Original Research Article

Morphometric Analysis of DachigamDrainage Basin using Geo-SpatialTechnology (GST)

Abstract

The examination of morphometric parameters through quantitative analysis proves highly valuable in assessing river basins, prioritizing watersheds for soil and water conservation, and natural resources management.In this study, an in-depth analysis of the Dachigam Catchment has been conducted, focusing on the quantification of various morphometric parameters. The research employs Geographic Information System (GIS) techniques to assess morphometric parameters in the micro-watersheds of the Dachigam Catchment. Linear and areal morphometric parameters were systematically derived and tabulated based on linear and shape characteristics of drainage channels, utilizing GIS and topographical maps (scale 1:50,000). The morphometric analysis conducted in the Dachigamcatchment indicates that the basin has an elongated shape, suggesting that peak discharges would generally exhibit a flat profile and take time to rise. The drainage network within the basin is predominantly of the dendritic type, signifying a degree of homogeneity in texture.

Keywords: Morphometry, linear and areal parameters, drainage basin, GIS, dachigam catchment.

1. Introduction

Morphometric analysis plays a crucial role in hydrological investigations and is indispensable for the effective management of drainage basins. Watershed management holds significant importance in the conservation of both underground and surface water resources. When formulating a watershed management development plan, various parameters must be taken into consideration, including erosional status, lithology, topography, and the drainage pattern of the area (Pisal *et al.*, 2013). Morphometric parameters serve as essential tools in identifying and comprehending the physical characteristics of a catchment, particularly in relation to flood conditions (Bhatt and Ahmed, 2014).

Morphometry encompasses the measurement and mathematical analysis of the Earth's surface configuration, as well as the shape and dimensions of its landforms (Agarwal, 1998; Obi Reddy *et al*., 2002). The pioneering works in hydrology on morphometric studies were conducted by (Horton, 1940; Strahler, 1957). The examination of drainage basin and channel networks using morphometry plays a vital role in comprehending the geo-hydrological characteristics of drainage basins. It provides insights into the influence of climate, geology, geomorphology, structural antecedents, and other factors on the catchment. Many researchers have recognized the relationships between various drainage parameters and the aforementioned factors (Horton, 1945; Strahler, 1957; Melton, 1958; Pakhmode*et al*., 2003; Reddy *et al*., 2004). Drainage basin analysis is essential in hydrological investigations, including groundwater potential assessment, groundwater management, pedology, and environmental evaluation. Hydrologists and geomorphologists acknowledge the significant relations between runoff characteristics and the geographic and geomorphic features of drainage basin systems. Physiographic characteristics like the dimensions, configuration, and slope of drainage areas, along with factors such as drainage density, size, and length of contributing elements, exhibit correlations with various hydrological phenomena. Geology, relief, and climate stand out as key factors determining running water ecosystems at the basin scale (Mesa, 2006). Conducting a thorough morphometric analysis of a basin is valuable for comprehending how the drainage morphometric network impacts the features and characteristics of landforms.

The quantitative analysis of morphometric parameters proves highly beneficial for assessing river basins, prioritizing watersheds for soil and water conservation, and managing natural resources effectively. Understanding the influence of drainage morphometric systems is crucial in examining landform processes, soil physical properties, and erosion characteristics. Numerous river basins and sub-basins worldwide have been investigated using traditional methods(Horton, 1945; Strahler, 1957, 1964; Krishnamurthy *et al*., 1996).

The application of Geographic Information System (GIS) techniques is currently prevalent in the evaluation of diverse terrain and morphometric parameters of drainage basins and watersheds. GIS offers a flexible environment and a robust tool for manipulating and analyzing spatial information.Remote sensing and GIS (Geographical Information System) are widely recognized as powerful geospatial tools used for generating drainage maps and assessing the morphometric characteristics of watersheds(Singh and Urmila, 2012). Numerous researchers and scientists have conducted morphometric analyses of watersheds utilizing remote sensing and GIS techniques. (Dhabale*et al.*, 2014, Asode*et al.*, 2016, Kumar *et al.*, 2017, Rai *et al.*, 2017, Savita*et al.*, 2017, Asfaw and Workineh 2019, Siddi Raju *et al.*, 2020 and Singh *et al.*, 2020).

The primary goal of this research was to examine the linear and areal morphometric features of the Dachigam catchment situated in the Kashmir valley, utilizing Geographical Information System (GIS). The purpose of this study was to offer a better understanding of the geo-hydrological attributes of the catchment, with the intention of facilitating the efficient management of water and other natural resources in the region.

2. Study Area

The research was conducted in the Dachigam watershed, depicted in Figure 1, situated within the geographical coordinates of 74˚55’28” - 75˚08’18” North longitude and 34˚08’58” - 34˚05’49” East latitude. The watershed spans an area of approximately 156.1 km². The Dachigam mountain ranges are a component of the larger Zanskar Range, which constitutes the north-western section of the central Himalayan axis. The principal Dagwan river, originating from Marsar lake and flowing into Harwan reservoir, is sustained throughout its course by a network of streams draining through numerous gullies.

