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Geomorphometric Insights into the Dharla and Teesta River Basins through GIS and RS Methods

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Abstract

This study employs morphometric analysis using Geographic Information System (GIS) and Remote Sensing (RS) techniques to evaluate and compare the geomorphometric and hydrological characteristics of the Dharla and Teesta river basins in northern Bangladesh. Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (30 m) data were used to delineate drainage networks and compute morphometric parameters from linear, areal, and relief aspects. Findings indicate that the Dharla River Basin (623.25 km²) is a fifth-order elongated basin characterized by moderate dissection, active erosion, and high flash flood vulnerability. In contrast, the Teesta River Basin (1,901.33 km²) exhibits a more complex drainage structure and regional-scale flooding patterns due to its Himalayan-fed origin and braided channels. By integrating SDG 6 (Clean Water and Sanitation) and SDG 13 (Climate Action)**,** this research underscores the importance of morphometric assessment for sustainable watershed management, erosion mitigation, and climate-resilient flood control in northern Bangladesh.

Keywords

Morphometric Analysis, GIS, Remote Sensing, River Basin, SDG 6, SDG 13

Introduction

River basins are the fundamental geomorphic and hydrological units that control the water movement, sediment transportation, and evolution of landforms. Quantitative description of basin and channels broadly known as morphometric analysis is essential for interpreting its hydrological behavior, dynamics of geomorphic processes, and general response to natural and human-induced stress (Grabowski et al., 2014). Morphometric analysis includes the quantitative measurement of basin geometry, stream networks, relief, and drainage patterns, provides a scientific way to evaluate watershed dynamics and geomorphic development (Raja Shekar & Mathew, 2024).

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Traditionally, such analyses relied on ground level field surveys and topographic maps but modern Geographic Information Systems (GIS) and Remote Sensing (RS) have transformed this field by enabling accurate, quick, and reproducible extraction of drainage networks, basin boundaries, and topographic derivatives extracted from digital elevation models (DEMs) and satellite images. The combined GIS and RS approach allows researchers to compute a wide range of linear, areal, relief, and shape indices at multiple scales and to compare basin behavior across spatio-temporal contexts. In South Asia, rivers originating from the Himalayas and their tributaries play a crucial role in supporting sustaining ecosystems, agricultural practices, and human settlements; however, they are also linked with recurring hazards such as flooding, channel migration, and riverbank erosion (Rasul, 2014). Among these, the Dharla and Teesta rivers in northern Bangladesh hold significant hydrological and geomorphological importance. The Teesta, a major Himalayan River, demonstrates significant seasonal variability in discharge, features extensive braided sections in its middle and lower courses, and is characterized by dynamic floodplain processes that profoundly influence agriculture and infrastructure (Khan, 2018). The Dharla despite being smaller in size, exhibits active channel movement, bank erosion, and specific flood risks within its course in Bangladesh (Rahman et al., 2023). Together, these river basins span contrasting physiographic settings (from steep, tectonically active headwaters to low-gradient alluvial plains), making them well suited to a comparative study that links morphometric characteristics with hydrological and geomorphic dynamics. Various studies have applied GIS-based morphometric and prioritization techniques in these basins (and their sub-watersheds), demonstrating both the practicality and the policy relevance of such analyses for erosion control and watershed management (Rahman et al., 2023; Uddin et al., 2024).

Despite being critical for drainage development and landscape evolution throughout these regions, comprehensive morphometric analyses throughout the Dharla and Teesta basins are rare and particularly performed with high-resolution DEMs and advanced GIS-RS methodologies. A number of morphotectonic and morphometric studies have focused on the Teesta catchment, especially in its upper tracts over the Sikkim Himalaya, where active tectonic activity and steep gradients create typical drainage regimes and high erosional potential (Sarkar & Gayen, 2025). Morphometric investigations of the Dharla basin and its sub-watersheds have applied GIS-derived parameters together with multivariate statistical techniques (such as principal component analysis and weighted-sum models) to prioritize erosion-prone sub-basins and inform soil-conservation planning (Mamun & Sobnam, 2020).

