Morphometric Analysis of Kajali River Basin Using Geospatial Techniques

ABSTRACT

Soil andwaterare the important natural resources and important input for agricultural production.The present study has been attempted to delineate and determine morphometric characteristics of Sakharpa watershed in Ratnagiri district by using Remote Sensing and GIS.The delineation of watershed was performed in QGIS 3.18.3 software. The study area was obtained from SRTM DEM with 30meter resolution after delineation.Sakharpa watershed shows a dendritic drainage pattern. The results found for morphometric parameters were Bifurcation Ratio (R_b)2-5.5, Form factor (F_f) 0.32, Elongation ratio (R_e) 0.63, Circulatory ratio (R_c) 0.32, Shape index (S_w) 3.18,Drainage density (D_d)1.18km/km^2, Stream frequency (F_s)1.48 km^{-2}, Texture ratio (R_t)1.08, Drainage texture (D_t)2.24,Constant of channel maintenance (C)0.84km^2/km,Length of overland flow (L_g) 0.42, Basin relief (R) 763.92 m,Relief Ratio (R_r) 0.045,Relative Relief (R_{hp}) 1.27,Ruggedness Number (R_n) 0.904. The study concluded that the watershed is elongated in shape, have dense vegetation and homogeneous with less structural disturbance.This morphometric analysis of drainage basin helps to planning and development of watershed also helps to understand relation between linear, areal and relief parameters of drainage basin.

Keywords: Morphometric characteristics, remote sensing and GIS, Watershed

1. INTRODUCTION

The two most essential natural resources for agricultural productivity are soil and water. "Soil without water is a desert, and water without soil is useless," states Dr. H. H. Bennett (Dipika et al, 2014). Water is necessary for all life to exist on Earth. Rapid population growth, urbanization, and industrialization are causing a depletion of land and water resources. Making the best use of these resources is essential for sustainable development in order to meet the demand for them.

A watershed describes an area of land that contains a common set of streams that, all drain to a single outlet. A given watershed responds differently to different hydrological processes, and its behaviour is influenced by a number of hydrological, geomorphological, and physiographic factors. The characterisation of a watershed gives insight into its behaviour because these reactions are particular to that watershed but are also very individual. According to Adhfur et al. (2014), “morphometry is the measurement and mathematical study of the landforms' dimensions and shape on Earth as well as the layout of the planet's surface”. In the realm of hydrology, morphometric studies were initially introduced by Horton (1940) and Strahler (1950). Because it allows us to compare different drainage basins developed in different geologic and climatic regions and to understand the relationships between various aspects of the watershed's drainage pattern, quantitative morphometric characterization of a watershed is thought to be the most appropriate method for the proper planning and management of watersheds. A watershed must be estimated using a variety of morphometric characters, such as the following: areal aspects (area, perimeter, drainage density, form factor, circulatory ratio, and elongation ratio), relief aspects (relief, relative relief, relief ratio, and ruggedness number), and linear aspects (number of streams, stream order, length, bifurcation ratio, and length ratio). Numerous morphometric traits aid in determining the watershed's form and in identifying relationship of various aspects in the area.

"One easy, affordable way to investigate the river basin with good quality and high accuracy is to use quantitative morphometric analysis with remotely sensed data and GIS tools. The study and measurement of linear, areal, and relief features can be done quickly and easily using a GIS-based technique. A practical strategy to sustainable watershed management and development requires the identification of watersheds. Watershed delineation is often accomplished by sketching the watershed's borders on topographic maps. These maps' drainage systems and contours are used to determine the direction of the water flow. This procedure takes a long time and a lot of labor" (Keskar*et al*, 2023).So that the present study has been taken to comprehending the complex interplay among the linear, areal and relief parameters of watershed using the GIS and remote sensing. It also helps in prioritization of watershed.

2. MATERIAL AND METHODOLOGY

Study Area

The Konkan is somewhat blessed with soil and climatic conditions. The temperature in Konkan not crosses 35°C to 36°C with an average humidity of 50% around the year. The average rainfall is ranging from 2500 to 4000mm and soils are highly percolative (Bagwat*et al*, 2023).In Kajali river basin, Sakharpa watershed in district Ratnagiri was selected as study area for present research. Kew river and Gad river are the tributaries of Kajali river. Kew river originates in Sahyadri hills. Gad river meets the Kew river at Sakharpa and forms a Kajali river. The length of Kajali river is 72 km which is Western flowing river falling in Arabian Sea at Bhatye near Ratnagiri. The watershed is located at Sakharpa in Sangameshwar Tehsil and Ratnagiri District of Maharashtra. It is bounded by 16°55'N to 17°01'N latitude and 73°47''E to 73°47''E longitude. It covers the geographic area of about 9037.07 ha. The elevation ranges from 71 m to 835 m above mean sea level. The location map of study area is shown in Fig1.

Data Collection

The digital elevation model (DEM) of shuttle radar topographic mission (SRTM) with 30 m resolution was downloaded from (http://earthexplorer.usgs.gov/).The software QGIS 3.18.3 which is freely available software has been used for processing the remotely sensed data for delineating watershed, extraction of drainage network.

