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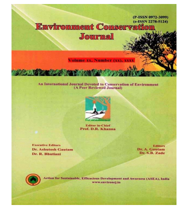

Morphometric evaluation of Ranikhola watershed in Sikkim, India using geospatial technique

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ABSTRACT

Morphological parameters are linked with the hydrological behaviour of the watershed. It helps to understand different basin characteristics. Characterization of quantitative morphology and river basin analysis is the way to implement proper river basin planning and management of soil and water conservation measures. In the present study, Cartosat-1 Digital Elevation Model (DEM) was used in Geographic Information System (GIS) environment to determine the morphometric parameters (stream length, stream order, stream frequency, bifurcation ratio, form factor, drainage density, circulatory ratio, etc.) of the Ranikhola watershed of Sikkim state, India. The slope of a major portion of the watershed area was found to be less than 30% (42 km^2) and has a drainage density of 0.585 km^{-1}. The lower value of drainage density in the watershed indicates a relatively lower streams frequency over the watershed. The elongation ratio, form factor, and circulatory ratio were estimated as 0.665, 0.347, and 0.510, respectively, which indicate that the watershed is elongated in shape, having gentle slopes and long flow paths. The relief ratio for the watershed was estimated to be 0.187, which indicates the watershed has a low elevation difference, low runoff, and high groundwater potential. This kind of morphometric analysis is required for the watershed characterization and helps to understand the hydrogeological behavior of the watershed.

Introduction

A watershed is a portion of land that drains water to a common outlet. It is a topographically delineated area that captures rainfall and contributes runoff to a single outlet in the main flow channel. The study of the watershed is essential for any developmental activities and sustainably managing the natural resources, namely, land and water, in order to minimize the negative impacts of exploitation. The watershed management practices require the qualitative and quantitative analysis of a large number of watershed features. The morphological analysis is generally performed to solve various literary problems in the basin, planning and implementing soil and water quality conservation measures, groundwater development and management, erosion control measures, etc. Morphometric measurement is the dimensional measurement and mathematical analysis of the surface composition, shape, and size of the land (Clarke, 1966). Morphometric studies of river basins were first proposed by Horton (1932), and then the ideas were developed by Schumm (1956), Coates (1958), and Strahler (1964). The watershed analysis is used as the elementary and reasonable

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approach to identify the different watershed characteristics. It offers a quantitative explanation of the drainage patterns (Strahler 1964), which helps in hydrological investigations. Drainage morphometry has a significant impact on understanding the geomorphological processes, soil physical properties, and erosion properties (Meshram *et al.,* 2020; Rai *et al*., 2017). The analysis of the watershed morphology helps to discover the correlations between hydraulic parameters and topographical features (Abdeta *et al.,* 2020; Yadav *et al*., 2014). Morphological analysis is suitable for areas with limited access to information and the diversity of highly distributed soils (Rahmati *et al*., 2019; Sangma and Guru, 2020; Trivedi *et al*, 2021; Gautam *et al*., 2022).

The morphometric analysis includes the estimation of various basin geomorphological characteristics, which can be categorized into three groups: linear aspects (steam length, stream order, bifurcation ratio, etc.), areal aspects (shape factor, form factor, drainage density, stream frequency, elongation ratio, circulatory ratio, etc.) and relief aspects (relief ratio, relative relief, ruggedness number, geometric number, etc.). These factors are either directly or inversely belong to runoff, peak flow, soil erosion, and risk of sedimentation (Bhattacharya *et al*., 2003; Gajbhiye and Sharma, 2017). Computation of morphometric parameters using conventional methods is a tedious and time-consuming task (Sreedevi *et al*., 2005; Rao *et al.,* 2010; Ahamad *et al.,* 2022). Further, such a task is unreasonably difficult if the study area has a large areal extent. Gautam *et al.* (2021) determined the Geomorphological Characteristics of the Jakham River Basin using the GIS Technique. They analyzed that the mean bifurcation ratio ranges from 3.28 to 4.02, which indicates the effect of geological formations on the drainage pattern in the basin. Drainage density (D =1.82 km km^{-2}) of the watersheds shows the course nature of the drainage pattern and permeability for infiltration. Shape factor (circulatory and elongation ratio) indicates that sub-watersheds are less to moderate elongated in shape have less susceptibility to peak flood.

