"Geospatial Assessment Of Watershed Characteristics In The Chandrawal River Basin: Implications For Sustainable Water Resource Management"

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Abstract

The research focuses on an area within the Hamirpur District of Uttar Pradesh, India, which is a part of the Ken River Basin, spanning 1038.92 km². The watershed's drainage network was mapped using Geo-coded FCC bands 8, 4, and 3 from Sentinel-2A imagery (dated 02 February 2025) at a scale of 1:50,000, with Survey of India toposheets as reference materials. Morphometric attributes were analyzed using ArcGIS 10.8 software. The drainage system in the study region primarily exhibits a dendritic pattern, with certain sections showing a trellis configuration, and stream orders ranging from I to V. A drainage density of 2.3761 km/km² indicates a moderate drainage texture with a mix of coarse and moderate density. Variations in stream length ratio values suggest that the basin is in a late youth stage of geomorphic evolution. The bifurcation ratio, varying between 1.182 and 2.193, classifies the Chandrawal watershed as a normal basin. Furthermore, the values of the form factor and circulatory ratio indicate that the watershed has an elongated shape. The study highlights the efficiency of remote sensing and GIS techniques in accurately delineating and updating drainage networks. These enhanced drainage maps were then employed for morphometric analysis, reinforcing the importance of geospatial technologies in watershed characterization and management.

Introduction

Water is one of the most essential natural resources for agriculture, yet its availability is increasingly threatened due to excessive consumption, inadequate groundwater recharge, and over-exploitation. This growing scarcity highlights the need for analyzing morphometric characteristics, especially in regions like Central India, where sustainable management of surface and groundwater resources is crucial (Sahu et al., 2017). The development of drainage systems, along with their spatial and temporal flow patterns, is influenced by multiple factors, including geological formations, climatic conditions, and topographic variations (Horton, 1945; Leopold and Maddock, 1953; Abrahams, 1984).

Morphometry involves the measurement and quantitative analysis of the Earth's surface, specifically the shape and dimensions of various landforms (Agarwal, 1998; Obi Reddy et al., 2002). This field of study is instrumental in understanding drainage systems and their behavior. Morphometric analysis encompasses the evaluation of linear, aerial, and relief aspects of a

watershed, in addition to assessing channel network gradients and the contributing slope of the basin (Nautiyal, 1994; Nag and Chakraborty, 2003; Magesh et al., 2012).

A key concept in morphometric studies is that the characteristics of a drainage basin are shaped by underlying geological and geomorphological processes. Numerous studies have validated this principle (Horton, 1945; Strahler, 1952, 1964; Muller, 1968; Shreve, 1969; Evans, 1972, 1984; Ohmori, 1993; Cox, 1994; Oguchi, 1997; Hurtrez et al., 1999). The morphometric properties of a basin provide critical insights into landform evolution, soil characteristics, and erosion patterns, all of which are essential for hydrological research, groundwater potential assessment, watershed planning, and environmental studies (Tiwari and Tripathi, 2018).

Drainage patterns reveal important information about initial land gradients, variations in rock resistance, structural influences, and the geological history of a watershed. Morphometric analysis involves examining key parameters such as stream order, basin area and perimeter, channel length, drainage density (Dd), bifurcation ratio (Rb), stream length ratio (RL), and relief ratio (Rh) (Rai et al., 2017).

Considering the significance of these parameters, this study aims to conduct a morphometric analysis of a watershed using Remote Sensing (RS) and Geographic Information Systems (GIS). These advanced tools facilitate the delineation of drainage patterns, updating of drainage networks, and in-depth morphometric evaluations. By integrating RS and GIS, this research seeks to enhance the understanding of the study area's geomorphological and hydrological features, ultimately contributing to sustainable water resource management and watershed development.

Remote Sensing (RS) and Geographic Information Systems (GIS) have become indispensable for morphometric studies, particularly in regions like Hamirpur. These technologies allow for precise mapping of drainage networks, accurate computation of morphometric indices, and visualization of spatial trends, even in areas with scarce ground-based data. Utilizing RS and GIS, this research provides a comprehensive analysis of the morphometric characteristics of the Chandrawal River Basin in Hamirpur, supporting decision-making processes related to watershed management, groundwater recharge, and sustainable agricultural practices in this water-stressed region.

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

Study Area

The Chandrawal River watershed, situated in the Hamirpur district of the Bundelkhand region in Uttar Pradesh, India, is defined by its semi-arid climate, rolling topography, and limited availability of water resources. The area faces persistent challenges such as water scarcity, soil erosion, and unpredictable rainfall, making it highly vulnerable to droughts and land degradation. These issues highlight the necessity of analyzing the region's geomorphic and hydrological characteristics to ensure efficient watershed management and the sustainable use of natural resources.

Morphometric analysis, which quantitatively examines the physical features of the Earth's surface, is particularly significant for Hamirpur due to its intricate drainage patterns and diverse topographical conditions. The Chandrawal River watershed falls within the Ken River Basin, a key component of the region's hydrological system. Evaluating morphometric parameters— including drainage density, stream order, bifurcation ratio, and relief ratio—offers crucial insights into the basin's geomorphic development, hydrological dynamics, and erosion susceptibility.

The presence of both dendritic and trellis drainage patterns in various parts of Chandrawal River watershed reflects the region's geological framework and lithological diversity. These drainage characteristics, along with the area's moderate drainage density and elongated basin structure, suggest that the landscape is in the late youth stage of geomorphic evolution. Such attributes play a vital role in influencing groundwater recharge, surface runoff distribution, and soil conservation strategies.