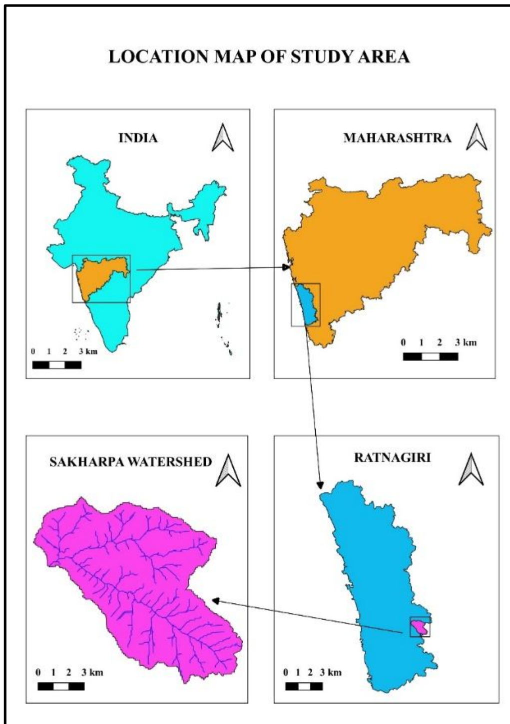

Fig 1. Location map of study area

Morphometric analysis

Morphometry is defined as the measurement and mathematical analysis of the arrangement of the earth's surface and of the shape and dimension of its landforms (Adhfur*et al.* 2014). Morphometric studies in the field of hydrology were first introduced by Horton (1940) and Strahler (1950). Watershed analysis based on morphometric parameters is very important for watershed planning. Computation of morphometric parameters was done from DEM with the help of QGIS software. For the present study SRTM DEM having 90 m resolution was downloaded from the USGS earth explorer.

Basic Morphometric parameters

The basic parameters of watershed include Area of watershed, perimeter of watershed, length of basin, maximum elevation and minimum elevation. The basic morphometric parameters have been calculated and details has been shown in Table 1.

1. Watershed Area (A)

Watershed area (A) is the area enclosed by the ridgeline. Area of watershed was obtained by using QGIS software.

2. Watershed Perimeter (P)

Perimeter shows the length of the ridgeline or boundary of watershed. The perimeter of watershed was also calculated by using QGIS software.

3. Length of Basin (L_b)

Length of basin (L_b) is the length of the greatest straight line from the outlet of the stream to thefarthest point of ridgeline.The formula for estimation oflength of basin (L_b) for is given in Table 1.

4. Maximum Elevation (H)

Maximum elevation is the point showing highest elevation on the Digital Elevation Model (DEM). It was demarked in QGIS.

5. Minimum Elevation (h)

Minimum elevation is the point showing lowest elevation on the Digital Elevation Model. It was demarked in QGIS.

Table 1. Basic morphometric parameters of watershed

Sr No.	Morphometric characteristic	Formula	Unit	Reference
1.	Area of Basin (A)	QGIS Software	km^2	-
2.	Perimeter (P)	QGIS Software	km	-
3.	Length of Basin (L_b)	$L_b = 1.312 \times A^{0.568}$ Where, L_b= Length of Basin km, A = Area of Basin km^2	km	Nookaratnam*et al.* (2005)
4.	Max. Elevation (H)	QGIS Software	m	-
5.	Min. Elevation (h)	QGIS Software	m	-

Linear Aspects of Watershed

The linear aspects are the one-dimensional morphometric properties of drainage basin. The linear aspects of watershed consist of stream order, stream number, stream length,mean stream length, stream length ratio, bifurcation ratio,mean bifurcation ratio. Table 2 shows formulae used to calculate linear aspects of watershed.

1. Stream Order (u)

The stream is the water flow path over the earth's surface. The designation of stream orders of watershed is the first step in analysis of watershed. Stream order is the hierarchical rank given to the streams in the watershed. When two streams of same order joins, it forms stream of next higher order. Lowermost order is given to the smallest streams in the watershed and higher order is given to the largest streams. Stream Ordering has been proposed by Strahler (1964). The highest order stream is known as principal stream. Stream orders are designated in terms of I^{st}, II^{nd} and so on.

These are explained as:

1. The smaller finger tips like tributaries are the I^{st} order streams.

2. When twoI^{st} order streams are joined in one, then resulting stream segment is termed as II^{st} order streams, and so on.

2. Stream Number (N_u)

The count of orderwise stream segments in the watershed is known as stream number (Horton, 1945). Streamnumber is inversely proportional to stream order. So, stream number decreases as stream order increases.

3. Stream length (L_u)

Stream length is the length of all the streams of order u. The stream length of each order is measured by using QGIS software. As the stream order increases stream length decreases. The stream length is used to determine the basin parameters such asbasin length, drainage density etc.

4. Mean stream Length (L_{sm})

Mean Stream Length (L_{sm}) is the ratio of total stream length (L_u) of order u and the total number of streams of that order (N_u). According to method proposed by (Horton 1945), mean stream length (L_{sm})is measured with respect to streams orders.Horton'slawof stream lengths supportsthetheorythatgeometric resemblances preservedgenerallyinwatershedofincreasingorder(Strahler1964).

