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Hydro-morphological investigations of Neeru watershed using DEM and geospatial techniques

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Abstract
Morphometric analysis is very popular among the hydro-geomorphological investigation of the river basins that deals with the linear, areal, shape and landscape aspects of river catchment. Neeru watershed, a left-bank tributary of the Chenab River (Doda, Jammu and Kashmir, India). Carto-DEM, Sentinel-2B multispectral satellite image and Topographical maps taken into account for extracting and computing watershed's various parameters adopting the geospatial techniques. This northern aligned watershed has a length, width, and perimeter of 65 km, 22.4 km, and 106.03 km, respectively, and covers 415.19 sq. km area. It is a 5th stream order watershed, with lower-order streams predominating. The drainage density of 0.81 km/km^2 indicates that it is highly permeable and thus has increased subterranean water storage capacity. The bifurcation ratio varies from 2 to 4.74, with a mean of 3.67, demonstrating strong structural control over drainage development. The study area's elongation ratio (0.67) indicates that it has an elongated shape with high relief, steep slope, high sediment load discharge, and susceptible soil erosion. The assessment indicates the role of geospatial techniques in quick appraisal of ecological indicators they will be helpful for decision makers in managing natural resource, planning, and watershed management.

Keywords: Himalayan watershed, Neeru river, Chenab river, morphometric parameters, digital elevation model

1. Introduction

Water is valuable resource and vital for all biological lives, as it gives us life and vocation (Loucks, 2000) [11]. The demand for water has risen dramatically due to population growth, water irrigation systems, and industrialization. Watershed management is necessary to achieve sustainability, and the study of watershed morphometry is an essential aspect of (Javed *et al*., 2009; Yadav *et al*., 2018; Kumar *et al*., 2021) [8, 15, 10]. Morphometric analysis is required for any hydrological investigation, including assessing and managing groundwater potential, sub-watershed prioritization, Pedology, and environmental impact (Sreedevi *et al*., 2009; Choudhari *et al*., 2018; Kumar *et al*., 2021; Kumar *et al*., 2022) [14, 7, 10]. Horton first developed it (1932) and the idea was later developed by Strahler (1952) and Coates (1956).

Morphometric analysis is the measurement and mathematical computation of the Earth's surface morphology and shape and size of its landforms (Clarke, 1966). It is the quantitative analysis of the area's shape, altitude, density, slope, profile, and drainage basin features (Savinder Singh, 1972). Drainage basin analysis is one of the most important components of any hydrological investigation. It provides essential information on the quantitative assessment of the drainage system, which is an integral aspect of basin characterization (Strahler, 1957). The analysis may assess by measuring the particular watershed's linear, aerial, and relief aspects (Nag & Chakraborty, 2003) [12]. The watershed is a natural hydrological unit delineated by topographic highs that regulate the progression and occurrence of surface water. Rivers, which are pretty significant landforms, are susceptible to tectonic movements and work efficiently as the primary component of fluvial landforms, permitting us to grasp quaternary tectonic activity in a particular area (Strahler, 1952).

In geomorphological studies, geospatial morphometric analysis is an effective technique (Kumar & Negi, 2016) [9]. Currently, remote sensing and GIS techniques have emerged as influential assets for watershed management. Previously, Srivastava and Mitra (1995), Srivastava (1997), and Agarwal (1998) [2] initiated morphometric analysis utilizing remote sensing techniques, and they believe that remote sensing techniques provide vital tools for morphometric analysis. The present study investigates numerous morphometric parameters utilizing remote sensing and GIS technologies to demonstrate the diverse geomorphic aspects of the Neeru watershed in the Bhaderwah Valley. In order to enhance watershed management, calculated morphometric parameters are used to determine characteristics such as drainage frequency, drainage density, slope and aspect, relative and absolute relief, geomorphology, and topographic conditions of the watershed.

2. Study area
The Neeru watershed is situated in the district Doda of Jammu and Kashmir (Fig. 1) and encompasses an area of 415.19 km^2. The Neeru River is an important left-bank tributary of the Chenab River (Western Himalayan region). It is located in the southern part of the district and extended between 32° 46' 59"N to 33° 04' 5.84" N latitude and 75° 32' 41" to 75° 45' 78" E longitude. The river originates from the Kailash Kund (3982 m Asl) at 32° 52' 31.63" N latitude and 75° 41' 7.86" E longitude, which flows northward in the Bhaderwah valley and makes its confluence with the holy Chenab at Pul Doda (837 m Asl). It is a perennial river fed by the melting snow and ice from the peaks of Kablas, Seoj, Khol, and Ghatti. The climate in the area is cold and arid, with hot summers and long dry winters. In the winter, the temperature in the region drops freezing point and varies primarily with altitude.

