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Prioritization Based on Morphometric Analysis - A Case Study of Mandakini River Basin

Sandeep Kumar[1*] • S. K. Bansal[2]

[1] *Department of Geography, Govt. College, Dujana, Jhajjar,124102[Haryana]*
[2] *Department of Geography, M. D. University, Rohtak, 124001 [Haryana]*

*Corresponding Author Email: phalswalsk@gmail.com

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Abstract: The delimitation and prioritization of river basins within a large river basin is necessary for appropriate arrangement and management of natural resources for sustainable development. Morphometry is the science that deals with the quantitative dimension of the form of any natural substance like rivers, forests, and mountains. It is a numerical examination of the setup of the Earth's surface, shape and measurements of its territory's structures. The present work/study is based on spatial data acquired form of Survey of India topo-sheets and ASTER GDEM (2011). Mandakini river is a main tributary of Alaknanda River and drain in near about 1666.34 Km² areas. The present study deals the parameters of the morphometry (Linear, Areal and Relief Aspects) have been calculated using Arc-Hydro tool in Arc GIS software. Stream ordering has been calculated by A.N. Strahler's method. The basin is classified as 5th order drainage basin and with mainly dendritic type of drainage pattern. Mandakini river basin is also very prone to land sliding which is the major contributor of sediment to river catchment. Land sliding and clouds bursting are most common in this river basin. The Geo-informatics-based study of morphometry analysis of river basin characteristics can be used by local people for sustainable development of this area.

Keywords: Morphometry • Arc-Hydro tool • Dendritic • Remote Sensing and GIS

Introduction

Understanding the Geomorphology of the drainage basin is significantly aided by the morphometric analysis of the channel system and river basin. The configuration of the Earth's surface, as well as the size and measurement of its territorial structures, are estimated and scientifically examined. Geologists and geomorphologists claim that the structure and shape of rivers and their surrounding areas are constantly changing as a result of erosion and sedimentation, which are the direct results of the movement of water and silt. These adjustments could include things like inclination, form, size, material layer area, and more. Engineers are primarily interested in these techniques to assess sediment movement and deposition in rivers as well as erosion processes. In order to comprehend different forms of imbalances in rock hardness, the continuous catastrophic and structural geomorphological changes, and the history of land infiltration in the basin, the morphometric analysis shows the quantitative aspects of the geometry of the river basin. In the context of managing natural resources, particularly in relation to river basin management, the prioritisation of river basins has gained importance. A morphometric investigation is used to prioritise the sub-basins for the current examination.

Location and Extraction

Mandakini river is a main tributary of Alaknanda river which flows in the part of the Rudraprayag and Tehri Garhwal district in the higher Garhwal Himalaya (Fig 1). It originates from the Chorabari glacier, which is only 2 Kms upstream from Shri Kedarnath Shrine. The total catchment area of Mandakini river basin is about 1666.34 Km². The basin lies between 30º 17' 18" to 30º 48' 43" N latitudes and 78° 48'57" E to 79° 21'27" E longitudes. The Southern point of Rudraprayag is at the height of 580 mts while the Northern point of Kadernath peak is above 6600 mts. The main tributary of this river is Madhyamaheshwar Ganga, while smaller tributaries are; “Lastar Gad, Kyunja Gad, Helaun Gad, Kakra Gad, Kyar Gad, Ghasta Gad, Markanda Ganga, Kali Ganga and Vasuki Ganga.” The Mandakini river eventually flows into Alaknanda river in Rudraprayag.