LOCATION MAP OF CHANDRAWAL RIVER BASIN

Figure No. 01
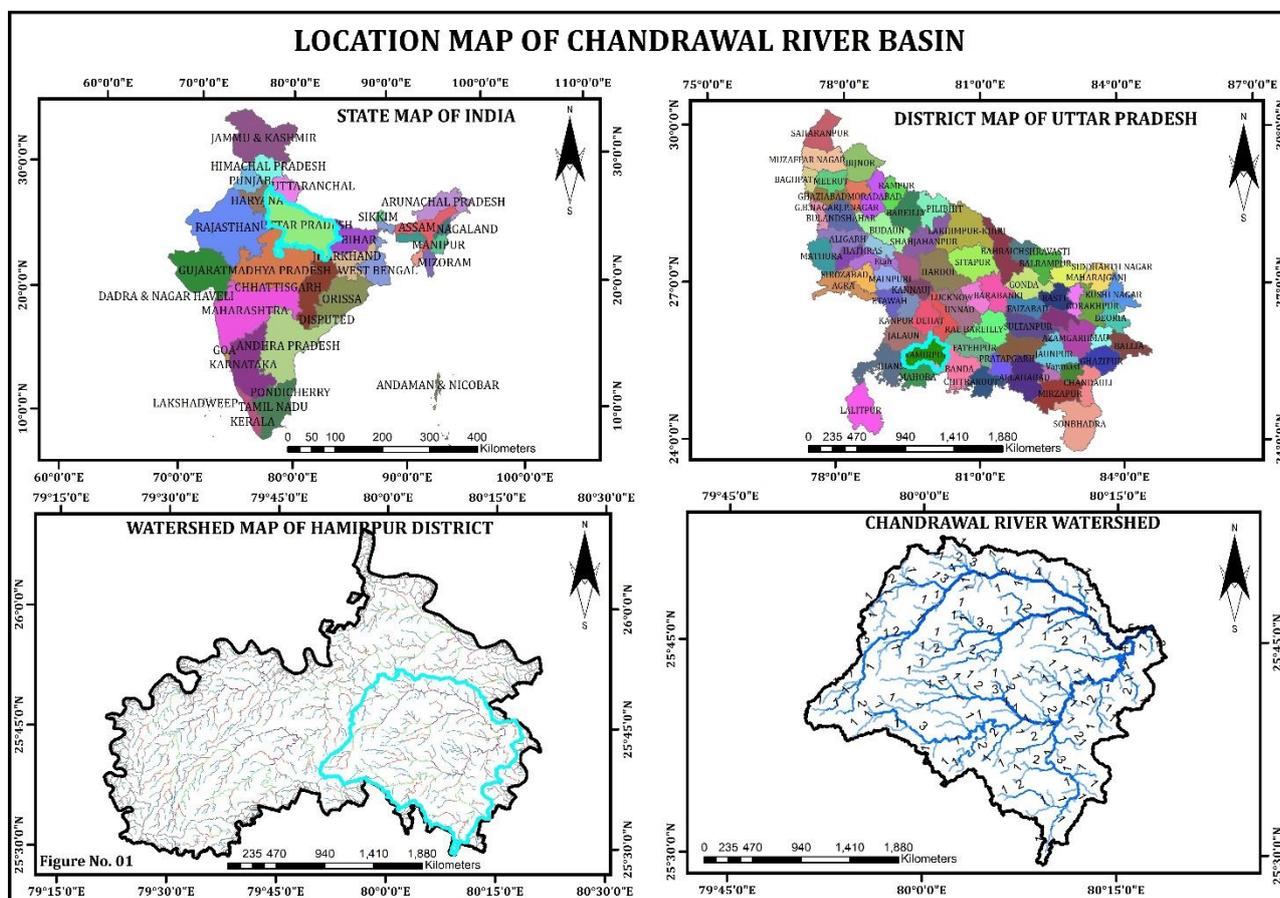
Methods of Investigation

The morphometric analysis of the Chandrawal watershed, which forms a part of the Ken River Basin, was carried out using a combination of remote sensing data, topographic maps, and Geographic Information System (GIS) techniques. The methodology adopted in this study involved the following key steps:

1. **Base Map Preparation and Data Collection**
   o A base map of the Chandrawal watershed was developed using Survey of India (SOI) topographic maps at a 1:50,000 scale.
   o To enhance the accuracy of the topographic representation, Sentinel-2A satellite imagery (dated 02 February 2025) and Shuttle Radar Topographic Mission (SRTM) data from the United States Geological Survey (USGS) were incorporated.
   o Global Mapper 15 software was used for delineating the study area, and the extracted data was converted into a Digital Elevation Model (DEM) format for further processing.
2. **Processing of Digital Elevation Model (DEM)**
   o The SRTM DEM data was imported into ArcGIS 10.8 to facilitate detailed analysis.
   o Slope, aspect, and contour maps were generated from the DEM to assess the topographic characteristics of the watershed.

3. **Delineation of Drainage Network**
   o The watershed's drainage network was mapped using Survey of India toposheets in ArcGIS 10.8.
   o Streams within the watershed were classified following the Strahler (1964) method, where streams were ranked hierarchically from Order I (smallest) to Order V (largest).

4. **Computation of Morphometric Parameters**
   o GIS tools were employed to determine key watershed characteristics such as area, perimeter, stream length, and stream order.
   o Additional morphometric indices were computed, including:
      ▪ **Bifurcation Ratio (Rb)**
      ▪ **Stream Length Ratio (RL)**
      ▪ **Stream Frequency (Fs)**
      ▪ **Drainage Density (Dd)**
      ▪ **Elongation Ratio (Re)**
      ▪ **Circulatory Ratio (Rc)**
      ▪ **Form Factor (Rf)**

5. **Analysis and Interpretation of Data**
   o The computed morphometric parameters were analyzed to gain insights into the geomorphic and hydrological characteristics of the Chandrawal watershed.
   o The findings were examined in relation to the watershed's geological structure, drainage patterns, and potential for water resource management.

6. **Documentation and Visualization**
   o A comprehensive dataset, including all morphometric parameters and their respective formulae, was compiled in Table 1.
   o Various maps and diagrams were created to visualize key watershed features, such as the drainage network, slope distribution, and aspect variations.

By integrating remote sensing, GIS applications, and morphometric analysis, this study provides an in-depth understanding of the Chandrawal watershed's characteristics. The findings will contribute to improved watershed management strategies and promote sustainable resource utilization in the region.