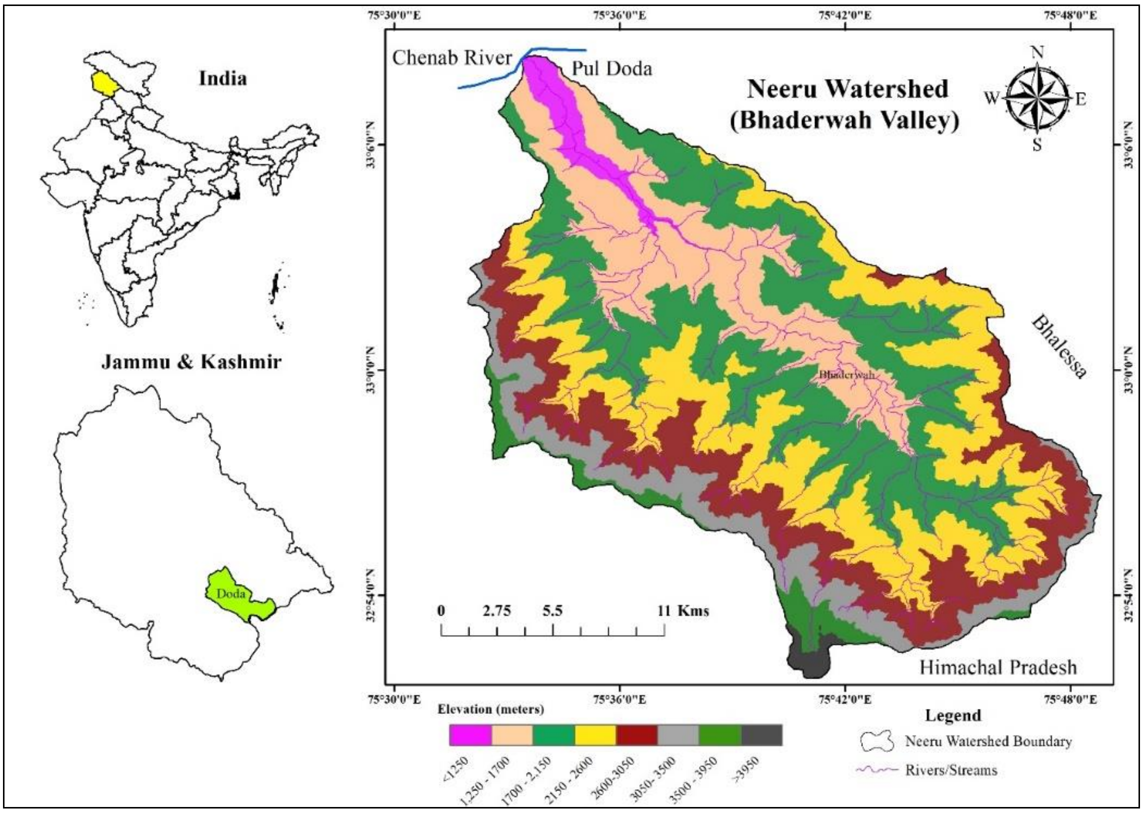

Fig 1: Location and Absolute relief map of the Neeru watershed.

Table 1: Landuse/Landcover distribution and its areal coverage in Neeru river watershed

Class	Area (sq km)	%
Evergreen Broad-leafed Forest	14.46	3.48%
Evergreen Needle-leafed Forest	283.3	68.23
Deciduous Broad-leafed Forest	55.06	13.26
Deciduous Needle-leafed Forest	8.01	1.93
Agricultural Land	23.45	5.65
Build-up Land	13.65	3.29
Shrubland	0.2	0.05
Waterbodies	11.03	2.66
Wasteland	0.33	0.08
Wetland	1.5	0.36
Snow Cover	4.2	1.01

3. Data used and methodology
The present study focuses on morphometric analysis of the Neeru watershed to ascertain various morphometric parameters. The drainage network and watershed boundary were extracted using Survey of India topographical sheets (43O/2 and 43J/3) at a scale of 1:50,000. Further, the Sentinal-2B satellite images (10 m spatial resolution) were also used to modify the drainage network. Additionally, a Cartosat DEM with a spatial resolution of 30m was employed to assess the parameters such as slope, aspect, and relief. The geological data were obtained from the Geological survey of India (http://bhukosh.gsi.gov.in/Bhukosh/Public).

For landuse/landcover, Landsat-8 satellite images were acquired from the USGS Portal (www.earthexplorer.usgs.gov), and the final map was generated in ArcGIS using supervised classification (Fig. 2). The study is divided into three significant aspects: linear, areal, and relief (Fig. 2). Measurement of parameters such as stream order, stream length, stream length ratio, length of overflow, bifurcation ratio, and drainage patterns are included in the linear aspect (Table 3). The areal aspect comprises the following: watershed area, length, width, perimeter, form factor, elongation ratio, circulatory ratio, drainage texture, drainage density, drainage frequency, and drainage intensity (Table 3). The relief aspect comprises relative relief, absolute relief, relief ratio, slope/aspect, hypsometric integral, ruggedness number, and dissection index.

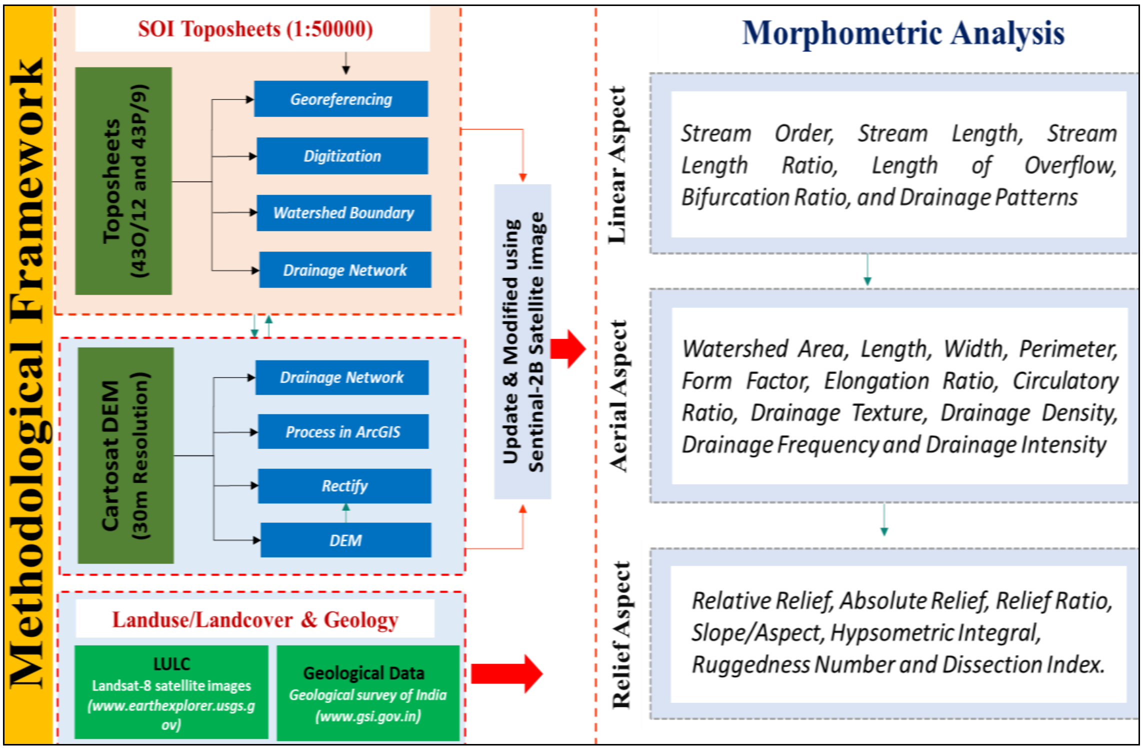

Fig 2: Methodological framework and data used in the study.

Table 2: Litho-tectonic succession and different rock groups.