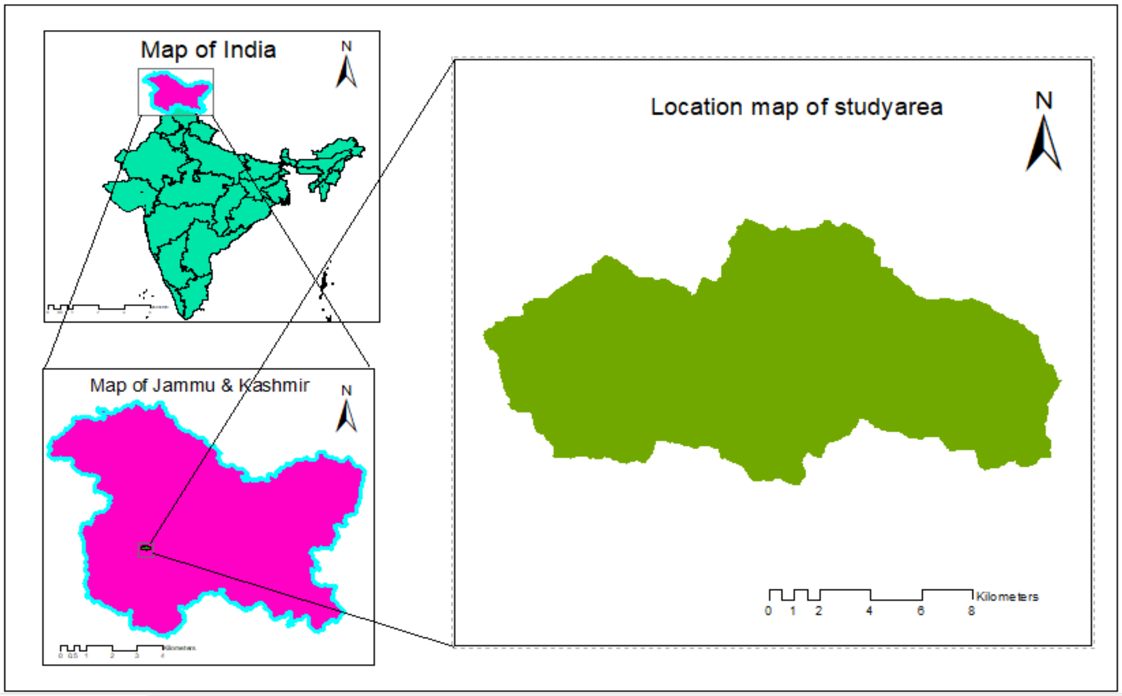

Fig. 1. Location of study area

The climate in the region can be characterized as Sub-Mediterranean to typically Temperate, displaying considerable variability in both precipitation and aridity. Throughout the study period, the annual precipitation in the research area varied from 575 mm to 856 mm.

In the Dachigam Catchment sub-watershed, the predominant soil types include undifferentiated brown soils, lacustrine sediment, moraine tongues, and patches of recent alluvium. While the majority of the Dachigam National Park is covered by forests, some gentle slopes at lower elevations have been cleared for agricultural purposes. The soil depth in the study area, particularly on slopes from lower to middle reaches, is less than 25 cm, categorizing it as very shallow soils.

3. Materials and Methods

Morphometric analysis of the Dachigam Catchment was conducted utilizing Indian remote sensing satellite imagery, which was collected and aligned with Survey of India topographical sheets at a 1:50,000 scale. The digitization process was carried out using the ArcGIS 10.2 system. Various morphometric parameters, including area, perimeter, stream length, stream number, bifurcation ratio, drainage density, stream frequency, drainage texture, circulatory ratio, compactness coefficient, and others, were computed using established methods and formulae as outlined in Table 1.

Table 1. Morphometric parameters with formulae

S.No.	Morphometric Parameters	Formula	Reference
Linear Morphometric Parameters			
1.	Stream Order (S_u)	Hierarchial rank	Strahler(1964)
2.	Stream Length (L_u)	Length of the stream (Kilometers)	Horton(1945)
3.	Mean Stream Length (L_{sm})	$L_{sm}= L_u / N_u$ L_u=Total stream length of order “u”. N_u=Total number of stream segments oforder “u”	Strahler(1964)
4.	Stream Length Ratio(R_l)	$R_l=L_{sm}/ L_{sm-1}$ L_{sm}= Mean stream length of a given order. L_{sm-1}= Mean stream length of next lower order	Horton(1945)
5.	Bifurcation Ratio(R_b)	$R_b =N_u /N_{u+1}$ N_u= No. of stream segments of order “u”. N_{u+1}= Number of stream segments of the next higher order	Schumm(1956)
6.	Length of Overland Flow (L_g)	L_g = 1/2D Km D = Drainage density (Km/Km^2)	Horton (1945)
Areal Morphometric Parameters			
7.	Drainage Density(D_d)	$D_d=L_u/A$ L_u=Total stream length of all orders A= Area of the basin (Km^2)	Horton(1932)
8.	Drainage Frequency (F_s)	$F_s = N_u/A$ N_u = Total number of streams of all orders A= Area of the basin (Km^2)	Horton(1932)
9.	Drainage Texture (D_t)	$D_t = N_u/P$ N_u = No. of streams in a given order	Smith (1950) & Horton (1945)

		P = Perimeter (Km)	
10.	Circulatory Ratio(R_c)	$R_c = 4\pi A/P^2$ A = Basin Area (Km^2) P= Perimeter of the basin (Km) Or $R_c = A/ A_c$ A = Basin Area (Km^2) A_c = Area of a circle having the same perimeter as the basin	Miller (1953)

The delineation of the watersheds in the Dachigam Catchment was performed using the codification system outlined in the Watershed Atlas of India (AIS&LUS) on 1:50,000 Survey of India topographical sheets. The total area of the Dachigam watershed is 156.1 km².

