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CONTENTS

Application of geospatial techniques in morphometric analysis of sub-watersheds of Nanak Sagar Catchment

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ABSTRACT: The present study highlights the effectiveness and advantages of remote sensing and Geographic Information System (GIS)-based morphometric analysis for quantitative and qualitative assessment of Nanak Sagar catchment, Uttarakhand. For mapping remotely sensed data, GIS have been proven to be the most powerful advanced technology. The fundamental areal, linear and relief aspects of morphometric analysis were calculated after processing the DEM (Digital Elevation Model) in GIS software. The entire catchment area was divided into 13 sub-watersheds and 21 morphometric parameters were calculated for each one of them. SRTM-DEM was used in the analysis, to extract the drainage network as well as various thematic maps. Stream order (N_u), stream length (L_u), mean bifurcation ratio (Rb_m), drainage density (D_d), length of overland flow (L_g), basin length (B_L), circulatory ratio (C_r), elongation ratio (R_e), form factor (F_f), shape factor (S_f), infiltration number (I_n), stream frequency (St_f), relief (R), relief ratio (R_h), ruggedness number (R_n) were the parameters considered. With the total area of 407.20 km^2, drainage basin was found of having dendritic nature, and is classified as 6th order basin. SW7 is more vulnerable to erosion than other sub-watersheds, with high values of I_n, St_f, and D_t and should be consider for planning and management followed by SW6 and SW5. Overall analysis shows that reservoir have nearly fewer structure wise disturbances as D_d values lies between 3 to 6 and elongated shape of all sub-watersheds shows minimum runoff potential but increased yield of sediment load due to high infiltration numbers and relief.

Key words: GIS, remote sensing, SRTM-DEM, soil and water conservation

Soil and water are two critically important natural resources that are rapidly depleting. These two resources are valuable to humanity because they meet all needs while also safeguarding the environment and civilization. The watershed management and water supply control are critical for micro-prioritization, which aids in sustainable growth and the selection of appropriate land use patterns. According to few of important morphometric studies, “Principle of morphometry which says, a drainage basin can reflect geological and geomorphological processes eventually, is highly acknowledged. It is approved that the impact of drainage morphometry is substantial in incorporating landform stages and processes, soil physical properties and erosional characteristics” (Biswas *et al.,* 1999; Gray, 1961; Horton, 1945; Reddy *et al.* 2004; Pike and Wilson, 1971; Qadir *et al.*, 2020; Schumm, 1956; Strahler, 1964).

Systematic research is needed for effective hydrological investigation such as groundwater potential assessment, groundwater management, pedology, basin management and environmental assessment. Fast emerging spatial information technologies have become powerful methods over traditional data processing to control problems of natural resources, their planning and management (Rao *et al.*, 2010). Bishop *et al.* (2012) looked at principles, problems and exploratory studies in emerging geospatial technologies and geomorphological mapping.

Various researchers, (Horton, 1945; Reddy *et al.*, 2004; Qadir *et al.*, 2020; Sahu *et al.*, 2017; Vittala *et al.*, 2004; Rai *et al.*, 2018) studied drainage characteristics and analysed morphometric condition of watershed with the help of advanced GIS technology in different parts of India. Biswas *et al.* (1999); Chowdary *et al.* (2013); Meshram and Sharma (2018); Rahaman *et al.* (2015) and Sharma and Mahajan (2020) used the same techniques to prioritize watershed. Prabhakar *et al.* (2019) studied geomorphometry which can help in watershed management of resources while Meshram *et al.* (2017) and Samanta *et al.* (2016), spatially modelled erosion susceptible zones through morphometric analysis. The placement of water harvesting structures was done by Patel *et al*. (2012) using morphometric analysis and the geo-visualization theory. Ratnam *et al*. (2005) used morphometric analysis to determine where control dams should be placed.