Age	Group	Formation	Lithology	Area (Km^2)	%
Pleistocene - Holocene	Un-diff. Quaternary	----	Alluvium, Moraines, Hill wash & Scree	12.58	3.03
Neoproterozoic	---	Manjir = Langera	Diamictite, Shale, Slate, Sandstone, Limestone	8.46	2.04
Proterozoic (Un-diff)	Vaikrita	Chamba	Carbonaceous Slate, Phyllite, Quartzite	130.21	31.36
Neoproterozoic	---	Katarigali	Slate, Phyllite, Quartzarenite, Limestone, Metabasics	12.47	3
Palaeozoic	---	Kaplas Granite / Kazinag / Hant / Pipra	Leucocratic To Mesocratic Biotite Granite	150.55	36.26
Pleistocene - Holocene	Un-diff. Quaternary	---	Alluvium, Moraines, Hillwash & Scree	14.63	3.52
Proterozoic (Un-diff)	---	Salkhala	Carbonaceous Phyllite with Marble & Quartzite	78.16	18.83
Neoproterozoic	---	Bhaderwah	Slate, Phyllite, Quartzite, Limestone & Schist	8.11	1.95

4. Landuse/landcover and geological setup

Land cover refers to the biophysical cover observed on the earth's surface, whereas land use defines how these biophysical assumptions are utilised by humans. Land use has been defined in terms of economic activity as an area of land used by humans for various reasons, including agriculture, settlement, and industry (Anderson *et al*, 1976) [1]. The study of LULC cover changes is essential for proper planning, utilization, and management of natural resources. The Neeru watershed's land use has been mapped using Landsat 8 satellite data (from the USGS portal) and the supervised classification method in ERDAS software. It is also divided into eleven categories (Table 2). Evergreen needle-leafed forest occupied the largest area (68.23%), followed by deciduous broad-leafed forest (13.26%), agricultural land (5.65%), evergreen broad-leafed forest (3.48%), build-up land (3.29%), waterbodies (2.66%), wetlands (0.36%), snow cover (1.01%), and wasteland (0.08%) (Fig. 3). The forest area is dominated by Deodar, Pine, Moru, Banj, and Sal trees.

Geology is the most valuable natural resource, with characteristics like litho-stratigraphy, faults, and folds influencing variation in other resources (Bandooni, 2004) [5]. Lithology influences the strength and permeability of rocks and soils (Kavzoglu *et al.*, 2014). The lithological characteristics strongly influence the physical properties of the surface and sub-surface material and thus affect the likelihood by land sliding (Kamp *et al.*, 2008).

The lithological formation of the Neeru watershed is illustrated in Table 2 & Fig. 3. The maximum area (31.36%) of the region is covered by the carbonaceous slate, phyllite & quartzite rocks of Vaikrita group (Proterozoic age) while the minimum area (1.95%) is under the Slate phyllite quartzite, limestone, and schist rocks of Bhaderwah formation (Neoproterozoic age).

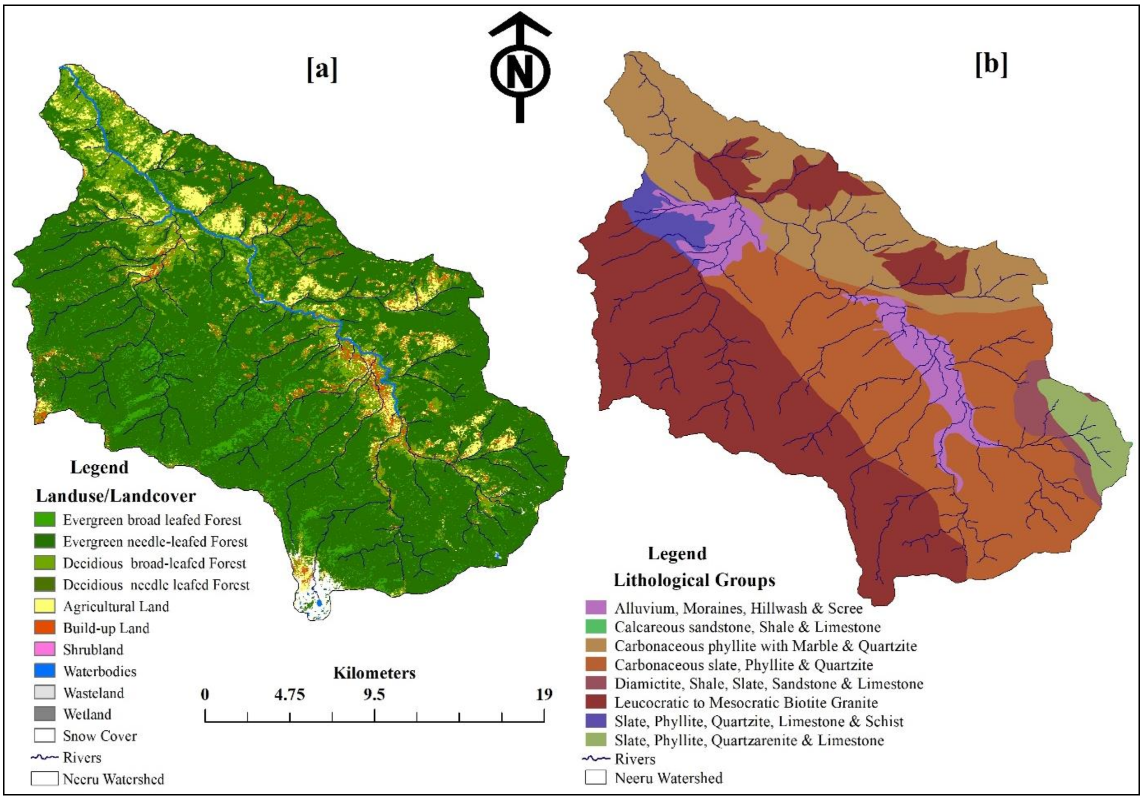

Fig 3: Showing and (a) Landuse/Landcover; (b) geological (lithology and structures) of the watershed

Table 3: Mathematical expressions for morphometric parameters (linear, aerial & relief) and their results.

