **Sentinel-2A imagery** and **SRTM data**, were used for morphometric analysis. This approach ensures the accuracy and reliability of the drainage network, enabling a more precise evaluation of the basin's geomorphic and hydrological properties.

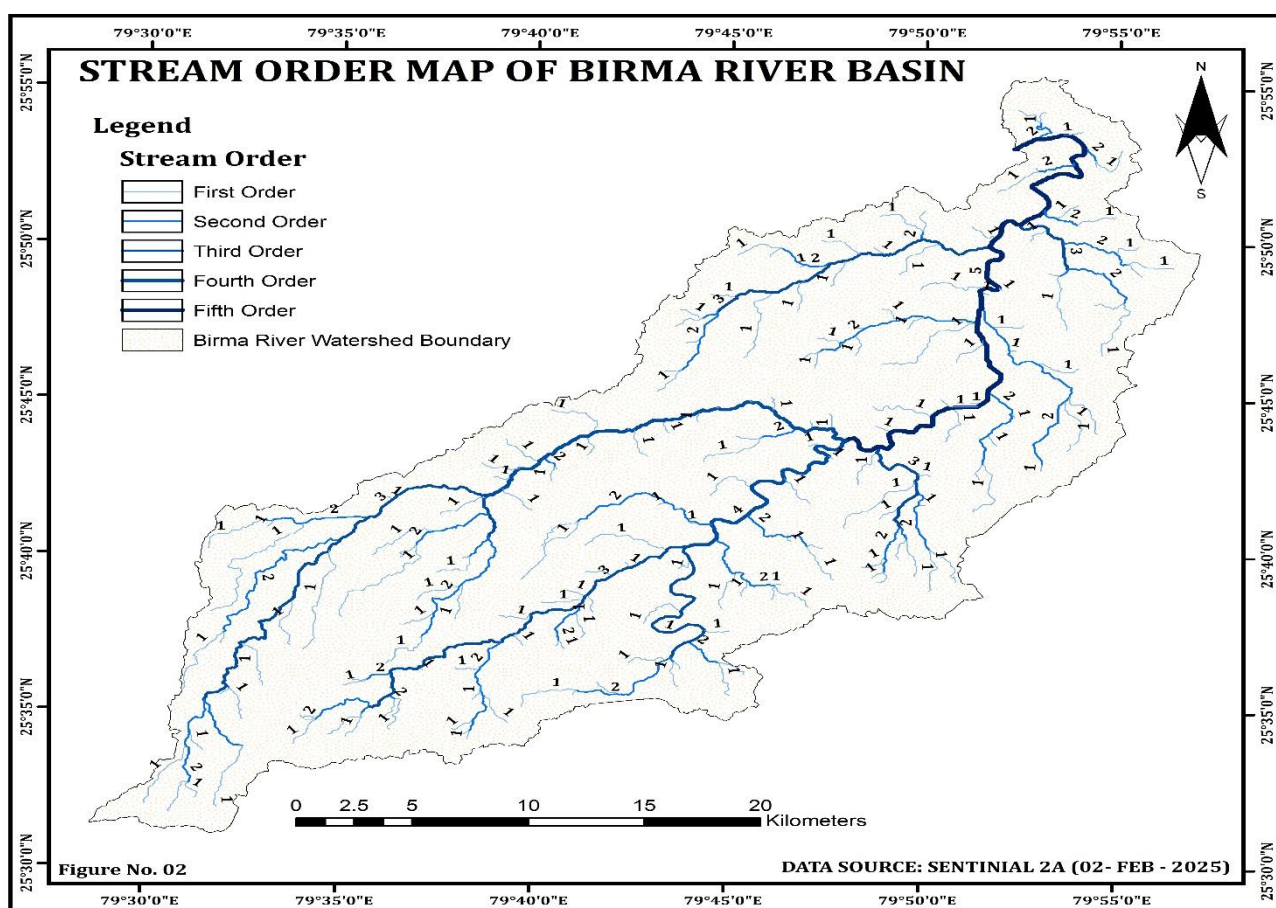
The integration of remote sensing and GIS techniques has proven to be an effective method for morphometric analysis, providing valuable insights into the basin's structure, drainage patterns, and potential for water resource management. The results of this analysis can aid in the development of sustainable watershed management strategies and the mitigation of environmental challenges in the region.

