GIS-Based Morphometric Analysis of the Eastern Nayar Watershed, Uttarakhand, India

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Abstract

Morphometric analysis provides a quantitative framework for understanding the drainage characteristics, geomorphic evolution, and hydrological response of a watershed. The present study evaluates the morphometric parameters of the Eastern Nayar watershed, located in the Lesser Himalayan region of Uttarakhand, India, using Geographic Information Systems (GIS) and Digital Elevation Model (DEM)-based techniques. A CartoSat-1 DEM was used to delineate the watershed and extract the drainage network using a stream initiation threshold of 600, and stream ordering was carried out following the Strahler method. The watershed is identified as a fifth-order basin comprising 933 stream segments with a total stream length of 910 km. Linear morphometric analysis shows a systematic decrease in stream number with increasing order, consistent with Horton's law, while the mean bifurcation ratio (1.83) suggests limited structural control over drainage development. Areal parameters indicate a drainage density of 0.90 km/km² and stream frequency of 0.92 streams/km², reflecting moderate drainage development and infiltration capacity. The basin exhibits an elongated shape, as indicated by a low form factor (0.03) and elongation ratio (0.28), implying reduced peak discharge and prolonged runoff duration. Relief analysis reveals high basin relief (2548.64 m) and a ruggedness number of 2.29, indicating steep terrain and significant erosion potential. Slope and aspect analyses further highlight terrain variability and its influence on hydrological processes

Keywords: Morphometric analysis, Drainage density, GIS, CartoSat-1 DEM, Eastern Nayar watershed, Uttarakhand

1. Introduction

Generally, watersheds are considered as fundamental hydrological units for the study of interaction between terrain and drainage systems and water flows processes (Patel et al., 2012). They offer a natural representation of the function of precipitation, runoff, infiltration and groundwater recharge in a specific catchment. During recent decades, however, humans have put increasing stress on natural resources, which in turn has upset the balance of many watershed systems. In several river basins, environmental quality and hydrological conditions have been impacted by unplanned urban development, deforestation, agricultural development, and overuse of water and soil resources. Water quality degradation and soil degradation are critical environmental issues in many localities. Some of these problems are related to poor watershed management and unsystematic land use.

Due to these concerns that continue to increase, watershed studies are now being widely utilized in environmental planning and resource management. Physical attributes of a watershed directly affect runoff behavior, erosion intensity, sediment transport, and groundwater conditions. Hence, Quantitative Assessment of drainage basins is crucial to understand the hydrological response and evolution of the landscape (Mani & Kumar, 2020). Of the various methods, morphometric analysis has been widely used in geomorphological and hydrological studies. Morphometric analysis involves the numerical measurement of the geometry and relief of drainage basins (Horton, 1945; Strahler, 1964). It assists in the understanding of the development of drainage networks and the effect of basin characteristics on the hydrological processes.

The concept of quantitative geomorphology was first introduced and significantly advanced by Horton, (1945) , who analyzed relationships between stream numbers, lengths, and basin characteristics, thereby laying the foundation for modern morphometric analysis (Joy et al., 2023; Mohaimen et al., 2024). Later, Strahler (1957) added modifications to the stream ordering techniques that were significant for drainage basin analysis. Since then, morphometric applications have been used in various environments to investigate the watershed features and their association with geology, slope, soil and vegetation. Morphometric parameters are typically classified under linear, areal and relief categories (Ahad et al., 2022; Kant et al., 2023; Magesh et al., 2011; Pradeep et al., 2024; Thomas et al., 2012). Linear parameters refer to the arrangement and hierarchy of streams; areal parameters refer to information related to drainage texture, infiltration and potential

runoff. The relief parameters are primarily related to slope of the terrain, ruggedness, and erosional properties of the basin.

The use of Remote Sensing and GIS techniques has grown significantly in the last twenty years in morphometric studies. Previous studies primarily used the topographic maps and manual recordings, which were more time consuming and labor intensive. The availability of DEMs has facilitated comparatively easy and accurate drainage extraction and terrain analysis. In recent years, watershed delineation and hydrological analysis based on a DEM have been increasingly applied, especially in mountainous areas where field investigations are challenging (Moore et al., 1991; Tarboton, 1997). GIS based techniques also offer more effective visualization and systematic analysis of drainage basin characteristics.

The geomorphological sensitivity of the Himalayan region is attributed to steep slopes, active tectonics, fragile lithology and high relief conditions. Due to its geographical location in the Himalayas, Uttarakhand is a land of frequent environmental issues like landslides, erosion, flash floods and slope instability etc. Environmental stress in the region has also been exacerbated by human activities and interventions like road construction, deforestation and unplanned development. Therefore, studies on watershed characteristics and hydrological response are gaining greater significance in the context of sustainable use of the watershed resources (Bhandari & Pande, 2025; Gupta et al., 2021; Valdiya, 2014).