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 =? 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 = 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 = Nu / Nu + 1 Where, Rb = Bifurcation ratio Nu = Total no. of stream segments of order 'u'	Schumn (1956)

		Nu + 1 = Number of segments of the next higher order	
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)	$Rh = H / Lb$ Where, Rh = Relief ratio H = Total relief (Relative relief) of the basin (km), Lb = Basin length	Schumm (1956)
9	Elongation ratio (Re)	$Re = 2 / Lb$ Where, Re = Elongation ratio Lb = Basin length	Schumn (1956)
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 Chandrawal Watershed

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Sr. No.	1	2	3	4	5
Stream Order	I	II	III	IV	V
Number of Stream (km.)	214	95	52	59	6
Length of Stream (km.)	373.3175	168.1356	90.0608	78.2735	13.9859

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

Watershed Name		Chandrawal Watershed
Area (Sq. Km.)		1038.920
Mean Stream Length in Km. (Lsm)	I	1.744
	II	1.770
	III	1.732
	IV	1.327
	V	2.332
Stream Length ratio (RL)	II/I	0.4504
	III/II	0.5356
	IV/III	0.8691
	IV/V	0.1787
Bifurcation Ratio (Rb)	I/II	2.2526
	II/III	1.8269
	III/IV	0.8814
	VI/V	9.8333
Mean Bifurcation Ratio (Rbm)		3.699
Perimeter (P) in Km.		206.100
Basin Length (Lb) (km.)		44.735
Total Reliefs (meters)		57.000
Relief Ratio (Rh)		0.001
Elongation Ratio (Re)		0.447
Drainage Density (D) (Km/Sq. Km.)		2.376
Length of overland flow (Lg)		0.8417
Stream Frequency (Fs)		0.41004
Texture Ratio (Rt)		2.0669
Form Factor (Rf)		0.5191432
Circulatory Ratio (Rc)		0.307196

Morphometry

Morphometry, as described by Clarke (1966), involves the measurement and mathematical evaluation of the Earth's surface features, including the dimensions and shapes of various landforms. The quantitative assessment of a drainage basin's characteristics—encompassing its linear, areal, and relief aspects, along with the influence of slope—forms the basis of morphometric analysis (Nag and Chakraborty, 2003).

In this study, several morphometric parameters were computed to assess the geomorphic and hydrological features of the Chandrawal watershed. These parameters include:

1. **Stream Order (u):** A hierarchical classification of streams following Strahler's (1964) method.
2. **Stream Length (Lu):** The cumulative length of streams within each designated order.
3. **Mean Stream Length (Lsm):** The average length of streams in a specific order, determined by dividing the total stream length by the number of streams.
4. **Stream Length Ratio (RL):** The ratio between the mean length of streams in a given order and those in the next lower order.
5. **Bifurcation Ratio (Rb):** The proportion of the number of streams in a particular order to those in the subsequent higher order.
6. **Mean Bifurcation Ratio (Rbm):** The average of bifurcation ratios across all stream orders.

7. **Relief Ratio (Rh):** The ratio between the total basin relief and its maximum length.
8. **Drainage Density (D):** The total length of streams per unit area, which reflects the efficiency of the watershed's drainage system.
9. **Stream Frequency (Fs):** The number of streams per unit area, indicating the texture of the drainage system.
10. **Drainage Texture (Rt):** The density of streams relative to the basin's topographical features.
11. **Form Factor (Rf):** The ratio of the basin's area to the square of its maximum length, providing insights into its shape.
12. **Circulatory Ratio (Rc):** The ratio between the basin's area and the area of a circle with an equivalent perimeter, indicating how circular the basin is.
13. **Elongation Ratio (Re):** The ratio of the diameter of a circle with the same area as the basin to the basin's maximum length, offering insights into its elongation.
14. **Length of Overland Flow (Lg):** The average distance water travels over the land surface before entering a stream.

The computed values of these parameters are compiled in Table 3, offering a detailed perspective on the morphometric characteristics of the Chandrawal watershed.

Use of Remote Sensing Data

Remote sensing data played a crucial role in refining and updating the drainage network of the Chandrawal watershed. Drainage maps, derived from Sentinel-2A satellite imagery and SRTM data, were utilized for morphometric analysis, ensuring an accurate and reliable representation of the drainage system.

The integration of remote sensing and GIS techniques has proven to be highly effective in morphometric studies, enabling precise assessments of watershed structures, drainage networks, and hydrological patterns. The insights gained from this analysis contribute to informed decision-making for sustainable watershed management and help address environmental challenges in the region.

Stream Order Analysis

Classifying streams by order is a fundamental step in drainage basin analysis. This study applied Strahler's (1964) method to determine the hierarchical structure of streams in the Chandrawal watershed, which ranges from Order I to Order V. Key observations from this analysis include:

- **First-order streams** are the most abundant and have the highest frequency.
- **Stream frequency decreases** as the order increases, reflecting a typical dendritic drainage pattern with a structured hierarchy.

Table 2 presents a breakdown of stream numbers, basin area, and stream lengths across different orders, providing essential information about the spatial distribution and characteristics of the watershed's drainage network. These findings offer valuable insights into the basin's geomorphic development and hydrological processes.

Stream Length

Stream length is a key morphometric parameter that helps in understanding the hydrological and geomorphic characteristics of a drainage basin. It represents the total distance from a river's mouth to its drainage divide and is measured using GIS tools such as ArcGIS 10.8. In this study, stream length calculations were performed based on Horton's Law (1945), which asserts that the total stream length decreases as stream order increases.