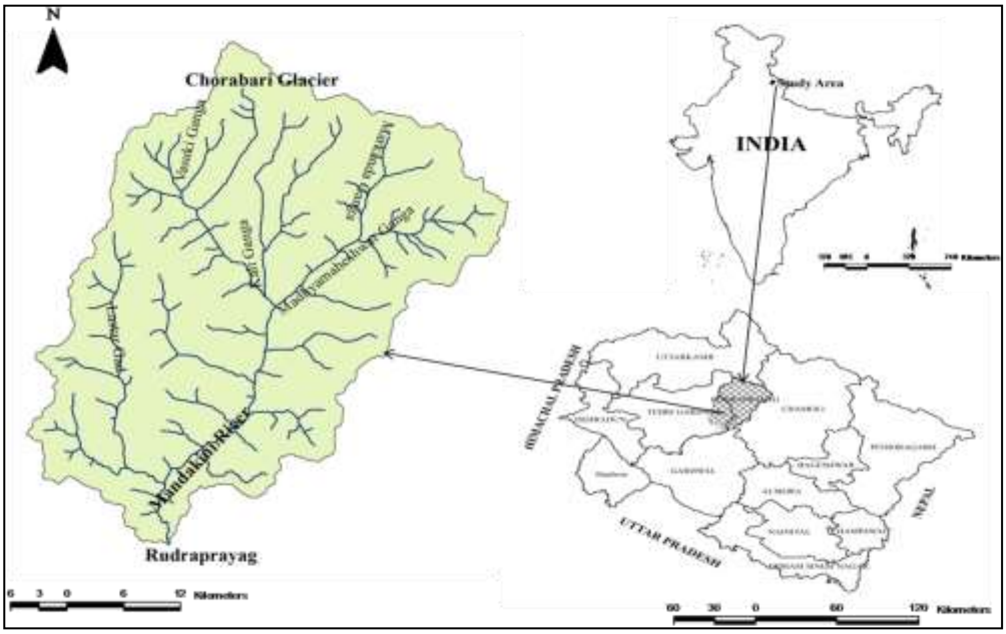


Fig 1: Location Map of Study Area

Database and Methodology

For the study purpose secondary data have been used. The secondary data collected from the satellite imagery ASTER GDEM (2011), LISS - III (2013) and Google Earth Image, Survey of India (SOI) topo-sheets (53J/14, 53/J15, 53N/1, 53N/2, 53N/3, 53N/4 and 53N/6) on 1:50,000 scale. Boundary map of Mandakini river has been prepared with the help of topo-sheets and then base map of ASTER GDEM (2011) was also prepared. With the help of which, contours and drainage network have been prepared. Hydrological tool of Arc GIS 9.3 has been utilized for the preparation of drainage network. The whole river basin gets dissected into 1797 grids where each grid is one square Kilometres and on the basis of these grids, morphometric study was carried out. In the present study, the morphometric examination is completed for the Mandakini river basin and four sub-basins. The boundary of such basins, based on the streams order and the 4th order, are selected for morphometric analysis. The names of river sub-basin are based on the name of main tributary or main river which flows in that particular area. These are Upper Mandakini, Lower Mandakini, Madhyamaheshwar Ganga and Lastar Gad. For the study of drainages network, Strahler’s method is followed. The sub-basins prioritization has been done via morphometric analysis of the present study. Prioritization of four sub-basins of Mandakini basin is done using 13 morphometric parameters. A number of morphometric parameters have been applied to the study of drainage basin. These are presented in Table -1.

Table – 1: Formulae adopted for computation of morphometric parameters

Sr. No.		Morphometric Parameters	Formulae	Reference
1		Stream Order (u)	Hierarchical rank	Strahler(1964)
2		Mean Stream Length	Lsm= Lu /Nu	Strahler

		(Lsm)	Where, Lsm = Mean stream length Lu =Total stream length of order'u' Nu = Total no. of stream segments of order 'u'	(1964)
3	LINEAR	Stream Length Ratio (RL)	RL = Lu /Lu -1 Where, RL = Stream length ratio Lu =The total stream length of the 'u' Lu - 1 = The total stream length of its next lower order	Horton (1945)
4		Bifurcation Ratio (Rb)	Rb = Nu / Nu +1 Where, Rb = Bifurcation Ratio Nu = Total no. of stream segments of the order 'u' Nu +1= Number of segments of the next higher order	Schumn (1956)
5		Mean Bifurcation Ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	Strahler (1957)
6		Channel Index(CI)	Channel Length (CL) / Air Length (AL)	J.E.Miller (1968)
7		Valley Index (VI)	Valley length (VL)/Air Length (AL)	J.E.Miller (1968)
8		Hydrological Sinuosity Index (HSI)	% equivalent of CI-VI/CI-1	J.E.Miller (1968)
9		Topographic Sinuosity Index (TSI)	% equivalent of VI-1/CI-1	J.E.Miller (1968)
10		Standard Sinuosity Index (SSI)	Channel Length (CL) / Valley Length (VL)	J.E.Miller (1968)
11	ARIAL	Stream Frequency	F = Nu/A Where, F is Stream Frequency Nu is total number of stream basin A is total basin area	Horton (1932, 1945)
12		Drainage Density	Dd = ∑Lu / A where Lu=Total stream length of all orders Ad= Area of the basin (km²)	Horton (1932, 1945)
13		Drainage Texture	Dt = Dd × Fs Where, Dd = Drainage Density Fs= Stream Frequency	Horton (1945)
14		Length of Overland Flow	Lg = 1/2Dd Where Lg – Length of overland flow Dd – Drainage density	Horton (1945)
15		Form P	F = A÷L Where F= Form factor indicating elongation of basin shape A = Basin Area L = Basin Length	Horton (1932)
16		Circulatory Ratio	C = Area of basin ÷ Area of circle with the same perimeter as the basin $C = 4\pi A \div P^2$ Where C = Circulatory Ratio π = 3.14, A = Area of Basin, P = Basin Perimeter	Miller's (1953)
17		Elongation Ratio	E = Diameter of the circle with same area as the basin ÷ basin length	Schumm's (1956)

