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Morphometric Analysis of Dhela River Watershed of Uttarakhand using GIS and Remote Sensing

Meenal Parashar[1], Yogendra Kumar[2], Vinod Kumar[3]

ABSTRACT

The present study involves the integration of Geographic Information System (GIS) and Remote Sensing techniques for the evaluation of morphometric parameters of Dhela river watershed. The study area falls under the *Tarai* and *Bhabhar* region of Udham Singh Nagar and Nainital districts of Uttarakhand and lies between 29º 28' 0" N to 29º 16' 0" N latitudes and 78º 57' 0" E to 79º 9' 0" E longitudes with an area of 252.062 km^2 and a perimeter of 140.625 km. It has been further sub-divided into 11 sub-watersheds, namely, SWS1 to SWS12 and consists of two types of soils, *i.e. Tarai* soil and Stony loamy soil. ArcGIS and QGIS software were used for preparation of drainage map, contour map, ordering of various streams and computation of linear, areal and relief aspects of the morphometric parameters. The drainage pattern of the study area was dendritic with stream orders ranging from first order to sixth order. The drainage density of the Dhela river watershed was 2.635km^{-1} which suggested a very fine drainage texture. The bifurcation ratio of the study area was 14.55 indicating a mountainous or highly dissected terrain. The elongation ratio and form factor values showed that the study area was elongated in shape with lower peak of flow.

INTRODUCTION

Groundwater is considered to be one of the most vital resources present on the earth. Rapidly growing population, industrialization, urban development, frequent failure of monsoon and various other developmental activities have increased stress over the groundwater available and thus have resulted in over- exploitation of the groundwater resource. The integration of remote sensing and GIS has proved as an effective tool for understanding and management of the available groundwater resources. The analysis of morphometric parameters of a watershed helps in evaluation of groundwater potential zones as well as in identification of the suitable locations for water harvesting structures, geographic characteristics of the drainage system and natural resources management. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape, dimension of its landforms (Clarke, 1966). The morphometric analysis provides a quantitative description of the basin geometry to understand initial slope or inequalities in the rock hardness, structural controls, recent diastrophism, geological and geomorphic history of drainage basin (Strahler, 1964). Several researchers (Singh *et al*., 2003, Pankaj and Kumar, 2009, Aravinda and Balakrishna, 2013, Kumar *et al*. 2014, Jawale and Bowlekar, 2020) have used the approach of GIS and remote sensing for the analysis of morphometric parameters of different area for groundwater resource management.

In the present study, the evaluation of morphometric parameters of Dhela river watershed was done on the basis of linear, aerial and relief aspects and slope contribution of the basin. The evaluation of stream parameters through the measurements of various stream properties was also involved in the morphometric study. The analysis of the study area was done using ArcGIS and QGIS software on the basis of the drainage lines as represented over the topographical maps (scale 1:50,000) along with its slope and terrain.

[1]. Ex- Research Scholar, [2, 3] Professor
Department of Irrigation & Drainage Engineering
College of Technology
G.B.Pant University of Agriculture & Technology
Pantnagar- 263145, Uttarakhand (India)

MATERIALS AND METHODOLOGY

Study area

The selected study area is a part of the catchment of river Dhela, near Kashipur town, in Udham Singh Nagar district. The Dhela River is a non-perennial river originating from the Ramnagar forest area of Nainital district and joining the Ramganga river at village Bhojpur, upstream side of Moradabad city of Uttar Pradesh. The water of the Dhela river is diverted to the Tumaria dam located on the upstream side of Kashipur town, from where water is channelized for irrigation purposes resulting in the situation that most of the time no natural discharge is observed in the river. The study area falls under the *Tarai* and *Bhabhar* region of the districts Udham Singh Nagar and Nainital. As per the world soil classification, this area consists of two types of soils, i.e., stony loamy soil and *Tarai* soil. Geographically, the study area is spread from between 29º 28' 0" to 29º 16' 0" N latitude to 78º 57' 0" E to 79º 9' 0" E longitude (Fig. 1). The total study area of this watershed is estimated to be 252.062 km^2 with a perimeter of 140.625 km (Table 1).