Ingole (2015) evaluated sedimentation rate after investigating morphological changes in Nanak Sagar reservoir for 45 years (1962-2007). Their study revealed, reservoir was highly affected by sedimentation with overall rate of 1.29 Mm^3/year i. e., 0.59 % and further highlighted, reservoir area was reduced by 55% of the existing area.

The aim of this research was to obtain precise data on measurable stream topologies. Researchers can comprehend the landform evolution process, structural settings and actual erosion cycle stages by studying the morphometric parameters with drainage patterns.

MATERIALS AND METHODS

Nanak Sagar reservoir is located near the town of Nanakmatta, below lower Himalaya to the south of Kumaon division, Uttarakhand. Catchment area comprises of three districts namely, Udham Singh Nagar, Nainital, Champawat and covers *Bhabhar* and *Tarai* zones. Catchment is drained by Deoha, a major tributary of Ramganga river and Kaman River. Small streams such as, Kumia nadi, Lebar nadi, Bhainsiya nala, Sariyapani nala are also drain into the reservoir. The *Bhabhar* tract elongated from NW-SE and merges with *Tarai* occurring in the south. The study area is spread over 28°56'06'' to 29°08'49.2'' N latitude and 79°42'43.2'' to 80°00'46.8'' E, covering total catchment area of 407.20 km^2 as represented in Fig 1. Wheat, rice, maize, soybean, ragi, ginger, lentil, pea, tomato, potato, brinjal, cauliflower, mango, lime, peach and pear, etc. are the principal crops grown in *Bhabhar* plane including foothill and lower hills. The topography lies between rough to fragile, with high, steep mountains to plains and elevations ranging from 206 m to 1188 m above mean sea level. As per the SLUSI classification, major part of area consists of fine loamy and coarse loamy soil texture. The annual rainfall of the project area wis 1475.1 mm per annum. The hottest months of the year are May and June. The temperature in the Nanakmatta town goes up to 40ºC (May) during the summer and the minimum temperature is 8ºC (January).

The geological data for the study was obtained from USGS (United State Geological Survey) website. The SRTM DEM having resolution of 30 m was used for preparation of different thematic maps and drainage network after georeferencing and mosaicking in GIS. SOI Toposheets Nos 53O/12, 53O/16 and 53P/13 with scale of 1:50,000 were used for verification. The SRTM-DEM was processed in GIS environment using ArcGIS 10.4 software. The watershed was delineated using hydrology tools of spatial analyst arctool box. For sub-watershed delineation, Archydro extension of ArcGIS was used. ArcHydro converted map of stream for whole reservoir into smaller ones using highest points of flow accumulation.

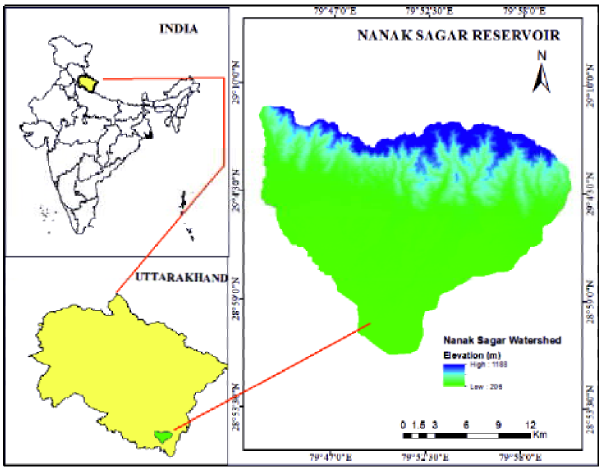

Fig. 1: Location map of study area

RESULTS AND DISCUSSION

The present research was carried out with the purpose of measuring and analysing morphometry of Nanak Sagar catchment located in Udham Singh Nagar district of Uttarakhand (India). The parameters were calculated using standard formulae listed in Table 1.