			$E = 2\sqrt{A/\pi} \div L$ Where E = Schumm's (1956) A = Basin Area, π = 3.14,L = Basin Length	
18		Relative Relief (RR)	Relative Relief (RR) = Maximum Elevation - Minimum Elevation	(Smith, 1935)
19		Relief Ratio	Relief Ratio = H÷ Lb Where, H = Relative relief of the basin in meters Lb = Basin Length	Schumm (1956)
20	**RELIEF**	Gradient Ratio	Gradient ratio = (a - b) ÷ L Where, a = height of river source of the basin b = height of river Mouth of the basin L= Length of the main river	Sreedevi et al. (2005)
21		Dissection Index (Di)	Dissection Index = Relative Relief ÷ Absolute Relief	Dov Nir (1957)
22		Ruggedness Number (Rn)	Ruggedness Number (Rn) = (Drainage Density × Relative Relief) ÷ 1000	Chorley's (1972)
23		Average Slope	Tan Ǿ = (N × I) ÷ 636.66 Where, N = numbers of counter cutting per Km I = contour interval in meters, 636.66 = is a constant value	C.K. Wentworth Method (1930)

Results and Discussion

The geometry of the drainage basin and its system helps in the quantitative depictions of the waste system, investigating the effect of various variables like lithology, rainfall, rock structure, comparing different drainage networks. Stream ordering has been calculated by A.N. Strahler's method. The basin is classified as 5th order drainage basin and with mainly dendritic type of drainage pattern. Morphometric parameters (Linear, Areal and Relief aspects) have been applied to understand the groundwater potential in each sub basin.

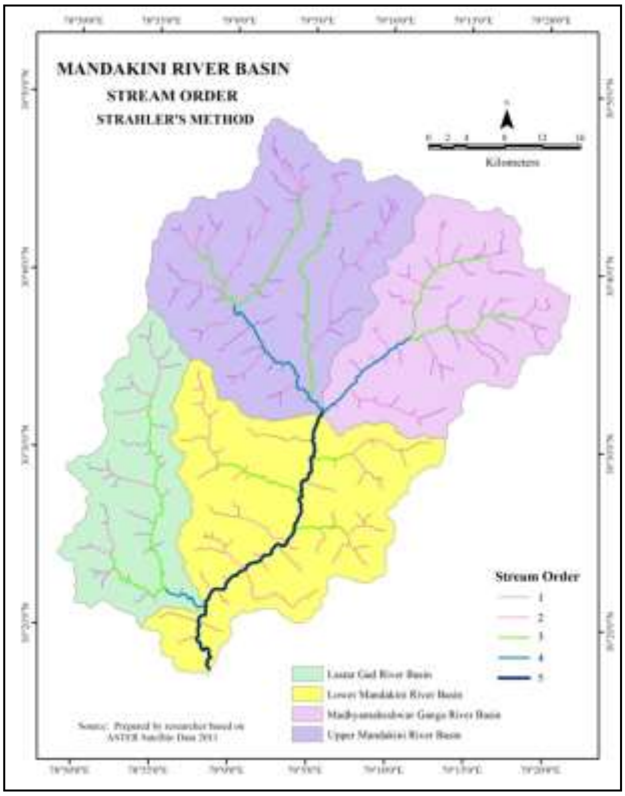


Fig 2.

Morphometric Parameters

Linear Parameters: Linear aspect is one dimension. It studies all types of the channel pattern, open links, topological characteristics stream segment of basin.

Stream Order (u)

"The stream order is defined as a measure of position of a stream in the hierarchy of tributaries" (Leopol, Wolman and Miller, 1969). There are many types of methods to find out the stream ordering like – Gravelius (1914), Horton's (1945), Strahler's (1952, 1964), Shreve (1966) etc. In the present study, the river basin has been ranked according to Strahler's ordering system (Fig 2).

Mean Stream Length (Lsm)

"Mean stream length is a characteristic property related to the drainage network components and its associated basin surfaces" (Strahler, 1964). The mean stream length variations are from 1.71 to 38 for the whole Mandakini basin.

Stream Length Ratio (RL)

The stream length ratio is the ratio of the total stream length of one order to the following lower order of stream fragment. The stream length ratio of Mandakini river basin ranges from 0.28 to 0.97. The highest stream length ratio is between the 4th order and 5th order which is 0.97. The lowest stream length ratio is between 3rd order and 4th order which is 0.28

Bifurcation Ratio (Rb)

Bifurcation ratio is a ratio of number of stream of a given order to the number of streams of the next higher order. The maximum value of bifurcation ratio (Rb) is found to be 5.5 between 2nd and 3rd order in Madhyamaheshwar Ganga sub-basin. Table -2 is showing the linear parameters of Mandakini river basin and sub-basins.