Extraction of Data using GIS

The study area lies in the Survey of India (SOI) toposheets No. 53O/2, 53O/3, 53K/15 and 53K/16. Therefore, these toposheets on a scale of 1: 50,000 were used to prepare the base map (Fig.2). The satellite imageries (30m resolution) were downloaded from USGS Earth Explorer website and the digital data of the elevation [Advanced Spaceborne Thermal Emission and Reflection (ASTER) DEM with 15m resolution] in the form of Georeferenced Tagged Image File Format (GeoTIFF) were downloaded from Alaska Satellite Facility (ASF). The satellite imageries and the SOI toposheets to be used were reprojected at WGS84 (EPSG: 4236). The satellite images, ASTER DEM data and the SOI toposheets were used for different analysis using the softwares ArcGIS 10.4 and QGIS 2.18.

The drainage network map of the study area (Fig. 2) was prepared using the DEM raster file and flow direction and flow accumulation layer from the Hydrology section under "Spatial Analyst Tool" in Arc Toolbox in ArcGIS 10.4 software. The stream order was calculated using the method proposed by Strahler (1964). The drainage network of the study area shows that the Dhela river watershed was a 6^{th} order watershed as the highest order stream having was 6^{th} order.

Morphometric Analysis

In the present study, the morphometric analysis of Dhela river watershed was carried out using ArcGIS software. The total area of the watershed was divided into 11 sub-watersheds on the basis of drainage pattern and area of basin. The delineated sub-watersheds were named as SWS1 to SWS12 and the drainage network map of each sub-watershed was also prepared (Fig. 2)

The analysis of the morphometric parameters (carried out using standard formulae proposed by various researchers such as Horton, 1945; Strahler, 1952, 1964; Melton, 1957, etc.) for the Dhela river watershed was done on the basis of three different types of aspects of the basin namely, i) linear aspects, ii) areal aspects, and iii) relief aspects of the drainage basin.

RESULTS AND DISCUSSION

A. Linear Aspects

Basin Length (L)

The basin length can be defined as the distance between outlet and farthest point on the basin boundary. The basin length of the Dhela river watershed was estimated on the basis of the relationship proposed by Nooka Ratnam (2005) and was observed to be 41.555 km (Table 1). The basin length for each sub-watershed was also calculated and it was observed that SWS8 (27.32 km) has the maximum value for the basin length.

Stream Order

Stream ordering is a method of assigning a numeric order to link in a stream network. This order is a method for identifying and classifying types of streams based on their numbers of tributaries. The ordering of streams was carried out according to Strahler (1964). The Dhela river watershed was a sixth-order watershed. On the other hand, out of 11 sub-watersheds, the sub-watersheds SWS8, SWS9 and SWS11 were of sixth order, the sub-watersheds SWS1, SWS6 and SW7 were of fifth order, the sub-watersheds SWS2, SWS3, SWS4and SWS10 were of fourth order and the sub-watershed SWS5 was of third order (Table 2).

Stream Number (N_u)
The stream number is defined as the total number of streams in each order (Horton 1945). In Dhela river watershed, the stream number of first, second, third, fourth, fifth and sixth order was 875, 377, 243, 136, 65 and 1, respectively (Table 2). It was observed that with the increase in stream order, the number of stream decreases (Horton, 1932).The maximum (157) and minimum (31) number of first order streams, were found in sub-watershed SWS9 and SWS5, respectively.

Stream length (L_u)
The total length of individual stream segments of each order is the stream length of that order (Horton, 1945). The stream length was calculated as per the relationship proposed by Strahler (1964). The length of first, second, third, fourth, fifth and sixth order streams was found to be 311.951 km, 164.207 km, 93.996 km, 51.786 km, 23.906 km and 18.459 km, respectively (Table 2). It was observed that the sub-watershed SWS8 has the maximum stream length (L_u= 124.524 km) and the sub-watershed SWS5 showed the minimum stream length (L_u= 22.703 km).

Stream length ratio (R_L)
It is the ratio of the total stream length of the one order to the next lower order of stream segment (Strahler, 1964). The stream length ratio of watershed ranges from 0.462 to 0.772 (Table 3), whereas, the stream length ratio of the sub-watersheds was found to be in the range of 0.0001 to 568.533. Higher the stream length ratio, more are the chances of recharge.

Bifurcation ratio (R_b)
The bifurcation ratio is the ratio of the number of the stream segments of given order to the number of streams in the next higher order (Strahler, 1964). The mean bifurcation ratio of Dhela river watershed was obtained as 14.550 (Table 3). The bifurcation ratio of sub-watersheds was found to be in the range from 0.50 to 30.00. A bifurcation ratio of ≤3 (SWS9 and SWS12) indicate a flat terrain and a bifurcation ratio >3(SWS1-SWS8, SWS10 and SWS11) indicate a mountainous or highly dissected terrain (Horton, 1945).