Stream Order Analysis

The designation of stream order is the first step in drainage basin analysis. In this study, the ranking of streams was carried out based on the method proposed by **Strahler (1964)**. The Birma watershed exhibits streams ranging from **Order I to Order V**. The analysis reveals that:

- The **maximum frequency** of streams is observed in **first-order streams**, which are the smallest and most numerous.
- As the stream order increases, there is a **decrease in stream frequency**, indicating a hierarchical structure typical of dendritic drainage patterns.

The order-wise stream numbers, basin area, and stream length for the Birma watershed are presented in **Table 2**. This data highlights the distribution and characteristics of streams across different orders, providing insights into the basin's drainage network and geomorphic evolution.



Stream Length

Stream length is a crucial morphometric parameter that provides insights into the hydrological and geomorphic characteristics of a drainage basin. It is measured from the **mouth of a river** to the **drainage divide** using GIS tools such as **ArcGIS 10.8**. In this study, stream length was computed based on **Horton's Law (1945)**, which states that the total length of stream segments decreases as the stream order increases.

1. Stream Order Distribution:

- The **highest number of streams** is observed in **first-order streams (182)**, which are the smallest and most numerous in the watershed.
- As the stream order increases, the **number of streams decreases**, with only **22 fifth-order streams** present in the basin.

2. Stream Length Distribution:

- The **total stream length is maximum for first-order streams (304.92 km)**, reflecting their extensive distribution across the watershed.
- The stream length decreases progressively with increasing stream order, with **fifth-order streams** having a total length of **34.23 km**.

3. Hydrological Implications:

- The dominance of **first-order streams** indicates a well-developed drainage network in the upper reaches of the watershed.
- The decrease in stream length and number with increasing order aligns with **Horton's Law (1945)**, confirming the hierarchical structure of the drainage basin.

4. Geomorphic Significance:

- The distribution of stream lengths and numbers provides insights into the **basin's geomorphic evolution and drainage efficiency**.
- The presence of **fifth-order streams** suggests a mature drainage system with a well-defined channel network.

The stream parameters presented in **Table No. 2** highlight the hierarchical organization of the Birma watershed's drainage network. The dominance of lower-order streams and the progressive decrease in stream length and number with increasing order are consistent with established geomorphic principles. These findings are essential for understanding the basin's hydrological behaviour, erosion potential, and suitability for watershed management and conservation efforts.

Mean Stream Length

Mean stream length (Lsm) is a significant morphometric parameter that provides insights into the characteristics of a drainage network and its associated basin surfaces. As defined by **Strahler (1964)**, it represents the average length of streams of a particular order and is calculated by dividing the **total stream length of a given order (u)** by the **number of stream segments** in that order.

$$\text{Mean Stream Length (Lsm)} = \frac{\text{Total Stream Length of Order (u)}}{\text{Number of Streams of Order (u)}}$$

- The **mean stream length (Lsm)** values for the Birma watershed exhibit variation, ranging from **1.324 km to 1.696 km** across different stream orders. These variations reflect the differences in the spatial distribution and hierarchical organization of the drainage network.

Stream Length Ratio (RL)

The **stream length ratio (RL)** is a critical morphometric parameter that provides insights into the hierarchical structure and geomorphic evolution of a drainage basin. It is defined as the **ratio of the mean length of streams of one order to the mean length of streams of the next lower order**. Mathematically, it is expressed as:

$$\text{Stream Length Ratio (RL)} = \frac{\text{Mean Stream Length of Order (u)}}{\text{Mean Stream Length of Order (u-1)}}$$

- The **stream length ratio (RL)** values for the Birma watershed range from **0.405 to 0.994**, as presented in **Table 3**.
- These values indicate variations in the stream length ratios between different stream orders, reflecting changes in the basin's **slope, topography, and geomorphic development**.
- The RL values close to **1.0** indicate a more uniform distribution of stream lengths across orders, suggesting a mature drainage network.
- Lower RL values (e.g., **0.405**) reflect significant differences in stream lengths between orders, highlighting the influence of local topographic and geological factors.