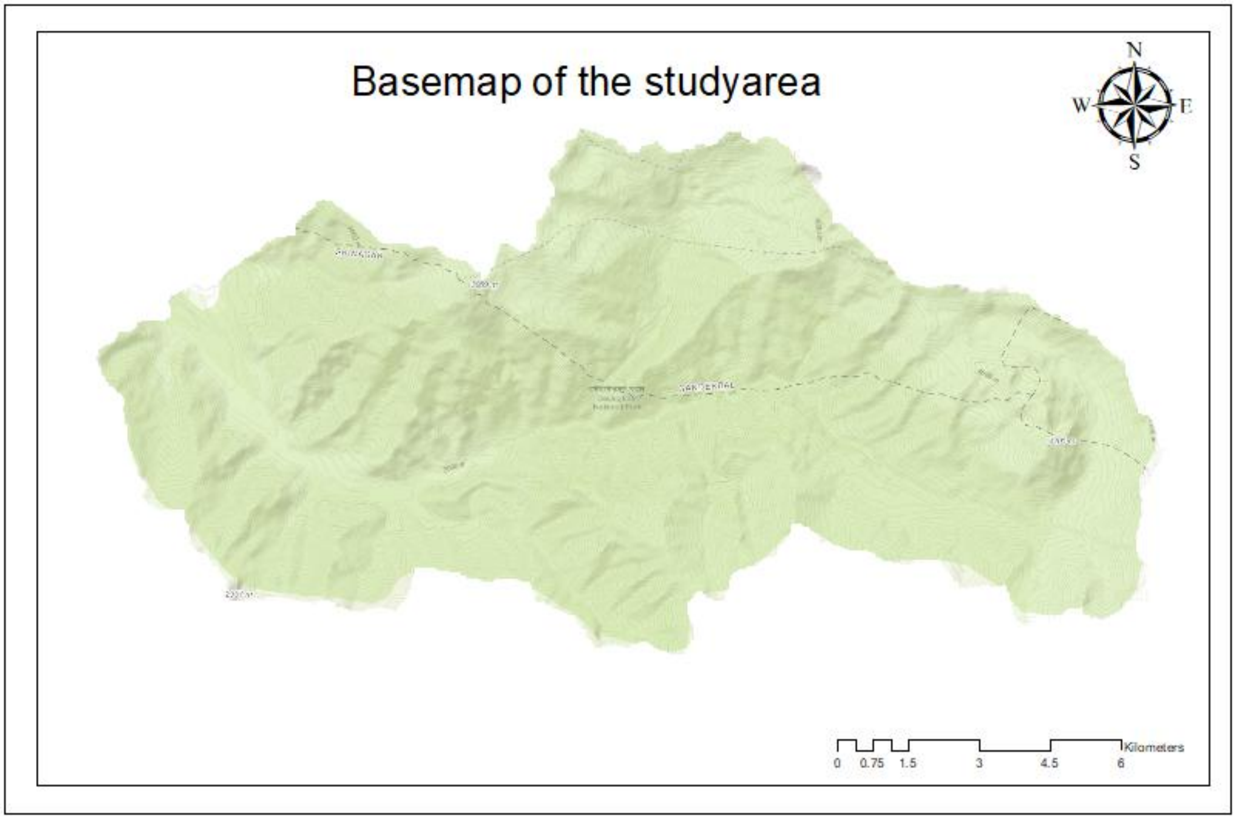

Fig. 2. Base map (toposheet) of study area

All the streams were digitally captured from Survey of India toposheets dated 1961 at a scale of 1:50,000. The digitization process utilized ArcGIS 10.2. Strahler's stream analysis system, recognized as one of the simplest and most widely used, was employed in the Watershed

Management study of Dachigam watershed using geospatial techniques. Adhering to Strahler's scheme, the analysis revealed that in the Dachigam watershed, there are a total of 170 streams. Among these, 85 are classified as first order, 36 as second order, 30 as third order, and 19 as fourth order (Figure 3).