Table -2: Mandakini River Basin and Sub-Basins: Linear Parameters

SN	**Linear Parameters**	**Upper Mandakini**	**Madhyamaheshwar Ganga**	**Lastar Gad**	**Lower Mandakini**	**Mandakini River Basin**
1	Stream Numbers	78	62	42	64	246
2	Stream Length (Kms)	237	165	125	214	741
3	Mean Stream Length (Kms)	3.03	2.66	2.98	3.34	3.01
4	Mean Bifurcation Ratio (Rbm)	3.99	3.96	3.5	4.4	3.775
5	Channel Index	1.45	1.4	1.4	1.31	1.43
6	Valley Index	1.17	1.16	1.1	1.08	1.14
7	Hydraulic Sinuosity Index (HSI) %	62.22	60	75	74.19	67.44
8	Topographic Sinuosity Index (TSI) %	37.78	40	25	25.80	32.56
9	Standard Sinuosity Index (SSI)	1.24	1.21	1.27	1.21	1.2

Source: Based on Author calculation from ASTER GDEM data (2011).

Mean Bifurcation Ratio (Rbm)

The mean bifurcation ratio is an average of bifurcation ratio of all the orders. The range of mean bifurcation ratio is from 3.5 to 4.4 for the whole basin where the highest value are 4.4 for Lower Mandakini sub-basin and lowest 3.5 in Lastar Gad.

Standard Sinuosity Index (SSI)

Sinuosity index defines the degree of deviation of observed path of river from their expected theoretical straight path. "The sinuosity value varies from a value of unity i.e. 1 to 4 or more, rivers having a sinuosity of less than 1.5 are called straight or sinuous and those rivers which are having a sinuosity index of 1.5 or more than 1.5 are called meandering" (Leopoled, wolman and miller, 1969). The standard sinuosity index for Mandakini river is found to be 1.25. In sub-basins, it ranges between 1.21 - 1.27. It reveals that the whole basin of river is in sinuous course. The hydraulic sinuosity index of the whole basin is 67.44 percent which ranges from 60-75 percent among sub-basins. Topographic sinuosity index is 32.56 percent which shows variation between 25-40 percent.

Areal Parameters

The areal aspect describes two dimensional characteristics of the region. It introduces the concept of area which explains the length and width of a basin area. Areal aspect expresses the shape of a basin which shows the stream discharge characteristics.

Stream Frequency

Stream frequency is the absolute number of streams of all frequency per unit zone. The total stream frequency in the present study is 0.15 per Km² and varies from 0.13 to 0.16 per Km² (Fig 3).

Drainage Density

It defines the closeness of channels in a particular river basin. The drainage density of Mandakini River is 0.44 Km² (Fig 4). The Mandakini sub-basins, Upper Mandakini and Lastar Gad have drainage density of 0.45 Km² while Madhyamaheshwar Ganga and Lower Mandakini have 0.44 Km².

Drainage Texture

Drainage texture is affected by lithology, infiltration capacity and reprieve aspect of basin. The drainage texture of Upper Mandakini is 0.067, Madhyamaheshwar Ganga is 0.070, Lastar Gad is 0.067 and Lower Mandakini is 0.057(Fig 5). The drainage texture of the basin is coarse as the values of drainage texture in all sub-basins are below 4.0.

Length of Overland Flow

Horton (1945) and Schumm (1956) concluded that length of overland flow is approximately equivalent to the half of the proportional of drainage density. The length of overland flow varies between 1.11 - 1.36(Map 1.6). Table -3 is showing the areal parameters of Mandakini river basin and sub-basins.

Table -3: Mandakini River Basin and Sub-Basins: Areal Parameters

Sr. No.	Areal Parameters	Upper Mandakini	Madhyamaheshwar Ganga	Lastar Gad	Lower Mandakini	Mandakini River Basin
1	Area (Km²)	521.62	378.83	277.52	488.37	1666.34
2	Perimeter (Kms)	104.20	93	98.55	131.28	204.17
3	Basin Length (Kms)	42	35	42	38	80
4	Drainage Frequency Per Km²	0.15	0.16	0.15	0.13	0.15
5	Drainage Density Per Km²	0.45	0.44	0.45	0.44	0.44
6	Drainage Texture	0.067	0.070	0.067	0.057	0.066
7	Length of Overland Flow	1.11	1.36	1.11	1.14	1.14
8	Form Factor	0.30	0.34	0.16	0.31	0.26
9	Circularity Ratio	0.60	0.55	0.36	0.36	0.50
10	Elongation Ratio (E)	0.61	0.63	0.45	0.66	0.58

Source: Based on Author calculation from ASTER GDEM data (2011).