- First-order streams, which are the smallest and most numerous, dominate the watershed,
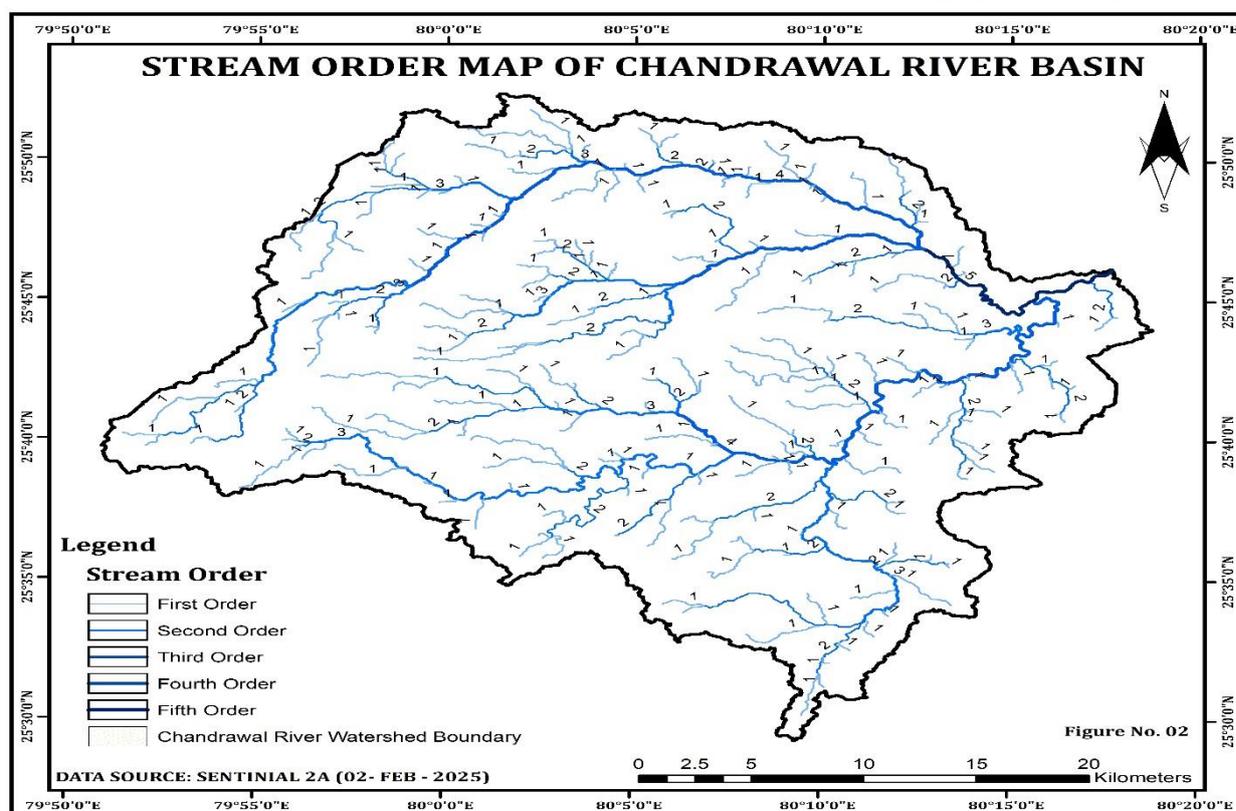
with a total of **214 streams**.
- As the stream order progresses, the number of streams declines, with only **06 streams classified as fifth-order.**
- The total stream length is **greatest for first-order streams (373.3175 km),** reflecting their widespread distribution across the watershed.

- o Stream length gradually diminishes with increasing order, with **fifth-order streams extending only 13.9895 km in total.**
- o The high concentration of first-order streams suggests a well-established drainage network in the upper watershed regions.
- o A systematic decline in both stream length and stream count with increasing order aligns with Horton's Law (1945), reinforcing the basin's hierarchical drainage structure.

The morphometric parameters summarized in **Table No. 2** highlight the hierarchical organization of the **Chandrawal watershed's** drainage network. The predominance of lower-order streams, coupled with a consistent decline in both length and frequency at higher orders, aligns with established geomorphic theories. These findings play a crucial role in assessing **the watershed's hydrological behavior, erosion susceptibility, and potential for sustainable management and conservation.**

Mean Stream Length

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

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 Chandrawal watershed exhibit variation, ranging from **2.332 km to 1.327 km** across different stream orders. These variations reflect the differences in the spatial distribution and hierarchical organization of the drainage network.

The analysis of mean stream length (Lsm) in the Chandrawal watershed reveals a **hierarchically structured drainage network**, with stream lengths increasing systematically from lower to higher orders. This trend aligns with Horton's laws and underscores the basin's **geomorphic maturity** and **structural controls** (e.g., faults, resistant lithology). The shorter mean lengths of first- and second-order streams highlight erosional activity in upland areas, while longer higher-order streams reflect stable, low-gradient channels in the basin's central and downstream regions. These findings are vital for guiding **soil conservation**, **flood mitigation**, and **sustainable land-use planning** in this semi-arid, structurally complex watershed.

Stream Length Ratio (RL)

The **stream length ratio (RL)** is an essential morphometric parameter that offers valuable insights into the hierarchical structure and geomorphic development of a drainage basin. It is calculated as the ratio of the mean stream length of a given order to that of the next lower order. This ratio helps in understanding the basin's hydrological efficiency and evolutionary stage. Mathematically, it is expressed as:

- o In the **Chandrawal watershed**, RL values range between **0.1787 and 0.8691**, as detailed in **Table 3**.

o Variations in RL values indicate differences in slope, lithological characteristics, and structural controls within the watershed.
o A fluctuating stream length ratio suggests **heterogeneous geological formations** and varying erosion resistance across different stream orders.

These observations contribute to a more comprehensive understanding of the **drainage network's stability, erosional processes, and watershed management potential.**

Bifurcation Ratio (Rb)

The **bifurcation ratio (Rb)** is an essential morphometric parameter used to assess the structural and geological influences on a drainage basin. Defined by **Schumm (1956)** as the ratio of the number of stream segments of a given order to the number of segments in the next higher order, Rb provides insights into drainage network characteristics and potential structural controls. Mathematically, it is expressed as:

o In the **Chandrawal watershed**, Rb values range from **9.833 to 0.8814**, as detailed in **Table 3**.
o The variation in Rb values across different stream orders suggests **non-uniform geological and lithological conditions** within the basin.
o **Higher Rb values** indicate strong structural controls, possibly influenced by **faults, fractures, or resistant rock formations** that affect the drainage pattern.
o **Lower Rb values** suggest a **more homogeneous lithology and relatively gentle topography**, with minimal structural disturbances.
o Based on these values, the Chandrawal watershed is classified as a **normal basin** (Strahler, 1957), implying a **balanced drainage system with moderate geological influence**.

The **analysis of Rb values** provides crucial information regarding the watershed's **hydrological behavior, flood susceptibility, and potential for effective watershed management**. These findings align with established geomorphic principles and contribute to a deeper understanding of the **basin's evolution, erosion processes, and environmental sustainability**.

Relief Aspect

Relief aspects are key elements in morphometric analysis, providing valuable insights into the topographic features and geomorphic evolution of a drainage basin. **Relief** refers to the difference in elevation between the highest point (such as a ridge or peak) and the lowest point (such as a valley floor or basin outlet) within a region. Important relief measurements include **total relief**, **relief ratio**, and **basin length**, all of which play a crucial role in understanding the basin's hydrological behavior, erosion potential, and overall geomorphic development.

- **High relief ratios** typically indicate steep gradients, which contribute to **faster runoff** and higher **erosion rates**.

