Morphometric Analysis of Mandakhali Watershed, Parbhani District of Maharashtra State

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***Abstract*—The study was undertaken at Mandakhali Watershed in Parbhani Taluka in Parbhani District of Maharashtra state. It is located at 19^{0}14' latitude and 76^{0}38' longitude. The geographical area of village was 1445.44 ha. For watershed management, different morphometric characteristics such as linear parameters (stream order, stream number, bifurcation ratio, stream length, mean stream length), areal or basin parameters (circularity ratio, elongation ratio, drainage density, drainage frequency), and relief parameters (dissection index, ruggedness index, hypsometric characteristics) are important. Watershed delineate by using Arc/Q GIS 10.3 software. The reference watershed first delineated from the drainage and terrain information from 1:50000 toposheet. Different thematic maps i.e., watershed map, drainage map, aspect map, hill shade map, contour maps are developed with the help of digital elevation model (DEM) and Toposheet in Arc/Q GIS 10.3 software. In this research work found 4th order stream order of the studied watershed. The total stream length was found 25.5 km. The average Rb of Mandakhali Watershed is 3.82. It shows that the large variation in frequencies between successive orders and indicates the mature topography. The basin area was recorded as 14.45 sq.km. The basin perimeter was recorded as 17.78 km. The drainage structure was found moderate coarse i.e., 5.72 km^{-1}. The elongation ratio of watershed was recorded as 0.40 which represented elongated watershed.**

***Index Terms*—Remote Sensing, GIS, Morphometry, Arc/Q GIS 10.3, Mandakhali**

I. INTRODUCTION

Remote sensing techniques give a synoptic overview of a broad region that is not feasible with standard ground survey methods, the data may be collected on a permanent basis, and the data are accurate, impartial, and suitable for interdisciplinary applications. For delineation of ridge lines, characterization, priority evaluation, problem identification, assessment of potentials and management needs, identification of erosion prone areas, evolving water conservation strategies, site selection for check dams and reservoirs, and other applications, remote sensing data can be used in conjunction with conventional data (Dutta et al., 2002).

Drainage morphometry is the measurement of a drainage basin's linear, areal, and relief features (Clarke 1966). Horton was the first to use drainage morphometry (1932). Understanding the underlain structure, geomorphological formations, and hydrological features of each basin relies heavily on drainage morphometric parameters (Morisawa 1985). The study of many geologists and geomorphologists has demonstrated the link between drainage morphometric parameters and their underlying geology, geomorphology, and hydrological features (Strahler 1952; Chorley et al. 1985). It's also crucial for determining soil erosion, food quality, and geomorphological processes (Chavare and Potdar 2014). The use of various terrain morphometric measures of drainage basins may be used to better understand the evolutionary history of any basin (Sharma and Sarma 2013). For any river basin management, different morphometric characteristics such as linear parameters (stream order, stream number, bifurcation ratio, strream length, mean stream length), areal or basin parameters (circularity ratio, elongation ratio, drainage density, drainage frequency), and relief parameters (dissection index, ruggedness index, hypsometric characteristics) are important.

The results of this research may be used to prioritise the basin's watersheds for soil and water conservation, analyse surface and groundwater resources, and plan water harvesting-cum-groundwater recharge structures. Runoff knowledge will provide an indicator of the amount of water available to refill water bodies in the basin's watersheds. Furthermore, its quantification will provide information on rainwater harvesting options. This help in making informed decisions on topics such as land and water resource management. It can also be used as a guide for those who want to undertake morphometric and hydrologic analytic work in the area.

II. MATERIALS AND METHOD

Study area: The study was undertaken at Mandakhali Watershed in Parbhani Taluka in Parbhani District of Maharashtra state. It is located 16 km towards West from District headquarters Parbhani. It is located at $19^{0}14'$ latitude and $76^{0}38'$ longitude. The geographical area of village was 1445.44 ha.