	Parameters	Formula	References	Results
Linear Aspect	Stream order (Su)	Hierarchical order	Strahler, 1964	5th Order
	Stream length (Lu)	Length of the streams	Horton, 1945	336.13 Km
	Mean stream length (Lsm)	Lsm = Lu/Nu where, Lu=Stream length of order 'U'	Horton, 1945	7.37 Km
	Stream Number (Nu)	Nu=Total number of stream segments of order 'U'		190
	Stream length ratio (Rl)	RL=Lu/Lu-1; where Lu=Total stream length of order 'U', Lu1=Stream length of next lower order.	Horton, 1945	Table 4
	Bifurcation ratio (Rb)	Rb = Nu/ Nu+1; where, Nu=Total number of stream segment of order'u'; Nu+1=Number of segment of next higher order	Schumn, 1956	Table 4
	Mean Bifurcation ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	Strahler (1964)	3.67
Arial Aspect	Basin Area (A)	Area of watershed in (Km^2)		145.19 sq km
	Basin Length (Lb)			65 km
	Basin Width			22.4 km
	Basin Perimeter (P)	Perimeter of watershed in (Km^2)		106.03 km
	Form factor (Rf)	Rf=A/(Lb)2; where, A=Area of watershed, Lb=Basin length	Horton, 1932	0.34
	Elongation ratio (Re)	Re=2√(A/π)/Lb; where, A=Area of watershed, π=3.14, Lb=Basin length	Schumm, 1956	0.67
	Circulatory ratio (Rc)	Rc=4πA/P2; where, A=Area of watershed, π=3.14, P=Perimeter of watershed	Miller, 1953	0.44
	Drainage density (Dd)	Dd=L/A where, L= Total length of streams; A= Area of watershed	Horton, 1945	0.81 Table 5
	Stream frequency (Fs)	Fs = Nu/A, where, N=Total number of streams; A=Area of watershed	Horton, 1945	Table 6
	Texture ratio (T)	Texture ratio (T) T = N1/P where, N1=Total number of first order streams; P=Perimeter of watershed	Horton, 1945	1.79
Relief Aspect	Relative relief (Rh)	Difference between maximum and minimum elevation of watershed	Schumm (1956)	Table 8
	Relief ratio (Bh)	Rr=H/Lb, where Rh = relief ratio, H = total relief (relative relief) of the basin in km, Lb = basin length	Schumm (1956)	Table 8
	Basin slope (Sb)	Sb=VI/HE (in degree), where Sb = basin slope, VI = vertical interval, HE = horizontal equivalent	Strahler (1950)	Table 10
	Hypsometric Integral (HI)	$HI = (Elev\_mean - Elev\_min)/(Elev\_mean - Elev\_min)$	Pike and Wilson (1971)	0.498 Fig. 6

5. Results and discussion

5.1 Linear aspect.

5.1.1 Stream order (Su)

Stream order refers to the progressive assimilation of streams within a drainage basin/watershed (Jadhav, 2014). Horton first proposed it in 1932. The stream-ordering analysis of a drainage basin provides a rough indication of the area's shape, size, topology, and structural features. In this study, the stream segments of the Neeru River were ranked using Strahler's (1964) stream ordering technique. As per his method, the 1st order rivers are small, unbranched fingertip streams with no tributaries. The 2nd order stream formed below the confluence of two 1st order streams, and similarly, a 3rd order stream forms beneath the junction of two 2nd order streams, and so on. The highest stream order (Su) in the study area is five; hence it was designated a 5th order river (Fig. 4). The maximum Su frequency in the study is observed in 1st order streams, i.e., 147 (Table 4).

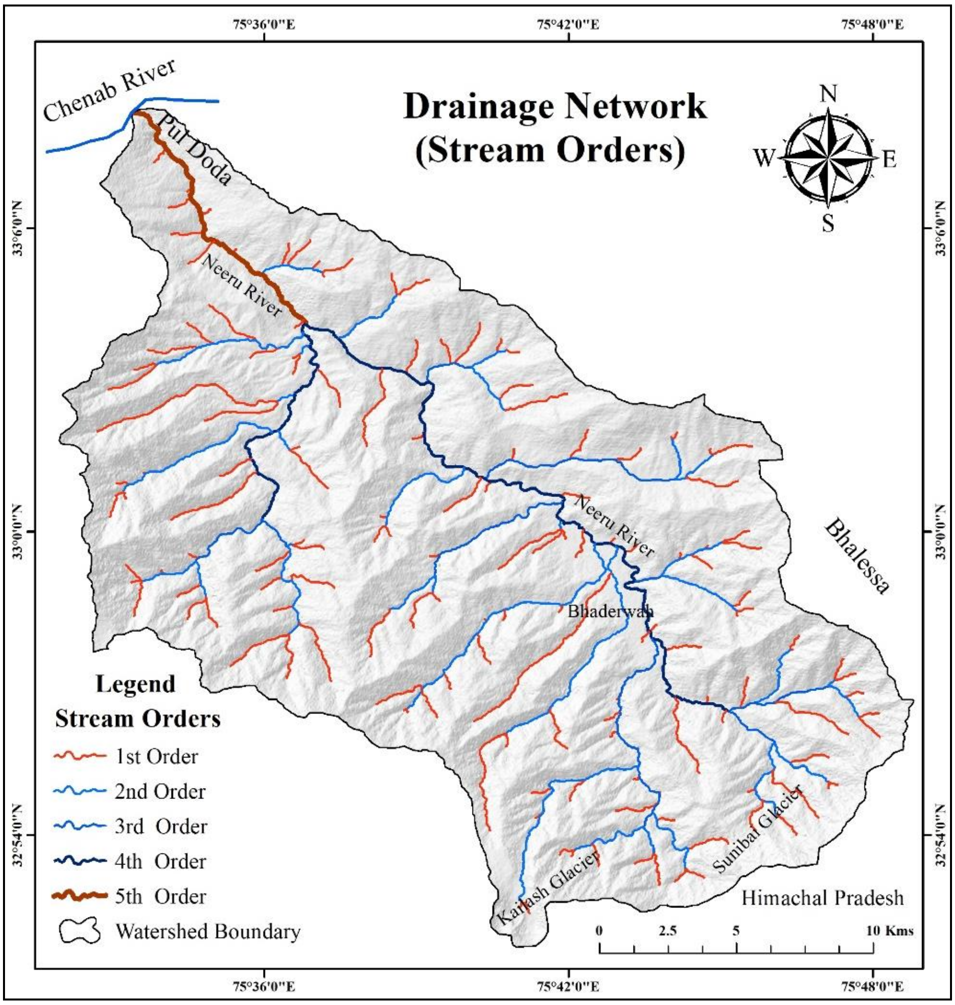

Fig 4: Showing the spatial characteristics of the drainage system (stream ordering) of the basin.

Table 4: Showing stream ordering (u), numbers (Nu), stream length, (Lu), Stream length ratio, (RL), bifurcation ratio (Rb) & mean bifurcation ratio (Rbm).

Stream Order (Su)	Nu	Lu (in km)	Lsm	RL=lu/lu-1	Bifurcation Ratio (Rb)		Mean Rbm
1st	147	162.85	1.11	-	1st/2nd	4.74	3.67
2nd	31	91.86	2.96	0.56			
3rd	9	34.72	3.86	0.38	2nd/3rd	3.44	
4th	2	35.81	17.91	1.03	3rd/4th	4.50	
5th	1	10.89	10.89	0.30	4th/5th	2.00	
Total	190	336.13	7.34	0.57			

5.1.2 Stream length (Lu)
The length of the river channels is a dimensional characteristic that demonstrates the size component of drainage lines (Jadhav, 2014). Stream lengths of different orders are assessed by measuring the total length of streams of the respective order (Horton, 1945). Streams with smaller lengths are characteristic of areas with steeper slopes and finer textures. Generally, as stream order increases, the total length of stream segments decreases. In the present study, Horton's law has been used to calculate the stream length (Table 3). The first-order streams have a maximum Lu of 62.85 kilometers, followed by the second-order (91.86 Km), third-order (34.72 Km), fourth-order (35.81 Km), and fifth-order (10.89 Km) (Table 4). The streams of various orders were counted and their lengths were measured in the Arc GIS software.