Average Stream Length (L_u')
It is defined as 'the ratio of the total length of all streams in a particular order to the total number of streams of same order' (Strahler, 1964). It was observed that the average stream length of the watershed and its sub-watersheds was found to be maximum for the 6^{th} order of the stream (Table 4).

B. Areal Aspects
Basin area (A)
The area enclosed within the boundary of the watershed divide is known as basin area. The area of the Dhela river watershed was found to be 252.062 km^2 and the area of each sub-watershed was also estimated (Table 1).

Basin perimeter (P_m)
Basin perimeter is the outer boundary of the sub-basin that enclosed its area. The perimeter of the Dhela river watershed was found to be 140.625 km and the perimeter of each sub-watershed was shown in the Table 1.

Drainage density (D_d)
It is defined as the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin (Strahler, 1964). The drainage density of the Dhela river watershed was obtained as 2.635 km^{-1} (Table 5). The drainage density of sub-watersheds ranged from 2.266 to 2.931 and represented coarse drainage texture (Smith, 1950).

Stream frequency (F_s)
The number of streams per unit area is known as stream frequency (Horton, 1945). The stream frequency of the Dhela river watershed was obtained as 6.732, whereas, the stream frequency of sub-watersheds ranged from 4.719 to 7.368 (Table 5).

Drainage texture (T)
Drainage texture is defined as the total number of stream segments of all orders in a basin per perimeter of the basin (Horton, 1945). The drainage texture of the study area was found to be 17.739 km^{-1} (Table 5) which lies in the category of very fine drainage texture (Smith, 1950).

Length of overland flow (L_g)
It is the length of water over the ground surface before it gets concentrated into definite stream channel (Horton, 1945). The value of length of overland flow for Dhela river watershed was calculated as 0.19 (Table 5), which represents low

length of overland flow and indicates short flow paths, high relief, more runoffs, and less infiltration (Chandrashekhar *et al.*, 2015).

Elongation ratio (R_e)
Elongation ratio is the ratio between the diameter of a circle of the same area as the drainage basin and the maximum length of the basin. The elongation ratio for the Dhela river watershed was estimated as 0.431 (Table 5) according to the relationship given by (Schumm, 1956), which represents elongated shape of watershed. The sub-watersheds SWS1-SWS12 falls under elongated category (Re<0.7) having high relief and steep ground slope (Strahler, 1952).

Circulatory ratio (R_c)
It is the ratio of the area of the basin to the area of the circle having the same circumference equal to the perimeter of the basin (Miller, 1953).The circulatory ratio for the study area was found to be 0.160, whereas, the circulatory ratio for the sub-watersheds ranged from 0.07 to 0.229 (Table 5).

Form factor (F_f)
The form factor is defined as the ratio of basin area to square of the basin length and is a quantitative expression of drainage basin outline. It was estimated according to the relationship proposed by Horton (1932). The value of form factor for whole study area was found to be 0.146 (Table 5) showing a slightly elongated shape of sub-basin and having lower peak flows for longer durations.

Compactness coefficient (C_c)
The compactness coefficient of a sub-basin is the ratio of perimeter of sub-basin to circumference of circular area (Gravelius, 1914). The compactness coefficient for whole watershed was found to be 2.499 representing elongating shape with more erosion and its value for sub-watersheds ranged from 2.09 to 3.779 (Table 5).

Shape factor (S_f)
Shape factor is inversely proportional to the form factor (Horton, 1932). The value of shape factor for the whole study area was 6.851 and its value for different sub-watersheds ranged from 2.95 to 18.868 (Table 5).

C. Relief Aspects
Basin relief
It is defined as the difference between the maximum elevation and minimum elevation in the basin (Strahler, 1952). The basin relief for the whole watershed was 0.814 km the value of basin relief for sub-watersheds varied from 0.036 to 0.75 km (Table 6).

Relative relief
The ratio of the basin relief to the perimeter of basin is known as relative relief (Melton, 1957). The value of relative relief for the Dhela river watershed was estimated to be 0.579 and for sub-watersheds, it varied from 0.103 to 2.75 (Table 6).