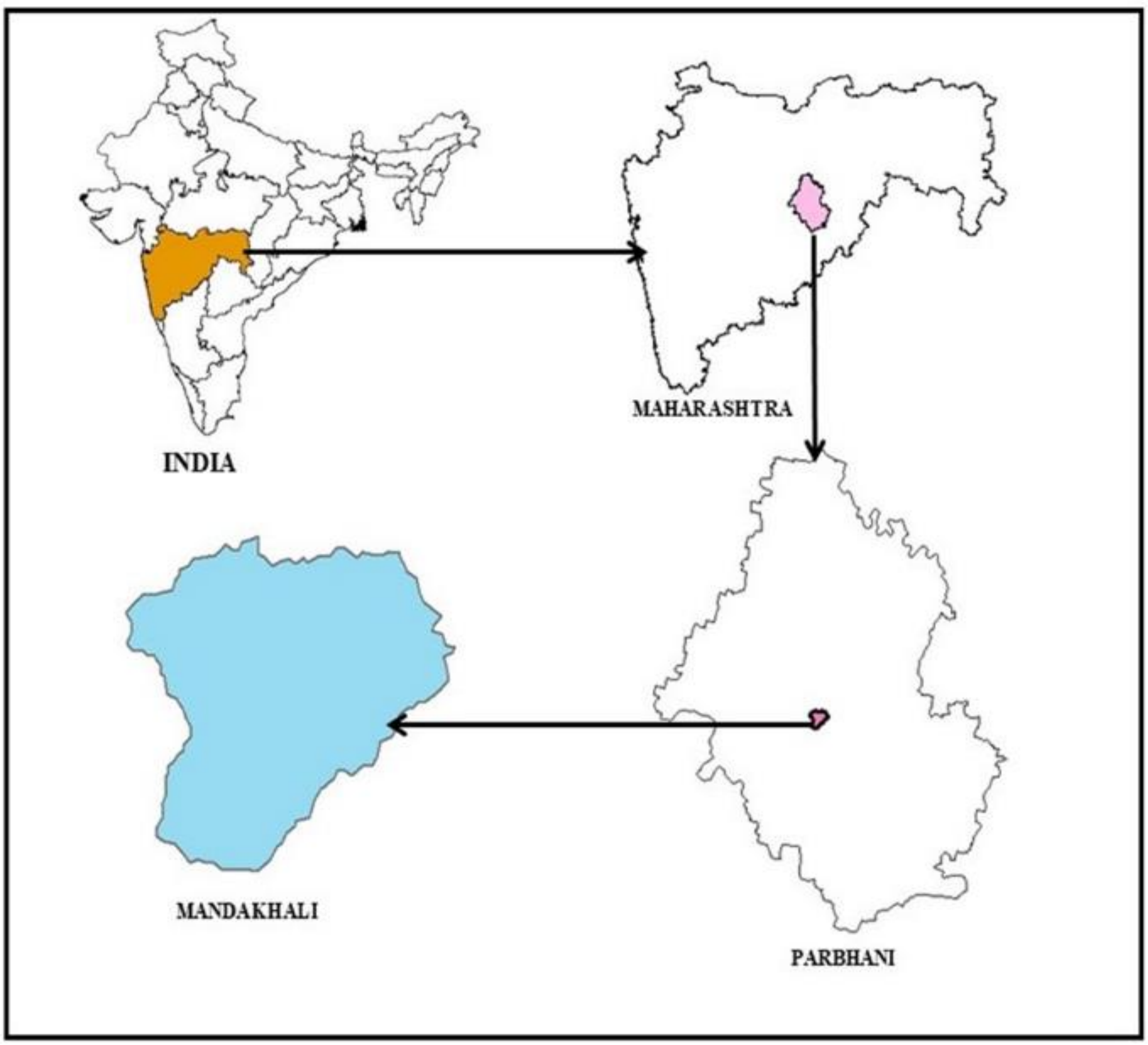

Fig - 1 Study area location

Methodology

Table 1: Remote Sensing and Hydrological data

Data	Description	Source
Remote Sensing data	Toposheet No. – E43E12 (56A/12) Scale on 1:50000	Survey of India
	Digital Elevation Model (DEM) of 30 m resolution	www.usgs.gov.in

Morphometric analysis of Mandakhali Watershed

For the present study to determine morphometric parameters by Arc/Q GIS 10.3 Software. The software developed by Environmental System Research Institute (ESRI). For the study area methodology adopted for morphometric characteristics analysis described below

2.1 Linear Aspects

Stream order: The streams in the Mandakhali watershed were ranked using Strahler's (1964) stream ordering system, with the number of streams in each segment (Nu) of the order (U) confirmed.