Although a number of GIS-RS morphometric studies exist for Himalayan rivers and for parts of Bangladesh, several gaps remain: (1) direct comparative studies that analyze two neighboring transboundary basins (one larger, tectonically fed, Teesta and one smaller and highly dynamic, Dharla) using the same high-resolution DEM and identical processing workflow are limited; (2) many prior works focus on sub-watershed prioritization or single-parameter assessments, whereas a systematic cross-basin comparison of a full suite of linear, areal, shape, and relief indices can better reveal contrasting geomorphic maturity and hydrological behavior; and (3) sensitivity analyses that document how DEM resolution, accumulation thresholds, and ordering methods affect moors are seldom reported in enough detail to ensure reproducibility.

By applying a replicable GIS–RS workflow to delineate basin boundaries, extract drainage networks, compute a set of comprehensive morphometric parameters, and compare the Dharla and

Teesta basins in a shared methodological context, this study aims,

- to delineate the drainage basin boundaries of the Dharla and Teesta Rivers using GIS and remote sensing data;
- to compute morphometric parameters for the Dharla and Teesta River basins;
- to assess the morphometric characteristics of both basins in their hydrological and geomorphological behavior;
- to demonstrate the effectiveness of GIS and RS techniques in morphometric analysis and geospatial characterization of river basins.

Study Area

This research focus on two major river systems in northern Bangladesh. The Teesta and the Dharla both rivers share a common origin in the Eastern Himalayas and eventually join the Brahmaputra-Jamuna River system (Jain et al., 2007). Despite sharing the same sources, the two basins are different significantly in size, hydrology, and geomorphic nature.

The Teesta River is sourced from the Tso Lhamo Glacier in Sikkim, India, at an elevation of more than 5,000 meters (Dahal et al., 2024). The river flows across the hill country of Sikkim and West Bengal and drains into Bangladesh in the district of Lalmonirhat. In Bangladesh, it flows through Rangpur and Nilphamari districts and into Brahmaputra at Chilmari in Kurigram. The Teesta's basin is large and complex. Overall size is 12,000 km^2, with some 2,800 km^2 in Bangladesh (Goyal & Goswami, 2018). It is characterized by its extremely seasonal variation: very low discharge in the dry season, followed by catastrophic floods in monsoon. The braided channel, migrating sand bars, and very dynamic floodplains of the river all mirror its geomorphologically dynamic nature. The Dharla River, rising in the Bhutan and Indian hills, it enters Bangladesh via Kurigram District and flows southwards further until it merges into the Brahmaputra (Baillie & Norbu, 2004). Its basin is much smaller than the Teesta's. About 1,500 km^2 inside Bangladesh, yet it is no less significant (Jain et al., 2007). The Dharla is a flood prone area with severe bank erosion and frequent channel shifting. These causes heavy damage to local communities and environment. The banks of Dharla river are highly unstable which make it more meandering than braided.

The Teesta and Dharla river basin together form fertile floodplains in northwestern Bangladesh, where agriculture dominates and livelihoods are linked to the cycle of the rivers. Figure 1 presents the study area map highlighting the drainage boundaries of the Dharla and Teesta River basins.