The use of satellite imagery along with remote sensing technology can be considered a practical tool for morphological analysis (Gautam *et al.,* 2022). The satellite data can offer an overview of a large area and are very useful for analyzing the morphology of the watersheds. It can be effectively used for morphological analysis and precise delineation of watersheds, sub-watersheds, mini-watersheds, and even micro-watersheds and other morphological features (Ahmed *et al*., 2010; Samal *et al*., 2015). Cartosat-1 DEM is the product of Indian satellite IRS-P5 with a spatial resolution of 30 m, and it can be considered high-precision remote sensing data (Dabrowski *et al*., 2008; Khadri *et al*., 2013). The images obtained by this satellite can be safely used for its designed purpose (Amulya and Dhanashree, 2018; Srivastava *et al*., 2007), which is to collect high accuracy elevation data. The integration of RS and GIS for assessing the diverse topographic and morphological features of the drainage basins and watersheds provides a pliant atmosphere and an invaluable tool for the operation and analysis of spatial data (Sharma *et al*., 2014; Vincy *et al*., 2012; Singh *et al*., 2020).

In the state of Sikkim, India, few studies were carried out regarding these perspectives. Therefore, an attempt was made to estimate the morphological characteristics of the Ranikhola watershed using RS datasets in the GIS environment. Combined with the previous research, this study has the potential to provide scholars, decision-makers, and municipalities with valuable information for designing and implementing soil and water management structures along with suitable management practices.

Study Area

The Ranikhola watershed lies between the latitude 27°17' to 27°22' N and the longitude 88°31' to 88°38' E in the East district of Sikkim, India, with an area of 62.49 km^2. The watershed has hilly terrain in which Gangtok (Sikkim) is the primary urban centre with an average yearly rainfall of 3626 mm. Figure 1 represents the location map of the study area. The Ranikhola River flows into the Teesta River (a tributary of the Brahmaputra) near Singtam. The other urban settlements in the watershed include Deorali, Tadong, Sixth Mile, Rumtek, etc. (Figure 2). The major land use in the watershed is forest, followed by urban settlements and agriculture.

Material and Methods

The Cartosat-1 DEM (30-meter spatial resolution) was obtained from the Bhuvan portal. The first step was to delineate the Ranikhola watershed (Figure

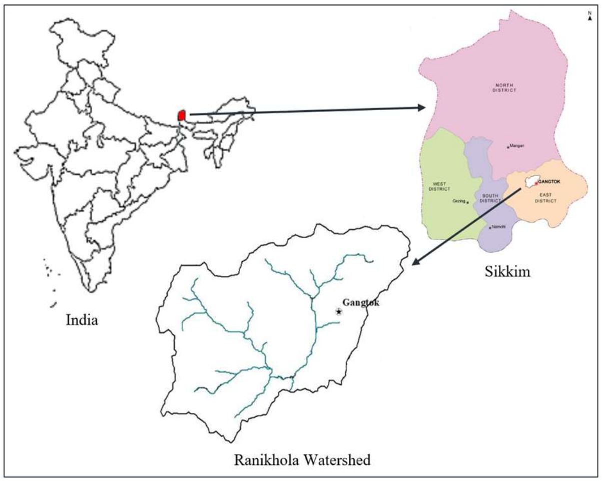

Figure 1: Location map of the Ranikhola watershed.

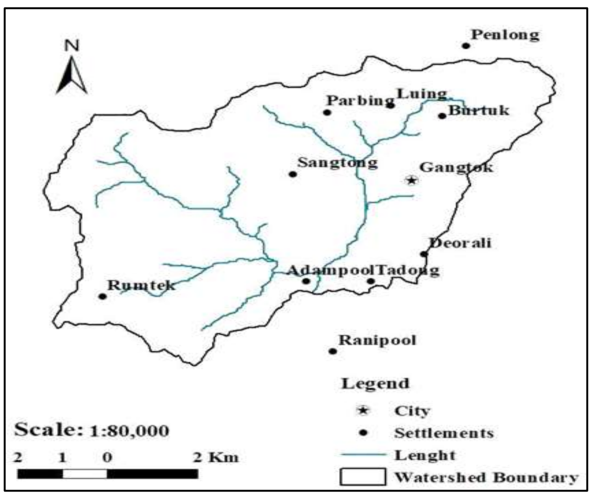

Figure 2: Urban settlements in the Ranikhola watershed.