Bifurcation ratio: Horton (1932) used the term "bifurcation ratio" (Rb) to describe the ratio of the number of streams in one order to the number in the next lower order. The Rb is defined as the ratio of the number of streams of a particular order (Nu) to the number of segments of the higher order (Nu+1), according to Strahler (1964).

$$Rb = \frac{Nu}{Nu + 1}$$

Where,

Rb = bifurcation ratio

Nu = number of streams of order u

Nu+1 = number of streams of order u+1

Stream length: The stream length (Lu) was calculated using Horton's suggested law. The length of a stream is one of the most important hydrological parameters of the basin since it exposes the characteristics of surface runoff. The stream with a shorter length is typical of places with steeper slopes and finer textures. Streams with longer lengths typically have a flatter grade. The overall length of stream segments is often greatest in first-order streams and decreases as stream order increases.

Stream number: Stream number refers to the number of streams of each order in a specific watershed. The number of streams in each order forms an inverse geometric sequence against stream order, according to the law of stream order (Horton 1945).

Stream length ratio: The average length of a stream in one order divided by the average length of streams in the next order is known as the stream length ratio (RL). According to Horton's law of stream length, mean stream length segments of each of a basin's consecutive orders tend to resemble a straight geometric series, with stream length rising as the order of streams increases.

$$RL = \frac{Lu}{Lu + 1}$$

Where,

RL = stream length ratio

Lu = average length of streams of order u

Lu+1 = average length of streams of next order

2.2 Aerial aspects of watershed

Drainage Density: Drainage density is a metric for describing the physical characteristics of a drainage basin. Drainage density is defined as the entire length of channel in a drainage basin divided by the total area, as first established by Robert E. Horton. The climatic and physical features of the drainage basin influence drainage density. The runoff in a watershed is affected by soil permeability (infiltration difficulties) and underlying rock type; impermeable ground or exposed bedrock will result in increased surface water runoff and, as a result, more frequent streams. If the other features of the drainage basin are the same, rugged locations or those with high relief will have a greater drainage density than other drainage basins.

$$Dd = \frac{Lu}{A}$$

Where,

Dd = Drainage density

Lu = total stream length of all orders

A = area of watershed (km^2)

Drainage texture: Climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief, and stage of development are all elements that influence drainage texture (T) (Smith, 1950). Fine texture is produced by soft or weak rocks that are not covered by vegetation, whereas coarse texture is produced by huge and resistant rocks. Arid climates have less flora, which results in finer textures than those produced on comparable rocks in humid climates. The texture of a rock is usually determined by the type of flora and the environment (Darnkamp and King, 1971). T is the product of Dd and Fs in basic terms.

$$T = \frac{Nu}{P}$$

Where,
T = drainage texture (km)
Nu = total no. of streams of all orders
P = perimeter of the basin (km)

Stream frequency: The number of streams per unit area in a basin is known as stream frequency (Horton 1945). A greater stream frequency indicates more surface runoff, a steeper land surface, impermeable subsurface scarce vegetation, and high relief. Low stream frequency suggests low relief and high permeable bedrock.

$$Fs = \frac{N}{A}$$

Where,
Fs = stream frequency
N = total number of streams
A = area of watershed (km²)

Circularity Ratio: The circularity ratio, according to Miller (1953), is the ratio of the basin area (A) to the area of a circle with the same perimeter as the basin. When the basin form is a complete circle, the ratio value is unity, and when the basin shape is significantly elongated and extremely permeable homogenous geologic materials, the ratio value is between 0.4 and 0.5. The slope, relief geologic structure of the basin, and land use/landcover all impact the circularity ratio.