Relief ratio
The ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is termed as relief ratio (Schumm, 1956). For Dhela river watershed, the relief ratio was obtained to be 0.02 and its value for different sub-watershed ranged from 0.008 to 0.357 (Table 6).

Ruggedness number
It is estimated as the product of the basin relief and drainage density (Baker *et al.*, 1979). The ruggedness number for the whole watershed was estimated to be 2.145 (Table 6).

CONCLUSIONS

Remote sensing and GIS techniques has been found very effective for the analysis of morphometric parameters of the Dhela river watershed. It was observed that the drainage pattern of the study area was dendritic with stream orders ranging from first order to sixth order. The drainage density of the Dhela river watershed was 2.635km^{-1} which suggested a very fine drainage texture. The bifurcation ratio of the study area was 14.55 indicating a mountainous or highly dissected terrain. The elongation ratio and form factor values showed that the study area was elongated in shape with lower peak flows for longer durations.

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Table 1. Area, Perimeter and Basin Length of Dhela river watershed and its sub-watersheds

Sub watersheds	Area (km^2)	Perimeter (km)	Basin Length, L (km)
SWS1	24.596	37.825	12.032
SWS2	13.016	26.725	8.538
SWS3	33.995	50.075	18.063
SWS4	23.332	39.625	16.157
SWS5	8.592	23.800	7.920
SWS7	19.705	36.300	7.627
SWS8	39.620	84.325	27.323
SWS9	42.481	65.300	20.463
SWS10	19.441	39.325	9.457
SWS11	16.264	44.525	13.447
SWS12	11.019	33.800	9.915
BASIN	**252.062**	**140.625**	**41.555**

Table 2. Order wise number of streams and stream length values of sub-watersheds

Sub watersheds	No. of streams (N_u)							Stream length (L_u) in km						
	For Order No.							For Order No.						
	1st	2nd	3rd	4th	5th	6th	Total	1st	2nd	3rd	4th	5th	6th	Total
SWS1	86	36	23	15	1	0	161	28.643	16.034	9.878	4.453	2.933	0.00	61.941
SWS2	47	21	14	1	0	0	83	14.386	8.317	3.977	2.820	0.00	0.00	29.5
SWS3	109	48	29	1	0	0	187	34.669	23.719	12.443	10.499	0.00	0.00	81.33
SWS4	71	37	30	1	0	0	139	25.525	18.338	12.209	1.667	0.00	0.00	57.739
SWS5	31	9	1	0	0	0	41	12.051	3.858	6.794	0.00	0.00	0.00	22.703
SWS7	77	39	22	3	1	0	142	27.850	14.362	7.801	0.948	5.286	0.00	56.247
SWS8	128	50	22	21	1	0	222	48.470	22.765	8.342	8.398	15.671	0.00	103.646
SWS9	157	77	42	36	0	1	313	58.700	32.857	18.602	14.350	0.00	0.015	124.524
SWS10	73	22	27	1	2	1	126	27.561	9.828	8.482	0.001	0.015	8.528	54.415
SWS11	61	25	15	1	0	0	102	21.478	7.934	5.468	8.631	0.00	0.00	43.511
SWS12	36	13	0	2	0	1	52	12.618	6.195	0.00	0.017	0.00	9.915	28.745
BASIN	**875**	**377**	**243**	**136**	**65**	**1**	**1697**	**311.951**	**164.207**	**93.996**	**51.786**	**23.906**	**18.459**	**664.305**

Table 3. Values of stream length ratio and bifurcation ratio for Dhela river watershed and its sub-watersheds