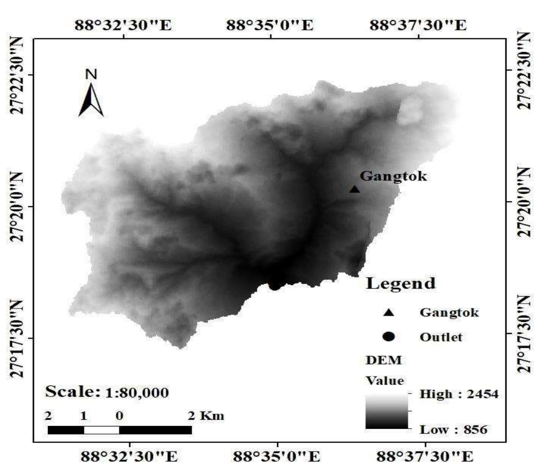

Figure 3: DEM of the Ranikhola Watershed

3). This step includes the generation of a sink, filling, flow direction, and flow accumulation maps using ArcGIS software. An outlet point was created using the generated maps, and contributing area to the outlet was delineated as the watershed. The morphometric parameters were estimated from the Cartosat-1 DEM using ArcGIS software. The formulae given by Horton (1945), Schumm (1956), Hadley and Schumm (1961) (as given in Table 1) were used to determine the morphometric parameters of the Ranikhola watershed, including linear, areal, and relief aspects. The complete methodology is presented with a flow diagram (Figure 4).

Results and Discussion

Cartosat-1 DEM data in the GIS environment is used to estimate the different geomorphological parameters. The different aspects of watershed characteristics are discussed below.

Linear Aspects

Linear aspects of a watershed deal with the rivers and their network. Generally, these are one-dimensional characteristics. They include various parameters such as stream lengths, stream order, stream frequency, bifurcation ratio, etc. The summary of linear aspects of the Ranikhola watershed is given in Table 2.

Stream order (U)

The stream order determines the size of the stream according to the hierarchical structure of the tributaries. The highest stream order in a watershed is called an order of a watershed. In the Ranikhola watershed, the highest order stream was found as fourth-order (Figure 5). The dendritic pattern of drainage of the watershed represents the homogenous soil texture and weak structural control.

Stream Number (N_u)

The Law of stream numbers asserts that the number of streams of each order is the inverse geometric function of stream order (Horton 1945; Leopld et al. 1964). The Ranikhola watershed consists of fifteen 1st order, nine 2nd order, four 3rd order, and one 4th order stream (Table 2). The results of the steam number support Horton's law. The decreasing number of streams (N_u) with the increase in stream order shows that the watershed has a hilly terrain with undulating topography.