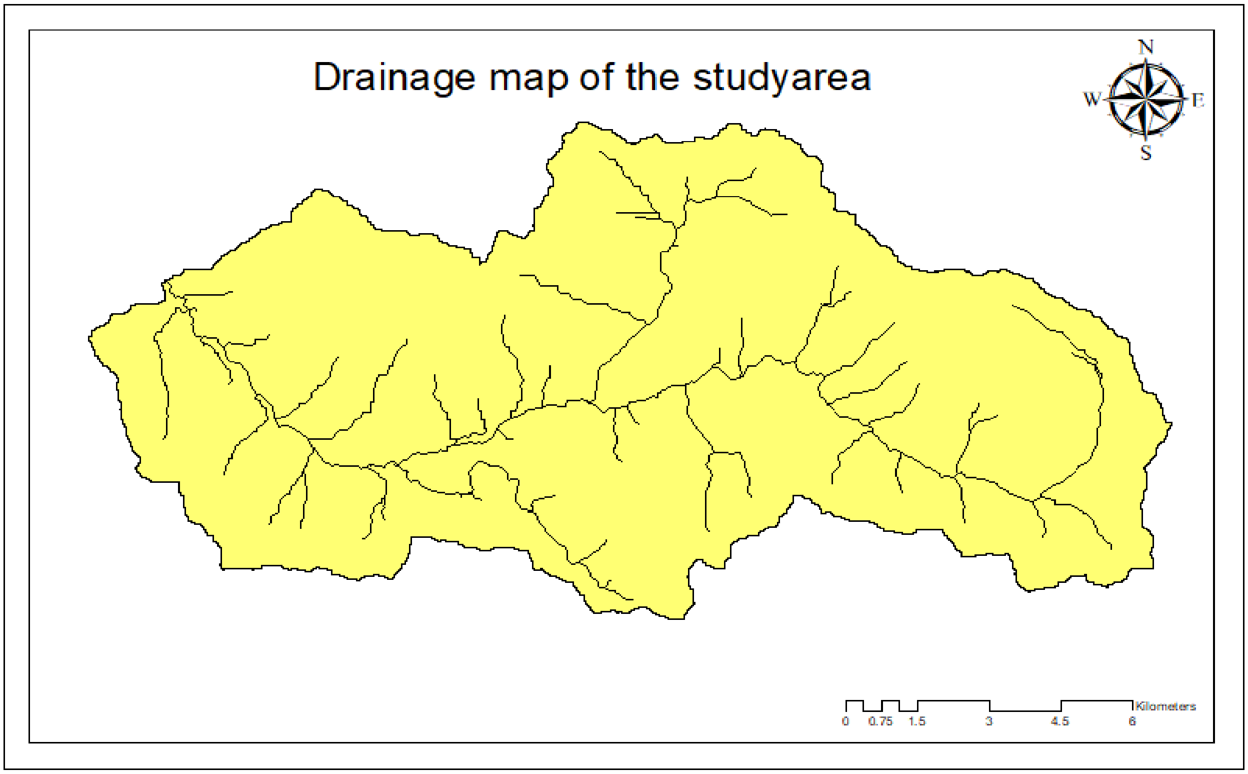

Fig. 3. Drainage map of study area

A 20 meter interval Digital Elevation Model(DEM) was generated for the study area (Figure 4).

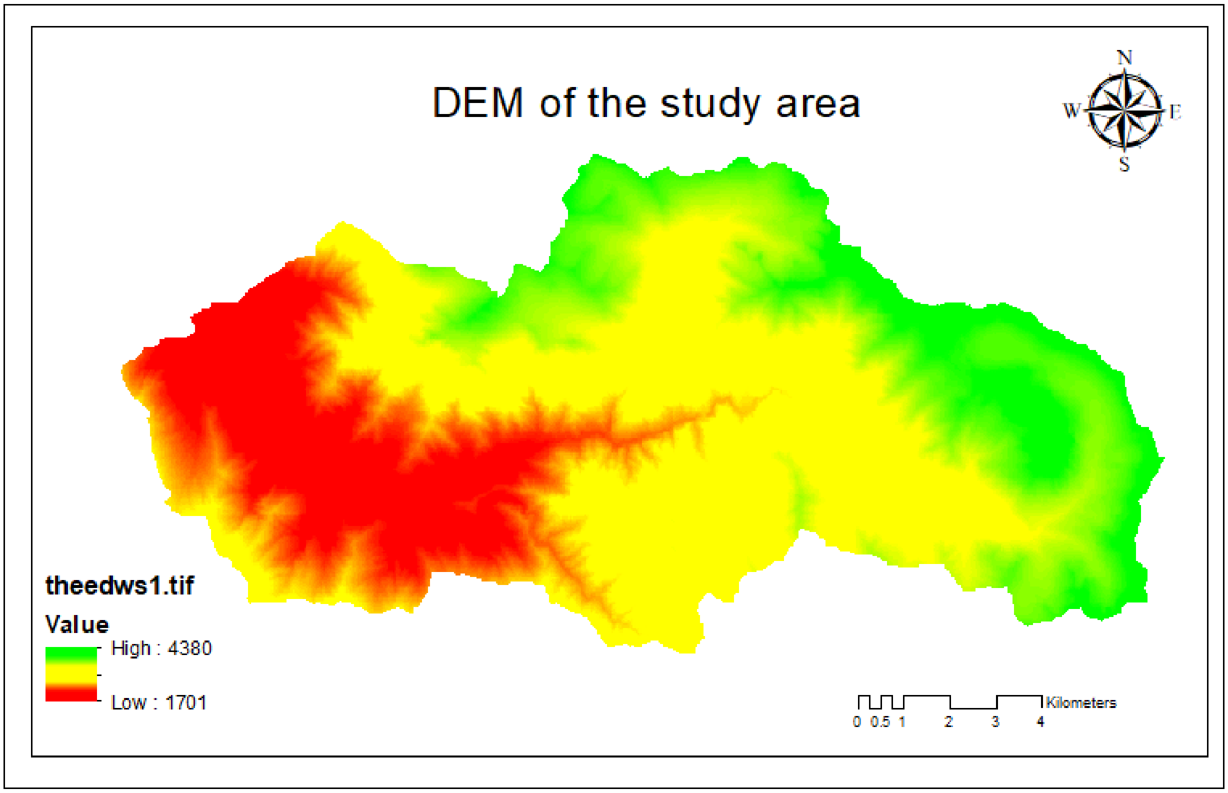

Fig. 4. Digital Elevation Model (DEM) of the study area

A Percentage Slope Map was generated for the study area by employing the Digital Elevation Model (DEM) file. The slope map, categorized into various slope ranges based on land capability classification, was created using the Digital Elevation Model. In this study, the DEM was converted into a grid format, and the model builder module of ArcGIS 10.2 was utilized for the production of the slope map (Fig. 5).