$$Rc = \frac{4\pi A}{P^2}$$

Where,
Rc = Circularity ratio
A = area of watershed (km²)
P = perimeter of watershed (km)

Elongation ratio: The diameter of a circle with the same area as the basin divided by the maximum basin length is known as the elongation ratio (Schumm 1956). It's a crucial metric for determining basin shape. Analysis of elongation ratio reveals that the regions with greater elongation ratio values have high infiltration capacity and minimal runoff. A circular basin is more effective in the discharge of runoff than an extended basin (Singh and Singh, 1997). (Singh and Singh, 1997). This ratio varies between 0.6 and 1.0 over a wide range of climatic and geologic conditions (Strahler and Chow, 1964).

$$Re = \frac{\sqrt{(4A/\pi)}}{Lb}$$

Where,
Re = Elongation ratio
A = area of watershed (km²)
Lb = maximum basin length (km)

Texture ratio: The total number of stream segments of all orders per perimeter of that area is known as the drainage texture ratio (T) (Horton, 1945). Climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief, and stage of development are all aspects to consider.

$$T = \frac{N1}{P}$$

Where,
T = texture ratio
N1 = total no. of streams first order streams
P = Perimeter of watershed (km)

Length of overland flow: The Length of Overland Flow (Lg) is the distance that water travels over the ground surface before condensing into a stream channel (Horton, 1945). Lg is one of the most significant independent factors influencing drainage basin hydrologic and physiographic development. The reciprocal of drainage density divided by half equals the length of overland flow. This component is inversely proportional to the channel's average slope and is, to a considerable extent, identical with the length of sheet flow.

$$Lof = \frac{1}{2Dd}$$

Where,
Lof = length of overland flow
Dd = Drainage density

Constant channel maintenance: This parameter specifies how many units of watershed surface are required to support one unit of channel length. As a characteristic called constant of channel maintenance, Schumm (1956) utilized the inverse of the drainage density with the dimension of length. Drainage density will be lower in drainage basins when this characteristic is higher.

$$C = \frac{1}{Dd}$$

Where,
C = constant channel maintenance
Dd = drainage density

Form factor: The form factor of a drainage basin is a dimensionless ratio of its area (A) to its maximum length (Lb) (Horton 1932). Simple dimensionless ratios of the fundamental measures area, perimeter, and length may be used to index basin shape (Singh 1998).

$$Rf = \frac{A}{(Lb)^2}$$

Where,
Rf = form factor
A = area of watershed (km²)
Lb = basin length (km)

2.3 Relief Aspects
Basin relief: The computation of basin relief to demonstrate spatial variation is the most common, according to Rao et al. (2011). The maximum vertical distance between a basin's lowest and highest point is known as basin relief. The stream gradient is determined by basin relief, which also impacts flood patterns and the amount of material that may be carried (Hadley and Schumm 1961). It is crucial to comprehending the basin's denudation features (Sreedevi et al. 2009).

Relief ratio: The relief ratio is a dimensionless ratio of basin relief to basin length that is an effective measure of the watershed's gradient aspects (Schumm 1956). It depicts the overall steepness of a drainage basin and serves as a measure of the intensity of erosion processes on the basin's slopes (Javed et al. 2009).

$$Rh = \frac{Bh}{Lb}$$

Where,
Rh = Relief ratio
Bh = Basin relief
Lb = Basin length

Ruggedness number: A dimensionless ruggedness number is defined as the combination of basin relief and drainage density to integrate the attributes of slope steepness and length (Strahler 1958). It's a measure for surface irregularity (Selvan et al. 2011).

$$Rn = Bh \times Dd$$

Where,
Rn = Ruggedness number
Bh = Basin relief
Lb = Basin length

III. RESULT AND DISCUSSION

The morphometric analysis was carried out through measurement of linear, areal, and relief aspects of the watershed morphometric parameters. It includes the analysis on systematic description of the watershed’s geometry and its stream channel system to measure the linear aspects of drainage network, aerial aspects of the drainage basin and relief aspects of the channel network and contributing ground slope too. The first two categories of measurement treat the projected property of watershed on a horizontal plane, whereas third category of measurement, counts the vertical inequalities of forms of drainage basin.