Sub watersheds	Stream length ratio(R_{LS}) $R_{LS} = L_u/L_{u-1}$						Bifurcation ratio $R_B = N_u/N_{u-1}$					
	L_2/L_1	L_3/L_2	L_4/L_3	L_5/L_4	L_6/L_5	Mean	N_1/N_2	N_2/N_3	N_3/N_4	N_4/N_5	N_5/N_6	Mean
SWS1	0.560	0.616	0.451	0.659	-	0.571	2.389	1.565	1.533	15.000	-	5.122
SWS2	0.578	0.478	0.709	-	-	0.588	2.238	1.500	14.000	-	-	5.913
SWS3	0.684	0.525	0.844	-	-	0.684	2.271	1.655	29.000	-	-	10.975
SWS4	0.718	0.666	0.137	-	-	0.507	1.919	1.233	30.000	-	-	11.051
SWS5	0.320	1.761	-	-	-	1.041	3.444	9.000	-	-	-	6.222
SWS7	0.516	0.543	0.122	5.576	-	1.689	1.974	1.773	7.333	3.000	-	3.520
SWS8	0.470	0.366	1.007	1.866	-	0.927	2.560	2.273	1.048	21.000	-	6.720
SWS9	0.560	0.566	0.771	-	-	0.632	2.039	1.833	1.167	-	-	1.680
SWS10	0.357	0.689	0.0001	15.000	568.533	116.916	3.318	0.815	27.000	0.500	2.000	6.727
SWS11	0.369	-	1.578	-	-	0.974	2.440	1.667	15.000	-	-	6.369
SWS12	0.491	-	-	-	-	0.491	2.769	-	-	-	-	2.769
BASIN	**0.526**	**0.572**	**0.551**	**0.462**	**0.772**	**0.577**	**2.321**	**1.551**	**1.787**	**2.092**	**65.000**	**14.550**

Table 4. Order-wise values of average stream length of sub-watersheds

Sub watersheds	Average stream length (L_u/N_u)					
	For Order No.					
	1st	2nd	3rd	4th	5th	6th
SWS1	0.333	0.445	0.429	0.297	2.933	-
SWS2	0.306	0.396	0.284	2.820	-	-

SWS3	0.318	0.494	0.429	10.499	-	-
SWS4	0.360	0.496	0.407	1.667	-	-
SWS5	0.389	0.429	6.794	-	-	-
SWS7	0.362	0.368	0.355	0.316	5.286	-
SWS8	0.379	0.455	0.379	0.400	15.671	-
SWS9	0.374	0.427	0.443	0.399	-	0.015
SWS10	0.378	0.447	0.314	0.001	0.008	8.528
SWS11	0.352	0.317	0.365	8.631	-	-
SWS12	0.351	0.477	-	0.009	-	9.915
BASIN	**0.357**	**0.436**	**0.387**	**0.381**	**0.368**	**18.459**

Table 5. Hydrological and Physical areal aspects of the Dhela river watershed and its sub-watersheds

Sub watersheds	Drainage density (D_d)	Stream frequency (F_s)	Drainage texture ($T=D_d$ xF_s)	Elongation ratio $R_e=1.128\sqrt{A}/L$	Length of overland flow ($L_g=1/2$ D_d)	Circulatory ratio $R_c= 4\pi(A/P_m^2)$	Form factor $F_f =A/L^2$	Compactness coefficient $Cc=0.2821(P_m/A^{0.5})$	Shape factor $S_f= L^2/A$
SWS1	2.518	6.546	1.303	0.465	0.199	0.216	0.170	2.152	5.882
SWS2	2.266	6.377	1.409	0.477	0.221	0.229	0.179	2.09	5.587
SWS3	2.392	5.501	1.150	0.364	0.209	0.170	0.104	2.423	9.615
SWS4	2.475	5.957	1.203	0.337	0.202	0.187	0.089	2.317	11.236
SWS5	2.642	4.772	0.902	0.417	0.189	0.191	0.137	2.291	7.299
SWS7	2.854	7.206	1.261	0.657	0.175	0.188	0.339	2.307	2.95
SWS8	2.616	5.603	1.070	0.260	0.191	0.07	0.053	3.779	18.868
SWS9	2.931	7.368	1.260	0.359	0.171	0.125	0.101	2.826	9.901
SWS10	2.799	6.481	1.160	0.526	0.179	0.158	0.217	2.516	4.608
SWS11	2.675	6.272	1.173	0.338	0.187	0.103	0.09	3.115	11.111
SWS12	2.609	4.719	0.887	0.378	0.188	0.121	0.112	2.872	8.929
BASIN	**2.635**	**6.732**	**17.739**	**0.431**	**0.190**	**0.160**	**0.146**	**2.499**	**6.851**