The Easter Nayar watershed is located in Lesser Himalayan region of Uttarakhand and is a mountainous watershed having diversified topographic and geomorphological characteristics. Although the watershed is significant for ecological and agricultural systems, the relationship between detailed morphometric information and basin characteristics is still not well understood. The current research is concerned with morphometric analysis of Eastern Nayar watershed, which is of hydrological importance, by applying GIS based techniques with DEM. The study tries to assess linear, areal and relief parameters to analyze the characteristics of drainage and geomorphic nature of the watershed.

2. Data and Methodology

2.1 Study Area

The Eastern Nayar watershed is located in the Lesser Himalayan region of Uttarakhand and is primarily located in Pauri Garhwal district. It is an important sub-basin of the Ganga River system and a typical Himalayan mountainous watershed characterized by steep slopes, rough

terrain, limited valleys and highly dissected drainage networks. Combined influence of fluvial processes and tectonic events linked with Himalayan orogeny has governed geomorphological evolution of the basin. Continuous incision, erosion and slope instability have had a considerable role in the existing landform layout of the watershed. The watershed is located in the geographical coordinates of 29°45′ N to 30°08′ N latitude and 77°40′ E to 79°10′ E longitude with an area of about 1010.11 km². The elevation of the basin varies from around 508 m to 3056 m above mean sea level (MSL) suggesting a considerable topographic variation in the watershed.

The lithological and structural characteristics of the watershed have been a major factor in the development of its drainage that has resulted in the formation of deep valleys, gorges and complex stream networks. The Eastern Nayar watershed like other Himalayan watersheds is characterized by a monsoon dominated environment with bulk of the annual precipitation occurring during southwest monsoon season. Inside the basin, climatic conditions vary greatly with altitude, with higher elevations experiencing milder temperatures, and the lower valleys remaining relatively warmer (Bhandari & Misha, 2023). The study area map is shown below in Figure 1.

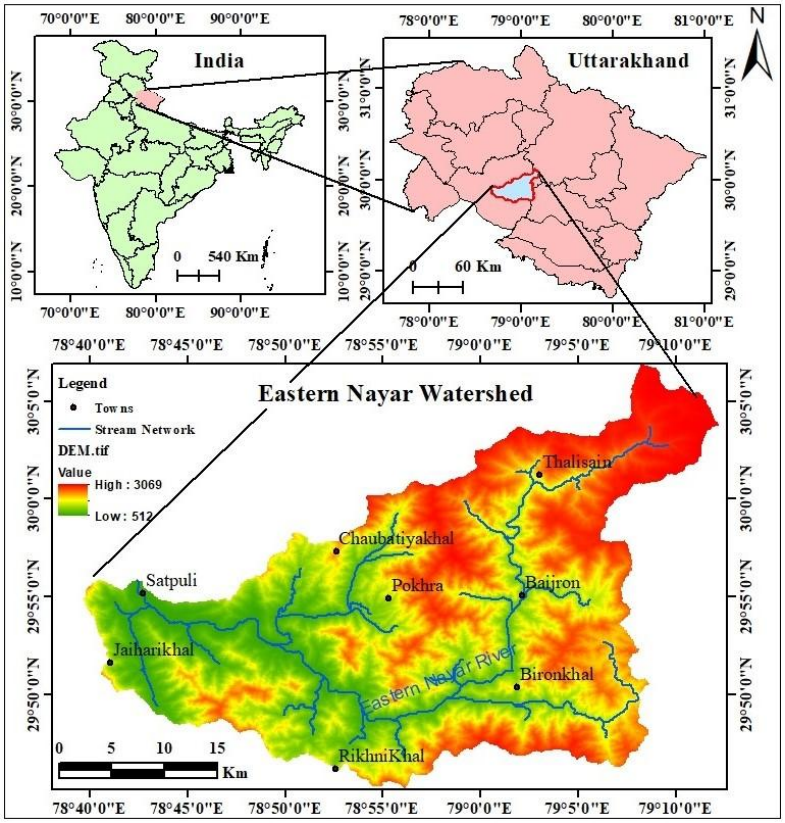

Figure 1. Location map of Eastern Nayar Basin.

2.2. Data Source

The present study is primarily based on CartoSat-1 DEM data and topographical sheets. The CartoSat-1 DEM with a spatial resolution of 30 m was used for watershed delineation, drainage extraction, and terrain analysis of the Eastern Nayar watershed. The DEM data were obtained from the Bhoonidhi ISRO ES's Data HUB [https://bhoonidhi.nrsc.gov.in/bhoonidhi/index.html(assessed on 18/11/2025)]. In addition, Survey of India (SOI) topographical sheets numbered 53J/16, 53K/9, 53K/13, 53N/4, and 53O/1 on a scale of 1:50,000 were used for reference, drainage verification, and preparation of the base map of the study area.