3.1 Linear aspects

Table 2: Linear aspects of Mandakhali Watershed

Stream Orders (U)	Stream No. (Nu)	Stream Length (Lu) (km)	Mean Stream Length (Lsm) (km)	Stream Length Ratio (SRL)	Bifurcation Ratio (Rb)
1st	24	13.20	0.55	-	-
2nd	14	6.52	0.46	0.49	1.71
3rd	8	5.48	0.68	0.84	1.75
4th	1	0.30	0.33	0.54	8
Total	47	25.5		Avg. = 0.62	Avg. = 3.82

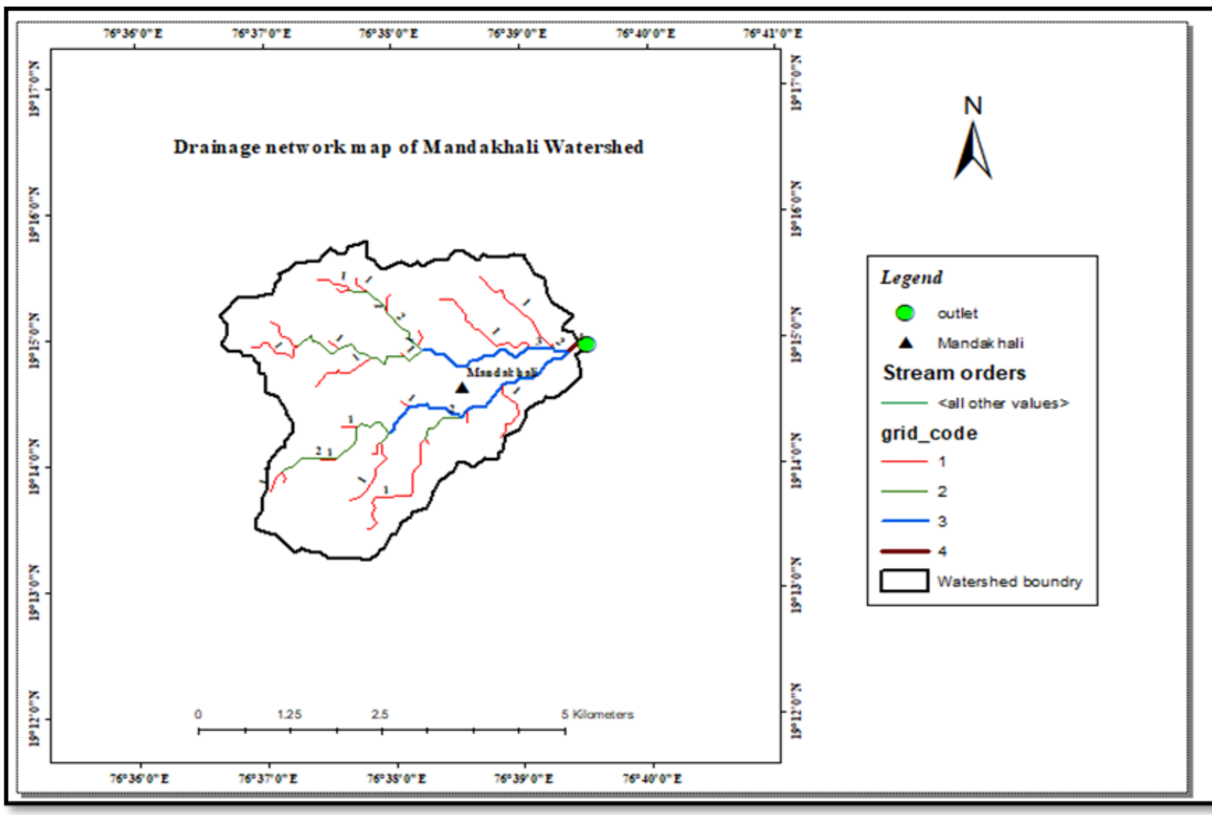

Fig – 2 Drainage Network Map of Mandakhali Watershed

Stream order (U): Table 2 shows that in Mandakhali watershed river tributaries are of fourth order. In all 47 streams are identified of which 24 are first order, 14 are second order,8 is third order and 1 is of fourth order. Drainage patterns of stream network from the basin have been observed as mainly of dendritic type which indicates the homogeneity in texture and lack of structural control.