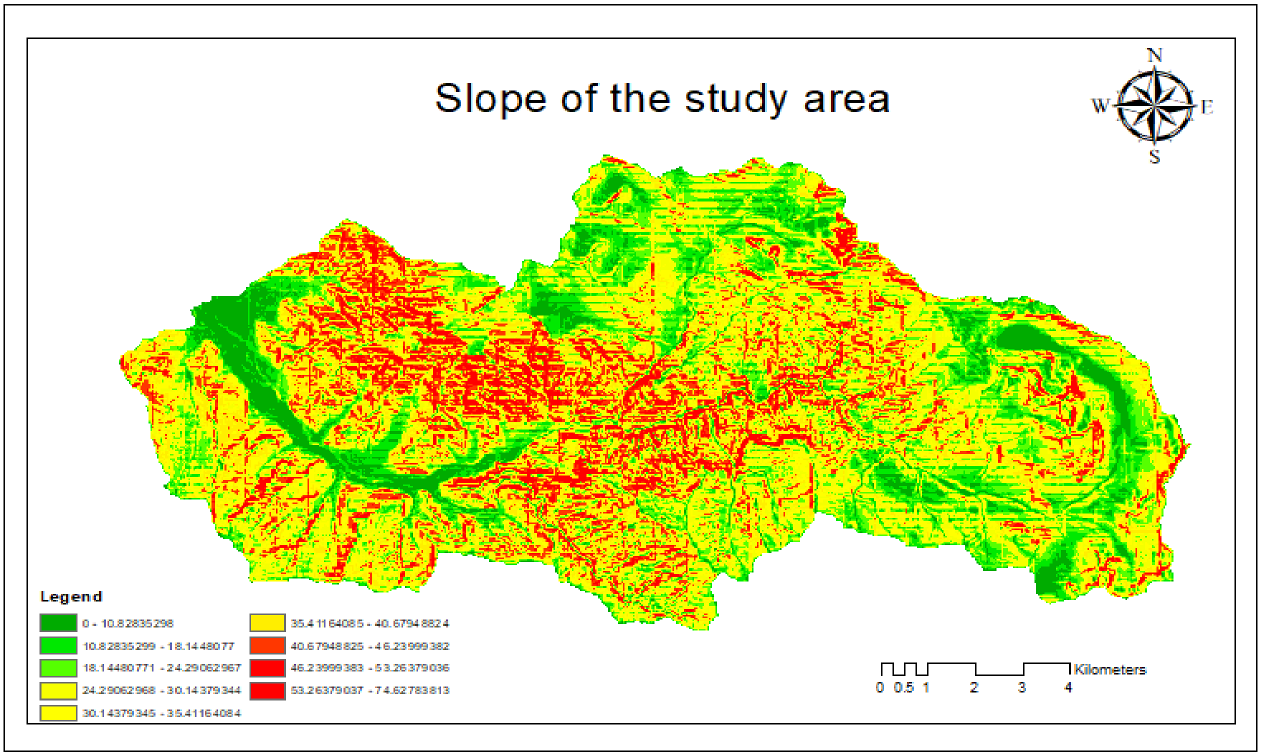

Fig. 5. Slope map of study area

Aspect indicates the slope direction and its correlation with the solar exposure of the surface. The Surface Aspect Map was created using the model builder module of ArcGIS 10.2 software in ArcMap 10.2. The previously prepared DEM file served as the input for generating the aspect map for the study area (Fig. 6).

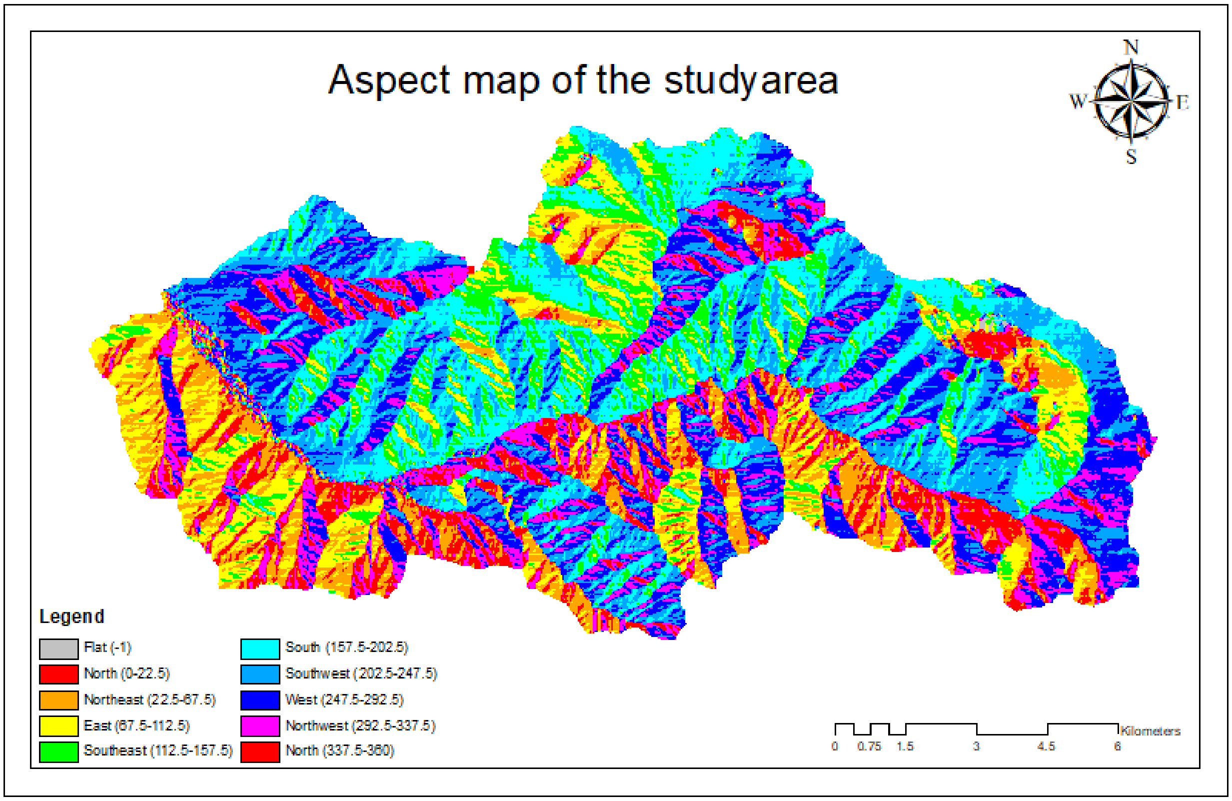

Fig. 6. Aspect map of study area

A contour map illustrates imaginary lines, known as contour lines, that represent equal elevations, providing valuable insights into the terrain's characteristics. To create the contour map for the study area, the DEM file was employed. A detailed contour map, encompassing both regular and index contour lines, was generated using the model builder module within ArcGIS 10.2 software. The previously prepared DEM file served as the input for generating the contour map of the study area(Fig. 7).