Drainage map: Drainage map was prepared using ArcGIS software's spatial analyst tool. The catchment was having order VI and the total length of I, II, III, IV, V and VI order streams was found as 687.81, 252.93, 143.97, 112.50, 59.93 and 35.13 km respectively (Table 2). Since the catchment was divided into 13 sub-watersheds for management purposes, each drainage network was examined separately. Fig 2 shows stream network of whole catchment. Fig. 3 shows individual sub-watershed's stream network. The sub-watersheds SW2 and SW5 were of IV order, SW9, SW11, SW1 and SW13 were of VI order and remaining 8 were of V order. The details of drainage network such as stream number and stream length of different orders of all sub-watersheds is given in Table 2.

Thematic maps of study area

The following are the basic thematic maps of the study area that were generated and imported using ArcGIS10.4.

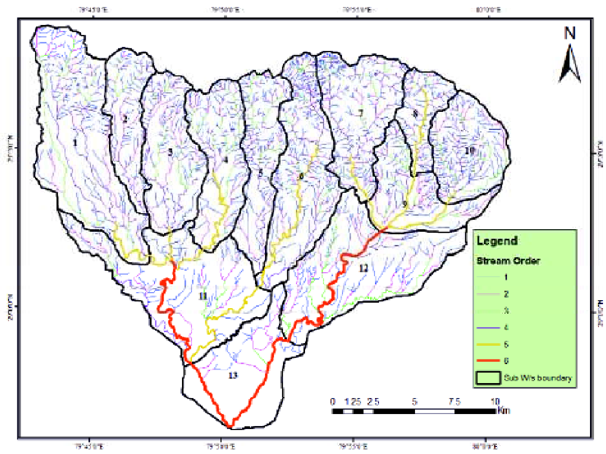

Fig. 2: Drainage map of study area

Slope and Aspect map

The extent and alignment of the slope determine the landscape use that it can support, the slope but rather aspect of an area are important elements in determining appropriate land use (Vittala *et al.*, 2004). By giving elevation as a layer input aspect

Table 1: Formulae to calculate morphometric parameters

S. No.	Parameters	Formulae	Method
1	Area (A), km^2	GIS output	ArcGIS 10
2	Perimeter (P), km	GIS output	ArcGIS 10
3	Stream order (u)	Hierarchical Rank	Strahler (1964)
4	Stream number (N_u)	No. of streams in 'u' order	Horton (1945)
5	Stream length (L_u), km	Length of the streams, obtained from GIS software	Horton (1945)
6	Bifurcation ratio (R_b)	$R_b = N_u/(N_{u+1})$	Horton (1932)
		N_u= entire streams of 'u' order	
		N_{u+1}= no. of streams in next higher order	
7	Basin length (B_L)	$B_L = 1.312 * A^{0.568}$	Gray (1961)
8	Drainage density (D_d)	$D_d = L_u/A$	Horton (1945)
9	Stream frequency (S_{Fs})	Fs = Nu / A	Horton (1945)
10	Drainage Intensity (D_i)	$D_i = F_s/D_d$	Horton (1932)
11	Infiltration Number (I_r)	$I_r = St_f * D_d$	Faniran (1968)
12	Drainage texture (Dt)	Dt = Nu / P	Horton (1945)
13	Length of overland flow (L_g)	$L_g = 1 / D * 2$	Horton (1945)
14	Form factor (Ff)	$F_f = A / L^2$	Horton (1945)
15	Shape factor (Sf)	$S_f = B_L^2 / A$	Smart and Surkan (1967)
16	Circularity ratio (R_c)	R_c = 4ÀA / P^2	Strahler (1964)
17	Elongation ratio (R_e)	$Re = (2/Lb) * (A/P)^{1/2}$	Strahler (1964)
18	Compactness coefficient (C_c)	$C_c = 0.2821 * P/A^{0.5}$	Horton (1945)
19	Relief (R)	R = H – h	Strahler (1952)
		H- higher elevation, m	
		h- lower elevation, m	
20	Relief ratio (R_h)	$R_h = R / L$	Schumm (1956)
21	Ruggedness ratio (R_n)	$R_n = B_h * D_d$	Strahler (1964)