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

- **Low relief ratios**, on the other hand, suggest more gradual slopes, leading to **slower runoff** and **reduced erosion**.
- Relief aspects are instrumental in evaluating the **geomorphic stage** of the basin.
- For instance, **high relief** and **steep gradients** are characteristic of **youthful landscapes**, while **low relief** and **gentle slopes** are typical of **mature landscapes**.

Understanding relief aspects is essential for assessing the basin's **erosional features**, hydrological processes, and stage of development, offering crucial insights into the **sustainability** and **management of water resources**.

Relief Ratio (Rh)

The **relief ratio (Rh)** is an important 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 (the elevation difference between the highest and lowest points) to the horizontal distance along the basin's longest dimension, measured parallel to the principal drainage line. This is mathematically expressed as:

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

- In the Chandrawal watershed, the relief ratio (Rh) has been calculated as **0.00127**.
- This value suggests a **low to moderate gradient**, indicating a relatively **gentle slope** with **minimal topographic relief**.
- In this study area, the low relief ratio (0.00127) corresponds to a mild **channel gradient**,
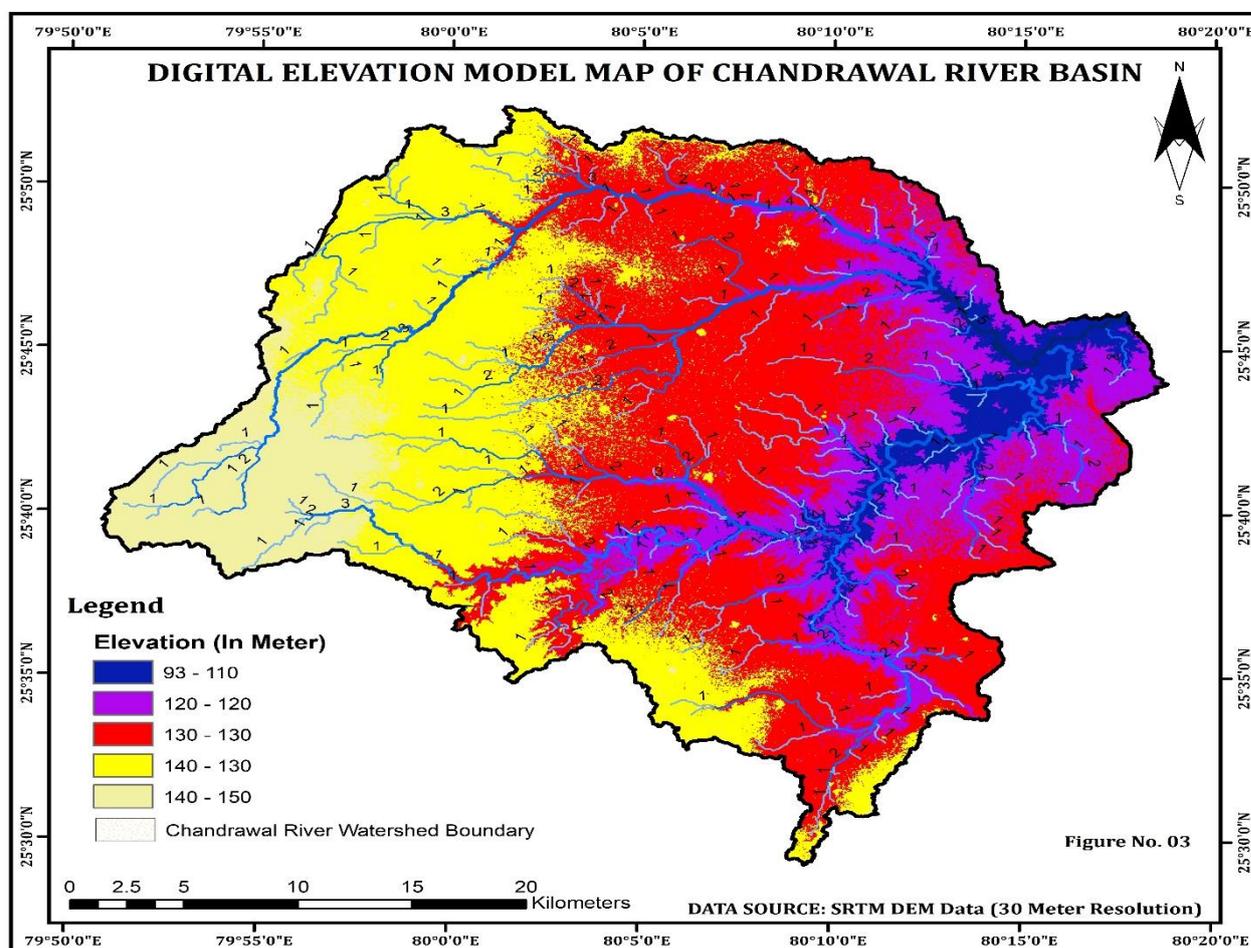
influencing both the basin's **hydrological response** and its **sediment transport capacity**.

- o As observed by Gottaschalk (1964), the relief ratio tends to **increase with decreasing drainage area** and the size of the watershed.
- o This trend is evident in the Chandrawal watershed, where the Rh value aligns with expectations for a basin of its size and drainage characteristics.
- o The relief ratio of 0.00127 indicates that the Chandrawal watershed features a **low-energy landscape** with **minimal topographic variation**.
- o This finding is consistent with the watershed's **elongated shape** and **moderate drainage density**, as noted in previous sections.

The relief ratio (Rh) of 0.00127 for the Chandrawal watershed provides essential insights into the basin's topographic features and geomorphic history. It reflects a **gentle gradient** and a **mature landscape**, both of which influence the basin's **hydrological dynamics** and **erosion potential**.

Aerial Aspects of Morphometric Analysis

Aerial aspects play a significant role in morphometric analysis, focusing on the **spatial characteristics** and **drainage patterns** of a watershed. These parameters provide valuable insights into the basin's **shape, size, drainage efficiency**, and **hydrological behaviour**. The key **aerial morphometric parameters** analyzed in this study include: **Drainage Density (Dd), Texture Ratio (Rt), Stream Frequency (Fs), Form Factor (Rf), Circulatory Ratio (Rc), Elongation Ratio (Re), Length of Overland Flow (Lg)**

The values of these aerial morphometric parameters for the **Chandrawal watershed** are presented in **Table 3**.