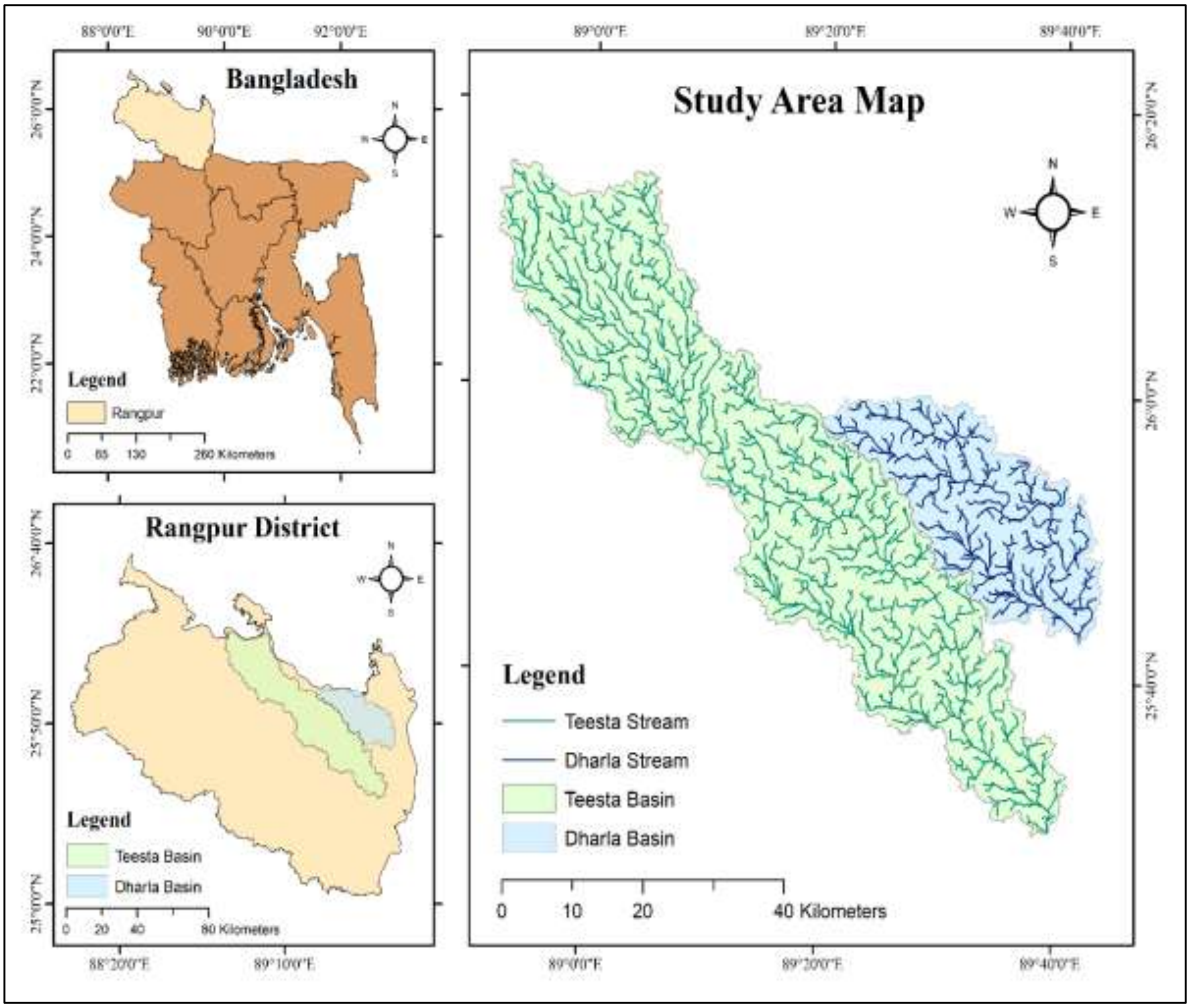


Figure 1: Study Area Map.

(Source: Compiled by Authors, 2025)

Methodology

The morphometric analysis of the Dharla and Teesta River basins was carried out using an integrated approach that combined remote sensing data, digital elevation models (DEMs), and GIS-based tool. The entire methodological process was structured into five stages: (i) data acquisition, (ii) preprocessing and standardization, (iii) drainage network and watershed delineation, (iv) computation of morphometric parameters, and (v) analysis, interpretation, and cartographic presentation. The methodological framework adopted in this study is illustrated in the flowchart below (Figure 2).