5.1.3 Stream number (Nu)
The stream number (Nu) is the total number of stream segments in different stream orders. Hurton's (1945) "Law of Stream Number" states that the number of streams of different orders (Su) in a particular watershed tends to approximate an inverse geometric series closely. In general, as the stream order increases, the number of streams decreases progressively (Table 4). A total of 190 streams were recognized in the Neru watershed, with 147 identified as 1st order rivers, thirty-one as 2nd order, nine as 3rd order, two as 4th order, and one as 5th order rivers (Fig. & Table 4). The high 1st order stream values indicate the possibility of flash floods downstream during heavy rainfall (Chitra *et al*. 2011)

5.1.4 Mean stream length (Lsm)
Mean stream length (Lsm) is a dimensional parameter that

shows the characteristic size of stream network components and their contributing watershed surfaces (Strahler 1964). The mean stream lengths (Lsm) of various orders have been computed by dividing the total stream length (Lu) of a specific order (Su) by the number of streams (Nu) in that order (Table 3). The mean stream length value for the Neru watershed ranges from a minimum of 1.11 km for the 1st stream order to a maximum of 17.91 km for the 4th stream order (Table 4). The Lsm of any specific order is higher than that of the lower order (Horton, 1945). The average Lsm of the watershed is recorded as 7.34 km (Table.2a).

5.1.5 Stream length ratio (Rl):

The stream length ratio (RL) is defined by Horton (1932) as "the ratio of stream lengths (Lu) in one order to the total stream length in the next lower order (Lu-1)." The RL values in the Neeru watershed range from 0.30 to 1.03, with a mean stream length ratio of 0.57 (Table 4), and are highly influenced by topography and slope. It is closely related to the surface flow discharge and erosional stage of the watershed.

5.1.6 Bifurcation ratio (Rb)

Hurton (1945) defined the bifurcation ratio (Rb) as the ratio of the number of stream segments in one order (Nu) to the number of stream segments in the next higher order (Nu+1). He also considered the bifurcation ratio (Rb) as an index of relief and dissection, while Strahler (1957) considered that the, Rb exhibits only a small variation for different areas with different environments, except where powerful geological control predominates. Bifurcation ratios usually range from 2 to 5 in watersheds where geologic structure does not distort the drainage pattern. (Strahler, 1964). The higher the Rb value, the stronger the structural control, and the lower the value, the less structurally disturbed the area (S K Nag, 1998). The Rb value ranges from 2 to 4.74 in the study area, with a mean Rbm of 3.67 (Table 4). This demonstrates effective structural control over drainage development.

5.2 Areal Aspect

5.2.1 Basin Area

The Neeru watershed has a total area of 415.18 km^2 (Table 3), calculated by digitizing the watershed boundary from the toposheet into polygon form using Arc-GIS software.

5.2.2 Basin length, width & perimeter

The basin length was defined by Schumm (1956) as "the longest dimension of the watershed parallel to the main drainage line". The author used Schumm's (1956) method to calculate the length of the watershed. The total length, width, and perimeter of the Neru watershed are 65 km, 22.4 km, and 106.03 km (Table 3) respectively

5.2.3 Form factor (R_f)

The form factor is measured by dividing the watershed area to the square of the watershed length (Horton, 1932). The form factor (Rf) value ranges from 0 to 1 (Kumar & Negi, 2016) [9]. With a value less than 0.78 indicating an elongated watershed and a value greater than 0.78 indicating a circular watershed (Sukristiyanti *et al*., 2018). The form factor value for the Neeru watershed is 0.34 (Table 3), indicating an elongated shape with flatter peak flows of longer duration, which eventually results in groundwater percolation.

5.2.4 Elongation ratio (R_e)

The elongation ratio (Re) is used to determine the shape of a watershed, which provides information about its hydrological characteristics. According to Schumm (1956), it is "the ratio of the diameter of a circle with the same area as the watershed to the watershed's maximum length (Lb)." The value of Re varies from 0.6 to 1.0 (from elongated to circular watershed) due to variations in climate and geology. If the value is 1, the watershed is circular and discharges runoff more efficiently than an elongated watershed (Singh and Singh, 1997). If the value of Re is close to 1, then the region has extremely low relief, whereas values between 0.6 and 0.8 are associated with strong relief and a steep ground slope (Strahler,1964). These values are classified as circular (>0.9), oval (0.8 to 0.9), less elongated (0.7 to 0.8), elongated (0.5 to 0.7), and more elongated (0.5) (Kumar & Negi, 2016) [9]. The elongation ratio (Re) of the study area is 0.67 (Table 3), indicating an elongated shape with high relief, steep slope, high sediment load discharge, and susceptible soil erosion.

5.2.5 Circulatory ratio (R_c)

Miller (1953) defined the circularity ratio (Rc) as "the ratio of the area of a watershed to the area of a circle with same perimeter as the watershed." He also defines it as a significant ratio representing the watershed's dendritic stage. This ratio largely influences the length and frequency of streams, geological characteristics, land use/land cover, climate, relief, and slope of the watershed (Altaf *et al*., 2013). The low, middle, and high values of Rc correspond to the youth, maturity, and elderly stages of a watershed's life cycle. The Rc value of the study watershed is 0.44 (Table 3), suggesting that the rivers of this watershed are in the dendritic stage.

5.2.6 Drainage density (D_d)

The total length of stream segments (Lb) per unit area (A) is considered the drainage density (Horton, 1932). Drainage density (Dd) is an essential landform indicator that quantifies landscape dissection and runoff capability (Chorley 1969). It is determined by the intensity of the runoff, relief, density, viscosity of the water, proportional factors, and gravity acceleration (Kumar & Negi, 2016) [9]. Drainage density (Dd) values are generally lower in regions underlain by highly resistant permeable material with vegetative cover and low relief. High Dd values are seen in areas with weak and impermeable underlying material, sparse vegetation, and mountainous relief. The Neeru watershed area has a Dd value of 0.81, indicating that it is underlain by permeable material with vegetation cover and moderate relief. The entire watershed is categorized into five drainage density classes (Fig. 5d), i.e., extremely coarse (< 2 km^2), coarse (2.1 to 3.0 km^2), moderate (3.1 to 4.0 km^2), fine (4.1 to 5.0 km^2), and extremely fine (> 5.0 km^2). The maximum area (48.6%) falls in the moderate drainage density class, followed by fine (37.86%), coarse (7.67%), extremely fine (3.64%), and extremely coarse (2.21%) (Table 5).