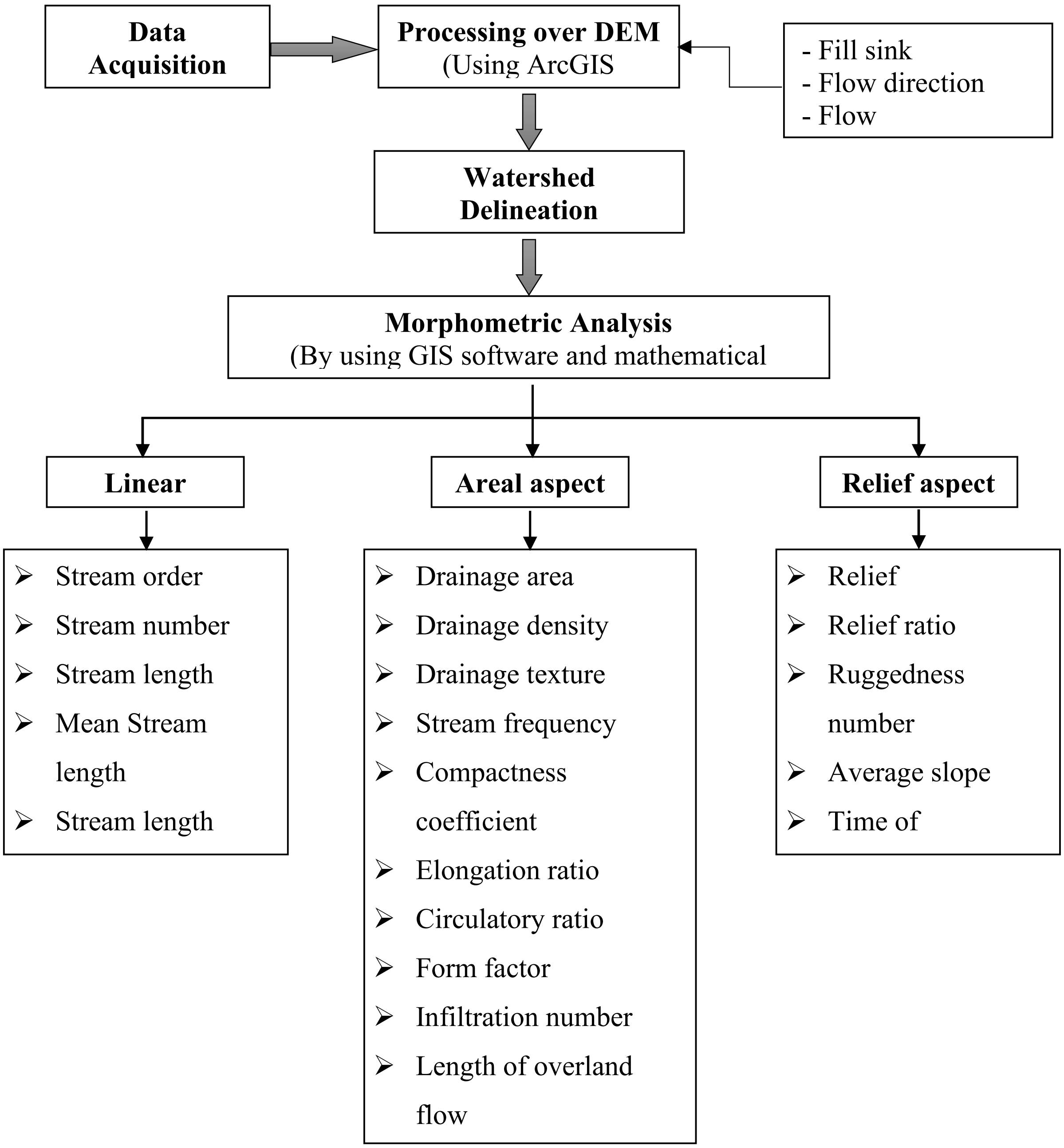

Figure 4: Methodological flow diagram for watershed morphometric analysis.

Stream Length (L_u)

Horton (1945) defined stream length as the sum of the lengths of all stream segments of each order within a watershed. It indicates the hydrological characteristics and the drainage extent of the basin. The short length of the stream represents steep slopes and finer texture, whereas longer lengths represent a relatively flatter gradient and permeable bedrock (Chitra *et al.*, 2011; Withanage *et al.*, 2014). For the Ranikhola watershed, the total length of all streams was estimated as 36.535 km. The longest stream length in the watershed is 10.929 km. The stream length of the 1^{st}, 2^{nd}, 3^{rd}, and 4^{th} order streams were found to be 17.785, 12.219, 5.906, and 0.624 km, respectively (Table 2).

Results showed that the stream length is an inverse function of stream order; hence Horton law is followed. This represents the variation in slope and

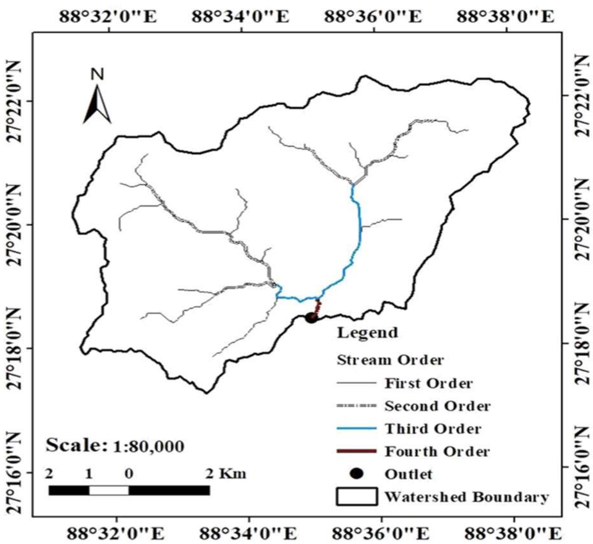

Figure 5: Stream order map of the Ranikhola watershed.

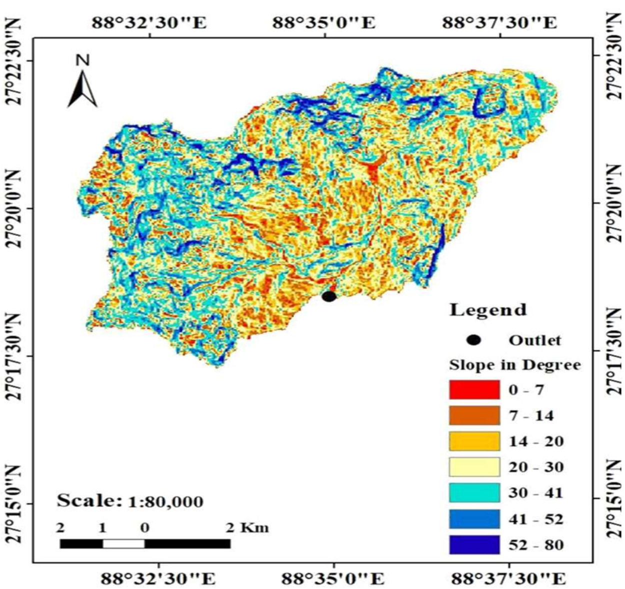

Figure 6: Slope map of the Ranikhola watershed.

the physiographic characteristics of the watershed. It further means that infiltration capacity varies with stream order across the watershed.