Table 6. Relief aspects of the Sub-watersheds of Dhela river watershed

Sub watersheds	Perimeter (km)	Max. elevation H (km)	Min. elevation h (km)	Drainage density (D_d)	Basin length L (km)	Basin relief (H-h)	Relative relief $R_r=[(H-h)/P_m]x100$	Ruggedness number $R_n=(H-h)x D_d$	Relief ratio (H-h)/L
SWS1	37.825	0.798	0.321	0.199	12.032	0.477	1.261	0.095	0.040
SWS2	26.725	0.621	0.314	0.221	8.538	0.307	1.149	0.068	0.036
SWS3	50.075	0.986	0.236	0.209	18.063	0.750	1.498	0.157	0.042
SWS4	39.625	0.655	0.235	0.202	16.157	0.420	1.060	0.085	0.009
SWS5	23.800	0.504	0.245	0.189	7.920	0.259	1.088	0.049	0.033
SWS7	36.300	0.272	0.209	0.175	7.627	0.063	0.174	0.011	0.008
SWS8	84.325	0.966	0.209	0.191	27.323	0.757	0.898	0.145	0.028
SWS9	65.300	0.638	0.189	0.171	20.463	0.449	2.750	0.768	0.022
SWS10	39.325	0.245	0.188	0.179	9.457	0.057	0.145	0.010	0.006
SWS11	44.525	0.218	0.172	0.187	13.447	0.046	0.103	0.009	0.003
SWS12	33.800	0.208	0.172	0.188	9.915	0.036	0.186	0.007	0.357
BASIN	**140.625**	**0.986**	**0.172**	**2.635**	**41.555**	**0.814**	**0.579**	**2.145**	**0.020**