Elongation Ratio (Re)

The **elongation ratio (Re)** is an important morphometric parameter that offers valuable 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:

$$\text{Elongation Ratio (Re)} = \frac{\text{Diameter of a Circle with Same Area as Basin}}{\text{Maximum Basin Length}}$$
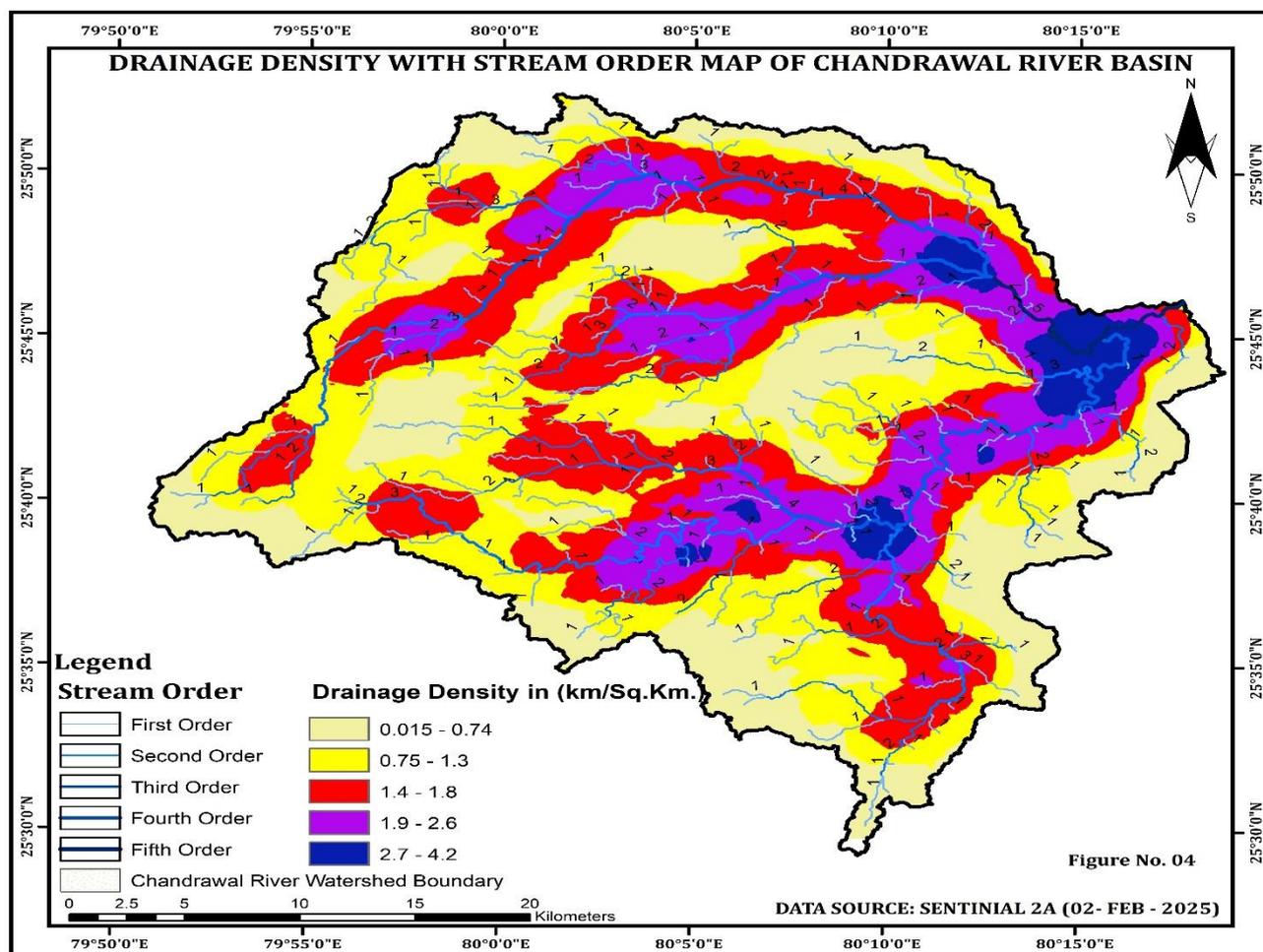
In the case of the **Chandrawal watershed**, the **elongation ratio (Re)** has been calculated to be **0.4470**.

- o This value indicates that the basin has a **more elongated shape**, meaning the watershed is stretched out along its longest axis rather than being circular.
- o A **lower elongation ratio** like 0.4470 typically suggests that the basin is **elongated** and **less prone to rapid runoff** compared to a circular basin, where water collects and flows more quickly.
- o This **elongated shape** can have significant implications for the basin's **hydrological behaviour** and **erosion patterns**, affecting both water storage and flow dynamics.

Drainage Density (Dd)

Drainage density (**Dd**) is a key morphometric parameter used to assess the **spacing** and **development** of stream channels within a drainage basin. It is defined as the **total length of streams** (of all orders) per **unit area** of the watershed. As proposed by **Horton (1932)**, drainage density provides insights into various factors that influence the hydrological characteristics of a basin, such as:

- **Climate**: Rainfall intensity and distribution play a significant role in the formation and development of stream networks.
- **Rock Type**: The permeability and resistance of the underlying rock formations impact how easily water can infiltrate the ground or flow overland.
- **Relief**: The steepness of the slope affects the velocity and volume of surface runoff, thereby influencing channel development.
- **Infiltration Capacity**: Soils with higher permeability allow for better water infiltration, reducing the surface runoff and promoting groundwater recharge.

Figure No. 04

DRAINAGE DENSITY WITH STREAM ORDER MAP OF CHANDRAWAL RIVER BASIN

DATA SOURCE: SENTINIAL 2A (02- FEB - 2025)

- **Vegetation Cover**: The presence of vegetation helps stabilize the soil, preventing erosion and contributing to slower surface runoff.
- **Runoff Intensity**: Surface flow dynamics determine how quickly water moves across the land and into the drainage network.