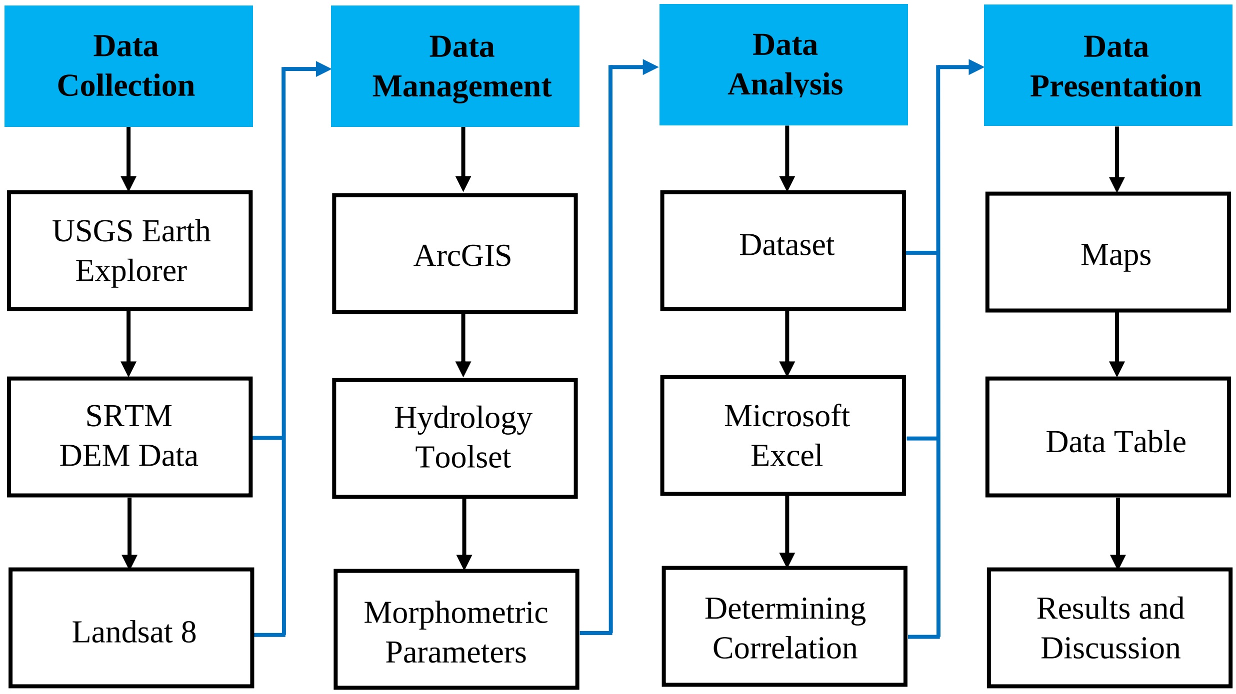


Figure 2: Methodological Framework *(Source: Compiled by Authors, 2025)*

A 30 m resolution Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) was obtained from the USGS Earth Explorer, while Landsat-8 OLI imagery was used to validate drainage networks and basin boundaries. All datasets were projected to UTM Zone 45N (WGS 84 datum) for spatial consistency, and DEM preprocessing (mosaicking, clipping, and sink filling) was performed to ensure accuracy in hydrological modeling.

Hydrological tools in ArcGIS 10.8 were applied to delineate drainage networks and watershed boundaries. Flow direction and flow accumulation raster were generated using the D8 algorithm, and stream networks were extracted based on flow accumulation thresholds. Stream ordering was performed according to the Strahler (1952) method. Basin polygons were delineated using identified pour points at the confluence of the Dharla and Teesta with the Brahmaputra–Jamuna and validated against satellite imagery and topographic maps.

Morphometric parameters were calculated in four groups: (i) linear aspects (stream order, stream number, stream length, bifurcation ratio, drainage density, stream frequency), (ii) areal aspects (basin area, perimeter, length, form factor, elongation ratio, circularity ratio, compactness coefficient), (iii) relief aspects (basin relief, relief ratio, ruggedness number) and (iv) basin geometry (basin perimeter, length of basin, maximum elevation, minimum elevation). Standard formulae by Horton (1945), Strahler (1952), and Schumm (1956) were applied, with computations carried out in ArcGIS 10.8 and results tabulated in Microsoft Excel. (Table 1) represent morphometric parameters, formula with references used in this research.