Digital Elevation Models (DEMs) are frequently used to examine drainage network and terrain properties of hydrology and geomorphology, due to the ability to automatically extract drainage networks and terrain properties with high accuracy (Moore et al., 1991; Tarboton, 1997).

2.3 Methodology

The methodology utilized in the present study is DEM pre-processing, watershed delineation, drainage extraction, stream ordering and computing of morphometric parameters. The methodology approach for the study is presented in Figure 2. The main processing phases are outlined below:

2.3.1 DEM Preprocessing

Initially the CartoSat-1 DEM was processed by employing the Fill tool in ArcGIS to remove sinks or depressions. Sink filling is necessary to remove discontinuities in the drainage network and to keep a continuous surface flow over the landscape. The traditional hydrological algorithms were subsequently employed to construct flow direction and flow accumulation maps. The flow direction map shows the direction of surface runoff for each cell and the flow accumulation map shows places where runoff converges and concentrates, thereby revealing potential stream flows. These processes are crucial for DEM-based hydrological modelling (Tarboton, 1997).

2.3.2 Watershed Delineation

The watershed boundary was generated utilizing the flow direction and flow accumulation layers. A Pour point was identified at the basin outlet, and the drainage basin boundary was

delineated utilizing the Watershed tool. The output polygon represents the spatial extent of the East Nayar watershed.

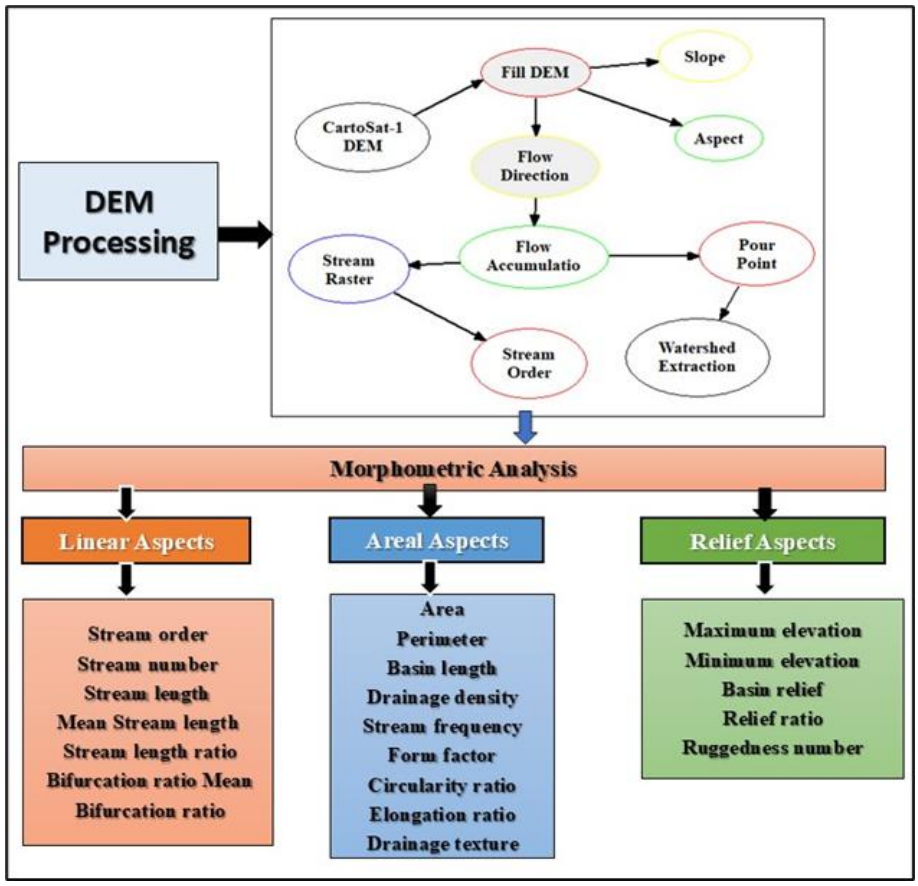

Figure 2. Flow chart of morphometric analysis.

2.3.3 Drainage Network Extraction

Minor discrepancies in the bifurcation ratio were noted in higher stream orders, potentially due to the utilization of high-resolution DEM data, stream-threshold sensitivity, and possibly stream segmentation during raster-to-vector conversion. Similar observations have been reported in DEM-based morphometric studies of structurally complex basins (Nag, 1998; Tarboton et al., 1991). To examine the sensitivity of stream extraction, flow accumulation thresholds of 150, 300, and 600 were tested. Among these, the threshold value of 600 produced a more realistic stream hierarchy with fewer fragmented higher-order streams and was therefore selected for the final morphometric analysis. Cells with accumulation values greater than or equal to the selected threshold were classified as stream pixels. The selected threshold produced an ideal balance

between overgeneralization and undue fragmentation of the drainage network (Nag, 1998; Tarboton et al., 1991).