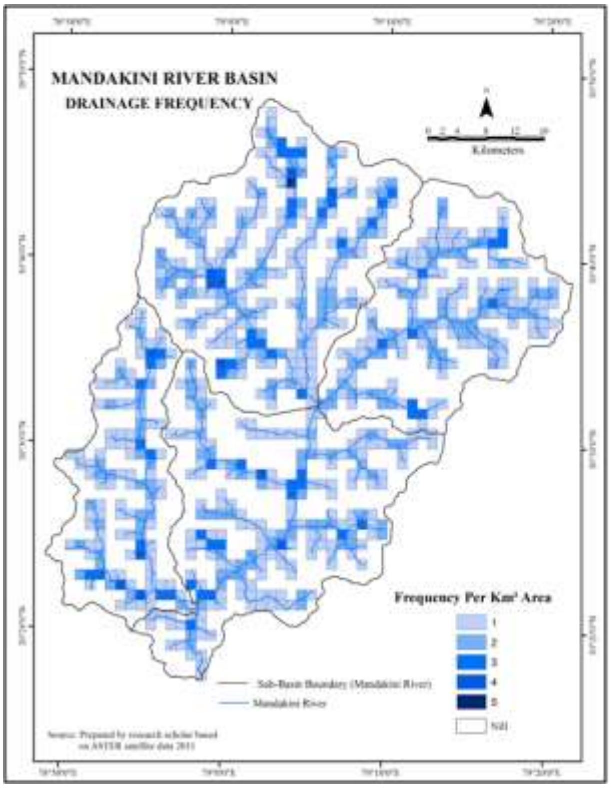


Fig 3

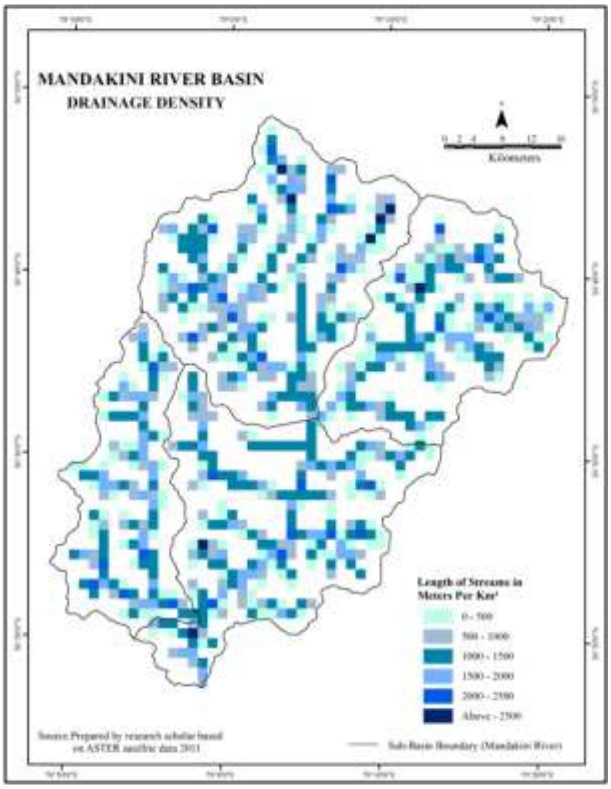


Fig 4

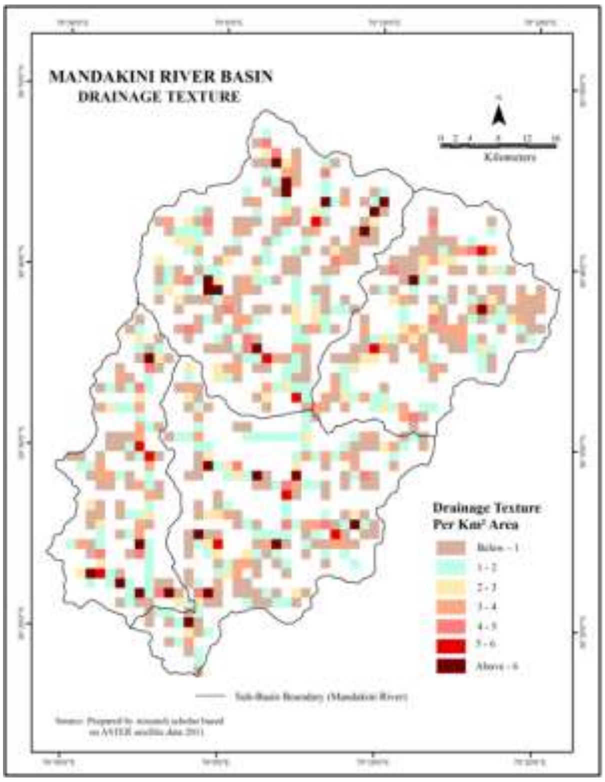


Fig 5

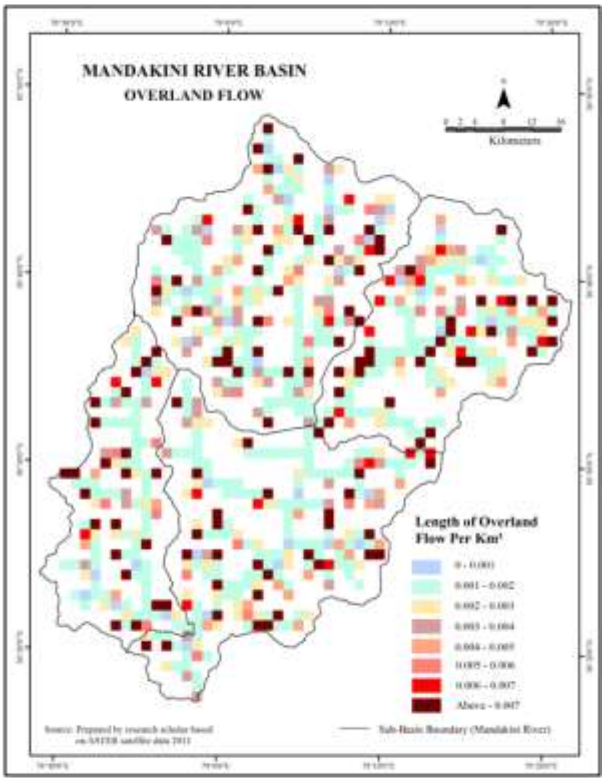


Fig.6

Form Factor (P)

As indicated by Horton (1932) form factor might be characterized as the value of basin territory to the square of basin length. The basin would be an ideal circle if the shape factor is 1, progressively; lower factors represent more convoluted flock, and near 0 moving toward a line. The calculated value of form factor for Mandakini river basin is 0.26 while the range of form factor among sub-basins exists between 0.16 - 0.34.

Circularity Ratio (C)

As per Miller's (1953) "Circularity ratio can be characterized as the ratio of a territory of the basin to the region of hover with the same border as the basin". The circularity ratio of Mandakini river sub-basins ranges between 0.36 - 0.60.

Elongation Ratio (E)

According to Schumm's (1956) "elongation ratio is the ratio of diameter of circle with same area as the basin to the basin length". The elongation ratio for Mandakini river basin comes to be 0.58 and varies from 0.45 to 0.66 for sub-basins. These values of elongation ratio for sub-basins of Mandakini river indicate that these have elongated shape, high relief and steep slope of basin.

