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Morphometric Analysis of Burhner River Watershed Using Remote Sensing and GIS Technique

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ABSTRACT

Proper knowledge of hydrological response of a watershed is of utmost importance in order to implement watershed development works in the watersheds. Morphometric analysis of a watershed thus helps in understanding the hydrological response of watersheds in hydrological data-scarce conditions. The present study attempts to perform the morphometric analysis of sub-watersheds inherent in Burhner river watershed situated in Mandla, Balaghat and Dindori districts of Madhya Pradesh, India. A total of 17 sub-watersheds were delineated in the study area using CARTOSAT DEM (Digital Elevation Model), having a spatial resolution of 30 m. Stream network of the study area was obtained using DEM in ArcGIS 9.3®. The findings of the study revealed that out of 17 sub-watersheds, three sub-watersheds were of 8th order, eight sub-watersheds were of 7th order and six sub-watersheds were of 6th order. The drainage pattern of the study area was found as dendritic to sub-dendritic, approaching like the branching of a tree. Linear, areal, shape and relief morphometric parameters were calculated using the standard formulas. High values of a linear morphometric parameter such as mean bifurcation ratio revealed geomorphological control over the entire watershed. In addition, higher values of areal morphometric parameters such as drainage density, stream frequency, texture ratio with lower values of length of overland flow and constant of channel maintenance suggested channel flow as dominating in the sub-watersheds with a higher risk of soil erosion in the sub-watersheds. Analysis of shape morphometric parameters (*i.e.* form factor, circularity ratio, elongation ratio, compactness coefficient and shape factor) and relief morphometric parameters (*i.e.* relief ratio, relative relief and ruggedness number) also revealed that sub-watersheds are more prone to soil erosion. The study aided in understanding the hydrological behaviour of sub-watersheds of Burhner river watershed which can be further considered for sustainable management of natural resources in sub-watersheds.

HIGHLIGHTS

- The study was conducted in Burhner river watershed situated in Mandla, Balaghat and Dindori districts of Madhya Pradesh, India, to determine morphometric parameters of inherent sub-watersheds.
- Hydrological response of 17 sub-watersheds of Burhner river watershed was studied, indicating that sub-watersheds are more prone to soil erosion.

Keywords: Morphometric analysis, drainage basin characteristics, remote sensing, geographic information system

A watershed is a natural hydrological unit that generates surface runoff from the rainfall, which flows through channels, streams, river, lakes or oceans (Gajbhiye *et al.* 2015a; Meshram *et al.* 2017). Mismanagement of natural resources (*i.e.* land and water) for the fulfilment of human needs has substantially caused watershed deterioration at a rapid pace in recent times (Sharma *et al.* 2008; Gajbhiye and Sharma 2016; Sharma *et al.* 2016).

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Watershed deterioration is one of the common issues in India and it also influences at global scale (Prabhakar *et al.* 2019).

Watershed is a geographical unit with a natural boundary where it is a logical choice to practice morphometric analysis in order to understand its hydrological response (Ahmed *et al.* 2018). Morphometric analysis is the science of measurement and mathematical estimation of the earth's shape, size and dimension of its landform (Clarke, 1966; Agarwal, 1998; Sharma *et al.* 2012).

Basin or watershed morphometry, among other aspects of morphometric analysis, is of great importance to hydrologists, geomorphologists to address serious environmental issues like soil erosion, slope instability, flood, landslides and extreme surface runoff (Sharma *et al.* 2011; Sharma *et al.* 2014; Mangan, 2019). Other basin characteristics such as travel time, time to peak and intensity of erosional processes can be predicted with better insights and accuracy through morphometric analysis (Altaf *et al.* 2013; Patil *et al.* 2017). Furthermore, it could be a good alternative in ungauged watersheds where information on hydrology are scarce (Romshoo *et al.* 2012; Gajbhiye *et al.* 2015b; Meshram and Sharma, 2017; Puno and Puno, 2019). A well-planned watershed management practice can mitigate the effect of prominent watershed deterioration, causing factors such as excessive runoff, low productive yield, accelerated soil erosion and poor infiltration, natural hazards such as droughts and floods (Choudhari *et al.* 2018).

In earlier times, the studies based on morphometric analysis were executed using traditional methods, which were time-consuming, laborious and were prone to errors and subsequently required information related to physiography, slope, geology, soil data through topographic maps and field surveys (Sreedevi *et al.* 2013). But due to the recent advancement of remote sensing and GIS (Geographic Information System) techniques has made it very easy and convenient to assess morphometric characteristics of any drainage basin, as it provides recent information with a large spatial synoptic view (Mundetia *et al.* 2018). The applications of GIS are competent, time-saving and appropriate for three-dimensional planning due to their capability to handle multifaceted problems and big databases for manipulation and retrieval (Kumar *et al.* 2016).