The raster-based stream network was transformed into polyline (vector) format using the Stream to Feature tool in ArcGIS. The output polyline enabled accurate identification of stream characteristics, including stream length and stream order. Stream lengths were obtained using polyline geometry in a projected coordinate system (meters) and then converted to kilometers for morphometric analysis, ensuring consistency and measurement accuracy.

2.3.4 Stream Ordering

Stream ordering was determined using the Strahler method (Strahler, 1964), which is one of the most widely utilized hierarchical classification systems in morphometric analysis. this method considers the tributaries without branches as first order streams. When two first order streams combine, they form a second order stream. In a similar way the confluence of two second order streams give rise to a third order stream, and so on for higher stream orders. But when streams of multiple orders come together the higher order persists. this method is preferred due to its simplicity and consistency in depicting the drainage hierarchy.

2.3.5 Morphometric Parameter Calculation

Morphometric parameters were calculated under three major categories:

a) Linear parameters describe the characteristics of the drainage network. It includes stream order, stream number, and stream length. These parameters were computed using standard relationships proposed by Horton (1945) and Strahler (1957). Linear aspects help in understanding drainage development, structural control, and basin maturity.

b) Areal morphometric parameters were computed from the delineated watershed boundary derived from the DEM. These factors provide information about the basin geometry such as its area, shape, drainage pattern, capacity of water flow and infiltration properties (Horton, 1945; Schumm, 1956). The standard formulae for these computations were developed by Horton (1945), Strahler (1956), Miller (1953), and Smith (1950) based on measurements of the basin area, perimeter, and length from GIS to ensure uniformity and precision in the technique.

c) Relief morphometric parameters that characterize the vertical size of a basin were derived from elevation data based on DEM. The basic parameters of basin relief, relief ratio and roughness number were calculated by the established methods suggested by Horton (1945), Strahler

(1957) and Schumm (1956). These calculations are based on extreme elevation measurements to evaluate the diversity of the topography and slope characteristics in the watershed.

Table 1. Formulas and Parameters for computation of morphometric analysis

S. No.	Morphometric parameter	Symbol	Formula	Reference
Linear aspects				
1	Stream order	u	Hierarchical ranking	(Strahler, 1964)
2	Stream number	N_u	Count of streams of order	(Horton, 1945)
3	Stream length	Lu	Length of streams of order	(Horton, 1945)
4	Mean stream length	L_{sm}	Lu / Nu	(Horton, 1945)
5	Stream length ratio	R_L	$Lu / (Lu-1)$	(Strahler, 1964)
6	Bifurcation ratio	R_b	$Nu / (Nu+1)$	(Schumm, 1956)
6	Mean bifurcation ratio	R_{bm}	Average of Rb	(Strahler, 1964)
Areal aspects				
7	Drainage density	D_d	$\Sigma Lu / A$	(Horton, 1945)
8	Stream frequency	F_s	Nu / A	(Horton, 1945)
9	Form factor	F_f	A / Lb^2	(Horton, 1945)
10	Circularity ratio	R_c	$4\pi A / P^2$	(Strahler, 1964)
11	Elongation ratio	R_e	$2\sqrt{(A/\pi)} / Lb$	(Schumm, 1956)
12	Drainage texture	T	Nu / P	(Smith, 1950)
Relief aspects				
13	Basin relief	R	$Hmax - Hmin$	(Hadley & Schumm, 1961)
14	Relief ratio	R_r	R / Lb	(Schumm, 1963)
15	Ruggedness number	R_n	$(R / 1000) \times Dd$	(Strahler, 1964)

2.3.6 Slope, Aspect, and Drainage Density Mapping

Slope and aspect maps were created from the DEM using spatial analysis tools in ArcGIS. Slope is the rate of change in elevation and is a primary factor determining runoff and erosion. Aspect is the direction of slope and affects sun radiation and vegetation patterns.

A drainage density map was produced using the Line Density tool and classified into five categories using the Natural Breaks (Jenks) method, which optimizes class intervals based on data distribution.

3. Results and Discussion

This study reveals the morphometric analysis of Eastern Nayar river basin in three aspects (Linear, Areal and Relief). The slope, aspect and drainage density of the basin are also assessed, which forms the basis for understanding the watershed management. These aspects can be determined on the basis of different hydrological parameters that are listed below:

3.1 Linear Morphometric Parameters

Linear morphometric parameters reflect the attributes of drainage network and the geometry of the drainage basin and are important for understanding drainage development, geometry and structural control. These include stream order, stream number, stream length, mean stream length, bifurcation ratio, and length ratio, which are essential for understanding the hierarchical organization of a drainage basin (Horton, 1945; Strahler, 1957).

The number of streams in successive orders follows geometric sequence as shown in Figure 2. The watershed is classified as a fifth order watershed according to Strahler stream ordering system, as shown in Figure 4(a). There are 933 streams in the entire basin with a total stream length (ΣLu) of 910 km (Table 2). The decreasing trend of stream numbers with increasing stream order conforms Horton's law of stream numbers, and suggests a well-organized drainage network (Horton, 1945).