Relief Parameters: The relief aspect is the third dimensional aspect of landforms lies on an Earth surface. Relief aspect measures the height variation at various points in the river basin along with the channels.

Relative Relief (RR)

It describes the variation in altitude between lowest points and highest points covering a unit area like one Km or one mile. Smith method has been used for the study of relative's relief of Mandakini river basin area. Relative relief variations occurred from minimum 200 mts to maximum 1400 mts. Map 1.7 and Map1.8 is showing the absolute relief and relative relief.

Relief Ratio

"The relief ratio is the ratio of the maximum relief to the horizontal distance along the longest dimension of the basin equivalent to the principle drainage line" (Schumm, 1956). The total relief ratio of the present study is 75 and the value varies from 73.68 to 154.28 of the basin

Gradient ratio

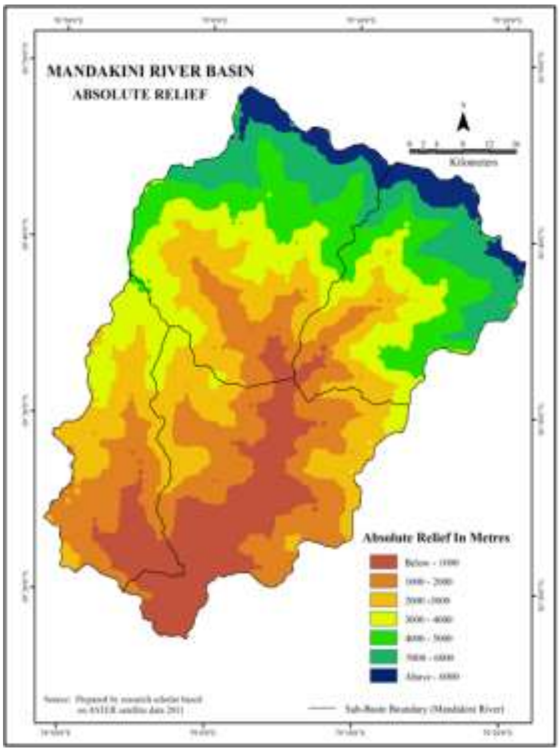
Gradient ration is the ratio between falls in height from the source to the mouth of the stream and the length of the main drainage line. Madhyamaheshwar Ganga sub-basin has the most noteworthy gradient ratio 117.14 mts/Km followed by Upper Mandakini as 102.38 mts/Km and the Lower Mandakini has the lowest gradient of 13.15 mts/Km. Table -4 is showing the relief parameters of Mandakini river basin and sub-basins.