Table 1. Morphometric Parameters, Formula with References

SI No	Parameters	Formula	References
		Drainage Network (Linear Aspect)	
1	Stream order	Hierarchical Rank	Strahler (1964)
2	Stream number (Nu)	Nu =N1+N2+…….Nn	Strahler (1964)
3	Stream Length (Lu)	Lu =L1+L2+……..Ln Lu = Total stream length of order 'u'	Horton (1945)
4	Mean Stream Length (Lsm)	Lsm = Lu/Nu Lsm = mean stream length, Lu = total stream length of order u, Nu = total no. of stream segments of order u	Strahler (1964)
5	Bifurcation Ratio (Rb)	Rb = Nu/Nu+1 Rb = bifurcation ratio,	Schumm (1956)
6	Mean bifurcation ratio (Rbm)	Rbm = average of bifurcation ratios of all orders	Strahler (1957)
7	Drainage Density (Dd)	Dd = ΣLu / A (ΣLu = total length of streams, A = basin area)	Horton (1932)
8	Stream Frequency (Fs)	Fs = ΣNu / A (ΣNu = total no. of streams, A = basin area)	Horton (1932)
		Basin Texture analysis (Aerial Aspect)	
1	Basin Area (A) (km^2)	GIS analysis	
2	Form Factor (Ff)	Lar = A/Lb2	Horton (1932)
3	Circulatory Ratio (Rc)	$Rc = 4\pi A / P^2$ (A = basin area, P = perimeter of basin)	Miller (1953)
4	Elongation Ratio (Re)	$Re = (2\sqrt{(A/\pi)}) / Lb$ (A = basin area, Lb = basin length)	Schumm (1956)
5	Compactness Coefficient (Cc)	$Cc = 0.2821 \times (P / \sqrt{A})$ (P = perimeter, A = basin area)	Gravelius (1914)
		Relief Characteristic (Relief Aspect)	
1	Basin Relief (Hb)	Hb = Ma – Mi	Schumm (1956)
2	Relief Ratio	Rh=Hb/ Lb	Schum (1963, 1956)

3	Ruggedness number	Rn = Hb × Dd (Hb = basin relief, Dd = drainage density)	Strahler (1958)
		Basin Geometry	
1	Basin Perimeter (P) km	GIS analysis	Horton (1932)
2	Length of Basin	GIS analysis	Schumm (1956)
3	Maximum elevation	Obtained from DEM	
4	Minimum elevation	Obtained from DEM	

(Source: Compiled by Authors, 2025)

Finally, a comparative analysis of the Dharla and Teesta basins was performed to assess their geomorphometric signatures and interpret hydrological and geomorphic behavior, with specific attention to flood potential, erosion susceptibility, and basin maturity.

Results and Discussion

Linear Aspects

The Dharla Basin is classified as a fifth-order basin containing 260 streams. Among these, 201 are first-order, 44 second-order, 11 third-order, three fourth-order, and one fifth-order stream. The predominance of first-order streams reflects youthful geomorphic conditions and active erosional processes. The total stream length of the basin is 530.74 km, of which first-order streams alone account for 279.71 km. This conforms to Horton's law, with stream length generally decreasing as stream order increases. The mean bifurcation ratio (Rb) of the Dharla Basin is 3.81, which lies within the normal range of 3–5, suggesting that the drainage network is structurally stable and largely influenced by topography. The basin's drainage density (0.852 km/km²) and stream frequency (0.417) indicate a moderately dissected terrain with a balance between infiltration and surface runoff (Table 2).