Bifurcation Ratio (Rb)

The **bifurcation ratio (Rb)** is a key morphometric parameter that provides insights into the structural and geological controls on a drainage basin. According to **Schumm (1956)**, the bifurcation ratio is defined as the **ratio of the number of stream segments of a given order to the number of segments of the next higher order**. Mathematically, it is expressed as:

$$\text{Bifurcation Ratio (Rb)} = \frac{\text{Number of Streams of Order (u)}}{\text{Number of Streams of Order (u+1)}}$$

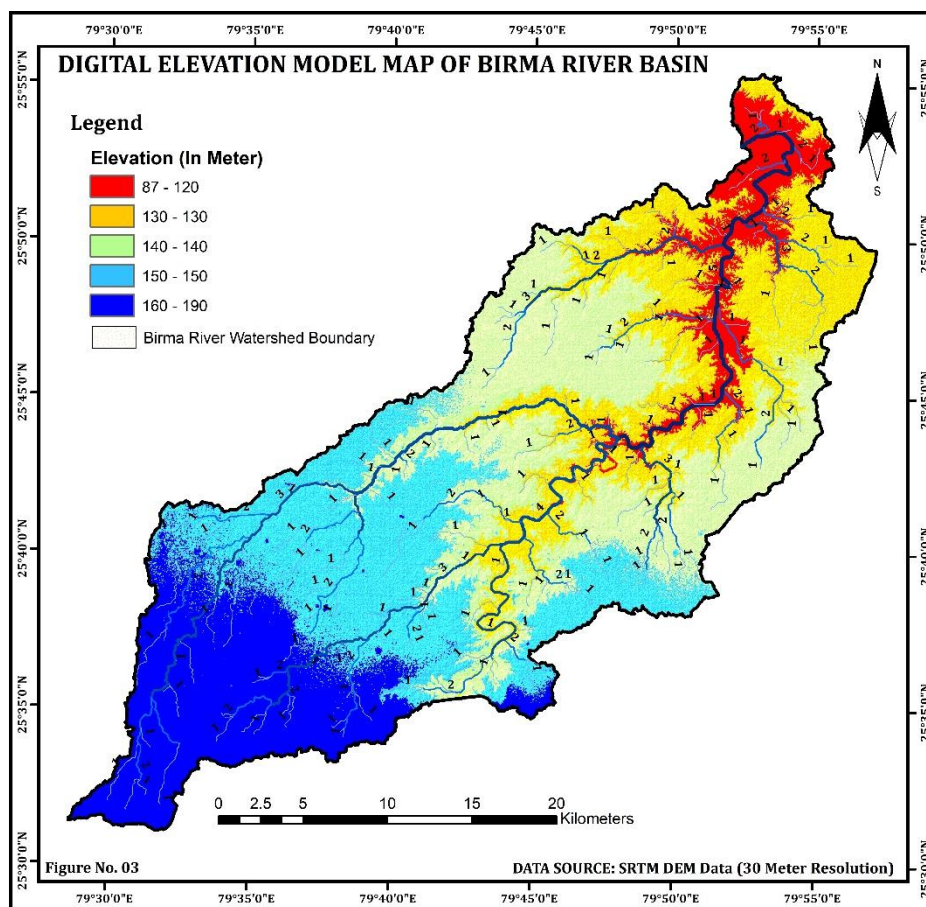
- In the Birma watershed, the **bifurcation ratio (Rb)** values range from **1.181 to 2.192**, as presented in **Table 3**.
- These values indicate that the Rb is **not constant** from one order to the next, reflecting variations in the **geological and lithological** development of the basin.
- **Higher Rb values** suggest a **strong structural control** on the drainage pattern, indicating the influence of factors such as faults, fractures, or resistant rock types.
- **Lower Rb values** indicate that the watershed is **less affected by structural disturbances**, with a more homogeneous lithology and gentle topography.
- The Rb values in the study area (ranging from **1.181 to 2.192**) classify the Birma watershed as a **normal basin** (Strahler, 1957).
- This classification implies that the basin has a balanced drainage network without extreme geological constraints.