Mean Stream Length (L_{sm})

A watershed's mean stream length reflects the typical size of the drainage network and its contributing surfaces. It can be determined by dividing the total stream length of order 'U' by the total number of streams of the same order. The 'L_{sm}' of the Ranikhola watershed was found to be in the range of 0.624 km for the fourth-order to 1.476 km for the third-order stream, with the mean 'L_{sm}' of 1.161 km (Table 2). The smaller 'L_{sm}' was found in lower-order streams, indicating the areas with steep land slopes and finer textures, while the longer 'L_{sm}' in higher stream orders indicates the area with flatter gradients.

Stream Length Ratio (R_L)

It is the ratio of the length of stream of order 'U' to the length of stream of the next lower order, i.e., 'U-1' (Horton, 1932). The 'R_L' is the primary function of streamflow discharge and stage of erosion. 'R_L' between two successive stream order changes with the variation in slope and topography of the basin. For the Ranikhola watershed, 'R_L' was found to be ranging from 0.106 for the third-order to 0.687 for the first-order stream. These variations in 'R_L' from one order to the next show the early stage of geomorphic evolution.

Bifurcation Ratio (R_b)

It is expressed as the ratio of the total number of streams of any order 'U' to the total number of streams of the next higher-order 'U+1' (Hortan, 1932). The 'R_b' is a significant parameter in the analysis of drainage basins as it correlates the hydrological characteristics of a basin with the geological characteristics and climatic conditions (Hortan, 1945). If the 'R_b' value is between 3 and 5, it indicates the drainage pattern of the stream is independent of the geology of the watershed (Verstappen, 1983). Similarly, 'R_b' less than 3.0 indicates the flat and homogenous geological structure of the basin (Strahler, 1957). It has been found that for the Ranikhola watershed, the 'R_b' ranges from 1.67 to 4. This suggests that part of the stream network is under the influence of geological formations of the watershed and the remaining part is independent of it.

Aerial Aspects

The areal aspects of watersheds are their two-dimensional properties. These are critical to the development of watersheds. The summary of aerial aspects of the Ranikhola watershed is given in Table 3.

Table. 1 Formulae used to compute various morphometric parameters.

Sl. No.	Parameter	Formula	Originator
1.	**Stream order (U)**	Hierarchical rank	Strahler (1964)
2.	**Stream length (L_u)**	Length of stream	Horton (1945)
3.	**Mean stream length (L_{sm})**	$L_{sm} = L_u/N_u$	Strahler (1964)
4.	**Stream length ratio (R_L)**	$R_L = L_u/L_{u-1}$	Horton (1945)
5.	**Bifurcation ratio (R_b)**	$R_b = N_u/N_{u+1}$	Schumm (1956)
6.	**Mean bifurcation ratio (MR_b)**	$MR_b = (R_{b1}+ R_{b2}+\ldots+ R_{bn})/n$	Strahler (1957)
7.	**Drainage density (D_d)**	$D_d = L_{Total}/A$	Horton (1945)
8.	**Stream frequency (F_S)**	$F_S = N_{Total}/A$	Horton (1945)
9.	**Infiltration number (I_N)**	$I_N = D_d \times F_S$	Smith (1950)
10.	**Elongation ratio (R_e)**	$R_e = D_c/L_{bm}$	Schumm (1956)
11.	**Circulatory ratio (R_c)**	$R_c = 4\pi A/P^2$	Strahler (1964)
12.	**Form factor (F_f)**	$F_f = A/L_{bm}^2$	Horton (1945)
13.	**Time of concentration (t_c)**	$t_c = 0.01947\ L^{0.77}\ S^{-0.385}$	Kirpich (1940)
14.	**Relief (R)**	R = H - h	Schumm (1956)
15.	**Relief ratio (R_R)**	$R_R = R/L$	Schumm (1963)
16.	**Drainage texture (D_T)**	$D_T = L_{Total}/P$	Horton (1945)
17.	**Average slope (S)**	S = (m × N × 100)/A	Carlier and Leclerc (1964)
18.	**Compactness coefficient (C_c)**	$C_c = P/2\sqrt{(\pi A)} = P/P'$	Luchisheva (1950)
19.	**Length of overland flow (L_g)**	$L_g = 1/2D_d$	Horton (1945)
20.	**Constant of channel maintenance (C)**	$C = 1/D_d$	Schumm (1956)
21.	**Ruggedness number (HD)**	$HD = R \times D_d$	Strahler (1968)