Studies on morphometric analysis of river basins using remote sensing and GIS technique have been executed by numerous researchers (Nautiyal, 1994; Agarwal, 1998; Nag and Chakraborty, 2003; Chopra *et al.* 2005; Yadav *et al.* 2014; Bogale, 2021). Vijith and Satheesth (2006) performed morphometric analysis of two major upland sub-watersheds of the Meenachil river in Kerela. Altaf *et al.* (2013) performed morphometric analysis to infer hydrological behavior of Lidder watershed, Western Himalaya, India. Madolli *et al.* (2021) studied the drainage characteristics and their implications for watershed management in Dharma river basin of Karnataka state in India.

The integrated use of remote sensing and GIS techniques can aid in understanding the hydrological behavior of sub-watersheds through morphometric analysis. Keeping in view the above facts, the present study aims at assessing the morphometric characteristics of sub-watersheds inherent in Burhner river watershed situated in Mandla, Balaghat and Dindori districts of Madhya Pradesh, India using remote sensing and GIS technique.

MATERIALS AND METHODS

Study area

Burhner river watershed lies between 80°34′40″E to 81°23′20″E longitudes and 22°49′45″N to 22°31′00″N latitudes coinciding with Mandla, Balaghat and Dindori districts of Madhya Pradesh. The watershed elevation varies from 393 m to 954 m covering a total geographical area of 3959.813 km^2. The rainfall in the watershed prominently occurs from the middle of June to the middle of September. The watershed receives rainfall from the southwest monsoon and the normal annual rainfall of the watershed is 1647.8 mm/year (Pai *et al.* 2014). The location map of the study area is shown in Fig. 1.

Data source and methodology

The delineation of watershed boundary and sub-watersheds of study area were performed in ArcGIS 9.3® environment by using CARTOSAT DEM (Digital Elevation Model). CARTOSAT DEM of 30 m spatial resolution was procured from Bhuvan ISRO's

Geoportal with URL: https://bhuvan-app3.nrsc.gov.in/data/download/index.php. The delineation was performed using snap pour point methodology in case of watershed delineation, whereas the automatic watershed delineation tool of ArcSWAT was considered for sub-watersheds delineation. The sub-watersheds code map of the study area is shown in Fig. 2.

Stream network of the study area was obtained from DEM using the fill, flow direction, flow accumulation tools of the Arc toolbox. A channel initiation threshold value of 30 was used to obtain the stream network of the study area. Strahler (1952; 1964) method of stream ordering was adopted in the present study.

For preparing the base map of the study area, a total number of fourteen toposheets coinciding with the study area were used. Toposheets of Survey of India (SOI) with toposheet number as 64B/9, 64B/10, 64B/11, 64B/12, 64B/13, 64B/14, 64B/15, 64B/16, 64F/2, 64F/3, 64F/4, 64F/6, 64F/7 and 64G/1 with a scale of 1:50000 were used. The toposheets were georeferenced in ERDAS IMAGINE® 2011 using Geographic Coordinate System (GCS) as WGS 1984. The georeferenced toposheets were further merged so as to validate the stream order obtained from DEM.