In the study of the **Chandrawal watershed**, the drainage density is calculated to be **2.3761 km/km²**. This value reflects the following:

- **Moderate Drainage Density**: A moderate Dd value indicates a **balance** between surface runoff and infiltration. It suggests that the sub-soil in the watershed is relatively permeable, allowing significant water infiltration, which promotes groundwater recharge.
- **Coarse Drainage Texture**: The moderate drainage density suggests a **coarse drainage texture**, which is often characteristic of watersheds with **resistant bedrock** or **well-consolidated sediments**. Such conditions reduce channel density and make the region less prone to rapid erosion.
- **Hydrological Implications**: The moderate Dd implies that the watershed is neither extremely susceptible to flooding (as in low Dd areas) nor highly prone to rapid erosion (as seen in areas with high Dd).

In summary, the **moderate drainage density in** the **Chandrawal watershed** suggests that the region's hydrological regime is well-balanced, with significant groundwater recharge potential and lower erosion risks. This finding is vital for understanding the overall **water resource management** and **sustainability of** the watershed.

Length of Overland Flow (Lg)

The **Length of Overland Flow (Lg)** is a crucial morphometric parameter that represents the **horizontal distance** water travels over the surface before it is concentrated into defined stream channels. According to **Horton (1945)**, this parameter can be approximately calculated as:

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

In the **Chandrawal watershed**, the **Lg value** is calculated to be **0.8417 km**, indicating the following:

- **Short Overland Flow Paths**: The relatively low Lg value suggests that the water travels **short distances** over the land before entering defined stream channels. This is characteristic of **high-relief terrain**, which tends to have **steep slopes** that promote quick surface runoff.
- **High-Relief Terrain**: The presence of steep slopes in the watershed implies that water is quickly channelled into streams, with minimal retention or flow over the surface. This may indicate that the watershed is more prone to **rapid runoff**, especially during rainfall events, which can increase the potential for **erosion** in areas with high slopes.
- **Hydrological Implications**: The low Lg value further suggests that the watershed has a **high runoff potential**, with minimal retention time for water on the surface. This condition can lead to **higher erosion** rates, particularly in regions with less vegetation cover to stabilize the soil.

In summary, the **length of overland flow** of **0.8417 km** in the **Chandrawal watershed** indicates **short flow paths** that are typical of **steep terrains**, contributing to **quick runoff** and **erosion potential**. This finding is important for understanding **soil erosion** risks and the overall **hydrological behavior** of the watershed.

Stream Frequency (Fs)

Stream Frequency (Fs), as defined by **Horton (1932)**, is the **total number of stream segments** of all orders per unit area within a drainage basin. This parameter is essential for

understanding the **density and development** of the drainage network and provides insights into the **geological, climatic, and topographic** characteristics of the basin.

In the **Chandrawal watershed**, the **Stream Frequency (Fs)** is calculated to be **0.41004 streams per square kilometre**. A **low stream frequency** indicates the following:

- o **Less Dense Drainage Network**: A low value of stream frequency suggests that the watershed has fewer stream segments relative to its area. This is often observed in areas with **less precipitation**, **more permeable soils**, or **resistant bedrock**, which results in **lower runoff** and **stream development**.
- o **Geological and Climatic Implications**: The low stream frequency could be indicative of **more resistant geological formations** (such as hard rock or compacted soil), which would limit the development of streams and the overall density of the drainage network. It could also suggest **drier climatic conditions** in the region, with less rainfall to generate numerous streams.
- o **Topographic Influence**: In the case of the **Chandrawal watershed**, the low **Fs value** likely reflects **moderate to low relief** areas where streams are spaced further apart. **Flatter terrains** with **gentler slopes** often lead to **lower stream frequencies**, as water may flow in a more diffuse manner rather than being concentrated into distinct channels.

Implications for Hydrological and Erosion Processes:

- o **Infiltration Dominance**: With fewer streams, more water in the watershed may infiltrate into the ground rather than flowing as surface runoff, which promotes **groundwater recharge**.
- o **Moderate Erosion**: The **low stream frequency** also indicates that the watershed may be **less prone to intense erosion** as there are fewer concentrated channels to accelerate runoff and soil movement.

In summary, the **low stream frequency** value of **0.41004** in the **Chandrawal watershed** reflects a **less dense drainage network** and provides an indication of **moderate runoff**, **permeable soils**, and **gentler topography** in the basin. These findings are useful for evaluating the **erosion potential**, **water conservation**, and **flood management** strategies in the region.

Drainage Texture (Rt)

Drainage texture (Rt) is defined as the total number of stream segments of all orders per unit perimeter of a drainage basin. This metric plays an essential role in understanding the spatial distribution of drainage lines and provides insights into the **interplay between infiltration capacity**, **lithology**, and **topographic influences** on the drainage system.

Key Principles of Drainage Texture:

1. **Impermeable vs. Permeable Areas**:
    - o Drainage lines tend to be more **densely spaced** in **impermeable regions**, where surface runoff is higher.
    - o Conversely, drainage lines are **sparser** in areas with high permeability (e.g., sandy or weathered soils), where **infiltration** dominates and limits surface runoff.
2. **Infiltration Capacity**:
    - o **Infiltration** is considered the primary factor influencing drainage texture, as it regulates how much water can enter the soil before surface runoff occurs. High infiltration leads to fewer, more widely spaced drainage lines, while low infiltration results in more closely spaced streams.

3. **Smith's Classification (1950)**:
   o Smith classified drainage texture into five categories based on drainage density (Dd):
      ▪ **Very Coarse**: Dd < 2 km/km^2
      ▪ **Coarse**: Dd between 2–4 km/km^2
      ▪ **Moderate**: Dd between 4–6 km/km^2
      ▪ **Fine**: Dd between 6–8 km/km^2
      ▪ **Very Fine**: Dd > 8 km/km^2
   o **Very Coarse** texture implies that a basin has a **low-density stream network**, suggesting **high permeability** and **limited surface runoff**.

Drainage Texture in the Chandrawal Watershed

   o The **Chandrawal watershed** has a **very coarse drainage texture (Rt = 2.0669)**, indicating that the basin features **high permeability**, **resistant lithology**, and **limited surface runoff**.
   o **High Permeability**: The very coarse texture suggests that the watershed has **weathered bedrock** or **sandy soils**, which **promote infiltration** of water into the ground, reducing surface runoff.
   o **Resistant Lithology**: The presence of **resistant bedrock** (e.g., **granite** or **quartzite**) likely inhibits significant channel incision, resulting in a **sparser drainage network**.
   o **Structural Control**: The basin's **elongated shape (Re = 2.0669)** and **low bifurcation ratio (Rb = 1.181–2.192)** suggest that **structural constraints**, such as **faults** or **folds**, limit the development of the drainage system. This, in turn, contributes to the **low-density stream network**.