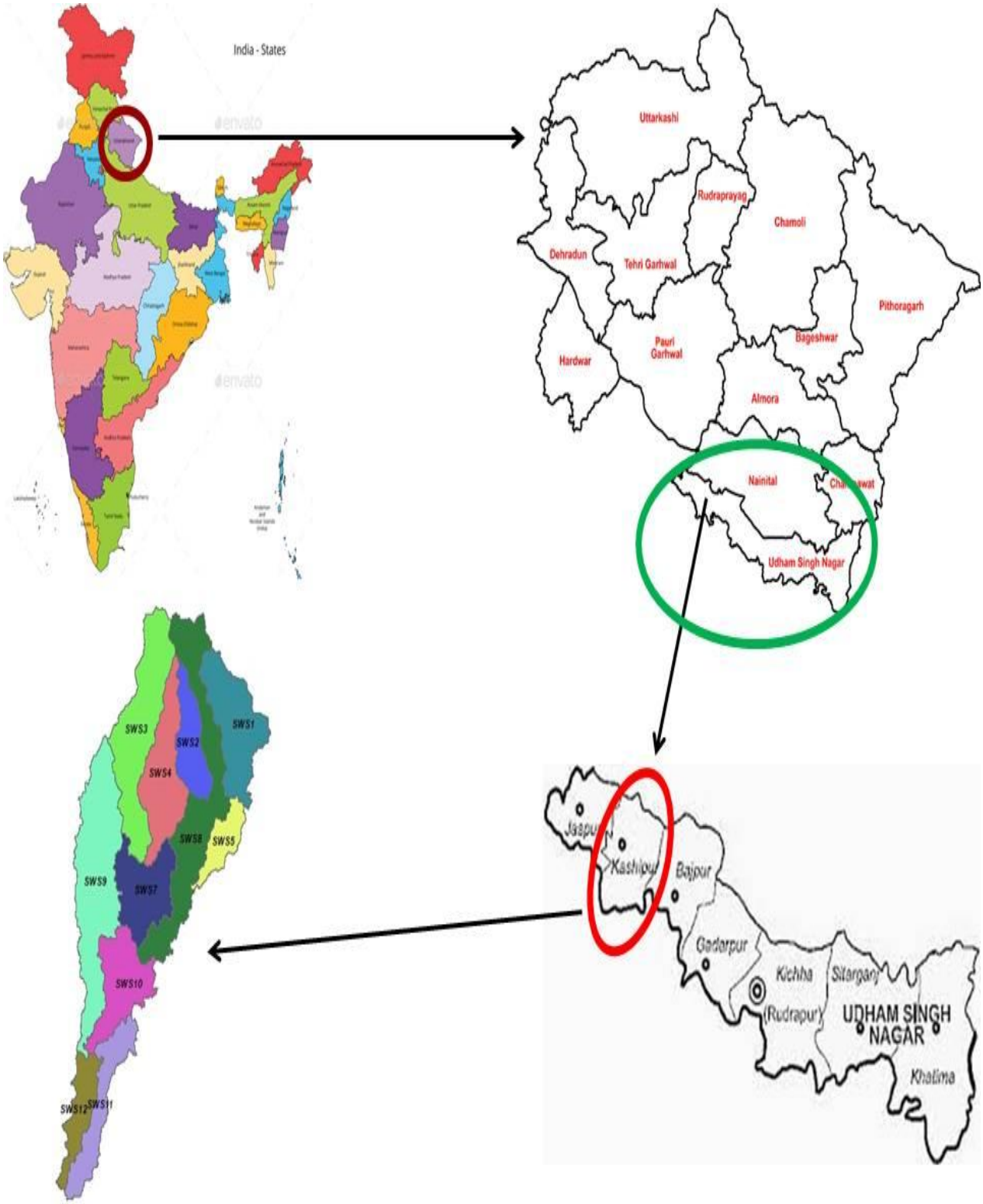

Fig. 1 Location and spread of the Dhela river watershed

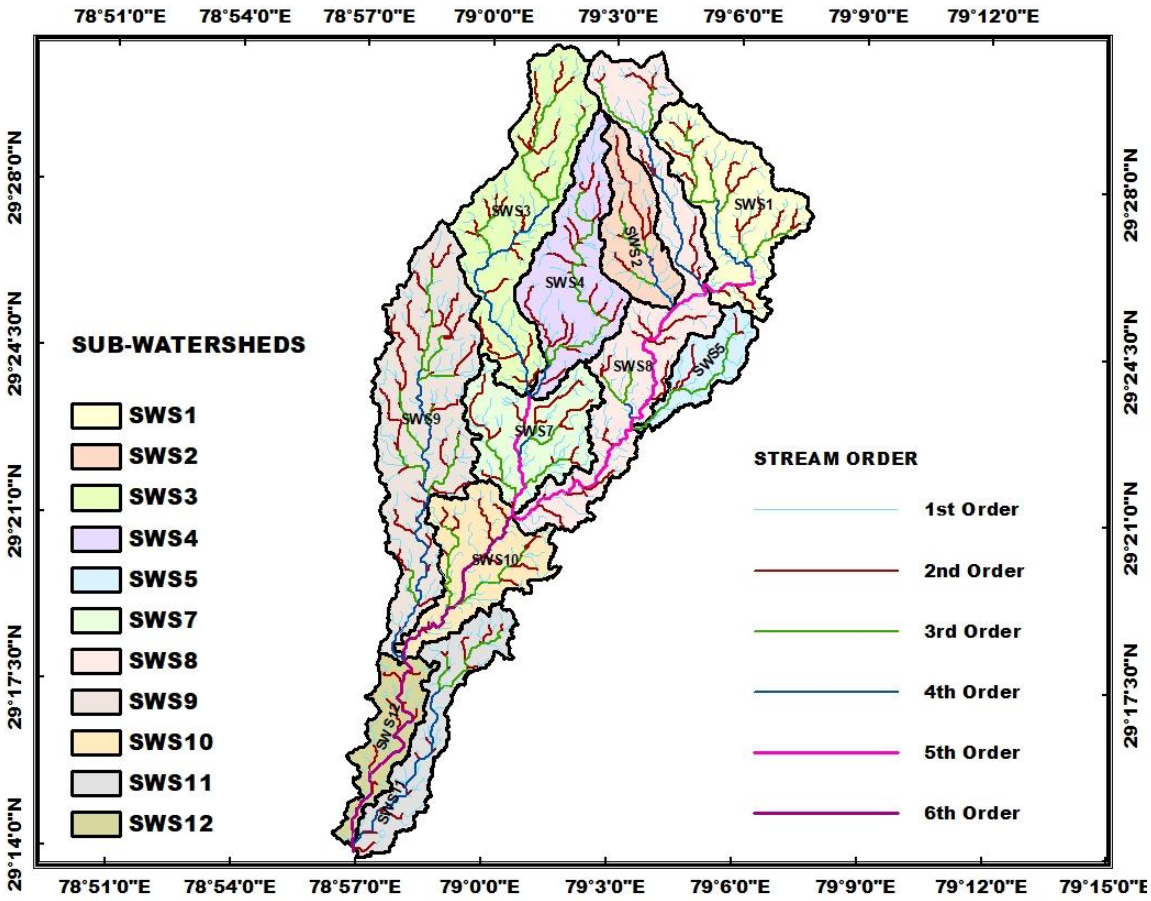

Fig. 2 Drainage Network Map of the sub-watersheds of Dhela river watershed