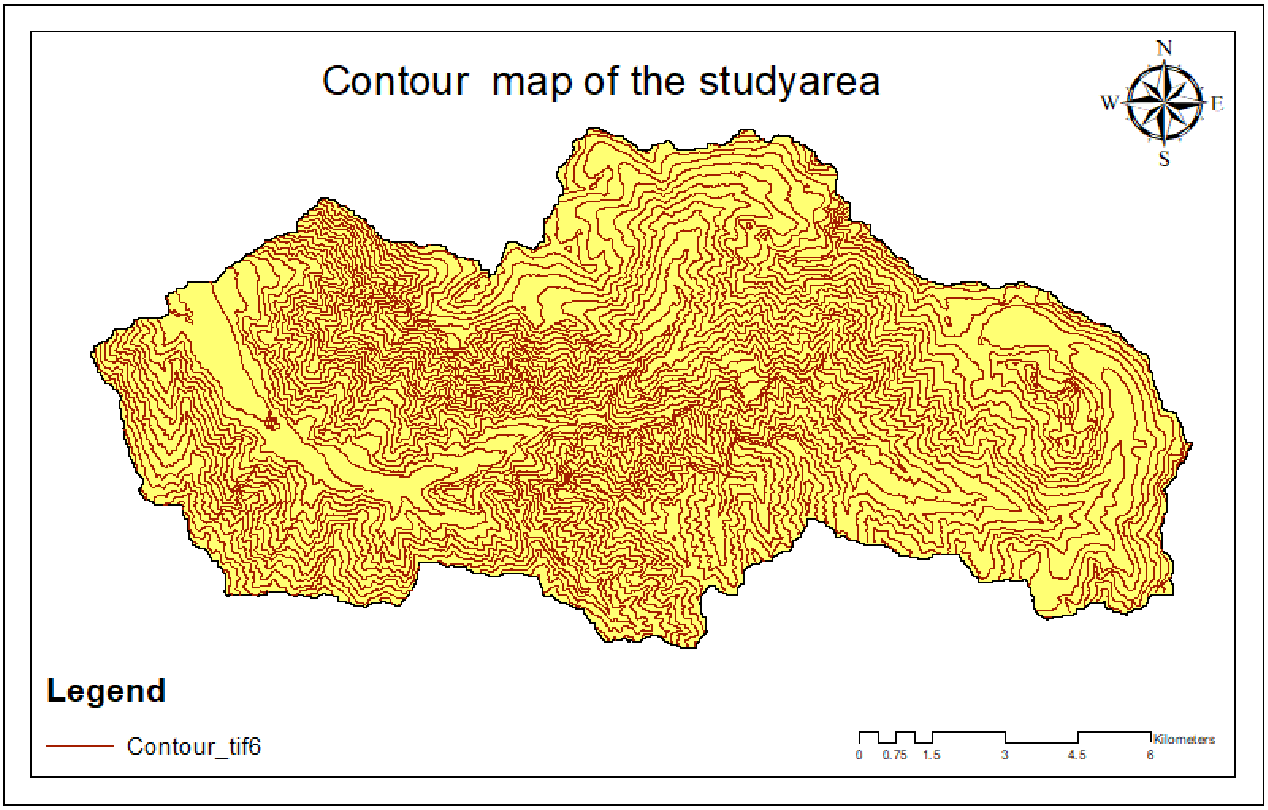

Fig. 7. Contour map of study area

4. Results and Discussion

The examination of basin morphometry involves the analysis of the geometries of basins and stream networks concerning the movement of water and sediment within the basin. To systematically characterize the geometry of a drainage basin and its stream channel, it is essential to measure linear aspects of the drainage network, areal aspects of the drainage basin, and relief (gradient) aspects of the channel network and contributing ground slopes, as proposed by Strahler in 1964. In this study, morphometric analysis was conducted, considering parameters such as stream length, bifurcation ratio, drainage density, drainage texture, stream frequency, compactness coefficient, circularity ratio, length of overland flow, etc. Mathematical formulas from Table 1 were employed for this analysis, and the results are summarized in Tables 2, 3, 4, and 5. Understanding the properties of stream networks is crucial for studying the processes involved in shaping the landforms(Strahler and Strahler, 2002).

4.1. Linear morphometric parameters:

The linear attributes of basins are linked to the channel patterns of the drainage network, encompassing an examination of the topological characteristics of stream segments, with a specific emphasis on the open links within the network system.The morphometric examination of linear parameters for basins encompasses metrics such as stream order (S_u), bifurcation ratio (R_b), stream length (L_u), mean stream length (L_{sm}), stream length ratio (R_l) and length of overland flow (L_g). The calculation of some key linear aspects is presented in Tables 2, 3, 4 and 5.