The highest percentage of stream segments are classified as being first order streams. This indicates active geomorphic processes and increased dissection in the watershed. The dominance of lower-order streams is common on and in mountainous areas where slope and relief have a greater influence on the development of drainage (Schumm, 1956; Strahler, 1957).

There is variation in the mean stream length (Lsm) between the stream orders, which reflects the variation in their slopes, topography and drainage characteristics. It is expected that stream length increases with order but some variations in stream order from this relationship may be found attributable to local topographic and lithologic controls (Strahler 1957).

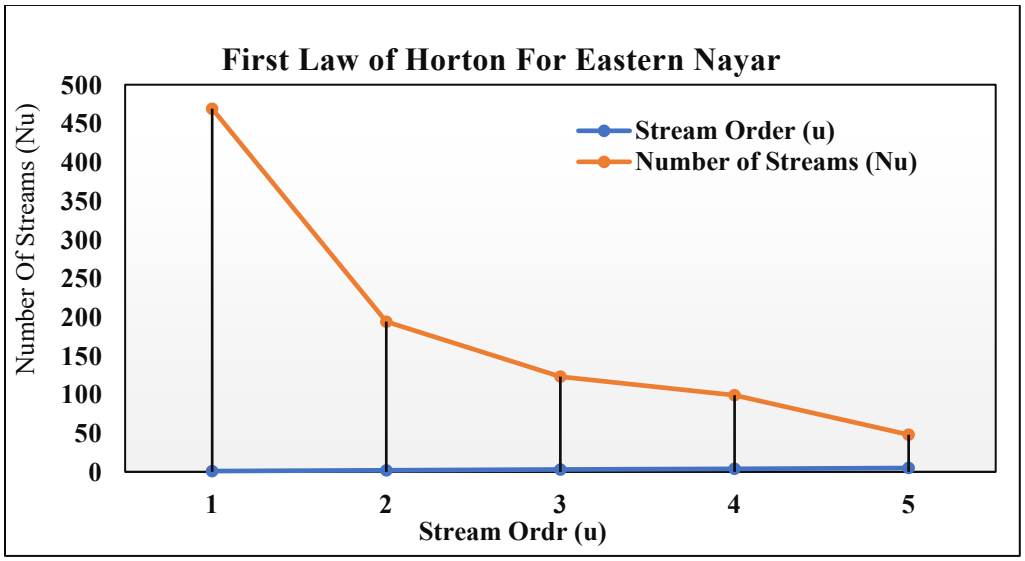

Figure 3. First Law of Horton for Eastern Nayar Basin.