5. Stream Length Ratio (R_L)

Stream Length Ratio (R_L), is the ratio of total stream length (L_u) of order u to the total stream length of its next lower order (L_{u-1}). It has major association with surface flow, discharge and erosion stage of the basin. An increasing trend in stream length ratio from lower order to higher order indicates their geographic stage. Therefore, there is no classification of R_L.

6. Bifurcation Ratio (R_b)

Bifurcation Ratio (R_b) is the ratio of the number of streams of any given order (N_u) to the number of streams of next higher order (N_{u+1}) (Schumm, 1956). BesidesBifurcation Ratio (R_b) shows the shape of watershed. Strahler (1957) has also demonstrated that bifurcation proportion shows a tiny number of changes withvarious areas instead of where geological influence is predominant. The value of Bifurcation Ratio (R_b) ranges from 2 to 4. Circular basins show higher bifurcation ratio while elongated basins show lower bifurcation ratio (Aravinda and Balakrishna 2013).

7. Mean Bifurcation Ratio (R_{bm})

Mean bifurcation ratio (R_{bm}) is calculated by taking the average of all the bifurcation ratios of consecutive streams in the watershed.

Table 2.Formulae for calculation of linear aspects of watershed

Sr. No	Morphometric characteristic	Formula	Unit	Reference
1	Stream order (u)	Hierarchical rank	Unitless	Strahler (1964)
2	Stream number(N_u)	Number of streams of order u	Unitless	Strahler (1964)
3	Stream length (L_u)	Length of the stream $L_u = L_{u1} + L_{u2} + L_{u3} + \cdots + L_{un}$	km	Horton (1945)
4	Mean Stream Length (L_{sm})	$L_{sm} = \frac{L_u}{N_u}$ Where, L_{sm}= mean length of channel of order u, L_u= Total stream length of order u N_u = Total no of streams of order u	km	Strahler (1964)
5	Stream Length Ratio (R_L)	$R_L = \frac{L_u}{N_{u-1}}$ Where, $\bar{L}_u$ = Average length of stream of order u, $\bar{L}_{u-1}$ =Average length of stream of order u-1	Unitless	Horton (1945)
6	Bifurcation Ratio (R_b)	$R_b = \frac{N_u}{N_{u+1}}$ R_b = Bifurcation ratio, N_u= No of streams of order u, N_{u+1}= No of streams oforder u+1	Unitless	Schumm (1956)
7	Mean Bifurcation Ratio (R_{bm})	R_{bm} = Average of bifurcation ratios of all orders	Unitless	Strahler (1957)

Areal and Shape aspects

Areal aspects of watershed include drainagedensity, streamfrequency, form factor, compactness coefficient, drainage texture, circulatory ratio, elongation ratio, constant of channel maintenance,length of overland flow. The formulae for calculation of areal and shape aspects of watershed are given in Table 2 and the explanation of above aspects is given below.

1. Form Factor (F_F)

Form factor (F_f) is defined as the ratio of area of watershed to the square of the basin length (Horton 1932). It is a shape parameter, which shows watershed is elongated, oval or circular. An elongated watershed with low value of form factor shows lower peak flow of longer duration while a watershed with a high value of the form factor shows high peak flows of shorter duration. Smaller the value of form factor, more elongated will be the basin.

2. Elongation Ratio (Re)

Elongation ratio is defined as the ratio between the diameter of the circle of the same area as the watershed and the maximum length of the basin (Schumm,1956). Elongation ratio generally vary from 0.6 to 1.0 over a wide variety of climate and geologic type (Strahler, 1964).If elongation ratio values near to 1.0 indicate the relief of watershedis very low, though values in the range of 0.6 - 0.8 usually occur in the areas ofhigh relief and steep ground slope (Strahler 1964). It is also shape parameter which shows shape of watershed. Table 3 shows the watershed shape ratio and its interface.

Table 3. Watershed shape ratio (Somashekhar *et al*. 2011)

Watershed	Shape ratio
Circular	0.9
Oval	0.8-0.9
Less elongated	0.7-0.8
Elongated	0.5-0.7
More elongated	0.5

3. Circularity Ratio (R_c)

"Circularity ratio(R_c) is the ratio of the watershed area to the area of circle having the same perimeter as the watershed. It expresses the degree ofcircularity of the basin" (Miller 1953). It is also dimensionless property. There is relation between circularity ratio and structural disturbances. Similar to bifurcation ratio, high value of circularity ratio shows existence of strong structural control on the watershed and low value of circularity ratio indicated no structural disturbance.

4. Shape index (S_w)

Shape index (S_w) is the shape parameter. It is defined as ratio of square of length of basin and area of watershed.

5. Drainage Density

"Drainage density is defined as the ratio of total stream length of all order to the area of watershed (A)" (Horton, 1932). It helps in determining thepermeability and porosity of the watershed. The area with dense vegetation cover and low relief shows lower value of drainage density.Low drainage density leads to coarse drainage texture. Based on the value of drainage density, the watershed texture has been classified is shown in Table 4.