Where,
N_u and N_{u+1} = Number of streams of order 'u' and 'u+1'
$\bar{L}_u$ and $\bar{L}_{u-1}$ = Average lengths of streams of order 'u' and 'u-1'
L_{total} = Total length of all streams of all order
N_{total} = Total number of streams of all order
D_c = Diameter of circle having area equal to as that of the watershed
L_{bm} = Maximum basin length; P = Perimeter of watershed;
A = Watershed area; H = Maximum elevation
h = Minimum elevation; N = Contour interval
L = Horizontal distance on which relief measured
m = Total length of contours within the watershed
P' = Perimeter of a circle having equal area as that of watershed

Drainage Area (A)

It is the area in which runoff from the basin's network of streams is released through a common outlet. It is one of the essential features since it directly represents the total volume of runoff generated in a watershed. The large size of a watershed intercepts greater rainfall and generates a high volume of runoff. The total drainage area of the Ranikhola watershed was estimated to be 62.49 km^2 (Table 3).

Drainage Density (D_d)

It is the ratio of the total length of all streams in the watershed to the entire area of the watershed. It reflects the infiltration capacity of the land, water and sediment discharge, and erosion susceptibility of the basin (Chorley, 1969). It is a very important measure of runoff potential and drainage texture of the basin. Smith (1950) categorized 'D_d' into five categories i.e., very fine (>8), fine (6-8), moderate (4-6), coarse (2-4), and very coarse (<2). A drainage basin with a high 'D_d' indicates the

Table. 2 Linear aspects of the Ranikhola watershed

Stream order	No. of streams	Stream length (km)	L_{sm} (km)	R_L	R_b
1st	15	17.785	1.185	0.687	-
2nd	9	12.219	1.357	0.483	1.67
3rd	4	5.906	1.476	0.106	2.25
4th	1	0.624	0.624	-	4.00
Total	29	36.535	-	Mean	2.64

Table. 3 Aerial aspects of the Ranikhola watershed

Parameter	Value
Watershed area (km^2)	62.49
Watershed perimeter (km)	39.26
Drainage density (D_d) (km^{-1})	0.585
Drainage texture (D_T)	0.931
Stream frequency (F_S) (km^{-2})	0.464
Compactness coefficient (C_c)	1.401
Elongation ratio (R_e)	0.865
Circulatory ratio (R_c)	0.510
Form Factor (F_f)	0.347
Infiltration number (I_N)	0.271
Length of overland flow (L_g) (km)	0.855
Constant of channel maintenance (C)	1.710

Table. 4 Relief parameters of the Ranikhola watershed

Parameter	Value
Relief (R)	1595 m
Relief ratio (R_R)	0.187
Ruggedness number (HD)	0.933
Average slope (S)	55.22 %
Time of concentration (tc)	52.58 minutes

Table. 5 Areas under different slope zones.

Slope (in °)	Area	
	(in km^2)	(in %)
0 – 7	1.53	2.45
7 – 14	6.85	10.97
14 – 20	11.71	18.74
20 – 30	21.18	33.90
30 – 41	14.11	22.58
41 – 52	5.35	8.56
52 – 80	1.74	2.79
Total	62.49	100

existence of a well-developed channel network, sparse vegetation, and high relief, which lead to quick runoff disposal and greater soil erosion potential of the basin (Strahler, 1964). In previous studies, it was observed that 'D_d' indirectly affects the groundwater potential of the watershed due to its surface runoff generation and permeability. The drainage density of the Ranikhola watershed was found to be 0.585 km^{-1}, which is very low. A lower value of 'D_d' indicates the low relief, weak channel network, and higher infiltration capacity, relatively good or coarser vegetative cover throughout the basin. The overland flow is the more prominent in the basin and results in low runoff disposal.

Drainage Texture (D_T)

It is the ratio of the total number of streams of all orders in a basin to the basin's perimeter (Hortan, 1945). It depends upon many factors such as climate, precipitation, soil type, vegetation, and basin relief (Darnkamp and King, 1971; Nag *et al*., 1998). Smith (1950) classified 'D_T' into five classes i.e., very fine (>8), fine (6-8), moderate (4-6), coarse (2-4), and very coarse (<2). The 'D_T'of the study area was found to be 0.931 (Table 3), which is less than 2, which indicates the Ranikhola watershed has a very coarse drainage texture; thus, the watershed is less susceptible to erosion due to its massive and resistant rocks structures.