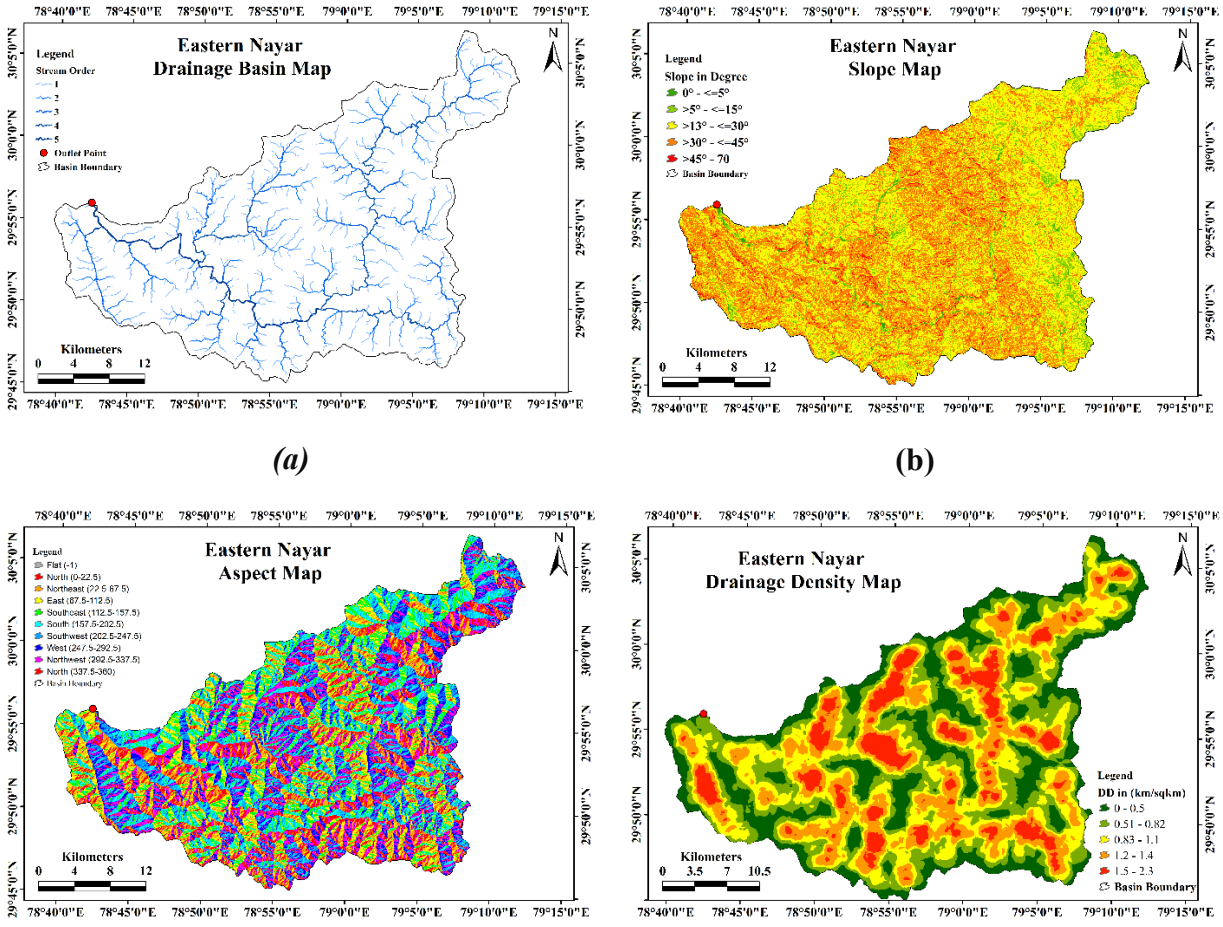

Figure 4. (**a**) Drainage Basin Map; (**b**) Slope Map; (**c**) Aspect Map; (**d**) Drainage Density Map.

Table 2. Linear Aspects of Eastern Nayar River Basin.

Stream Order (u)	No. of Streams (Nu)	Bifurcation Ratio (Rb)	Mean Bifurcation Ratio (Rbm)	Total Stream Length (Lu) (km)	Mean Stream Length (Lsm) (km)	Length Ratio (R_L)
1	469	2.42	1.83	450.57	0.97	—
2	194	1.58		213.81		1.15
3	123	1.24		117.13		0.86
4	99	2.06		86.5		0.92
5	48			41.99		1
Total	**933**			**910**		

The bifurcation ratio (Rb) which is the ratio of number of streams of a particular order to the next higher order varies from 1.24 to 2.42 with a mean bifurcation ratio of 1.83 (Table 2). Strahler (1957) stated that bifurcation ratios are usually between 3 and 5 for a structurally undisturbed basin. Lower values may signal that the basin is less structurally complicated or affected by a homogeneous lithology. The lower mean bifurcation ratio of the Eastern Nayar watershed indicates less structural disruption and it is regulated mostly by topography rather than tectonic processes (Schumm, 1956; Strahler, 1957).

The ratio of the length of the mean stream of successive orders of streams, called length ratio (RL), shows moderate variation among stream orders. This variation is a result of variations in the slope conditions and the geomorphic development of the basin. The uniformity of RL values is generally taken as evidence of uniformity of geological conditions, but if there is considerable variation, it could be a lithologic effect or a structural influence (Horton 1945).

The overall linear morphometric characteristics of the Eastern Nayar watershed suggest a well-developed drainage network with hierarchical structure, with lower order streams dominating. and with relatively low bifurcation ratios. The features as a group imply that the basin is more under surface process and topographic gradient control than by strong structural control.

3.2 Areal Morphometric Parameters

Areal morphometric parameters are parameters that define the two-dimensional qualities of a drainage basin and are essential for understanding the geometry, the drainage texture and the hydrological response of the drainage basin. These characteristics give information on the process of runoff generation, the change in infiltration capacity and the geometry of the basin, all elements that affect the flood response and the dynamics of the watershed (Horton, 1945; Schumm, 1956).

The Eastern Nayar watershed covers an area of 1010.11 km^2, with a basin perimeter of 191.26 km and a basin length of 179.80 km (Table 3). The dimensions and shape of the watershed are important for understanding its hydrologic response to a storm event. Horton (1945) and Schumm (1956) found that the larger basins have delayed peak discharge and longer flow duration than the smaller basins.

The calculated drainage density (Dd) of the watershed is 0.90 km/km^2, which represents coarse drainage texture. Horton (1945) found that lower drainage density values tend to be associated with permeable subsurface materials, dense vegetation cover and low relief, which increase the infiltration and decrease the surface runoff. The relatively low drainage density indicates moderate infiltration capacity and less intense surface runoff within the basin.

Table 3. Areal Aspects of Eastern Nayar River Basin.