The analysis of bifurcation ratios (Rb) in the Birma watershed reveals values ranging from **1.181 to 2.192**, classifying it as a **normal basin** with moderate structural control. The variations in Rb values reflect the influence of geological and lithological factors on the drainage network. These findings are essential for understanding the basin's hydrological behaviour, flood potential, and suitability for watershed management and conservation efforts. The results align with established geomorphic principles and provide a foundation for further studies on the basin's geomorphic evolution and environmental sustainability.

Relief Aspect

Relief aspects are critical components of morphometric analysis, providing insights into the **topographic characteristics** and **geomorphic evolution** of a drainage basin. Relief is defined as the **elevation difference** between the **highest point** (e.g., ridge or peak) and the **lowest point** (e.g., valley floor or basin outlet) within a region. Key relief measurements include **total relief**, **relief ratio**, and **basin length**, which are essential for understanding the basin's hydrological behaviour, erosion potential, and overall geomorphic development.

- **High relief ratios** indicate steep gradients, leading to **rapid runoff** and **higher erosion rates**.
- **Low relief ratios** suggest gentler slopes, which promote **gradual runoff** and **reduced erosion**.
- Relief aspects help in assessing the **stage of geomorphic development** of the basin.
- For example, high relief and steep gradients are typical of **youthful landscapes**, while low relief and gentle slopes characterize **mature landscapes**.



Relief Ratio (Rh)

The **relief ratio (Rh)** is a significant morphometric parameter that quantifies the relationship between the **vertical relief** and the **horizontal extent** of a drainage basin. According to **Schumm (1956)**, the relief ratio is defined as the ratio of the **maximum relief** (elevation difference between the highest and lowest points) to the **horizontal distance along the longest dimension of the basin**, measured parallel to the principal drainage line. Mathematically, it is expressed as:

$$\text{Relief Ratio (Rh)} = \frac{\text{Total Relief}}{\text{Maximum Basin Length}}$$

- In the Birma watershed, the **relief ratio (Rh)** is calculated to be **0.001653**.
- This value indicates a **low to moderate gradient**, suggesting that the basin has a relatively gentle slope with less pronounced topographic relief.
- The relief ratio has a **direct relationship** with the **channel gradient**. Higher Rh values indicate steeper slopes, while lower values suggest gentler gradients.
- In the study area, the low Rh value (**0.001653**) reflects a **mild channel gradient**, which influences the basin's **hydrological response** and **sediment transport capacity**.
- As proposed by **Gottaschalk (1964)**, the relief ratio **increases with decreasing drainage area** and **size of the watershed**.
- This trend is observed in the Birma watershed, where the Rh value aligns with the expected behaviour for a basin of its size and drainage characteristics.
- The relief ratio of **0.001653** indicates that the Birma watershed has a **low energy landscape** with minimal topographic variation.
- This finding is consistent with the basin's **elongated shape** and **moderate drainage density**, as discussed in previous sections.

The analysis of the relief ratio (Rh) in the Birma watershed provides valuable insights into the basin's **topographic characteristics** and **geomorphic evolution**. The calculated Rh value of **0.001653** reflects a **gentle gradient** and **mature landscape**, which influence the basin's hydrological behaviour and erosion potential.

Aerial Aspects of Morphometric Analysis

Aerial aspects are a critical component of morphometric analysis, focusing on the **spatial characteristics** and **drainage patterns** of a watershed. These parameters provide insights into the basin's **shape, size, drainage efficiency**, and **hydrological behaviour**. The key aerial morphometric parameters include:

1. Drainage Density (Dd)
2. Texture Ratio (Rt)
3. Stream Frequency (Fs)
4. Form Factor (Rf)
5. Circulatory Ratio (Rc)
6. Elongation Ratio (Re)
7. Length of Overland Flow (Lg)

The values of these aerial morphometric parameters for the Birma watershed are presented in **Table 3**. These parameters have been calculated and analysed to understand the basin's **drainage characteristics, shape, and hydrological behaviour**.