Table -4: Mandakini River Basin and Sub-Basins: Relief Parameters

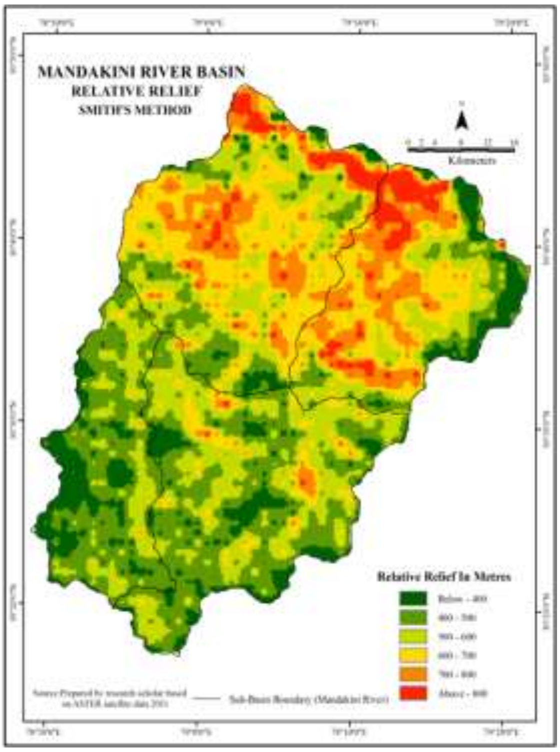
Sr. No.	Relief Parameters	Upper Mandakini	Madhyamaheshwar Ganga	Lastar Gad	Lower Mandakini	Mandakini River Basin
1	Maximum Heights(H)	6400	6600	3600	3400	6600
2	Minimum Heights(h)	1200	1200	800	600	600
3	Relative Relief (H –h)	5200	5400	2800	2800	6000
4	Relief Ratio (H –h ÷ L)	123.80	154.28	66.66	73.68	75
5	Gradient Ratio (a –b / L)	102.38	117.14	57.14	13.15	60
6	Dissection Index	0.81	0.81	0.77	0.82	0.90

7	Ruggedness Index	2.3	2.4	1.3	1.2	2.6

Source: Based on Author calculation from ASTER GDEM data (2011).



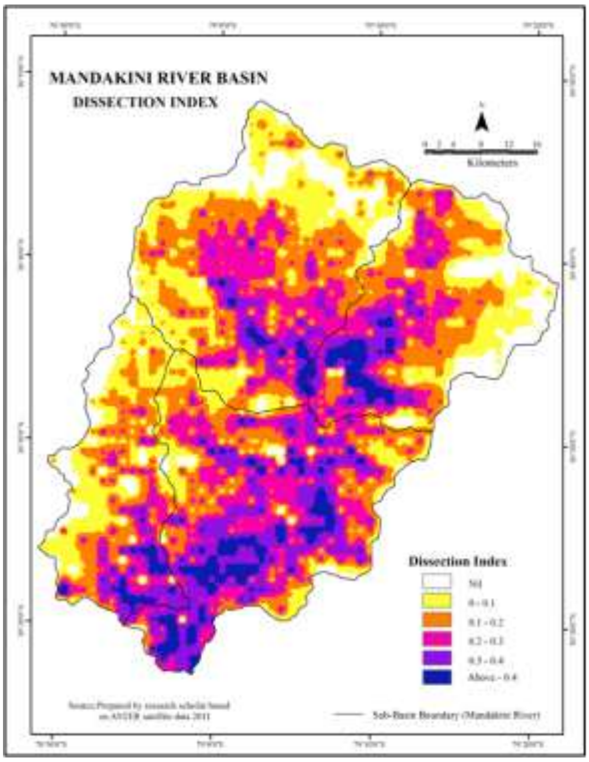
Map 1.7



Map 1.8

Dissection Index (Di)

Dov Nir (1957) computed the dissection index by the ratio between relative relief and absolute relief of an area. It is associated with the irregularity of plane shaped by several valleys or ravines. The dissection index of the present study is 0.90 and varies from 0.77 to 0.82 of the sub-basins (Fig 9).