4.1.1. Stream Order (S_u)

The stream order signifies the branching pattern within the river system of the sub-watershed, and it is influenced by the quantity and types of tributary intersections.The initial and most crucial parameter in drainage basin analysis is stream ordering, where the hierarchical position of streams is identified. In accordance with Strahler's classification, the study of the Dachigam watershed indicates a total of 170 streams. Among these, 85 are categorized as first order, 36 as second order, 30 as third order, and 19 as fourth order, as detailed in table 2. The findings demonstrate that the number of first-order streams in the watershed is the highest, and this count decreases with the increase in stream order. Consequently, the observations align with Horton's laws.

Table 2.Stream numbers of respective orders

S.NO.	**STREAM ORDER**	**STREAM NUMBER**
1.	N_1	85
2.	N_2	36
3.	N_3	30
4.	N_4	19

4.1.2. Stream length (L_u)

Stream length (L_u) is a measure representing the standard length of streams that distinguishes them from other order streams within the basin. Additionally, it is a mathematical expression where the normal length pertains to first-order streams. Typically, the highest stream order exhibits the shortest length (Horton, 1945). In general, shorter stream lengths are typically situated on upper, steeper slopes, while longer stream lengths are found in lower inclines, (Strahler, 1957). The length of streams provides insights into the hydrological characteristics and bedrock arrangement of the area. Generally, areas with porous bedrocks and depleted watersheds are associated with a lower stream count and longer stream lengths. Table 3 provides information on the lengths of streams of various orders in the Dachigam watershed, along with their corresponding mean lengths. The data from the table indicates that the total length of the drainage network in the Dachigam watershed is 2.769 km.

4.1.3. Mean stream length (L_{sm})

The mean stream length is an indicator of the average size of components in a drainage network and the corresponding contributing surfaces (Strahler, 1964). It is calculated by dividing the total length of streams of a particular order by the number of streams in that order. Table 3 provides information on the lengths of streams of various orders and their respective mean lengths. The data in the table highlights that the Dachigam watershed's drainage network has a total length of 2.769 km.

Table 3.Total stream length and average stream length of respective orders.

S.NO.	**STREAM ORDER**	**STREAMNUMBER (N_u)**	**TOTALSTREAMLENGTH(m)**	**AVERAGESTREAMLENGTH(L_u)(m)**
1.	1^{ST} ORDER	85	75965.31	893.71
2.	2^{ND} ORDE	36	23453.83	651.49

	R			
3.	3^{RD} ORDER	30	16072.98	535.77
4.	4^{TH} ORDER	19	13074.2	688.12
Total stream length=2769.09m				

4.1.4. Stream length ratio (R_l)

Horton (1945) proposed that the length ratio (R_l), representing the ratio of the mean length (L_u) of segments in order u to the mean length of segments in the next lower order (L_{u-1}), tends to be consistent across various orders in a watershed.

Table 4 presents the stream length ratio values at different hierarchical levels of the watershed. The observed trend supports the hypothesis that stream length ratios remain relatively constant within a specific region, with the exception of the 2nd and 3rd order, where more significant deviations are noted compared to other orders. The mean stream length ratio in the Dachigam watershed demonstrates a generally stable pattern, ranging from 0.76 (minimum) to 1.61 (maximum). The overall mean stream length ratio for the watershed is 1.18.

Table 4. Stream length ratio (R_l)

S.NO.	**STREAM LENGTH RATIO(R_l)**	
1.	$Rl1 = \frac{L2}{L1} = \frac{651.49}{893.71}$	0.73
2.	$Rl2 = \frac{L3}{L2} = \frac{535.77}{651.49}$	0.82
3.	$Rl3 = \frac{L4}{L3} = \frac{688.12}{535.77}$	1.28
MEAN STREAM LENGTH RATIO = 0.94		

4.1.5. Bifurcation Ratio (R_b)

Bifurcation ratios typically decrease in a given region as the order increases, primarily because a higher order involves a greater percentage of streams merging into a higher-order tributary. Table 5 provides bifurcation ratio values at different hierarchical levels of the watershed. The hypothesis that bifurcation ratios tend to decrease with increasing order holds true, except for the 3rd and 4th order, where the lowest bifurcation ratio of 1.2 is observed in any order.

While the bifurcation ratio may not be identical between consecutive orders due to potential changes in watershed geometry and lithology, it generally remains consistent throughout the series. The mean bifurcation ratio in the Dachigam watershed demonstrates a relatively stable pattern, ranging from 1.2 (minimum) to 2.36 (maximum). The overall mean bifurcation ratio for the watershed is 1.71. A low bifurcation ratio suggests that the watershed has not experienced significant distortion, as high bifurcation ratios (>5) are associated with distorted drainage patterns found in regions with steeply dipping rock strata and narrow valleys confined between ridges. The low bifurcation ratio also aligns with the roundness of the watershed, as elongated watersheds tend to have higher bifurcation ratios.

Table 5.Bifurcation ratio (R_b)

S.NO.	**BIFURCATION RATIO (R_b)**	
1.	$R1 = \frac{N1}{N2} = \frac{85}{36}$	2.36
2.	$R2 = \frac{N2}{N3} = \frac{36}{30}$	1.2
3.	$R3 = \frac{N3}{N4} = \frac{30}{19}$	1.58
MEAN BIFURCATION RATIO = 1.71		

4.1.6. Length of overland flow (L_g)

The length of overland flow (L_g) is typically considered to be approximately 50% of the corresponding drainage density in the study area (Horton, 1945). This parameter indicates the total distance covered by water flow over the surface as it converges into the main streams of the channel. Overland flow is notably influenced by processes such as infiltration (exfiltration) and percolation through the soil, both of which vary over time and space (Schmid, 1997). In the context of this study, the length of overland flow for the Dachigam watershed is determined to be 0.20 km, indicating a low level of surface runoff in the study area.