Table 4.Watershed texture based on drainage density (Zakaria *et al*. 2016)

Drainage density	Textures

<1.24	Very coarse
1.24-2.49	Coarse
2.49-3.73	Moderate
3.73-4.97	Fine
>4.97	Very fine

6.Stream frequency (Fs)

According to HortonStream Frequency(Fs)is the ratio of total number of all the streams in the watershed to the area of watershed. A large basin may contain as many accessible tributaries per unit of area as a small drainage basin usually contains a larger stream or streams (Horton 1932). It refers to the number of streams per unity area.

7. Texture ratio (R_t)

According to Horton (1945)texture ratio (R_t) is defined as the ratio of total number streams of first order to the watershed perimeter.

8. Drainage texture (D_t)

Drainage texture (D_t) is defined as the ratio of total number of streams of all order to the perimeter of watershed. Smith (1950) classified drainage texture into five classes such as i) very coarse (<2km^{-1}), ii) coarse (2-4km^{-1}), iii) moderate (4-6 km^{-1}), iv) fine (6-8 km^{-1}) and very fine (>8km^{-1}).

9. Compactness coefficient (C_c)

Compactness coefficient (C_c) is defined as the ratio of perimeter of watershed to the perimeter of equivalent circular area of watershed Horton (1945).

10. Constant of channel maintenance (C)

Constant of channel maintenance (C) is the inverse of drainage density (D_d) or it is the property of landform Schumm (1956).

11. Length of overland flow (L_g)

Length of overland flow (L_g) is equal to half of the reciprocal of Drainage density (D_d) (Horton, 1945). It is the length of water over a ground before it gets concentrated into certain stream channel.

Table 5. Formulae for calculation of areal, shape and relief aspects of watershed

Sr. No	Morphometric characteristic	Formula	Unit	Reference
1	Form factor (F_f)	$F_f = \frac{A}{L_b^2}$	Unitless	Horton (1932, 1945)

		Where, F_f =Form Factor, A = Area of Basin (km^2), L_b= Length of Basin (km)		
2	Elongation ratio (R_e)	$R_e = 2 \times \frac{\sqrt{A/\pi}}{L_b}$ Where, R_e= Elongation ratio, A = Area of Basin (km^2), L_b= Length of Basin (km)	Unitless	Schumm (1956)
3	Circulatory ratio (R_c)	$R_c = 4\pi \frac{A}{P^2}$ Where, R_c= Circulatory ratio, π=3.14, A= Area of Basin (km^2), P = Perimeter of basin (km)	Unitless	Strahler (1957)
4	Shape index (S_w)	$S_w = \frac{L_b^2}{A}$ Where, S_w= Shape index, L_b= Length of Basin (km), A = Area of Basin (km^2)	Unitless	Horton (1945)
5	Drainage density (D_d)	$D_d = \frac{L_u}{A}$ Where, D_d= Drainage density (km/km^2), L_u= Total stream length of all orders, A = Area of Basin (km^2)	km/km^2	Horton (1932, 1945)
6	Stream frequency (F_s)	$F_s = \frac{\sum N_u}{A}$ Where, F_s= Stream frequency, $\sum N_u$= Total no. of streams of all orders, A = Area of Basin (km^2)	km^{-2}	Horton (1945)
7	Texture ratio (R_t)	$R_t = \frac{N_1}{P}$ Where, R_t= Texture ratio, N_1= Total no. of first order streams, P= Perimeter of basin (km)	Unitless	Horton (1945)
8	Drainage texture (D_t)	$D_t = \frac{N_u}{P}$ Where, D_t= Drainage texture, N_u= Total no. of streams of order u P= Perimeter of basin (km)	km^{-1}	Horton (1945)
9	Compactness coefficient (C_c)	$C_c = 0.2821 \times \frac{P}{A^2}$ Where, C_c= Compactness coefficient, P= Perimeter of basin (km),	Unitless	Horton (1945)

		A= Area of Basin (km^2)		
10	Constant of channel maintenance (C)	$C = \frac{1}{D_d}$ C= Constant of channel maintenance, D_d= Drainage density (km/km^2)	km^2/km	Schumm (1956)
11	Length of overland flow (L_g)	$L_g = \frac{1}{2D_d}$ Where, L_g= Length of overland flow (km), D_d= Drainage density (km/km^2)	km	Horton (1945)
12	Basin relief (R)	$R = H - h$ Where, R= Basin relief (m), H=Maximum elevation (m), h=Minimum elevation (m)	m	Hadley and Schumm (1961)
13	Relief Ratio (R_r)	$R_r = \frac{R}{L}$ Where, R_r= Relief Ratio, R= Basin relief (m), L= Longest axis in km	Unitless	Schumm (1956)
14	Relative Relief (R_{hp})	$R_{hp} = \frac{R}{P} \times 100$ Where, R_{hp}= Relative Relief, R= Basin relief (m), P= Perimeter of basin (km)	Unitless	Melton (1957)
15	Ruggedness Number (R_n)	$R_n = R \times D_d$ Where, R_n= Ruggedness Number, R= Basin relief, D_d= Drainage density	Unitless	Strahler (1957)

Relief aspects of watershed

Relief aspects are related to the elevation difference between reference point in watershed. In general, these are three dimensional properties. Relief aspects include basin relief, relief ratio, relative relief, ruggedness number. Formulae for calculation of relief aspects of watershed are given in Table 5.