Stream Frequency (F_S)

Horton (1932) defined 'F_S' as the total number of stream segments of all orders in a unit area. It is generally expressed in km^{-2}. The number of streams at any place depends on the structure and vegetation cover, rocks type, precipitation, and permeability of the soil. The basin having higher drainage density will lead to higher stream frequency in the basin (Rai *et al.,* 2017). Results indicated that the Ranikhola watershed has a low (< 2.5/km^2) stream frequency which was estimated to be 0.464 km^{-2} (Table 3). It indicates a watershed has low relief and high permeability of the rock. The lesser the stream frequency in the watershed, the lower will be the runoff, and therefore, flooding is less likely to occur.

Compactness Coefficient (C_c)
It refers to the ratio of the perimeter of a watershed to the circumference of a circle having an area equal to the area of the watershed (Hidore, 1965). It depends only on the slope of the basin and is independent of the watershed area. The value of 'C_c' is 1 for a circular basin and increases with the increase in basin length. Thus, it directly represents the elongated nature of the basin. Lower values of C_c indicate a more elongated basin, while higher values indicate a less elongated basin (Patel *et al.,* 2016). The 'C_c' of the Ranikhola watershed was computed to be 1.40 (Table 3), indicating the elongated shape of the watershed. Thus, having a low runoff peak for a longer time base, therefore, the flood flow of the watershed is easier to manage. From the drainage point of view, a circular basin is very hazardous because of the short time of concentration.

Elongation Ratio (R_e)
It is the ratio of the diameter of a circle having an area equal to the basin and the basin's perimeter. A circular basin has a shorter time of concentration than an elongated basin (Schumm, 1956; Chopra, 2005). Strahler (1964) categorized 'R_e' into three categories i.e. less elongated (<0.7), oval (0.9 to 0.8), circular (>0.9). Higher values of 'R_e' represent strong infiltration capacity and low runoff, whereas lower 'R_e' values indicate high sensitivity to erosion and sediment load. (Reddy *et al.,* 2004). The 'R_e'of the Ranikhola watershed was found to be 0.865 (Table 3), which indicates the watershed falls in the oval category. This facilitates watersheds with strong infiltration capacity, low runoff, and high groundwater potential.

Circulatory Ratio (R_c)
It is the ratio of the basin's area to the area of a circle having a circumference equal to the basin perimeter (Miller, 1953). The value of the 'R_c' varies with the variation in the land use and land cover, geological structure, basin length, and relief of the basin (Miller, 1953). As stated by Ahmad *et al.* (2010), for the perfect circular basin, the value of 'R_c' is equal to 1, and for an elongated watershed, its value ranges from 0.4 to 0.5. Analysis output indicates that the 'R_c' of the Ranikhola watershed was found to be 0.50 (Table 3). This depicts that the watershed is elongated in shape with fewer structural disturbances. In an elongated watershed, runoff from different parts reaches gradually to the outlet; thus, the magnitude of runoff is lower compared to that of the circular watershed.

Form Factor (F_f)
It is the ratio of the basin area to the square of the basin length. It is generally used to indicate different shapes of the basin (Horton, 1932). The 'F_f' less than 0.78 indicates an elongated basin, and greater than 0.78 indicates a circular basin (Farhan *et al*., 2016). For the Ranikhola watershed, 'F_f' was found to be 0.347 (Table 3), which shows that the watershed is elongated and has a lower peak for a longer duration. The flow of such elongated basins is easier to regulate as compared to circular basins due to the high time of concentration.

Infiltration Number (I_N)
It is the product of drainage density (D_d) and stream frequency (F_S). 'I_N' provides an idea about the infiltration capacity of the basin. The higher value of 'I_N' indicates the lower infiltration capacity of the basin, which results in more runoff generation in the basin. The value of 'I_N' of the Ranikhola watershed was estimated to be 0.271 (Table 3), which shows the strong infiltration capacity of the bedrock, lower runoff, and less susceptibility to soil erosion within the watershed.

Length of Overland Flow (L_g)
It is the distance that water flows across the ground surface before reaching stream channels. Horton (1945) expressed 'L_g' as equal to half of the inverse of a drainage density. Ratnam *et al*., (2005) classified 'L_g' in three classes i.e., high value (>0.3), moderate value (0.2-0.3), and low value (< 0.2). A low value of 'L_g' depicts a high slope, short flow paths, high runoff, and slow infiltration, which will lead to increased vulnerability to flash floods. The 'L_g' of the Ranikhola watershed, as computed from 'D_d' was found to be 0.855 km (Table 3). This means runoff has to flow for 0.855 km as a sheet flow before it reaches a stream channel, which indicates watershed slope is gentle, flow paths are long, infiltration is more, and groundwater potential is high.