Basin area (A) (km^2)	Perimeter (P) (km)	Length (Lb) (km)	Drainage density (Dd) (km/km^2)	Stream frequency (Sf) ($streams/km^2$)	Form factor (Ef)	Circularity ratio (Rc)	Elongation ratio (Re)	Drainage texture (T)
1010.11	191.26	179.8	0.90	0.92	0.03	0.35	0.28	4.88

The stream frequency (Sf) is estimated to be 0.92 $streams/km^2$, which is the number of streams per unit area. The stream frequency is related to the drainage density and is a measure of the intensity of drainage. Lower stream frequencies are normally associated with less dissection of the land and a moderate hydrological response (Horton, 1945).

The shape of the basin is further analyzed by dimensionless parameters like form factor (Ff), circularity ratio (Rc) and elongation ratio (Re). The form factor value of the basin is 0.03, indicating highly elongated basin. Horton (1932) has shown that low form factor basins have low peak flows and longer runoff time.

The elongation ratio (Re) has been computed as 0.28, which confirms the elongated shape of the basin. Schumm (1956) suggested that elongation ratio values close to 1.0 represent circular basins, whereas lower values indicate elongated basins. Generally, elongated basins exhibit lower flood peaks and more sustained runoff.

The circularity ratio (Rc) is 0.35, indicating that the basin is far from circular and has moderate structural influence. Miller (1953) observed that elongated basins have diminished flood peak discharge while circular basins have higher flood peaks and runoff.

The drainage texture (T) is 4.88 indicating moderate drainage texture, suggesting a balance between lithology, slope and climatic factors. Smith, (1950) classified drainage texture into different categories, where moderate values indicate moderate dissection and terrain complexity.

In general, the morphological features of the Eastern Nayar watershed show a low drainage density and moderate drainage texture in the watershed. The following factors indicate a relatively low flood hazard, moderate infiltration and the distribution of the hydrological response over time rather than in short duration peak flows. The results demonstrate the importance of the influence of basin geometry and terrain conditions on the development of drainage and hydrological behavior.

3.3 Relief Morphometric Parameters

Relief morphometric parameters play a crucial role in the study of terrain characteristics, erosion and hydrological behaviour of a drainage basin. They primarily describe the changes in elevation, the slope of the watersheds, the effect of gravity on runoff and the overall energy conditions of the watersheds (Schumm, 1956; Strahler, 1957). Runoff velocity, slope instability and sediment movement processes are mainly regulated by relief in mountainous areas.

The highest elevation of the watershed (H_{max}) in Eastern Nayar watershed is 3056.72 m while the lowest elevation (H_{min}) is 508.08 m, giving a total basin relief (R) of 2548.64 m (Table 4). High basin relief is typically associated with mountainous terrain and indicates significant vertical dissection and potential energy for erosion processes (Schumm, 1956). The substantial elevation difference in the study area reflects the rugged topography of the Lesser Himalayan region

Table 4. Relief Aspects of Eastern Nayar River Basin.

Relief Parameter	Maximum Elevation (Hmax)	Minimum Elevation (Hmin)	Basin Relief	Relief Ratio	Ruggedness number
Unit	m			m/km	
Value	**3056.72**	**508.08**	**2548.64**	**14.17**	**2.29**

The relief ratio (Rr) is defined as the ratio of relief of the basin to the length of the basin and it is 0.014. This parameter is a measure of the total slope of the basin and reflects the rate of change of elevation along the main drainage line. The values of the relief ratios are generally reasonable at the extent of the basin, even for localities with great relief. Such conditions can result in moderate runoff velocities produced throughout the whole watershed (Schumm, 1956).

The roughness number (Rn) which integrates basin relief and drainage density is calculated to be 2.29. This metric represents the structural complexity and the degree of relief dissection in the basin. Ruggedness values higher than the normal suggest a highly dissected terrain highly prone to erosion and mass wasting processes (Strahler, 1956). The high value of the roughness number of the eastern Nayar watershed indicates the basin is geomorphologically active with steep slopes and high erosional processes.

Relief factors are important in determining hydrological processes such as runoff generation, sediment transport and slope stability. In mountainous areas, high topography and steep grades often result in rapid runoff, decreased infiltration and higher erosion rates (Schumm, 1956; Strahler, 1957). The investigated relief characteristics of the Eastern Nayar watershed reveal that topography is a controlling element for drainage development and hydrological behaviour.

In general, the relief morphometric study demonstrates substantial variability of the watershed's elevation, moderate slope at the basin scale and significant terrain roughness. The combination of these factors indicates a geomorphologically dynamic and changing environment with significant consequences for erosion, sediment yield and watershed management.

4.4 Slope

Slope is an important topography parameter that governs surface runoff, infiltration capacity, soil erosion, and the overall watershed hydrological response. An important control on geomorphic processes, especially in mountainous areas, is the rate of change in elevation. Slope characteristics derived from DEMs can provide a quantitative framework to assess terrain variability and its influence on watershed dynamics (Moore et al., 1991).

Table 5. Slope of Eastern Nayar River Basin.