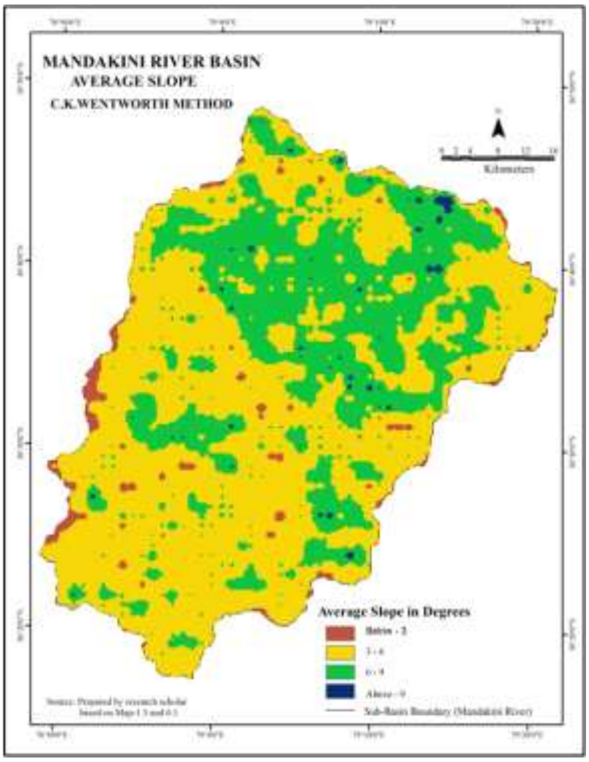


Fig 9

Ruggedness Number (Rn)

"Ruggedness number is a product of relative relief and drainage density in which both the terms are expressed in the same unit of measurement" (Sharma V.K, 1986). The total ruggedness number of present study is 2.6 and varies from 1.2 to 2.4 of the sub-basins.

Average slope

Wentworth's method has been used for the calculation and evaluation of slope division in Mandakini river basin. The analysis of basin shows that average slope of the basin is in between 1◦ to 16◦ and maximum area is present in moderate category (Fig 10).

Fig 10

Prioritization of Sub-Basins Using Morphometric Variables

The prioritization of river basins has become increasingly important in the management of natural resources, especially in the context of river basin management. Therefore, when prioritizing sub-basins, the highest value of morphometric parameters was ranked as rank 1, the second-highest value as rank 2, etc., and the lowest value was ranked as the last rank. Table 5 and Fig 11 show the final priority of the Mandakini river basin.

Table -5: Prioritization of Sub-Basins Based on Morphometric Analysis

Sub-Basins	Priority Based On														
	Df	**Dd**	**Dt**	**Rbm**	**Lg**	**R**	**Rr**	**Gr**	**Rn**	**Di**	**Ff**	**Cr**	**Er**	**CP**	**FP**
Upper Mandakini	2.5	1	2.5	2	3.5	2	2	2	2	2.5	2	4	2	2.3	**2**
Madhyamaheshwar Ganga	1	3.5	1	3	1	1	1	1	1	2.5	4	3	3	2.0	**1**
Lastar Gad	2.5	1	2.5	4	3.5	3.5	4	3	3	4	1	1	1	2.6	**3**
Lower Mandakini	4	3.5	4	1	2	3.5	3	4	4	1	3	1	4	2.9	**4**

Source: Based on Author calculation from ASTER GDEM data (2011). Df = Drainage frequency, Dd = Drainage density, Dt= Drainage texture, Rbm = Mean bifurcation ratio, Lg = Length of overland flow, R = Relative relief, Rr = Relief ratio, Rn = Ruggedness number, Di = Dissection index, Gr = Gradient ratio, Ff = Form factor, Cr = Circularity ratio, Er = Elongation ratio, Cp=Compound parameter, FP=Final Priority

Conclusion

This study reveals that the morphometric parameters are good for the calculation of shortage and surplus zones of groundwater for river basins. The standard sinuosity index for Mandakini river is found to be 1.25 and its sub-basins between 1.21 to 1.27. It reveals that the whole basin of river is in sinuous course. The texture of this region is intermediate. Intermediate texture is mainly occur in Upper Mandakini region and Eastern part of Lastar Gad sub-basin. The form factor, circularity ratio (Rc) and elongation ratio (Re) shows that the Mandakini river basin and sub-basins are elongated shape. The gradient ratio is indicating that the slope of Madhyamaheshwar Ganga and Upper Mandakini sub-basin is a steep slope while in Lower Mandakini sub-basin is gentle slope. Thus, the morphometric parameters are showing that the river basin is lies in mature stage. The sub-basin, which falls under high priority, is located in a very erosion-prone zone. Immediate attention is therefore required to take mechanical measures for soil conservation and to establish gully control structures such as dams and grass waterways to protect the topsoil loss. While low priority watersheds have a very low erosion susceptibility zone and may require agronomic measures to control stratification and gully erosion.

Fig 11

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