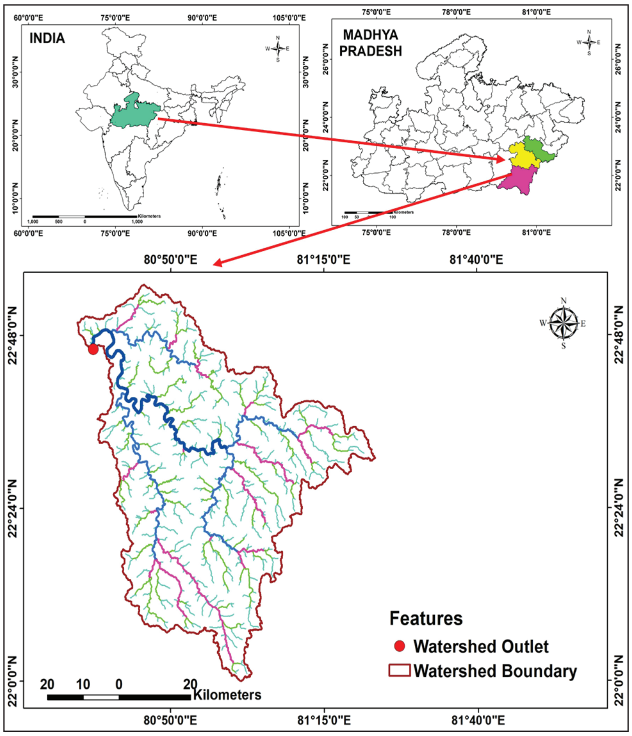

Fig. 1: Location map of the study area

Morphometric analysis

Morphometric analysis of a drainage basin is considered as the most satisfactory method; this method enables us to find interrelationship among different aspects of a drainage pattern (Biswas *et al.* 1999), facilitate a comparative evaluation of different drainage basins developed in various geologic and climatic regimes and define certain useful variables of drainage basins in practical terms (Nag and Chakraborty, 2003).

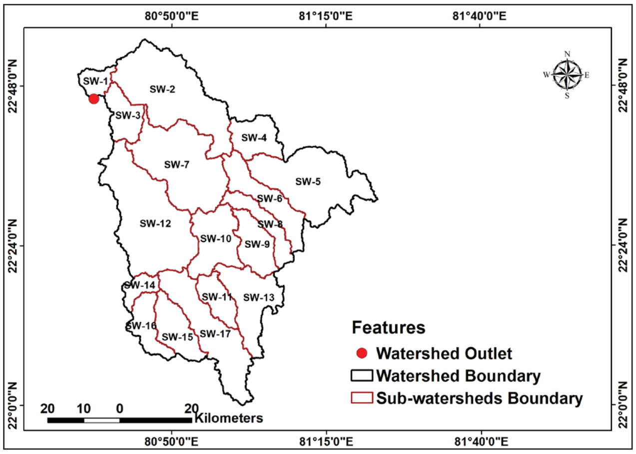

Fig. 2: Sub-watersheds code map of the study area

The preliminary process involved in morphometric analysis is the process of stream ordering (u). Gravelius (1914), Horton (1945) and Strahler (1952; 1964) have elaborated stream order in different ways. As Strahler's method of stream ordering is simple and widely accepted for applications and it is extensively used by geomorphologists for the morphometric analysis of a river basin (Wakode *et al.* 2013; Hayakawa and Oguchi 2013), the method of stream ordering as proposed by Strahler (1952; 1964) was adopted in the present study.

The basic morphometric parameters such as area (A), perimeter (P) and stream length (L_u) of sub-watersheds were calculated in GIS environment. The values of maximum watershed relief (H_{max}) and minimum watershed relief (H_{min}) were obtained from depressionless DEM after filling the sinks in the DEM. However, the basin length (L_b) and total relief (H) of the sub-watersheds were calculated using the standard formulas as given in Table 1.

Apart from basic morphometric parameters, linear morphometric parameter such as mean bifurcation ratio (R_{bm}), areal morphometric parameters such as drainage density (D_d), stream frequency (F_s), texture ratio (R_t), length of overland flow (L_o), constant of channel maintenance (C), shape morphometric parameters such as form factor (F_f), circularity ratio (R_c), elongation ratio (R_e), compactness coefficient (C_c), shape factor (B_s) and relief morphometric parameters such as relief ratio (R_h), relative relief (R_r) and ruggedness number (R_N) were calculated using standard formulas as stated by Gravelius (1914), Horton (1932; 1945), Strahler (1952; 1957; 1964), Schumm (1956), Smith (1950), Miller (1953), Melton (1957), Gregory and Walling (1973), Reddy *et al*. (2004) and Nooka Ratnam *et al.* (2005) as given in Table 1.

RESULTS AND DISCUSSION

Basic morphometric parameters

The Table 2 shows complete numeric details of the basic morphometric parameters obtained from GIS environment and standard formulas. The watershed with the maximum area was detected for SW-12 (*i.e.* 564.973 km^2), whereas it was least for SW-14 (*i.e.* 56.398 km^2). In the case of the perimeter, SW-2 indicated the highest value of perimeter (*i.e.* 181.260 km) and SW-1 indicated the least value of perimeter (*i.e.* 50.220 km). For basin length (L_b), the SW-12 indicated the highest values (*i.e.* 47.983 km) and SW-14 indicated the least value (*i.e.* 12.961 km). The high elevation value dominated in SW-5 (i.e. 954 m), whereas the least elevation value dominated in SW-1 (*i.e.* 393 m) near the watershed outlet. Among all the sub-watersheds, maximum elevation difference was indicated by SW-2 (*i.e.* 461 m).