Stream length (Lu): The total drainage length calculated by using Arc/Q GIS software in this watershed. The total stream length is found 25.5 km and number of streams of various orders in a watershed are counted and their lengths from mouth to drainage divide are measured with the help of GIS software. The length of 1st order streamis13.20 km,2nd order stream is 6.52 km, third order stream is 5.48 km and fourth order stream is 0.30 km.

Mean Stream Length (Lsm): The mean stream length (Lsm) is calculated by dividing the total stream length of all order by the number of streams. The mean stream length of 1st, 2nd, 3rd and 4thorderwere found 0.55 km, 0.46 km, 0.68 km and0.33km respectively. It is observed that the total length of stream may increases or decreases as the stream order increases. This may be to the geomorphologic, lithological and Structural control and contrast (Strahler, 1964).

Stream Length Ratio (RL): From Table 2 revealed that average stream length ratio of 2nd, 3rd and 4th order is found 0.49, 0.84 and 0.54 respectively and Average stream length ratio was found 0.62 of Mandakhali Watershed.

Bifurcation Ratio (Rb): From Table 2 it is seen that Rb is not the same from one order to its next order. For stream orders of 2nd, 3rd and 4thRb is observed as 1.71, 1.75 and 8 respectively. In that the higher bifurcation ratio of 4th order is 8. The average Rb of Mandakhali Watershed is 3.82. It shows that the large variation in frequencies between successive orders and indicates the mature topography (Strahler,1964).

3.2 Areal aspects

Length of basin (Lb): Many experts described the length of the basin as being the longest dimension of the basin parallels to the main drainage line (Schuum (1956)). The length of the basin was defined by Gregory and Walling (1973) as the longest in the basin in which mouth ends. Gardiner (1975) defined the length of the basin as the length of the line from the mouth of a watershed to a point on the perimeter equally in either direction. In the Mandakhali watershed the length of basin was recorded as 5.98 km.

Basin Area (A): Another essential characteristic such as the water drainage length is the watershed area. Schuum (1956), which is based on the contributing areas, developed an interesting relationship between the total watershed areas and the total water stream lengths. In Mandakhali watershed, the basin area was recorded as 14.45 sq.km.

Basin Perimeter (P): The basin perimeter of Mandakhali watershed was recorded as 17.78 km.

Table 3: Areal parameters of Mandakhali Watershed

Sr. No.	Name of Parameter	Count
1	Length of basin (Lb)	5.98 m
2	Basin Area (A)	14.45 q. km
3	Basin Perimeter (P)	17.78 km
4	Drainage density (Dd)	1.76 km/km²
5	Drainage Texture (T)	5.72 km^{-1}
6	Texture ratio (T)	1.34
7	Form Factor (Rf)	0.40
8	Elongation ratio (Re)	0.40
9	Stream Frequency	3.25 km^{-2}
10	Length of Overland flow	0.28 km
11	Constant channel maintenance	0.68

Drainage density (Dd): Drainage density is another aspect of drainage analysis that covers the stream length by unit area in the watershed area (Horton, 1945 and1932; Strahler, 1952 and 1958; Melton 1958). Drainage density is a better quantitative expression for land form deconstruction and analysis but it may finally be used as an indirect indication to explain these factors as well as morphogenesis of landform as a function of the region's climate, lithology and structure and relief recent behaviour. As shown in table 3 the drainage density of Mandakhali Watershed is 1.76 km/km²

Drainage Texture (T): One of the most significant terms in geomorphology is drainage texture, which refers to the relative spacing of drainage lines. Drainage texture is determined by the terrain's subsurface lithology, infiltration capability, and relief. Dt is the total number of stream segments of all orders per area's boundary (Horton, 1945). (Smith, 1950) divided drainage texture into five categories: extremely coarse (<2), medium (2–4), moderate (4–6), fine (6–8), and very fine (>8). The Mandakhali watershed drainage structure is found moderate coarse i.e., 5.72 km^{-1}.