Constant of Channel Maintenance (C)
Schumm (1956) defined 'C' as a reciprocal of the drainage density (D_d). This parameter signifies the area required to sustain unit channel length. Typically, a higher value of 'C' points toward the more permeable rocks in the basin. In the Ranikhola watershed, the value of 'C' was

estimated as 1.71 (Table 3), which is said to be higher (Dikpal *et al*., 2017). The greater the value of 'C' lesser the watershed is susceptible to soil erosion because of lower runoff. This also shows the dense vegetation in the watershed and higher soil infiltration rate.

Relief Aspects

The relief aspects are important terrain parameters used in assessing disaster-prone areas, erosion hazards, etc. They are of prime importance in decision-making on the needs of treatment with soil and water conservation structures in the watershed. The summary of relief aspects of the Ranikhola watershed is given in Table 4.

Relief (R)

Schumn (1956) defined relief (R) as the measure of elevation difference from the stream head to the point where it connects to the higher-order stream. It directly influences runoff velocity and sediment load transportation (Hadley and Schumm, 1961). The estimated elevations of the highest and the lowest points in the study area were 2454 m and 859 m, thus giving the maximum relief of the watershed to be 1595 m (Table 4).

Relief Ratio (R_R)

It refers to the ratio of the basin relief (R) to the maximum length of a basin parallel to the main drainage line (Schumm, 1956). It helps in comparing the relative relief of a basin regardless of the topography. 'R_R' indicates the steepness of the watershed and the erosion intensity on the slope of the basin, and morphometric characteristics (Hadley and Schumm, 1961). The high value of 'R_R' is the characteristic of hill regions whereas the low value represents plain area and valley. The longest dimension of the Ranikhola watershed measured parallel to the direction of the main channel was 8.513 km. The 'R_R' of the watershed was estimated to be 0.187 (Table 4), indicating the area has low relief, low runoff, and high groundwater potential. A lower 'R_R' indicates the characteristic features of less resistant rocks in the study location.

Time of Concentration (t_c)

It is the time required for runoff to move from the most remote point to the outlet point of a watershed. It depends on topography, geology, and land use/cover within the basin. The 't_c' of the Ranikhola watershed was found to be 52.58 minutes (Table 4). A high value of 't_c' shows a watershed with a dominant previous area, which leads to lower runoff, fewer erosion problems, and less structural disturbance in a watershed.

Ruggedness Number (HD)

It is the product of maximum basin relief (R) and drainage density (D_d) (Strahler, 1968). It indicates the degree of smoothness and roughness of the watershed topography (Dubey *et al*., 2015). Its values range from 0 to 1. The Values close to 0 show relatively smoother topography, and 'HD' close to 1 shows rough topographical characteristics. The Ruggedness value for the Ranikhola watershed was found to be 0.933 (Table 4), indicating the area has a rugged terrain. A rough topography of the watershed leads to high time of concentration and low runoff generation. This makes a watershed less susceptible to soil erosion.

Average Slope (S)

It provides information about the watershed topography. It is computed by dividing the area of the watershed by the multiplication of contour interval and the total length of all contours. The average slope of a basin has a significant impact on the time of concentration and directly affects the runoff generated into the basin. The basin slope (S) has a direct impact on the soil erodibility of the basin. Previous studies have shown that a higher land slope will lead to more erosion when other parameters remain the same. The results show the total length of all contours was estimated to be 1.38 km, and the contour interval was 250 m. It has been observed that the major portion (42 km^2) of the Ranikhola watershed has a land slope of less than 30%, as shown in Figure 6, which leads to low runoff generation in the watershed. However, the establishment of adequate soil and water conservation structures is essential in these areas to avoid soil erosion and water loss. The areas under different slope zones are given in Table 5.

Conclusion

Morphometric analysis of the Ranikhola watershed elucidates that the Ranikhola River is having a fourth-order stream, with the domination of lower-order streams. Homogeneous surface features and dendritic drainage patterns in the majority of the areas were also found, which are occupied by the streams of the first, second, and third order. The average value of 'R_b' for the selected watershed was estimated as 2.64, which indicates the good drainage pattern of the watershed. The lower value of the 'D_d' (0.585 km^{-1}) indicates a more permeable subsoil formation under the dense vegetation cover and lower watershed relief. The 'F_f', 'R_e', and 'R_c' of the watershed indicate an elongated shape associated with mild slopes and long flow paths. Thus, a watershed has a lower peak for a longer time base on the runoff hydrograph. The lesser relief ratio would lead the watershed to be less susceptible to soil erosion on the slope, probably because of forest-dominated land use. The morphometric analysis of the Ranikhola watershed will be used in the watershed evaluation process, decision-making for prioritization of conservation structures, and micro-level management of natural resources.

Conflict of interest

The authors declare that they have no conflict of interest.

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