Table 2: Basic morphometric parameters of study area

Sub-watersheds	Area (km²)	Perimeter (km)	Stream number in different orders							Stream length in different orders (km)						
			I	II	III	IV	V	VI	Total	I	II	III	IV	V	VI	Total
SW1	53.23	41.08	151	32	8	3	1	–	195	74.00	29.41	22.56	23.39	4.78	–	154.14
SW2	18.46	27.55	81	18	3	1	–	–	103	32.71	10.95	8.05	9.21	–	–	60.92
SW3	28.08	28.90	120	26	6	2	1	–	155	48.17	21.54	11.61	14.66	0.25	–	96.24
SW4	26.83	29.80	129	30	7	2	1	–	169	47.92	17.91	14.06	4.17	7.65	–	91.71
SW5	24.10	32.84	133	32	3	1	–	–	169	48.31	16.11	9.60	11.51	–	–	85.54
SW6	38.30	37.84	265	59	11	3	1	–	339	90.19	26.77	8.55	14.85	12.79	–	153.14
SW7	30.58	31.13	264	57	12	2	1	–	336	75.58	24.43	10.38	12.51	3.15	–	126.04
SW8	12.53	20.42	91	21	6	2	1	–	121	30.93	10.42	2.71	0.73	6.21	–	50.99
SW9	23.61	31.20	112	27	10	2	3	1	155	45.47	21.58	11.41	2.21	10.86	0.54	92.06
SW10	23.55	19.20	160	42	13	3	1		219	62.38	16.68	12.49	7.58	0.16	0.00	99.30
SW11	49.55	46.68	68	16	4	3	3	1	95	56.35	17.52	7.75	11.70	14.07	10.19	117.58
SW12	46.87	35.86	90	22	4	–	–	1	117	62.83	28.25	23.43	–	–	12.99	127.51
SW13	31.50	29.22	19	6	1	–	–	2	28	12.98	11.36	1.37	–	–	11.41	37.12

map was created and divided into 10 classes. Fig 4 shows distribution of different aspect classes. It was observed that maximum area (15.53%) falls under South-west aspect followed by south (15.39%) as depicted from Table 3. The spatial variation of multiple slope groups is depicted in Fig 5. Slope was divided into 9 classes as per the Soil and Land use Survey of India (SLUSI) recommendations. The per cent area extent of different slope classes in watershed has shown in Table 4. The dominant slope category was flat (0-1 degrees), 43.75 %.

Analysis of various morphometric aspects

Table 1 shows formulae used for calculating various basic, linear, areal and relief parameters. The results are discussed further below-

Basic Morphometric Parameters

1. Basin Area (A): It has a catchment area of 407.20 km^2, which is distributed in 13 sub-watersheds (Table 2). SW8 has least (12.53 km^2), while SW1 has largest drainage area (53.23 km^2).
2. Perimeter of Basin (P): It is the length of watershed boundary measured in km. which has been determined to be 98 km.
3. Stream order (u): Determination of stream order is most important and significant step in morphometric analysis. It was done by Strahler's method, in which stream with no tributary was ranked as 1st order, stream where two equal