Texture Ratio (T): The fundamental lithology, infiltration rate, and relief factors of the topography all influence the texture ratio, which is an important factor in drainage morphometric analysis. The texture ratio is defined as the ratio of first order streams to basin perimeter ($Rt = N1 / P$), and it is influenced by the terrain's underlying lithology, infiltration capacity, and relief aspects (Schumm 1965). The texture ratio of Mandakhali Watershed is calculated 1.34.

Form Factor (Rf): According to Horton (1932), the ratio of the basin area to the square can be described as the form factor. The shape factor is less, the shift will be more prolonged. The watershed with high shape factors has shorter peak flows. In Mandakhali watershed, form factor determined by using Arc/Q GIS 10.3 software was recorded as 0.40. It shows that the watershed is having sub-circular shape.

Elongation Ratio (Re): The elongation ratio is defined by the Schumm (1965) as the ratio of the circle's diameter to the greatest length of the basin from a circle in the same region. With aid of the elongation index (0.9-0.10), oval (0.8-0.9), less elongated (0.5-0.7), and longer (<0.5) the varied slopes of the hills of the hydromass slopes may be categorised. The elongation ratio of Mandakhali watershed is recorded as 0.40 which represented elongated watershed.

Stream Frequency (Fs): Horton (1932) defined drainage frequency as the number of stream segments per unit area, which he defined as stream frequency (or channel frequency) Fs. In the present study, the stream frequency of Mandakhali watershed is recorded as 3.25 km^2. Length of overland flow (Lg): The length of overland flow of Mandakhali watershed is found to be 0.28 km.

Constant of Channel Maintenance: As a characteristic of landforms, Schumm (1956) utilised the inverse of drainage density or the constant of channel maintenance. The constant is the number of km^2 of basin area necessary to build and maintain a 1 km long canal. The channel maintenance constant denotes the proportional size of landform units within a drainage basin and has a physiological implication (Strahler, 1957). The constant of channel maintenance of Mandakhali Watershed is observed as 0.68.

3.3 Relief aspects

Relief aspects as Mandakhali watershed are shown in Table 4.

Table 4: Relief Characteristics

Sr. No.	Name of Parameter	Count
1.	Relief Ratio	0.014
2.	Relative Relief	0.089 km
3.	Ruggedness Number	0.156

Relief Ratio: In this study area value of relief ratio is found to be 0.014.

Relative Relief: Relative relief at Mandakhali watershed is recorded as 0.089 km.

Ruggedness Number (Rn): In present study, ruggedness number is found as 0.15.

IV. CONCLUSIONS

The morphological and climatic characteristics of a basin govern its hydrological response to a considerable extent. The morphological characteristics are determined to study their influences on runoff. Mandakhali watershed river tributaries are of fourth order. In all 47 streams are identified of which 24 are first order, 14 are second order,8 is third order and 1 is of fourth order. The total stream length is found 25.5 km and number of streams of various orders in a watershed are counted and their lengths from mouth to drainage divide are measured with the help of GIS software. The length of 1^{st} order stream is13.20 km, 2^{nd} order stream is6.52 km, third order stream is 5.48 km and fourth order stream is 0.30 km. In the present study, the stream frequency of Mandakhali watershed is recorded as 3.25 km^{-2}. The length of overland flow of Mandakhali watershed is found to be 0.28 km. The constant of channel maintenance is observed as 0.68 for the study area. Relief aspects such as relief ratio, relative relief and ruggedness number for the area under study are recorded 0.014, 0.089 km and 0.156 respectively.

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