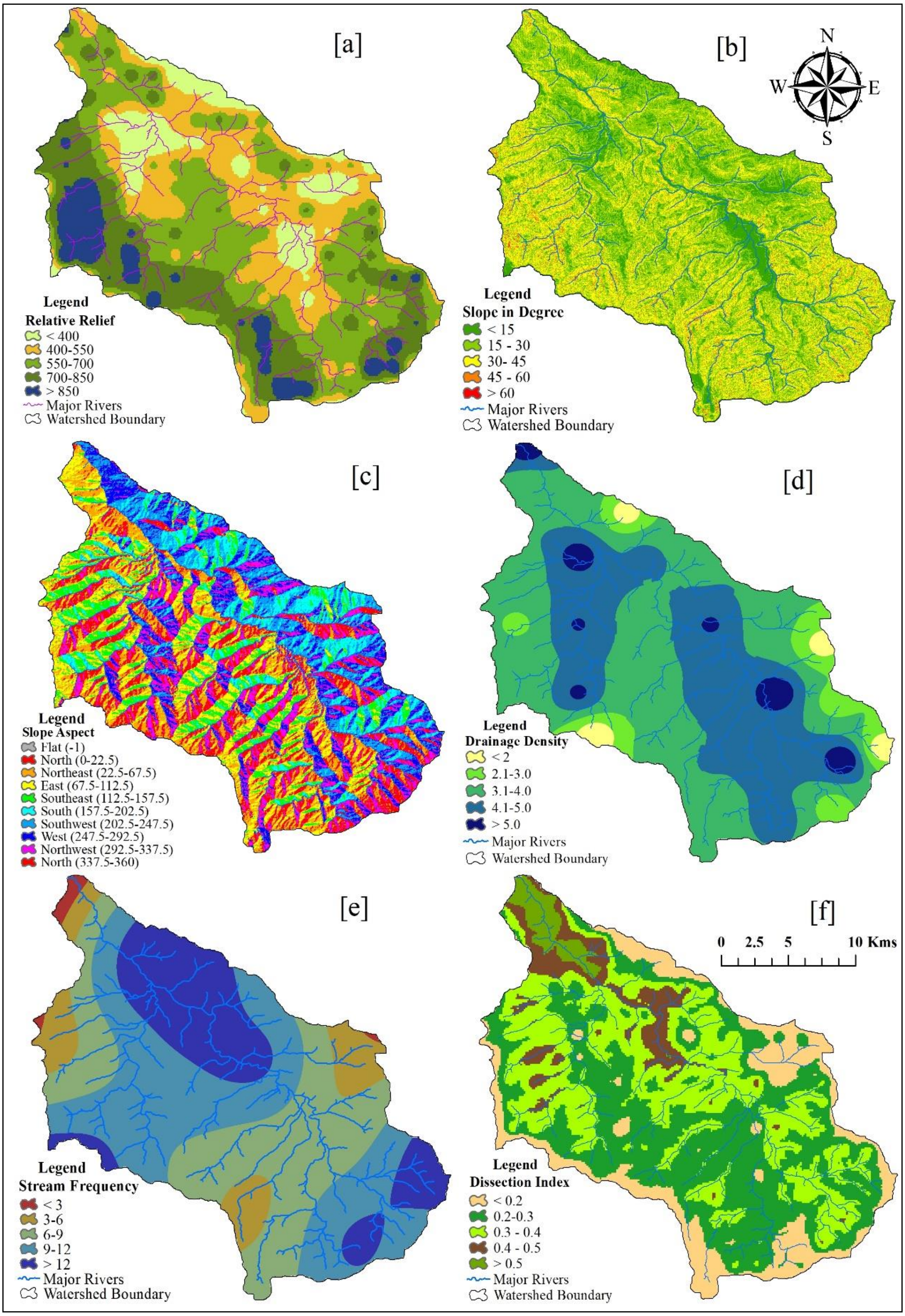

Fig 5: Showing (a) relative relief; (b) slope; (c) slope aspect; (d) drainage density; (e) stream frequency; and (f) dissection index of the study area

Table 5: Showing spatial distribution of drainage density and its areal coverage in Neeru river watershed

S. No	Range	Area (sq. km)	Area (in %)	Drainage Density class
1	< 2	9.182	2.21	Extremely Coarse
2	2.1-3.0	31.87	7.67	Coarse
3	3.1-4.0	201.80	48.6	Moderate
4	4.1-5.0	157.21	37.86	Fine
5	> 5.0	15.12	3.64	Extremely Fine

5.2.7. Stream frequency (Fs)
It is defined as the ratio of streams of all orders per unit area (km^2) of the watershed (Horton. 1945). It is influenced primarily by lithology, physiography, and rainfall, and it represents the texture of the stream network. High stream frequency (Fs) indicates impermeable subsurface material and steep slopes, whereas low stream frequency (Fs) suggests permeable subsurface material and low relief (Reddy *et al*., 2004). The stream frequency in the Neeru watershed ranges from 2 to 24, therefore it is classified as poor ($3/Km^2$), moderate ($3\text{-}6/Km^2$), moderate-high ($6\text{-}9/Km^2$), high ($9\text{-}12/Km^2$), and very high ($> 12/Km^2$) (Fig. 5e). The drainage frequency of the high (36.77%) and moderate-high (30.94%) classes corresponds to the largest area (Table 6). The very high, moderate, and poor drainage frequency categories show 21.88%, 9.47%, and 0.94%, respectively.