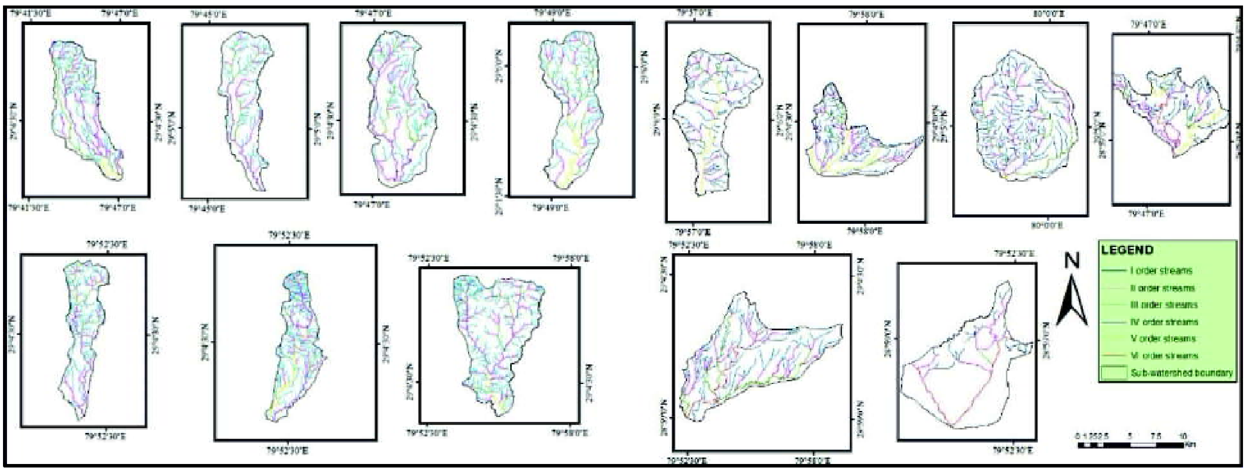

Fig. 3: Drainage map of sub-watersheds

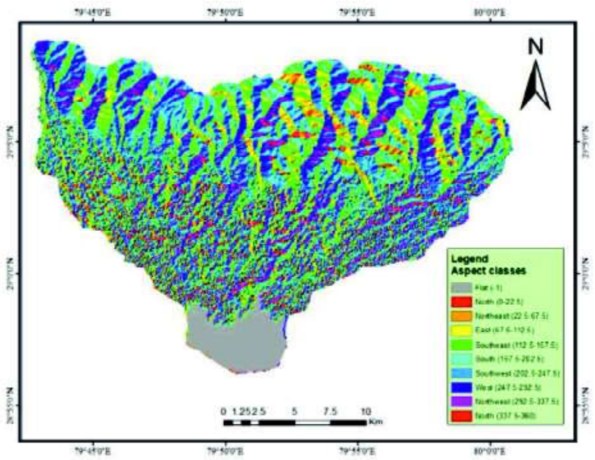

Fig. 4: Aspect map of study area

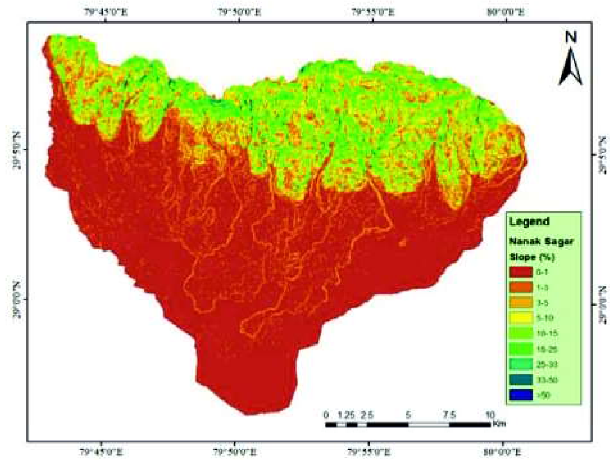

Fig. 5: Slope map of study area

Table 3: Aspect and its areal extent

Aspect	Area (km^2)	Area (%)
Flat	23.589	5.80
North	14.302	3.51
North-east	29.695	7.30
East	49.166	12.08
South-east	60.281	14.81
South	62.622	15.39
South-west	63.196	15.53
West	57.266	14.07
North-west	36.693	9.01
North	10.218	2.51
Total	**407.028**	**100.00**

order (u) streams meet became (u+1) order and so on. In Nanak Sagar reservoir, mainly 2 rivers, Deoha and Kaman contributes which were identified as 6th order according to hierarchy (Table 2).