1. **Drainage Density (Dd):**
 - A moderate drainage density suggests a **balanced drainage network** with **efficient runoff** and **moderate permeability**.
2. **Texture Ratio (Rt):**
 - The texture ratio indicates the **coarseness or fineness** of the drainage network, influenced by the basin's **lithology** and **slope**.

3. Stream Frequency (Fs):

- A higher stream frequency reflects a **well-developed drainage network** and a **higher susceptibility to erosion**.

4. Form Factor (Rf):

- A low form factor suggests an **elongated basin shape**, which influences the **runoff concentration time** and **flood potential**.

5. Circulatory Ratio (Rc):

- A lower circulatory ratio indicates a **less circular basin shape**, consistent with the elongated nature of the Birma watershed.

6. Elongation Ratio (Re):

- A low elongation ratio confirms the **elongated shape** of the basin, which affects its **hydrological response** and **erosion patterns**.

7. Length of Overland Flow (Lg):

- The length of overland flow influences the **runoff generation** and **soil erosion** processes in the basin.

Elongation Ratio (Re)

The **elongation ratio (Re)** is a key morphometric parameter that provides insights into the **shape** and **geomorphic characteristics** of a drainage basin. It is defined as the ratio of the **diameter of a circle with the same area as the basin** to the **maximum length of the basin**. Mathematically, it is expressed as:

$$\text{Elongation Ratio (Re)} = \frac{\text{Diameter of a Circle with Same Area as Basin}}{\text{Maximum Basin Length}}$$

- In the Birma watershed, the **elongation ratio (Re)** is calculated to be **0.0330**.
- This value is significantly lower than the typical range of **0.6 to 1.0** observed in basins with diverse climatic and geologic conditions.
- The low elongation ratio (**>0.02**) indicates that the Birma watershed is **highly elongated** and **geologically controlled**.
- This finding is consistent with other morphometric parameters, such as the **bifurcation ratio (Rb)** and **relief ratio (Rh)**, which also indicate significant geological control.
- The elongation ratio reflects the **shape of the basin**, with values closer to **1.0** indicating a more **circular shape** and lower values suggesting **elongation**.

Drainage Density (Dd)

Drainage density (Dd), as defined by **Horton (1932)**, is the **total length of streams of all orders per unit area** of a drainage basin. It reflects the spacing and development of channels within a watershed and is influenced by factors such as:

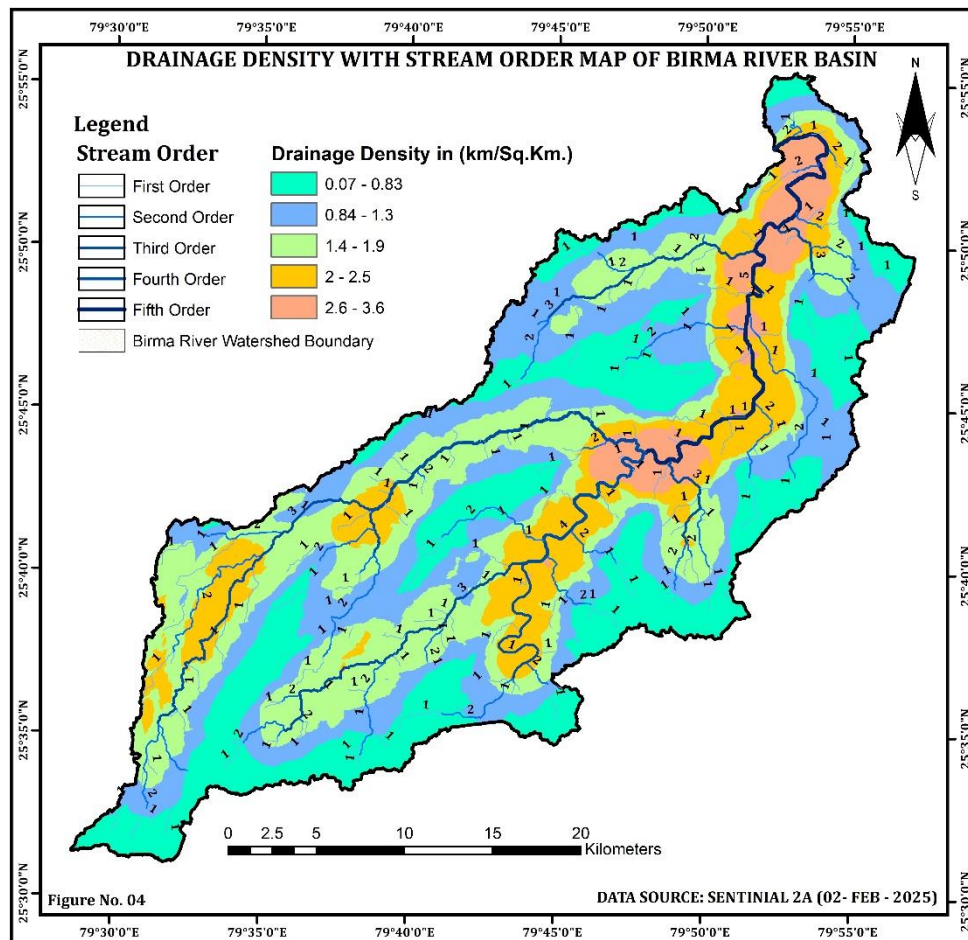
Climate (e.g., rainfall intensity and distribution), Rock type (permeability and resistance to erosion), Relief (slope steepness), Infiltration capacity (soil permeability), Vegetation cover (root systems that stabilize soil), Runoff intensity (surface flow dynamics).

Notably, Horton emphasized that **surface roughness** has no significant correlation with drainage density, as channel spacing is more strongly tied to subsurface permeability and climatic factors.

Moderate drainage density suggests **highly permeable sub-soil**, which allows significant infiltration of water into the ground. This reduces surface runoff and promotes groundwater recharge. Coarse drainage texture indicates **wider spacing between streams**, typical of basins with resistant bedrock or well-consolidated sediments. This reduces channel density and erosion

potential. Moderate Dd reflects a balance between **infiltration** and **runoff**, implying that the basin is neither overly susceptible to flooding (low Dd) nor prone to rapid erosion (high Dd).

The moderate drainage density (**2.87362 km/km²**) in the Birma watershed highlights its **permeable sub-soil, coarse drainage texture, and balanced hydrological regime**.



Length of Overland Flow (Lg)

The **length of overland flow (Lg)** is defined as the horizontal distance water travels over the land surface before it becomes concentrated into defined stream channels. According to **Horton (1945)**, this parameter is approximately **half the reciprocal of drainage density (Dd)**:

$$L_g = \frac{1}{2 \times D_d}$$

- The low Lg value (**0.69607**) indicates **short overland flow paths**, which are characteristic of **high-relief terrain** with steep slopes.
- In high-relief areas, water rapidly concentrates into streams due to steeper gradients, reducing the distance it travels as sheet flow.
- Since L_g is inversely proportional to D_d , the moderate drainage density (**2.87362 km/km²**) aligns with the low Lg value.
- This relationship highlights the **efficiency of the drainage network** in channelizing runoff quickly.

- The short overland flow length suggests **active erosional processes** and **youthful geomorphic stages**, consistent with the basin's **late youth stage** identified through stream length ratios.
- Steep slopes and high relief promote **rapid runoff, sediment transport**, and **gully erosion**, particularly in areas with sparse vegetation.

The low **length of overland flow ($L_g = 0.69607$)** in the Birma watershed underscores its **high-relief topography** and **dynamic geomorphic processes**. This parameter, combined with moderate drainage density, reflects a landscape where runoff rapidly concentrates into streams, shaping the basin's hydrological and erosional behaviour.

Stream Frequency (F_s)

Stream frequency (F_s), as defined by **Horton (1932)**, represents the **total number of stream segments of all orders per unit area** within a drainage basin. It quantifies the **texture and development of the drainage network**, reflecting the basin's **geological, climatic, and topographic characteristics**.