Slope Class (°)	Category	Area (km²)	Area (%)
0–5	Very gentle	**14.87**	**1.47**
5–15	Gentle	**104.36**	**10.33**
15–30	Moderate	**486.21**	**48.13**
30–45	Steep	**376.09**	**37.23**
>45	Very steep	**28.58**	**2.83**

The slope was estimated from the DEM using GIS based spatial analysis and classified as very gentle (0-5°), gentle (5-15°), moderate (15-30°), steep (30-45°) and extremely steep (>45°) in the present study. The classification shows that the moderate slope class (15–30°) is dominant in the watershed and occupies 486.21 km² (48.13%) followed by the steep slope class (30–45°) with 376.09 km² (37.23%) (Table 5 & Figure 4b). The two slope classes together account for about 85.37% of the basin area which indicates that the watershed is mostly dominated by moderate to steep slopes.

The gentle slope class (5-15°) and the very gentle slope class (0-5°) account for 10.33% and 1.47% of the basin area, respectively, mainly distributed in valleys and lower reaches. In these places, infiltration capacity is projected to be relatively high and runoff velocity is likely to be low. However, the very steep slopes (slopes>45°) are limited in extent but have substantial erosion potential and slope instability (Table 5 & Figure 4b).

The low percentage of flat slopes indicates the prevalence of moderate to steep slopes, which implies that the area is characterized by high relief and strong gravity influence on runoff processes. These circumstances are often associated with higher surface flow, greater soil erosion and lower infiltration capacity (Moore et al., 1991; Schumm, 1956). Spatial variation in slope classes suggests geomorphic activity in the upper and middle parts of the watershed whereas lower parts may be more hydrologically stable.

In general, the slope analysis shows the topographic heterogeneity of the Eastern Nayar watershed and highlights to the role of topography in controlling drainage development, erosion processes and hydrological response.

4.5 Aspect

Aspect is the direction slopes are facing and is one of the main terrain parameters affecting microclimatic conditions, solar radiation, soil moisture, vegetation distribution and hydrological processes within a watershed. It influences how much solar energy reaches a surface, which, in turn, affects evapotranspiration rates and surface runoff characteristics. Aspect is an important factor in the mountainous terrain as it has a strong influence on the spatial variability of geomorphic and biological processes (Moore et al., 1991).

In the current study, aspect was determined from the DEM using GIS-based spatial analysis and divided into typical directional classes, namely north, northeast, east, southeast, south,

southwest, west, northwest and flat (Figure 4c). The analysis reveals a varied distribution of slope orientations in the watershed, which reflects the complex topography of the Lesser Himalayan region.

South and south-western-facing slopes are typically more exposed to solar radiation, which can increase evapotranspiration and provide somewhat dry surface conditions. Conversely, north and northeast facing slopes are generally more shaded and exhibit higher soil moisture and more vegetation cover (Moore et al., 1991). Such variations in slope orientation contribute the variability in hydrological response and erosion processes across the watershed.

The diversity of aspect classes shows substantial spatial variation in microclimatic conditions in the Eastern Nayar watershed. This variability impacts not just hydrological processes but also land-use and vegetation dynamics in the basin. Flat areas are mainly confined to valley bottoms, and may be areas of sediment deposition and ground water recharge, but limited in extent.

In general, the aspect analysis highlights the relevance of the slope orientation in shaping the environmental and hydrological characteristic of the watershed. The integration of aspect with other morphometric parameters provides a more comprehensive understanding of terrain behaviour and assists in the development of informed watershed management strategies.

5. Conclusion

The present study reveals the efficacy of GIS and DEM based morphometric analysis for assessing the geomorphic and hydrological parameters of the Eastern Nayar watershed of the Uttarakhand Himalaya. The watershed was identified and analysed using linear, areal and relief morphometric parameters with the help of CartoSat-1 DEM and ArcGIS based hydrological tools. The watershed was classified as a fifth order basin with the predominance of first-order streams indicating active geomorphic processes and strong topographic control on drainage development. The relatively low mean bifurcation ratio indicates less structural disturbance and a relatively uniform lithological influence within the basin. Areal morphometric parameters suggest an elongated shape of the watershed with a somewhat delayed peak discharge and modest flood potential. The values of drainage density and stream frequency reveal moderate runoff and infiltration characteristics. Relief and slope analyses show wide variation in elevation and dominance of moderate to steep slopes which are indicative of strong runoff potential, active erosion processes and terrain instability in various portions of the watershed. The analysis of aspects also reveals the influence of the slope orientation on the microclimatic and hydrological

conditions. The distribution of drainage density shows regional heterogeneity in runoff concentration and erosion susceptibility in the basin. In general, the present study demonstrates that the terrain morphology has significant control over the hydrological behavior and geomorphic evolution in the Eastern Nayar watershed. The combined use of GIS and remote sensing techniques is a powerful and effective means for watershed characterization and can be beneficial for sustainable watershed management, soil and water conservation planning and erosion control measures in the Himalayan region.

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