4. Stream number (N_u): As per Horton's law of stream numbers, "the number of streams of various orders in a drainage basin appears to average as a reciprocal geometric sequence with the very first term equal to unity and the ratio equal to bifurcation ratio". N_u in every order was calculated in GIS platform. Out of total 2201 streams, 1683 were of I order, 388 were II order, 88 of III order, 24 of IV order, 13 of V order and 2 of VI order. Stream numbers of all stream orders under each sub-watershed are shown in Table 2.
5. Stream length (L_u): Horton's II law, principle of stream length was validated for selected basin.

Table 4: Slope and its areal Per centage

Slope (degree)	Area (km^2)	Per cent area
0-1	178.10	43.75
1-3	70.93	17.43
3-5	33.11	8.14
5-10	36.55	8.98
10-15	35.08	8.62
15-25	27.18	6.68
25-33	17.34	4.26
33-50	7.54	1.85
>50	1.21	0.30

The result of order wise stream length is shown in Table 2, it is clearly identified as cumulative L_u is greater for first-order streams. The 6th order stream has stream length of 35.13 km. L_u of sub-watershed's u-order is given in Table 2.

Linear Aspects

1. Mean Bifurcation ratio (Rb_m): According to Schumm (1956) "the term bifurcation ratio (R_b) may be defined as the ratio of the number of the stream segments of given order to the number of segments of the next higher order. It's a one-dimensional property that shows how well streams of different orders in a drainage basin are integrated". The basin's Rb_m values ranged from 2.72 to 5.94. As per Strahler (1964) Rb range between 3.00 and 5.00 when drainage basin having less structural disturbance. The higher Rb_m values (SW5) indicating a strong structural control in the drainage pattern and vice-vera (Rai *et al*., 2017; Vittala *et al*., 2004). The Rb_m value for basin was obtained 3.82,

Table 5: Calculated linear aspects of sub-watersheds of Nanak Sagar catchment and its sub-watersheds

Sub-watershed	Stream Order (u)	Stream Number (N_u)	Bifurcation ratio (R_b)	Mean bifurcation ratio (Rb_m)	Basin length, B_L(km)	Length of overland flow (L_g)
SW1	I	151	4.72	3.60	12.54	0.17
	II	32	4.00			
	III	8	2.67			
	IV	3	3.00			
	V	1				
SW2	I	81	4.50	4.50	6.87	0.15
	II	18	6.00			
	III	3	3.00			
	IV	1				
SW3	I	120	4.62	3.49	8.72	0.15
	II	26	4.33			
	III	6	3.00			
	IV	2	2.00			
	V	1				
SW4	I	129	4.30	3.52	8.50	0.15
	II	30	4.29			
	III	7	3.50			
	IV	2	2.00			
	V	1				
SW5	I	133	4.16	5.94	8.00	0.14
	II	32	10.67			
	III	3	3.00			
	IV	1				
SW6	I	265	4.49	4.13	10.40	0.13
	II	59	5.36			
	III	11	3.67			
	IV	3	3.00			
	V	1				
SW7	I	264	4.63	4.35	9.16	0.12
	II	57	4.75			
	III	12	6.00			
	IV	2	2.00			
	V	1				
SW8	I	91	4.33	3.21	5.51	0.12
	II	21	3.50			
	III	6	3.00			
	IV	2	2.00			
	V	1				
SW9	I	112	4.15	2.87	7.90	0.13
	II	27	2.70			
	III	10	5.00			
	IV	2	0.50			
	V	4	2.00			
	VI	2				
SW10	I	160	3.81	3.59	7.89	0.12
	II	42	3.23			
	III	13	4.33			
	IV	3	3.00			
	V	1				
SW11	I	68	4.25	2.72	12.04	0.21
	II	16	4.00			
	III	4	1.33			
	IV	3	1.00			

	V	3	3.00			
	VI	1				
SW12	I	90	4.09			
	II	22	5.50			
	III	4	4.00			
	IV			4.53	11.67	0.18
	V					
	VI	1				
SW13	I	19	3.17			
	II	6	6.00			
	III	1	0.50			
	IV			3.22	9.31	0.42
	V					
	VI	2				
Catchment				**3.82**	**39.83**	**0.16**