Low Stream Frequency ($F_s = 0.4224$):

A low F_s value suggests **fewer streams per unit area**, which is typical of basins with:

Highly permeable sub-soil: Promotes infiltration over surface runoff, limiting stream development.

Coarse drainage texture: Wider spacing between streams due to resistant bedrock or consolidated sediments.

Structural controls: Geological features (e.g., faults, folds) restrict stream branching.

The **low stream frequency ($F_s = 0.4224$)** in the Birma watershed highlights its **coarse drainage texture, permeable sub-soil**, and **geological constraints**. The positive correlation with drainage density underscores the interplay between stream numbers and total channel length, consistent with Horton's framework.

Drainage Texture (R_t)

Drainage texture (R_t), as defined by **Horton (1945)**, is the **total number of stream segments of all orders per unit perimeter** of a drainage basin. It quantifies the **spatial distribution of drainage lines** and reflects the interplay between **infiltration capacity, lithology**, and **topographic controls**. Key principles include:

- **Impermeable vs. Permeable Areas:** Drainage lines are more densely spaced in impermeable regions (due to higher surface runoff) and sparser in permeable areas (where infiltration dominates).
- **Infiltration Capacity:** Horton emphasized infiltration as the primary factor influencing drainage texture, as it governs surface runoff and stream development.
- **Classification by Smith (1950):**
- Smith classified drainage texture into five categories based on **drainage density (D_d)**:

Drainage Texture	Drainage Density (Dd)
Very Coarse	< 2 km/km ²
Coarse	2–4 km/km ²
Moderate	4–6 km/km ²
Fine	6–8 km/km ²
Very Fine	> 8 km/km ²

- **High Permeability:** Very coarse texture indicates **highly permeable sub-soil** (e.g., weathered bedrock, sandy soils), which promotes infiltration and limits surface runoff.
- **Resistant Lithology:** Sparse drainage lines suggest **resistant bedrock** (e.g., granite, quartzite) that inhibits channel incision.
- **Structural Control:** Elongated basin shape ($R_e = 0.0330$) and low bifurcation ratio ($R_b = 1.181\text{--}2.192$) imply structural constraints (e.g., faults, folds) limit stream development.
- The **coarse texture** under Smith's Dd system reflects **moderate stream spacing**, while the **very coarse R_t** highlights **low stream density relative to basin perimeter**.
- This discrepancy arises because R_t accounts for **basin shape** (perimeter), whereas Dd focuses on **area**. The elongated shape of the Birma watershed inflates its perimeter, reducing R_t .

The **very coarse drainage texture ($R_t = 1.7724$)** in the Birma watershed underscores its **high permeability, resistant lithology, and structural controls**. While Smith's Dd-based classification suggests **coarse texture**, Horton's perimeter-based R_t highlights the basin's elongated shape and sparse stream network. These findings align with earlier morphometric parameters (e.g., low elongation ratio, moderate Dd) and reinforce the need for **groundwater-centric management** in this semi-arid, structurally controlled watershed.

Form Factor (R_f) Analysis

The **form factor (R_f)**, as defined by **Horton (1932)**, is the ratio of the **basin area (A)** to the **square of its maximum basin length (Lb)**. It is expressed as:

$$\text{Form Factor } (R_f) = \frac{\text{Basin Area (A)}}{(\text{Maximum Basin Length (Lb)})^2}$$

- The low R_f value (**0.2349**) indicates that the Birma watershed is **far from circular** and exhibits a **strongly elongated morphology**.
- This aligns with the previously calculated **elongation ratio ($R_e = 0.0330$)**, which also underscores the basin's elongation.
- The elongation suggests **structural influences** such as tectonic activity, fault systems, or lithological variations that have shaped the basin's geometry.
- Elongated basins are often associated with **fluvial processes** in regions with linear geological structures (e.g., folded mountains, rift valleys).

The **low form factor ($R_f = 0.2349$)** confirms the Birma watershed's **highly elongated shape**, shaped by **structural and lithological controls**. This morphology influences its hydrological behaviour, emphasizing gradual runoff and reduced flash flood risks. The findings align with other morphometric parameters (e.g., R_e , R_b , Dd) and reinforce the need for **tailored watershed management strategies** that account for the basin's unique geometry and semi-arid conditions.