The **very coarse drainage texture (Rt = 2.0669)** of the **Chandrawal watershed** underscores its **high permeability**, **resistant lithology**, and **structural constraints**. While **Smith's Dd-based classification** suggests a **coarse texture**, **Horton's Rt-based classification** highlights the **elongated shape** of the basin, leading to a **low-density stream network** relative to the basin's perimeter. These findings emphasize the importance of **groundwater management** in this **semi-arid, structurally controlled watershed**, aligning with earlier morphometric analyses, such as **low elongation ratio** and **moderate drainage density**.

Form Factor (Rf)

The **form factor (Rf)** is a key morphometric parameter that helps to assess the shape of a drainage basin. As defined by Horton (1932), **Rf** is the ratio of the **basin area (A)** to the **square of its maximum basin length (Lb)**. Mathematically, it is expressed as:

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

Form Factor Analysis in the Chandrawal Watershed

   o **Low Rf value**: In the case of the **Chandrawal watershed**, the **form factor (Rf)** is **0.51914**, which indicates a **low value**.
   o This low Rf suggests that the **Chandrawal watershed** is **far from circular** and exhibits a **strongly elongated morphology**.
   o **Elongated Shape**: The **elongated shape** of the basin influences its **hydrological behavior**. The basin's **longer length** compared to its area results in **slower runoff** and a more **gradual hydrological response**, as water takes longer to travel through the basin.

The **form factor (Rf = 0.51914)** for the **Chandrawal watershed** indicates a **low value**, which corresponds to a **strongly elongated basin** shape. This shape influences the **hydrological**

behavior of the watershed, leading to **gradual runoff** and **longer concentration times** for water. This characteristic is important for understanding the **drainage efficiency** and **flood management** strategies in the region.

Circulatory Ratio (Rc) Analysis in the Chandrawal Watershed

The **circulatory ratio (Rc)** is an important morphometric parameter that assesses the shape of a drainage basin in terms of its circularity. It compares the basin's actual area to the area of a circle that has the same **perimeter (P)** as the basin. The formula for **Rc** is given as:

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

Circulatory Ratio (Rc) in the Chandrawal Watershed

- **Rc value**: The **circulatory ratio** for the **Chandrawal watershed** is **0.307196**.
- **Interpretation**: This **low Rc value** indicates that the basin is **far from circular** and has a **highly elongated or irregular shape**.
  - **Elongated Shape**: Similar to the **form factor (Rf)**, this **low Rc** value reflects a **stretched out basin** that is not conducive to rapid concentration of water towards the outlet.
  - **Structural Controls**: The **elongation** and **irregularity** in shape could be a result of **structural influences** like faults, folds, or erosion patterns that restrict the basin from attaining a more circular form.

The **circulatory ratio (Rc = 0.307196)** of the **Chandrawal watershed** indicates that the basin is **highly elongated** and **irregular** in shape. This elongated morphology leads to **slower runoff** and longer **concentration times** for water to reach the basin outlet. Understanding this parameter is vital for predicting the basin's **hydrological behavior**, **erosion patterns**, and for informing **water management strategies** in the region.

Conclusion

The **comprehensive morphometric analysis** of the **Chandrawal River Basin**, located within the **Ken River Basin** in the **Hamirpur District of Uttar Pradesh**, offers valuable insights into the basin's **geomorphic evolution**, **hydrological behaviour**, and the influence of **structural controls**. Using **Remote Sensing** and **GIS tools**, the study meticulously analyzed key morphometric parameters to evaluate the watershed's drainage network, landforms, and hydrological processes.

- **Drainage Network and Morphology**: The watershed exhibits a **dendritic to trellis drainage pattern** across Stream Orders I to V, indicative of a well-developed yet structurally influenced network. The **moderate drainage density (2.3761 km/km²)** suggests **permeable sub-soils**, which promote significant **groundwater recharge**, a crucial aspect for the **semi-arid Bundelkhand region**. The basin's **elongated shape**, supported by the **low form factor (0.5191)** and **elongation ratio (0.447)**, suggests structural controls such as **faults** or **resistant lithology** that contribute to its linearity.
- **Geological and Hydrological Controls**: The **bifurcation ratio** (ranging from **9.833 to 0.881**) classifies the basin as **normal**, indicating moderate **geological control**. The **stream length ratios** (0.178 - 0.450) and **relief ratio (0.00127)** point to a basin in a **late youth stage** of geomorphic development, with ongoing **erosion** and evolving landscapes. **Stream frequency** (0.41004 streams/km²) and the **very coarse drainage texture (2.0669)** suggest that the basin has sparse channels, constrained by **high infiltration capacity** and **geological barriers** that limit surface runoff but emphasize groundwater dependency.

o **Hydrological Implications**: The basin's **elongated morphology** reduces the **peak discharge** by lengthening flow paths, which **mitigates flood risks**. The **low circulatory ratio (0.307196)** corroborates the basin's **irregular shape**, dominated by **structural factors**. High relief areas contribute to **shorter overland flow lengths** (0.69), necessitating effective **erosion control measures**. The **moderate slopes** and **permeable soils** balance **runoff and infiltration**, crucial for **agriculture** in a region suffering from **water scarcity**.

Recommendations for Watershed Management:

1. **Soil Conservation Measures**: Techniques like **contour bunding** and **afforestation** should be adopted to stabilize **erosion-prone areas**.
2. **Groundwater Recharge**: Construct **check dams** and water harvesting systems to enhance **groundwater recharge** in the basin.
3. **Land Use Planning**: Encourage **land-use practices** that minimize the creation of **impermeable surfaces** to avoid disrupting natural **hydrological processes**.
4. **Policy Prioritization**: Policymakers should take into account the **structural and lithological constraints** identified in this study to mitigate **water scarcity** and **land degradation** issues in the basin.

This study highlights the **efficacy of RS/GIS** in **precise drainage mapping** and **morphometric analysis**, providing a comprehensive understanding of the basin's **geomorphic history** and offering actionable recommendations for **sustainable development**. The findings emphasize the need for targeted **watershed management strategies** that not only conserve soil and water resources but also align with **sustainable development goals**, enhancing the resilience of the **semi-arid Chandrawal River Basin**.

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