1. Basin relief (R)

Basin relief (R) is the difference between maximum elevation and the minimum elevation of the watershed. It is expressed in meters.

2. Relief Ratio(R_r)

Schumm (1956) relief ratio may be defined as the ratio of basin relief (R) to the maximum basin length (L_b). As the area and size of watershed increases, the relief ratio decreases.

3. Relative Relief (R_{hp})

Melton (1957) maximum basin relief was obtained from the highest point on the watershed perimeter to the mouth of the stream. Relative relief (R_{hp}) is defined as the ratio of basin relief to the watershed perimeter. It shows the elevation of the basin from the highest point to the outlet point.

4. Ruggedness number (R_n)

"Ruggedness number is defined as the product of the basin relief and drainage density. Ruggedness number depends on slope and drainage density. Lower value of ruggedness number indicates lesser stream flow velocity which recommends less prone to soil erosion. When slope is steep as well as long and drainage density is high, watershed shows an extremely high value of ruggedness number" (Strahler 1957). It is a dimensionless parameter.

RESULT S AND DISCUSSION

The basic morphometric characteristics were obtained from QGIS 3.18.3 software by processing the DEM of the study area. Various morphometric characteristics such as linear aspects, areal aspects and relief aspects were estimated using basic parameters of the watershed.

Basic Aspects

Basic aspects of watershed include Area of watershed (A), Perimeter of watershed (P) and Basin Length (L_b). Calculated values of these parameters using QGIS and are shown in Table 6.

1. Watershed Area (A)

Area of watershed is obtained by using QGISsoftware.Areaofthe Sakharpa Watershedwas found to be 9037.07ha.

2. Watershed Perimeter (P)

Perimeter shows the length of the ridgeline or boundary of the watershed. The perimeter of watershed is also calculated by using QGIS software. Theperimeter of the Sakharpa watershed is 59.83 km.

3. Length of Basin (L_b)

The value of length of basin (L_b) for Sakharpa watershed was 16.94 km which is shown in Table 6.

Table 6. Basic and Linear aspects of Sakharpa watershed

Sr No.	Morphometric characteristic	Unit	Results
1	Area of Basin (A)	km^2	90.37
2	Perimeter (P)	km	59.83
3	Length of Basin (L_b)	km	16.94

4	Max. Elevation (H)	m	835
5	Min. Elevation (h)	m	71.08
6	Stream order (u)	Unitless	1 to 5
7	Stream number(N_u)	Unitless	134
8	Stream length (L_u)	km	107.01
9	Mean Stream Length (L_{sm})	km	1.96
10	Stream Length Ratio (R_L)	Unitless	0.37 to 0.96
11	Mean Stream Length Ratio (R_{Lm})	Unitless	0.50
12	Bifurcation Ratio (R_b)	Unitless	2-5.5
13	Mean Bifurcation Ratio (R_{bm})	Unitless	3.49

Linear Aspects

Linear aspects of watershed includestream orders (u), stream number (N_u) stream length (L_u), mean stream length (L_{sm}), stream length ratio (R_l), and bifurcation ratio (R_b). The results for linear aspects have been given in Table06.

1. Stream Order (u)

It is the classification system of the streams according to hierarchical rank. In the present study ordering of streams has been performed by using method proposed by Strahler (1954). Higher stream order shows higher discharge and higher velocity (Costa, 1987). Sakharpa watershed is characterized with fifth order stream. It was found that, as stream order increases, stream frequency decreases, as shown in Table 7. Stream order map is shown in Fig 3.

2. Stream Number (N_u)

The law of stream number given by Horton (1945) stated that, the stream segments of each order form an inverse geometric sequence with the order number. In the Sakharpa watershed the total number of streams found to be 134. There are 98 streams of order Ist, 22 streams of order IInd, 11 streams of order IIIrd,2 stream of order IVth and 1 stream of order Vth. An order-wise stream number of Sakharpa watershed is given in Table 7