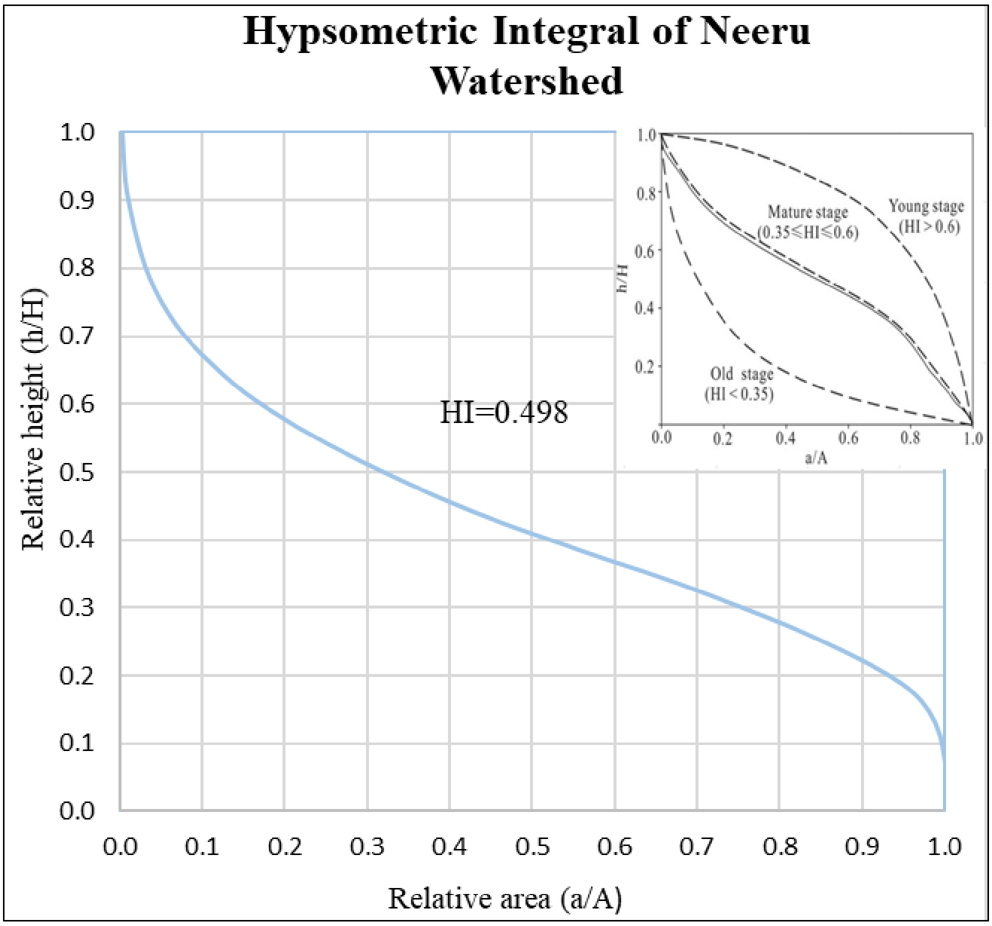

Fig 6: Hypsometric curve and integral of the watershed.

Table 6: Showing spatial distribution of stream frequency and its areal coverage in Neeru river watershed

S. No	Range	Area (sq. km)	Area (in %)	Stream Frequency class
1	< 3	3.89	0.94	Poor
2	3-6	39.31	9.47	Moderate
3	6-9	128.45	30.94	Moderate-High
4	9-12	152.68	36.77	High
5	> 12	90.86	21.88	Very High

Table 7: Showing absolute relief distribution and its areal coverage in Neeru river watershed

Absolute Relief Category			
S. No	Range (in m)	Area (sq. km)	Area (in %)
1	<1250	10.37	2.5
2	1250-1700	69.89	16.83
3	1700-2150	118.31	28.5
4	2150-2600	101.92	24.55
5	2600-3050	67.28	16.21
6	3050-3500	33.03	7.95
7	3500-3950	11.37	2.74
8	>3950	3.02	0.72

5.2.8 Texture ratio (T)
Drainage texture (Dt) is defined as the ratio of the total number of streams of all orders in a watershed to the watershed's perimeter (Smith, 1950). According to Smith's classification, the texture value less than two is designated as very coarse, two to four as coarse, four to six as moderate, six to eight as fine, and greater than eight as very fine. The drainage texture value calculated for the study area is 1.79 (Table 3), indicating very coarse drainage texture. In general, watersheds with very coarse textures have the longest watershed lag time period, followed by coarse, fine, and extremely fine textures (Esper Angillieri, 2008) [4]. The results suggest that the Neru watershed area has a longer duration to peak flow.

5.3 Relief aspect
5.3.1 Basin relief
Basin relief refers to the difference in elevation between the highest and lowest points of any particular region (the source and mouth of a river in a watershed). It also refers to the topography of the drainage basin, which affects the

quality and speed of drainage in the river catchment (Kumar *et al*., 2021) [10] Basin relief is an essential component in understanding the denudational characteristics of the watershed and plays a vital role in the development of landforms, surface and subsurface water flow, permeability, and erosional characteristics of the terrain (Magesh *et al*. 2011). The Neeru watershed lies between 801 m and 4294 m above sea level (Fig.1).

5.3.2 Absolute relief

Absolute relief refers to a region's maximum elevation above sea level. Its values for the study area range from 801 m in the northern portion (where its confluences with the Chenab River) to 4294 m in the southern part (at Kalash kund) (Fig. 1). For better understanding, the watershed has been divided into eight elevation zones with an equal interval of 450 meters (Table 7). The altitude of the watershed decreases rapidly toward the north (Fig. 1). The maximum area (118.31 km^2) of the study area falls in the elevation zone of 1700–2150 m, while the minimum (3.02 km^2) in > 3950 m (Asl), in the southern part near Kalash Kund (kalaish glacier).

5.3.3 Relative relief

Relative relief (Rb) is defined as the difference between the maximum and minimum elevations in a unit area, and it is also known as local relief. Relative relief can efficiently illustrate relief characteristics without considering sea level (Singh, 1992). The maximum relief is observed in the southern and southwest parts of the study area, ranging from less than 400 to greater than 850m (Fig. 5a). Further, the Neeru watershed's relative relief has been categorized into five relief classes with an interval of 150 m. The maximum percentage (33.58%) of relative relief occurs in the moderate relative relief class of 550–700 m, while the minimum percentage (7.2%) of relative relief occurs in the very high relief class of > 850 m (Table 8).

Table 8: Showing relative relief of basin surface and its areal coverage in Neeru river watershed

S. No	Range	Area (sq. km)	Area (in %)	Relative relief class
1	< 400	45.32	10.92	Very Low
2	400-550	105.71	25.46	Low
3	550-700	139.41	33.58	Moderate
4	700-850	92.35	22.24	High
5	> 850	32.4	7.8	Very High

5.3.4 Slope

The slope of a terrain refers to the angle at which a physical feature, such as a topographical landform, is inclined to the horizontal surface. Slopes are interdependent with stream networks and drainage basin geometry, but in geomorphology, the slope is a conjunction of form and processes that operate on the slope itself (Leopold, 1964). It is very influential in determining the infiltration vs. runoff relationship. Infiltration is inversely related to slope, which means that the gentler the slope, the higher the infiltration and lesser the runoff, and vice versa. Previously (in the past era), slope analysis was done manually by using the methods of Rich (1916), Wentworth (1930), Raisz and Henery (1937), Smith (1938), Calef and Newcombe (1953) [6], Strahler (1956), Miller and Summerson (1960). Meanwhile, all of these methods and techniques are very time-consuming, but nowadays, the average slope is determined using a digital elevation model (DEM) in GIS software. The slope map for the study area is prepared in Arc GIS software's spatial analysis tool using Cartosat DEM data, and it reveals that the slope angles vary from 3.06° to 78.27°, which exhibits high variations in the terrain configuration. Further, it is categorized into five classes (Fig. 5b), as Young (1972) suggested. The maximum area, i.e., 188.03 km^2 (45.29% area), is categorized as moderate slope, followed by the moderately steep slope (32.88%), gentle slope (16.11%), steep slope 5.54%, and very steep slope (0.18%) (Table 9) respectively.