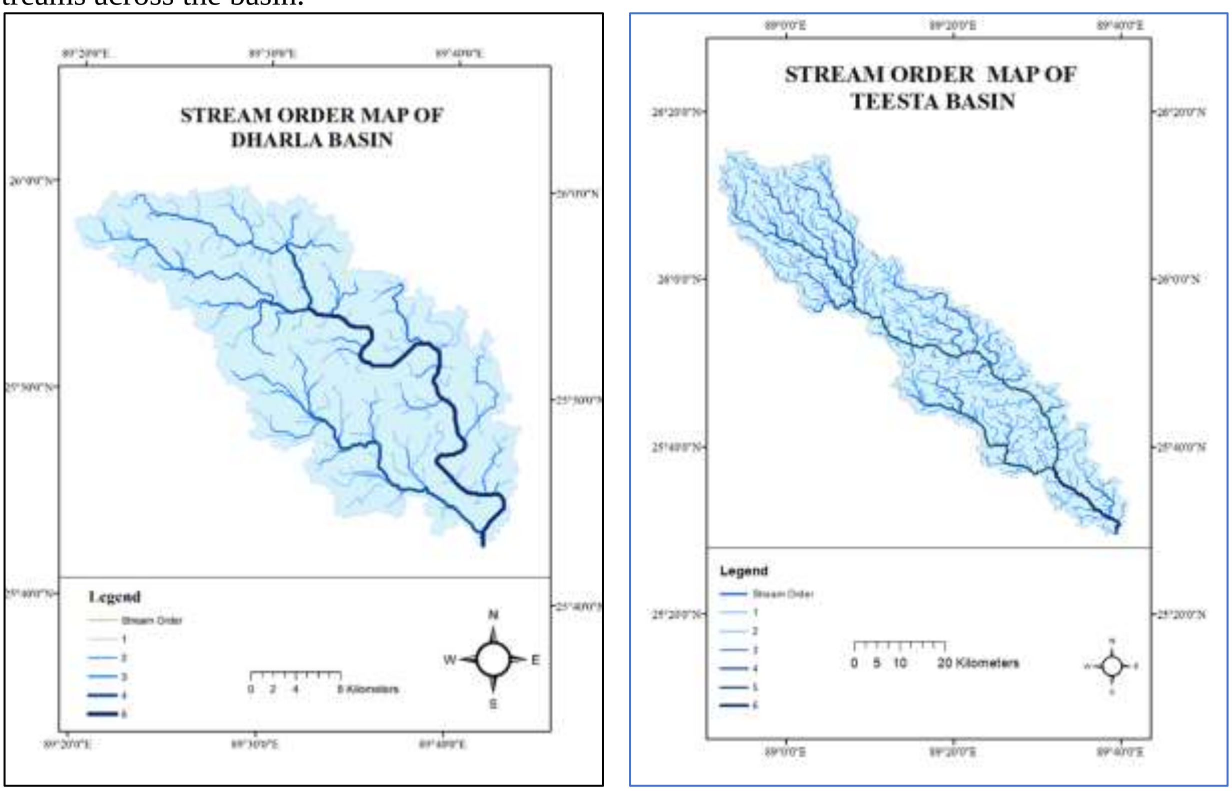
Table 2. Drainage Network (Linear Aspect) parameters of Dharla River

Basin	**Order**	**Number of Stream**	**Total Number of streams**	**Stream Length (km)**	**Total steam length (Lu) km**	**Bifurcation Ratio (Rb)**	**Mean Bifurcation Ratio (Rb)**	**Drainage Density (Dd)**	**Stream Frequency (Fs)**
Dharla	1st	201	260	279.71	530.74	4.568	3.81	0.852	0.417
	2nd	44		119.25		4			
	3rd	11		54.09		3.67			
	4th	3		34.76		3			
	5th	1		42.93		-			

Teesta	1st	612	771	780.72	1652	5.02	4.88	0.869	0.406
	2nd	122		463.34		4.2			
	3rd	29		218.33		5.8			
	4th	5		64.62		2.5			
	5th	2		101.93		2			
	6th	1		22.996		5.02			

(Source: Compiled by Authors, 2025)

The Teesta Basin, also a fifth-order system, contains a total of 771 streams. Of these, 612 are first-order, followed by 122 second-order, 29 third-order, five fourth-order, and three higher-order streams. This extensive branching network indicates strong hydrological activity and complex drainage organization. The total stream length of the basin is 1,652 km, with first-order streams accounting for 780.72 km. The decreasing trend of stream length with increasing order confirms Horton's law. The mean bifurcation ratio is higher in Teesta (4.88) than in Dharla, reflecting greater branching and a more complex drainage system, which can be attributed to its Himalayan-fed origin. The drainage density (0.869 km/km²) and stream frequency (0.406) suggest moderate to high surface runoff potential, especially during monsoonal floods, consistent with its braided channel system and high sediment load. The spatial distribution of stream orders for Dharla and Teesta river basin is illustrated in Figure 3, which clearly shows the dominance of first-order streams across the basin.