4.2. Areal morphometric parameters:

Area of the basin (A) and perimeter (P) are vital parameters in quantitative morphology. Area of the basin refers to the total area projected on a horizontal plane, encompassing contributions from all orders within the basin. Perimeter represents the length of the basin boundary, which can be delineated using GIS software. The basin's area directly influences the size of the storm hydrograph, as well as the magnitudes of peak and mean runoff. Interestingly, the maximum flood discharge per unit area shows an inverse relationship with the basin's size (Chorley, 1957). Aereal aspects of the drainage basin, were computed, and the results are presented in table 6.

4.2.1. Drainage density (D_d)

The spacing between channels, known as drainage density (D_d), serves as an indicator of the total length of stream segments per unit area and is influenced by various factors like weathering resistance, rock permeability, climate, and vegetation. Generally, regions with low D_d values are characterized by highly permeable materials, abundant vegetative cover, and gentle terrain. Conversely, high D_d values suggest areas with less permeable subsurface materials, sparse vegetation, and mountainous landscapes (Nautiyal, 1994). Coarse drainage texture is associated with low drainage density, while fine drainage texture is linked to high drainage density.

The Dachigam watershed exhibited a drainage density value of 17.74 m/km^2, signifying a notably high value that implies reduced infiltration rates and increased surface flow velocity. Such elevated drainage density is often associated with heightened sediment yield through the river network, elevated flood peaks, steep terrain, limited suitability for agriculture, and substantial relief.

4.2.2. Drainage texture (D_t)

The total number of stream segments across all orders per unit perimeter of an area, as defined by Horton (1945), is known as drainage texture. Smith (1950) categorized drainage texture into five classes: very coarse (<2), coarse (2–4), moderate (4–6), fine (6–8), and very fine (>8). In the case of the Dachigam watershed, the drainage texture value is 2.012/km, indicating a coarse drainage texture.

This value reflects the relative spacing between drainage segments, and in this watershed, the spacing between stream segments is considered moderate.

4.2.3. Drainage frequency (F_s)

Stream frequency (F_s), also known as drainage frequency, represents the total number of stream segments within a basin per unit area, as defined by Horton (1945). The values of F_s are positively correlated with drainage density, indicating that as drainage density increases, the stream population within a basin also increases. Higher drainage density and stream frequency in basins are associated with faster runoff, which elevates the risk of flooding (Kale and Gupta, 2001). Several factors, including lithology, slope gradient, fluvial cycle stage, and surface runoff volume, influence stream frequency. Areas with high stream frequency typically feature impermeable subsurface materials, sparse vegetation, high relief, and low infiltration capacity.

For the specific watershed under consideration, the stream frequency value is $1.089/km^2$. This value suggests the presence of stream segments of at least two different orders within a unit area of 1 km^2. The low stream frequency indicates characteristics such as permeable subsurface material, dense vegetation, low relief, and a high capacity for infiltration.

4.2.4. Circulatory Ratio (R_c)

Miller (1953) introduced the dimensionless circularity ratio (Rc), which is the ratio of the basin area to the area of a circle with an equivalent perimeter to that of the basin. A circulatory ratio less than 1 suggests that the watershed does not have a circular shape. Various factors, including stream length and frequency, geological structures, land use/land cover, climate, relief, and basin slope, influence the circulatory ratio (Rc).

The basin's circulatory ratio (0.27) aligns with Miller's specified range, suggesting that the basin has an elongated shape, experiences low runoff discharge, and exhibits highly permeable subsoil conditions.

The circulatory ratio proves valuable in assessing flood hazards. A higher $R_c$value indicates an increased flood hazard during peak precipitation at the outlet point. Conversely, a low R_c value signifies a lower risk of flooding during peak precipitation events.

4.2.5. Compactness coefficient (C_c)

The compactness coefficient serves to depict how a hydrologic basin compares to a circular basin with an equivalent area. A circular basin is considered more risky in terms of drainage since it results in the shortest time of concentration before the peak flow occurs in the basin. In the study area, the value of the compactness coefficient (C_c) is 0.206, aligning with the notion that the watershed deviates from an elliptical shape.

Table 6. Areal aspects of drainage basin.

S.NO.	MORPHOLOGICAL PARAMETERS	CALCULATED VALUE
1.	Drainage density	17.74 m/km^2
2.	Drainage Frequency	1.089 km^{-2}
3.	Drainage texture	2.012/km
4.	Circulatory ratio	0.27
5.	Compactness coefficient	0.206

5. Conclusion

The utilization of GIS software has proven to be highly effective in the examination of both linear and areal morphometric aspects within drainage basins. The study suggests that employing a GIS-based approach for assessing morphometric parameters at the river basin level is more advantageous compared to traditional methods. This approach facilitates the analysis of diverse morphometric parameters and allows for the exploration of relationships between drainage morphometry and landform characteristics. The integration of GIS and remote sensing data has demonstrated significant efficacy in extracting morphometric parameters for the Dachigam watershed.The findings of the study are consistent with Horton's law, indicating a reduction in stream frequency as stream order increases. The watershed is identified as elongated, suggesting that peak discharges would exhibit a flat profile with a delayed rise. The slope map highlights predominantly high slope gradients, with South and Southwest-facing slopes dominating the area. The drainage network follows a primarily dendritic pattern, featuring high drainage density indicative of lower infiltration rates and heightened surface flow velocity. This poses potential risks of sediment yield, high flood peaks, and steep hills.

Parameters such as bifurcation ratio and circularity ratio confirm the undistorted nature and elongated shape of the watershed. In summary, the research underscores the effectiveness of remote sensing and GIS techniques in morphometric analysis, providing valuable insights for informed watershed planning and management decisions.

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