Table 6: Areal aspects of Nanak Sagar catchment and its sub-watersheds

Sub-watersheds	D_d(km/km^2)	St_f(/km^2)	R_c	R_e	S_f	F_f	I_n(/km^3)
SW1	2.90	3.66	0.40	0.66	2.96	0.34	10.61
SW2	3.30	5.58	0.31	0.71	2.56	0.39	18.41
SW3	3.43	5.52	0.42	0.69	2.71	0.37	18.93
SW4	3.42	6.30	0.38	0.69	2.69	0.37	21.53
SW5	3.55	7.01	0.28	0.69	2.65	0.38	24.89
SW6	4.00	8.85	0.34	0.67	2.83	0.35	35.39
SW7	4.12	10.99	0.40	0.68	2.74	0.37	45.28
SW8	4.07	9.66	0.38	0.72	2.43	0.41	39.31
SW9	3.90	6.65	0.30	0.69	2.65	0.38	25.93
SW10	4.22	9.3	0.80	0.69	2.65	0.38	39.19
SW11	2.37	1.92	0.29	0.66	2.93	0.34	4.55
SW12	2.72	2.5	0.46	0.66	2.9	0.34	3.26
SW13	1.18	0.89	0.46	0.68	2.75	0.36	1.05
Catchment	**3.17**	**6.06**	**0.40**	**0.68**	**2.73**	**0.37**	**22.18**

Table 7: Relief aspects of Nanak Sagar catchment and its sub-watersheds

Sub-watersheds	H (m)	h (m)	R (km)	R_h	Slope	R_n
SW1	979	216	0.76	0.06	10.04	2.21
SW2	1120	225	0.90	0.13	7.21	2.95
SW3	1047	220	0.83	0.09	5.48	2.83
SW4	1120	220	0.90	0.11	8.23	3.08
SW5	1161	218	0.94	0.12	10.34	3.35
SW6	1188	218	0.97	0.09	14.09	3.88
SW7	1186	246	0.94	0.10	21.63	3.87
SW8	1143	267	0.88	0.16	8.34	3.57
SW9	755	228	0.53	0.07	4.90	2.05
SW10	1100	263	0.84	0.11	9.75	3.53
SW11	256	207	0.05	0.00	0.00	0.12
SW12	310	211	0.10	0.01	0.00	0.27
SW13	248	206	0.04	0.00	0.00	0.05
Catchment	**1188**	**206**	**0.67**	**0.08**	**7.69**	**2.44**

which shows, region is structurally well-controlled (Table 5).

2. Basin length (B_L): B_L is represented by the line joining 2 farthest point in a basin. B_L was calculated as per formula in Table 1 and results are shown in Table 5.