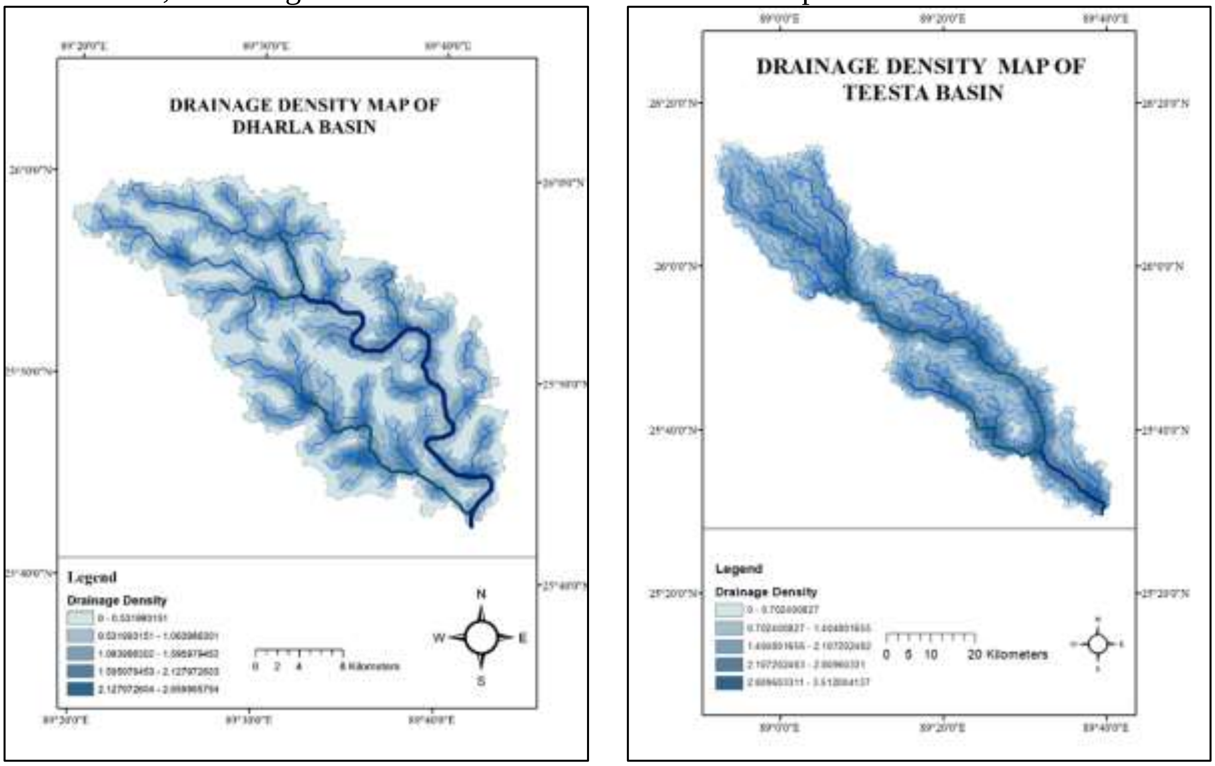


3(A) 3(B)

Figure 3. Spatial distribution of stream orders in Dharla and Teesta River Basin, where 3(A) and 3(B) represents Stream Orders of Dharla and Teesta Basin respectively.

(Source: Compiled by Authors, 2025)

The drainage density distribution (Figure 4) highlights zones of relatively higher channel concentration, reflecting localized terrain dissection and runoff potential.



4(A) 4(B)

Figure 4. Drainage density map of the Dharla and Teesta River Basin where 4(A) and 4(B) represents Drainage Density of Dharla and Teesta Basin respectively.
(Source: Compiled by Authors, 2025)

Areal Aspect

Table 3 presents the areal parameters of the Dharla and Teesta River basin highlighting the basin area, form factor, circulatory ratio, elongation ratio, compactness coefficient. The Dharla Basin covers an area of 623.25 km² with a basin length of 47.2 km and a perimeter of 196.65 km. Its form factor (0.28), elongation ratio (0.5968), and circulatory ratio (0.2025) reveal an elongated basin geometry. The compactness coefficient of 2.22 further supports this elongation. Such morphology tends to produce delayed hydrographs with prolonged runoff, reducing the risk of sudden flash floods but contributing to seasonal inundation.

Table 3. Aerial Aspects Parameters of Dharla and Teesta River

Basin	Basin Area (A) (km^2)	Form Factor (Ff)	Circulatory Ratio (Rc)	Elongation Ratio (Re)	Compactness Coefficient (Cc)
Dharla	623.249	0.28	0.2025	0.5968	2.22
Teesta	1901.332061	0.142	0.125	0.426	2.82

(Source: Compiled by Authors, 2025)

The Teesta Basin spans 1,901.33 km² with a length of 115.58 km and a perimeter of 436.36 km. Its form factor (0.142), elongation ratio (0.426), and circulatory ratio (0.125) all indicate an elongated basin shape. The compactness coefficient of 2.82 emphasizes this elongation, which contributes to delayed peak flows and extended flood durations. This morphological setup reduces flash flood intensity but enhances prolonged flood hazards, typical of the Teesta's lower floodplains.