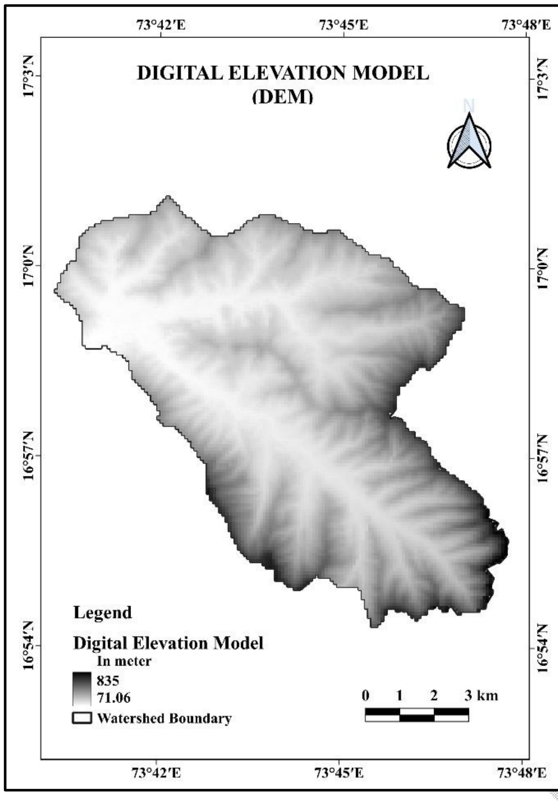

Fig 2. Digital elevation model of Sakharpa watershed

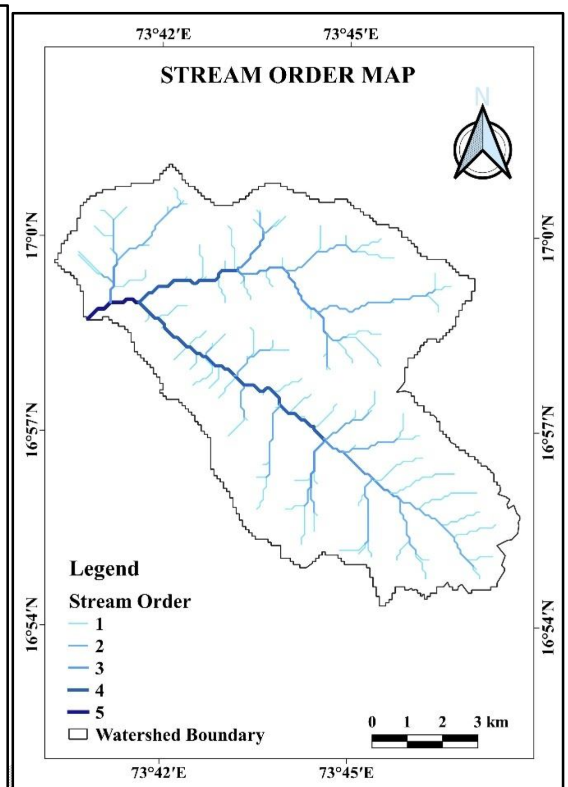

Fig 3. Stream order map of Sakharpa watershed

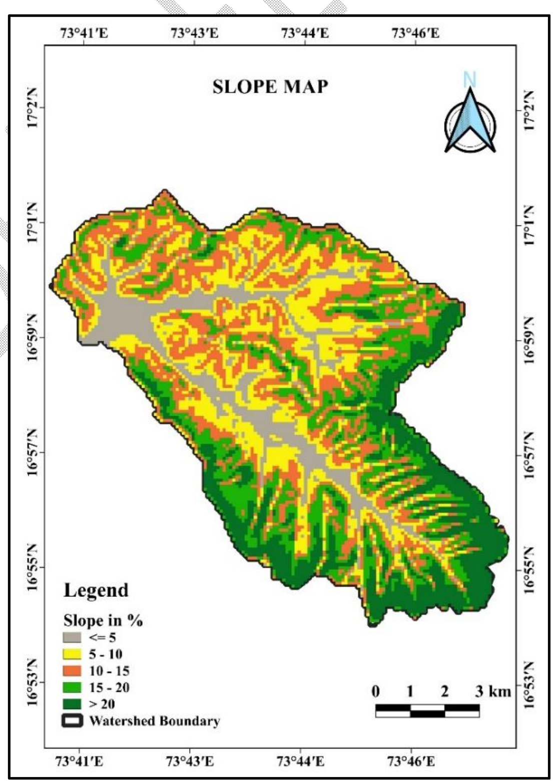

Fig 4. Slope Map of Sakharpa Watershed

3. Stream Length (L_u)

Stream length is the length of all the streams of order u. The stream length of each order is measured by using QGIS software. As the stream order increases stream length decreases. The total length of all streams in Sakharpa watershed was 107.01 km. In the Sakharpa watershed length of Ist order streams was 54.49 km, IInd order streams was 29.45 km, IIIrd order streams was 10.92 km, IVth order streams was 10.44 and the length of Vth order streams was 1.77 km.Stream order-wise stream number and stream length of Sakharpa watershed is given in Table 7.

4. Mean Stream Length (L_{sm})

Mean Stream Length (L_{sm}) is the ratio of total stream length (L_u) of order u and the total number of streams of that order (N_u). For the Sakharpa watershed mean stream length for Ist order streams was 0.56 km, IInd order was 1.34 km, IIIrd order was 0.99 km, IVth order was 5.22 km, and Vth order was 1.71 km.

Table 7. Stream order-wise stream number and stream length of Sakharpa watershed

Stream Order	Number of Streams	Stream Length (km)	Mean Stream Length (km)
Ist	98	54.49	0.56
IInd	22	29.45	1.34
IIIrd	11	10.92	0.99
IVth	2	10.44	5.22
Vth	1	1.71	1.71
Total	**134**	**107.01**	**-**
Mean	**-**	**21.40**	**1.96**

5. Stream Length Ratio (R_L)

Stream length ratio for Sakharpa watershed varies from 0.16 to 0.96. Mean stream length ratio of watershed was found 0.50. The result for orderwise mean stream length ratio are shown in Table 7. The stream length ratio for order II/I was 0.54, III/II was 0.37, IV/III was 0.96, V/IV was 0.16. Stream order-wise stream length ratio is given in Table 8. Similar results were also found by Nayar and Natrajan (2013).