Table 9: Showing surface slope distribution in the Neeru river watershed

S. No	Range	Area (sq. km)	Area (in %)	Slope class
1	< 15	66.88	16.11	Gentle
2	15-30	188.03	45.29	Moderate
3	30-45	136.56	32.88	Moderately Steep
4	45-60	22.99	5.54	Steep
5	> 60	0.73	0.18	Very Steep

5.3.5 Slope aspect

The terrain aspect is generally referred to as the direction it faces. The downslope direction of the maximum rate of change in value from each to its neighbour's is defined as aspect grid" (Gorokhovich and Voustianiouk 2006). Aspect is the slope's orientation, and it is measured clockwise in degrees from 0 to 360, where 0° is north, 90° is east, 180° is south, and 270° is west faced. The slope's direction is influenced by the local climate of the study area. In the present study, aspect analysis was done with the help of modern techniques by using DEM in Arc GIS software. Based on degree, the slope aspect is classified into nine classes and illustrated in Fig.5c. The northern aspect consists of 69.53 Km^2 area, which is 16.75% of the total study area, followed by the north-eastern (14.88%), eastern (13.74%), southeast (10.80%), southern (9.47%), southwest (11.01%), western (11.01%), and north-western (12.30%) aspects (Table 10). There is a 0.13 km2 (i.e., 0.03%) area under the flat aspect, which is seen near the Bhaderwah town (Fig. 5c) region of the study area.

Table 10: Showing slope aspects and its areal coverage in the Neeru river watershed

S. No	Aspect Type	Area (sq. km)	Area (in %)
1	Flat (-1)	0.13	0.03
2	North (0-22.5)	69.53	16.75
3	North-East (22.5-67.5)	61.77	14.88
4	East (67.5-112.5)	57.06	13.74
5	South-East (112.5-157.5)	44.86	10.80
6	South (157.5-202.5)	39.32	9.47
7	South-West (202.5-245.5)	45.69	11.01
8	West (247.5-292.5)	45.73	11.01
9	North-West (292.5-337.5)	51.09	12.30

5.3.6 Dissection index

The dissection index (Di) is the ratio of relative (Rb) to absolute relief, which enables understanding the landscape and development of any physiographic region. It is a natural indicator that indicates the magnitude of terrain dissection. It expresses the relationship between vertical relief distance from the erosion level and relative relief (Jha, 1996). In general, the value of Di ranges from 0 to 1 (i.e., from no dissection to a vertical cliff at sea level). In the present study, the dissection index value varied from below 0.2 (very low) to above 0.5 (very high), and it has been classified into five dissection index classes (Fig. 5f). Table 11 shows that, most of the watershed area is low to moderately dissected, and it seems to increase from flatted valley places to vertical cliffs and ridges. This means most of the study area comes under the low (39.71%) dissection, i.e., associated with flat-topped divides, ridges, and isolated peaks in the river watershed, and the moderate (33.41%) corresponds with gentle sloping topography. High (8.08%) and very high (3.25%) Di values (Table 11) are found in the upper part of the watershed, where high dissection and some patches occur in the steep slope area.

Table 11: Showing dissection index distribution in Neeru river watershed

S. No	Index class	Area (sq. km)	Area (in %)	Dissection Index class
1	< 0.2	64.57	15.55	Very Low
2	0.2-0.3	164.87	39.71	Low
3	0.3-0.4	138.71	33.41	Moderate
4	0.4-0.5	33.53	8.08	High
5	> 0.5	13.51	3.25	Very High

5.3.7 Hypsometric integral
Langbein (1947) proposed a "hypsometric integral" to establish the area-altitude relationship. Later, it was modified by Strahler (1952) to use relative heights and areas to create the curve for each unit to compare developmental phases. The hypsometric integral (HI) is the area below the hypsometric curve that varies from 0 to 1 (values near 0 represent highly eroded regions and close to 1 represent less eroded regions) (Pike and Wilson, 1971; Pedrera *et al*., 2009) [13]. The hypsometric integral and curves show the relative age of landforms and the degree of basin dissection. The hypsometric curve is created by plotting the proportion of total watershed height against the proportion of watershed area (Fig. 1). The concave curves with low integral values demonstrate old, eroded, and extensively dissected landscapes; smooth and s-shaped curves crossing from the centre of the hypsometric curve diagram represent mature and moderately eroded landscapes; and convex curves with high integral values represent young and slightly eroded landscapes (Kumar *et al*., 2021) [10]. The HI value and curve provide valuable information about the watershed's erosional stages and the lithological, tectonic, and climatic factors that influence them. The hypsometric integral value for the study area is calculated as 0.498 (Table 3) representing the Neeru watersheds mature stage (Fig. 6).

6. Conclusion
Appraisal of watershed’s resources using remote sensing satellite data and geographic information technologies has proven to be very effective in determining terrain characteristics such as surface runoff, infiltration, bedrock type, and so on. The adopted approach simplifies the analysis of various morphometric parameters and investigates the enables establish relationship between various hydrological parameters and the properties of landscapes, soils, and checking current status of various resources of the watershed.

The Neeru watershed is well-drained, with the stream order varying from first to fifth. The first-order streams dominate the watershed with a total length of 162.85 km; this leads to the possibility of a sudden flash flood after heavy rainfall in the study area. The bifurcation ratio value (3.67), suggests that the basin is normal and the drainage network is controlled by geomorphology. The low value of Rb shows that uniform materials underlie the watershed and the streams are systematically branched. The elongation ration (0.67) indicates that the area has moderate relief, high sediment load discharge, steep slopes, and is susceptible to soil erosion. Drainage density and stream frequency are the key criteria for morphometric classifications that control the watershed's runoff patterns, sediment yield, and other hydrological parameters. The Neeru River watershed has a moderate drainage density, indicating permeability, vegetative cover, and moderate to low relief. The morphometric parameters (linear, aerial, and relief) derived from Cartosat DEM data using GIS tools provide significant inputs for watershed prioritization and planning, which will be useful to government officials and decision-makers for watershed development.

7. Conflict of interest
The authors declare that they have no known competing financial interests or personal ties that might have influenced the research presented in this study.

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