Relief Aspects

The relief aspects parameters of the Dharla and Teesta River Basin are presented in Table 4. The Dharla exhibits a basin relief of 0.059 km and a relief ratio of 0.00125. Despite its relatively low relief, these values suggest moderate slope conditions and some degree of vertical dissection. The ruggedness number (0.0502) indicates a low but non-negligible susceptibility to erosion under intense rainfall events. Together, these relief parameters point to a basin that is geomorphologically active, prone to localized erosion and flooding, and sensitive to seasonal discharge fluctuations.

Table 4. Relief aspects parameters of the Dharla and Teesta River

Basin	Basin Relief (Bh)	Relief Ratio (Rh)	Ruggedness Number (Rn)
Dharla	0.059 km	0.00125	0.050268
Teesta	0.077 km	0.00067	0.0669

(Source: Compiled by Authors, 2025)

The Teesta Basin has a basin relief of 0.077 km and a relief ratio of 0.00067, slightly higher in vertical dimension than Dharla but reflecting generally flat alluvial plains in Bangladesh. The ruggedness number (0.0669) suggests moderate erosional susceptibility, particularly in upstream reaches with steeper slopes and higher discharges (Table 4).

Basin Geometry

Basin Geometry of the Dharla River Basin are presented in Table 5. The Dharla River Basin extends over a length of 47.2 km with a total perimeter of 196.65 km. Its maximum elevation reaches 0.053 km, while the minimum elevation drops slightly below mean sea level to –0.006 km, which is typical for low-lying floodplain environments in northern Bangladesh. On the other hand, Teesta River Basin have 0.080 km minimum drop in elevation rises maximum up to 0.003km within its 115.58km length and 436.36km perimeter.

Table 5. Basin Geometry of Dharla and Teesta River

Basin	Perimeter	Basin Length	Minimum elevation	Maximum elevation
Dharla	196.65 km	47.2 km	-0.006 km	0.053 km
Teesta	436.36 km	115.58 km	0.080 km	0.003 km

(Source: Compiled by Authors, 2025)

Comparative Insights'

Dharla and Teesta are elongated fifth-order and sixth-order basins respectively thus, their morphometric contrasts are clear. The Teesta, being larger, shows greater stream numbers, lengths, and bifurcation ratios, highlighting its higher hydrological responsiveness and sediment transport capacity. The Dharla, though smaller, records slightly higher relief ratio and stream frequency, indicating more intense localized erosion and channel instability. Both basins are prone to seasonal flooding, but the Teesta is associated with large-scale, prolonged inundations, whereas the Dharla tends to produce localized, high-energy floods and severe bank erosion.

Conclusion

The morphometric analysis of the Dharla and Teesta River basins, carried out using GIS and remote sensing techniques, provides valuable insights into their geomorphic and hydrological characteristics. Both basins are fifth-order drainage systems with dendritic patterns, yet they differ significantly in scale, structure, and geomorphic behavior.

The Dharla Basin, though relatively small (623.25 km²), is characterized by a higher stream frequency, moderate drainage density, and slightly higher relief ratio. These parameters suggest active local erosion, unstable channel migration, and susceptibility to flash floods. Its elongated shape indicates delayed runoff peaks but also reflects prolonged inundation during monsoonal rains. The Teesta Basin, in contrast, covers a much larger area (1,901.33 km²) with a more extensive drainage network and higher bifurcation ratio. Its hydrological response is strongly influenced by its Himalayan-fed origin, producing higher seasonal discharges, braided channel systems, and widespread but prolonged floods. Although its relief ratio is lower than that of Dharla, the Teesta's larger scale and complex drainage organization make it more influential in shaping the northern Bangladesh floodplain. Future studies could integrate hydrological time-series data (discharge and rainfall) with morphometric parameters to develop predictive flood and erosion models, further strengthening the link between geomorphometric characteristics and basin-scale hazards.

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