Table 8.Stream order-wise bifurcation ratio and stream length ratio

Stream Order	Bifurcation Ratio	Stream Length Ratio
I-II	4.45	0.54
II-III	2.00	0.37
III-IV	5.50	0.96
IV-V	2.00	0.16
Total	13.95	-
Mean	3.49	0.50

6. Bifurcation Ratio (R_b)

It is the ratio of the number of streams of given order (N_u) to the number of streams of next higher order (N_{u+1}) (Schumm, 1956). The bifurcation ratio is an index of relief and dissections (Horton,1945). The bifurcation ratio is higher in steep slope areas with narrow valley. The bifurcation ratio ranges between 3 to 5 for watersheds in which geology is homogeneous without structural disturbance to the drainage basin. The lower value of the bifurcation ratio indicated less structural disturbance in the watershed (Strahler, 1964). The value of the bifurcation ratio (R_b) for Sakharpa watershed ranges between 2 to 5.5. The total and mean bifurcation ratio (R_b) the for Sakharpa watershed was 13.95 and3.49respectively. which shows watershed has less structural disturbance. The streamwise bifurcation ratio (R_b) was 4.45for I/II, 2 for II/III, 5.5 for III/IV and 2 for IV/V. Stream order-wise bifurcation ratio is given in Table 8. Similar results were also claimed by Nayar and Natrajan (2013) and Kale *et al*. (2022).

Areal Aspects

Areal Aspects of watershed includes Density (D_d),Drainage texture, Stream frequency (F_s), length of overland flow (L_g). These parameters have been calculated based on mathematical formulae which are explained in chapter-III. The results for areal aspects of Sakharpa watershed are given in Table 6.

1. Drainage density (D_d)

It is defined as ratio of total stream length of all order to the area of watershed (A). This term was used by Horton (1932). As stream length increases, drainage density increases. In the area of dense vegetation, low relief and highly resistant substrata, drainage density is low. On the other hand, in the area of sparse vegetation, high relief and weak subsurface strata, drainage density is high. The value of Drainage density (D_d) for Sakharpa watershed is 1.18 km/km^2 which is low, showing dense vegetation and high relief. Also indicated porous sub-surface strata and coarse drainage texture. Lakshminarayn*et al.* (2022) determined morphological parameters of Tidi watershed using remote sensing and geographic information system approaches and reported similar results.

2. Drainage texture (D_t)

Higher value of drainage texture specifies the low infiltration rate and higher runoff, and the smaller value of drainage texture specify the plain basin with fewer slope variation. Smith (1950) classified drainage texture into five classes such as i) very coarse (<2km^{-1}), ii) coarse (2-4km^{-1}), iii) moderate (4-6 km^{-1}), iv) fine (6-8 km^{-1}) and very fine (>8km^{-1}). The value of drainage texture (D_t) for Sakharpa watershed is 2.24 km^{-1} which indicates coarse drainage texture of watershed. The similar results were also reported by Nayar and Natrajan (2013) and Sapkale*et al*. (2022).

3. Stream frequency (F_s)

Horton (1932) Stream frequency is defined as the ratio of total number of streams of all order to the watershed area (A). Runoff is faster in the watershed with greater drainage density (D_d) and Stream frequency (F_s). Greater the Stream frequency, higher will be the runoff. Stream frequency (F_s) of Sakharpa watershed is 1.48 km^{-2}.

4. Texture ratio (R_t)

Horton (1945) texture ratio (R_t) may be defined as ratio of total number of streams of I^{st} order (N_1) to the perimeter (P). Gupta *et al.* (2019) have categorized texture ratio as low(<3), moderately (3-4), moderately high (4-5), very high (>6). Texture ratio of Sakharpa watershed is 1.08. Similar results have been reported by Gunjan *et al*. (2020).

5. Length of overland flow (L_g)

Length of overland flow (L_g) is equal to half of the reciprocal of Drainage density (D_d) (Horton, 1945). Length of overland flow (L_g) for Sakharpa watershed was 0.42 km. similar results has been claimed by Gunjan *et al.* (2020).

Shape Aspects

Shape aspects show the shape of watershed. Shape aspects include the Form factor (F_e), Elongation ratio (R_e), Circulatory ratio (R_c), Shape index (S_w)and Constant of channel maintenance (C). The results for the shape aspects of Sakharpa watershed is shown in Table 9.

1. Form factor (F_f)

Shape of watershed is described using term Form factor (F_f), (Horton1932). Form factor (F_f) may be defined as ratio of watershed area (A) to the square of basin length (L_b). The value of form factor greater than 0.7854 indicated perfectly circular watershed. Lower value of form factor indicates elongated shape of watershed. For Sakharpa watershed value of form factor is 0.315, which indicates watershed is elongated. Similar results were also claimed by Dhabale*et al*. (2014).

2. Elongation ratio (Re)

Elongation ratio (R_e) vary from 0 to 1. The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e., for circular watershed R_e is (0.9 to 0.10), for oval watershed $R_e$is(0.8-0.9), for less elongated watershed R_e is(0.7 to 0.8), for elongated watershed R_e is(0.5 to 0.7), and for more elongated watershed R_e is< 0.5 (Nayar and Natarajan, 2013). The Elongation ratio (R_e) for Sakharpa watershed is 0.633which indicates elongated shape of watershed. Similar results were also computed by Dhabale*et al*. (2014)

3. Circulatory ratio (R_c)

It is the term which express the degree of circularity of watershed. Circulatory ratio (R_c) is defined as the ratio of the watershed area (A) to the area of the circle which perimeter is same to the perimeter of watershed. The value of R_c for Sakharpa watershed is 0.31, which indicated elongated shape of watershed. It is dimensionless parameter. The similar results were also reported found in Sapkale*et al*. (2022).