Circulatory Ratio (Rc) Analysis

The **circulatory ratio (Rc)** is a morphometric parameter that quantifies the **degree of circularity** of a drainage basin. It is defined as the ratio of the **basin area (A)** to the **area of a circle** with the same perimeter (P) as the basin. Mathematically, it is expressed as:

$$\text{Circulatory Ratio (Rc)} = \frac{\text{Basin Area (A)}}{\text{Area of a Circle with Perimeter (P)}}$$

For a perfectly circular basin, $R_c=1$. Lower values indicate increasing elongation or irregularity in basin shape.

- The low Rc value (**0.2572**) indicates the basin is **far from circular** and is instead **highly elongated** or irregular in shape.
- This contradicts the statement that the basin is "more or less circular," as $R_c=0.2572$ aligns with **strong elongation** (consistent with the earlier findings of $R_f=0.2349$ and $R_e=0.0330$).
 - The Birma watershed is **not circular**; it is **elongated**, as confirmed by:
 - **Form Factor (Rf = 0.2349)**: Far below 0.78 (circular basin).
 - **Elongation Ratio (Re = 0.0330)**: Extremely low, indicating pronounced elongation.
 - The misinterpretation of Rc as "circular" likely stems from conflating Rc with other parameters.

The **low circulatory ratio (Rc = 0.2572)** in the Birma watershed confirms its **highly elongated, non-circular shape**, shaped by **structural controls** and **moderate-to-high relief**. This aligns with other morphometric parameters and underscores the basin's **geological complexity** and **semi-arid hydrological dynamics**. Effective watershed management must account for its elongated morphology, structural constraints, and permeable sub-soil to ensure sustainable resource use in this water-stressed region.

Conclusion

The comprehensive morphometric analysis of the Birma River Basin, a sub-watershed within the Yamuna River Basin in Hamirpur District, Uttar Pradesh, reveals critical insights into its geomorphic evolution, hydrological behaviour, and structural controls. Utilizing advanced geospatial tools (Remote Sensing and GIS), the study delineated a dendritic to trellis drainage network spanning Stream Orders I to V, with moderate drainage density (2.87 km/km^2) indicating permeable sub-soil and coarse drainage texture. This permeability facilitates significant groundwater recharge, crucial for the semi-arid Bundelkhand region, while the elongated basin shape, evidenced by low form factor (0.23) and elongation ratio (0.03), underscores structural influences such as faults or resistant lithology that stretch the basin linearly.

Key parameters like bifurcation ratio (1.18–2.19) classify the basin as "normal" with moderate geological control, while stream length ratios (0.40–0.99) and relief ratio (0.0016) suggest a late youth stage of geomorphic development, marked by active erosion and evolving landforms. The low stream frequency ($0.42 \text{ streams/km}^2$) and very coarse drainage texture (1.77) reflect sparse channel networks, constrained by high infiltration capacity and geological barriers, reducing surface runoff but emphasizing groundwater dependency. The circulatory ratio (0.25) further negates circularity, aligning with elongation and structural dominance.

Hydrologically, the basin's elongated morphology lengthens flow paths, delaying peak discharge and mitigating flood risks, while high relief areas (evident from short overland flow length, 0.69) necessitate erosion control. The interplay of moderate slopes and permeable soils balances runoff and infiltration, vital for sustainable agriculture in this water-scarce region.

The study underscores the efficacy of RS/GIS in precise drainage mapping and morphometric analysis, providing a robust foundation for watershed management. Recommendations include soil conservation measures (e.g., contour bunding, afforestation) to stabilize erosion-prone zones, check dams to enhance groundwater recharge, and land-use practices avoiding impermeable surfaces. Policymakers must prioritize structural and lithological constraints in planning to address water scarcity and land degradation. These findings not only decode the basin's geomorphic history but also offer actionable strategies for resilience in semi-arid environments, aligning hydrological insights with sustainable development goals.

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