Areal Aspects

1. Drainage Density (D_d): D_d which depends on function of structural, climatic and lithologic properties, is another important parameter. Higher D_d shows higher dissected drainage watershed and quick response concerning rainfall events. It is primary length extent in the land surface, which is transformation point between scales where unstable channel forming processes yield stable diffusive processes. (Tarboton *et al*., 1992).
2. Stream frequency (St_f): "St_f is the ratio of N_u and area (A). St_f is mainly influenced by the lithology and represents the texture of the drainage network of the basin. The St_f and D_d has a positive correlation of the region, suggesting that St_f increases as D_d increases for a basin" (Horton, 1932). Channel frequency density highlight order of relief stages and ruggedness degree of area (Singh, 1980).
3. Drainage intensity (D_i): Faniran (1968) studied that D_i is the ratio of St_f and D_d. The lower values reflect increase in soil erosion susceptibility because surface runoff could not remove quickly in such cases. D_i for sub-watersheds varied between 0.75 (SW13) to 2.67 (SW7) (Table 6).
4. Infiltration number (I_n): It was calculated as per formula (Table 1) given by Faniran (1968) and was ranged between 1.05 (SW13) to 45.28 (SW7). Infiltration rate is inversely proportional to I_n.
5. Drainage texture (D_t): Horton defined, "drainage texture as the ratio of 'N_u' of all order to the perimeter of a basin (P)." Smith (1950) categorized D_t in five classes i. e., very coarser < 2, 2 < coarser > 4, 4< moderate >6, 6 < fine > 8 and very fine >8. D_t ranged between 0.96 (SW13) to 10.79 (SW7).
6. Length of overland flow (L_g): L_g denotes length of precipitation over land prior to concentration. This parameter is found dominant for small watersheds. L_g values ranges between 0.12 km (SW7, SW8, SW9) to 0.42 km (SW13).
7. Form factor (F_f): F_f is the ratio of 'A' to second power of 'B_L' (Horton 1932). A F_f value of more than 0.78 implies perfectly circular basins, while smaller values suggest elongated basins. The form factor varies from 0.34 to 0.41, indicating that no sub-watershed is completely circular (Table 6).
8. Shape factor (S_f): Shape factor was calculated as diving square of basin length (B_L) by its area (A) as defined by Smart and Surkan (1967). Results showed that S_f values found to lie between 2.43 to 2.96 (Table 6).
9. Circulatory ratio (C_r): Miller (1953) examined, "C_r is the ratio of area of watershed (A) to the area of circle having same circumference as perimeter of watershed". He further explained C_r is a significant ratio that indicates stages of watershed. Young, mature and old stages of lifecycle of watershed can be indicated by low, medium and high values of C_r (Wilson *et al*., 2012). C_r found between 0.29 to 0.46 (Table 6).
10. Elongation Ratio (R_e): Schumm (1956) defined "R_e as a dimensionless ratio of the diameter of the circle representing the same area as that of basin to the length of basin (BL). Over a broad range of environmental and geological conditions, it ranges between 0.6 and unity." The R_e value is found greater than 0.6 for all sub-watersheds reflecting elongated shaped basins (Fig. 4 and Table 6).
11. Compactness Coefficient (C_c): "It is defined as ratio of 'P' to the perimeter of circle having same area as the basin" Horton (1932). Watershed with C_c value of 1 denote circular basins. C_c is inversely proportional to erosion. (Ratnam *et al*., 2005). This parameter ranged from 1.47 to 1.89, which confirms that sub-watersheds are not circular ones (Table 6)

Relief Aspects

1. Relief (R): Difference in elevation between highest and lowest point, is the total relief of that watershed (Strahler, 1952). The R value found between 42 m (SW13) to 970 m (SW6) as shown in Table 7.
2. Relief ratio (R_h): According to Schumm (1956), "Relief ratio is nothing but the maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line". R_h is ratio of basin relief (R) to basin length (B_L) and is dimensionless

parameter". It is nothing but the measure of steepness of a watershed. So, higher values increase erosion probability if storm occurs (Vittala *et al*., 2004). R_h value ranged from 0.01 to 0.16 (Table 7).

3. Ruggedness number (R_n): R_n, a dimensionless parameter and obtained by multiplying drainage density (D_d) and basin relief (R) as defined by Melton (1957). It expresses the combined effect of length and slope characteristics. Table 7 depicted R_n values varied from 0.09 to 3.88.

CONCLUSION

1. The detailed analysis of drainage pattern discovered extensive utility in demarcating erosion prone areas/zones, which can help in suggesting conservation measures for soil and water at the parcel level. The Nanak Sagar catchment is distinguished by an elongated basin with sixth stream order, moderate drainage densities, high relief ratios and high infiltration numbers with moderate bifurcation ratio.

2.Rb_m indicates area has suffered less structural disturbance. The high R_e compared to C_r shows all sub-watersheds have an elongated shape, which makes less prone to flood and erosion and more capable of transporting sediment. High R_h values reflected that the watershed should be handle in soil and water conservation.

3. Drainage morphology and thematic map should be surveyed in subsequent years to identify and select water retention structures such as percolation tanks, ponds, and check dams. This work would be helpful to policy makers at micro level.

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