4. Compactness coefficient (C_c)

Compactness coefficient (C_c) is defined as the ratio of perimeter of watershed to the perimeter of equivalent circular area of watershed (Strahler, 1964). The more compact watershed shows value of compactness coefficient (C_c) greater than one. The value of compactness coefficient (C_c) for Sakharpa watershed is 1.77 which indicates greater compactness of watershed and elongated shape. The similar results were also found in Dahiphale*et al.* (2022).

5. Shape Index (S_w)

Horton (1945) shape index may be defined as the ratio of square of length of watershed (L_b) to the area of watershed (A). the value of shape index (S_w) for Sakharpa watershed is 3.18 which indicates elongated shape of watershed.

6.Constant of channel maintenance (C)

Constant of channel maintenance (C) may be defined as inverse of drainage density (D_d) Schumm (1956). It shows direct proportion with the watershed area (A). In the present study the value of constant of channel maintenance (C) for Sakharpa watershed is 0.84.

Table 9. Areal, Shape and Relief aspects of Sakharpa watershed

Sr No.	Morphometric characteristic	Unit	Result	Remark
1	Form factor (F_f)	Unitless	0.32	Elongated shape
2	Elongation ratio (R_e)	Unitless	0.63	Elongated shape
3	Circulatory ratio (R_c)	Unitless	0.32	Elongated shape
4	Shape index (S_w)	Unitless	3.18	Elongated shape
5	Drainage density (D_d)	km/km^2	1.18	Dense vegetation, porous subsurface strata
6	Stream frequency (F_s)	km^{-2}	1.48	Very low
7	Texture ratio (R_t)	Unitless	1.08	Very low
8	Drainage texture (D_t)	km^{-1}	2.24	Coarse texture
9	Compactness coefficient (C_c)	Unitless	1.77	Compact watershed
10	Constant of channel maintenance (C)	km^2/km	0.84	Less structural disturbance
11	Length of overland flow (L_g)	km	0.42	-
12	Basin relief (R)	m	763.92	High relief
13	Relief Ratio (R_r)	Unitless	0.045	Moderately gentle to steep slope
14	Relative Relief (R_{hp})	Unitless	1.27	-
15	Ruggedness Number (R_n)	Unitless	0.904	less prone to soil erosion

Relief Aspects

Relief Aspects of Drainage Basin includes basin relief (R), Relative Relief (R_{hp}), Relief ratio (R_r) and Ruggedness number (R_n). The results for relief aspects of Sakharpa watershed are given in Table 09.

1. Basin relief (R)

Basin relief (R) is the difference between maximum elevation and the minimum elevation of the watershed. Higher relief value shows higher runoff generation in watershed. Basin relief (R) of Sakharpa watershed is 763.92 m which shows high relief of watershed.

2. Relief Ratio (R_r)

Schumm (1954) relief ratio may be defined as the ratio of basin relief (R) to the maximum basin length (L_b). Relief ratio is inversely proportional to the drainage area and the sizeofgivendrainage.It shows steepness of relief in thebasin.Relief Ratio (R_r) of Sakharpa watershed is 0.045. Similar results were also claimed by Dhabale*et al*. (2014).

3. Relative relief (R_{hp})

Melton's (1957) maximum basin relief was obtained from the highest point on the watershed perimeter to the mouth of the stream. Relative relief of the Sakharpa watershed is 1.27. Similar results were also reported by Dhabale*et al.* (2014).

4. Ruggedness number (R_n)

Ruggedness number (R_n) is the product of maximum basin relief (R) and drainage density (D_d). The higher value of basin relief and drainage density indicates the steep and long slope of watershed. Ruggedness number (R_n) of Sakharpa watershed is 0.904

CONSLUSIONS

This Paper talk about morphometric analysis such as linear areal and relief parameters of Sakharpa watershed. The study was taken for understanding the intricate relationship among the linear, areal and relief parameters of sakharpa watershed. The watershed is characterized with 5^{th} order stream. From study it is concluded that, GIS is friendly tool for delineation of watershed based on DEM and satellite image data. The maximum stream order frequency was observed in case of first order stream and then second order stream. Hence it is noticed that, there is decrease in stream frequency as stream order increases and vice versa. Based on bifurcation ratio (2-5.5) it was observed that the watershed geology is homogeneous and less disturbance to the drainage basin or basin is structurally controlled. From the values of form factor (0.32), elongation ratio (0.63), circularity ratio (0.32) and shape index (3.18) it observed that the watershed is elongated in shape and having moderately gentle to steep slope. Drainage density (1.18 km/km^2) of Sakharpa watershed indicates dense vegetation, porous subsurface strata and coarse drainage texture. Thismorphometric analysis of drainage basin helps to planning and development of watershed. This study helps in watershed management.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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