Stream order (u)

Stream order is a type of classification that reflects a pattern of branches that unite to form the trunk stream leaving the catchment (Subramanya 2013). It is a measure of the position of streams in the hierarchy of the tributaries (Horton 1945). Stream order is a form of designation allocated to streams prevailing within the watershed boundaries and is a preliminary process in the morphometric analysis (Rao *et al.* 2020). The Burhner river watershed showed 8th order stream as a trunk stream. In addition, among the 17 delineated sub-watersheds, six sub-watersheds were of 6th order, eight sub-watersheds were of 7th order and 3 sub-watersheds were of 8th order (Table 3). The stream network map of the study area is shown in Fig. 3.

Drainage pattern

Stream order plays a crucial role in designating the nature of the drainage pattern of a watershed (Subramanya, 2013). The analysis of drainage patterns in Burhner river watershed revealed that the watershed comprises of dendritic to sub-dendritic drainage patterns. The dendritic drainage pattern is characterized by irregular branching in all directions, with the tributaries joining the mainstream at all angles (Zerntiz 1932). The word "dendritic" in the drainage pattern shows a close resemblance to a tree's branching. If the geologic setting is uniformly resistant to erosion, the land surface is gently sloped and surficial deposits are horizontally layered, a dendritic drainage pattern develops (Chow 1965). Such drainage patterns indicate homogenous soil and rock structures (Mishra and Rai 2020).

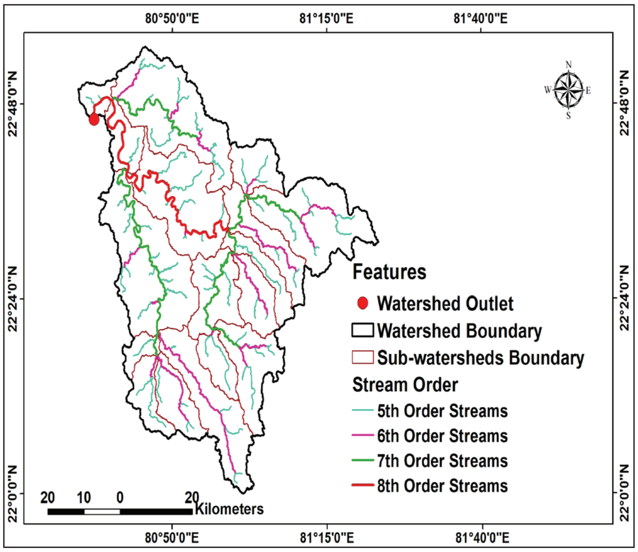

Fig. 3: Stream network map of the study area

Stream number (N_u)

Stream number refers to stream segments of different orders in a drainage basin (Horton 1945). The stream number is inversely proportional to the stream order (Meshram and Sharma 2017). The Table 3 shows the stream number of all sub-watersheds. The total number of first order streams in case of all sub-watersheds were highest as compared to the higher order streams. SW-12 indicated highest number of first order streams (*i.e.* N_1 = 5314) followed by SW-2 (*i.e.* N_1 = 4628) and SW-7 (*i.e.* N_1 = 4321).

Table 1: Formulas of different morphometric parameters

Sl. No.	Morphometric parameters	Symbol	Formula	Unit	References
Basic morphometric parameters					
1	Area	A	GIS environment calculation	km^2	—
2	Perimeter	P	GIS environment calculation	km	—
3	Basin length	L_b	$L_b = 1.312 \times A^{0.568}$	km	Schumm (1956); Nooka Ratnam *et al.* (2005)
4	Maximum watershed relief	H_{max}	Obtained from depressionless DEM in GIS environment	m	—
5	Minimum watershed relief	H_{min}	Obtained from depressionless DEM in GIS environment	m	—
6	Total watershed relief	H	$H = H_{max} - H_{min}$	m	Schumm (1956)
7	Stream order	u	Hierarchical rank	Dimensionless	Strahler (1952); Strahler (1964)
8	Stream length	L_u	Length of stream of a given order (u)	km	Horton (1945)
Linear morphometric parameters					
9	Bifurcation ratio	R_b	$R_b = \frac{N_u}{N_{u+1}}$ where N_u = number of streams of a given order (u), N_{u+1} = number of streams of next higher order (u+1)	Dimensionless	Horton (1945); Schumm (1956)
10	Mean bifurcation ratio	R_{bm}	R_{bm} = Average of bifurcation ratios of all orders	Dimensionless	Strahler (1957)
Areal morphometric parameters					
11	Drainage density	D_d	$D_d = \frac{\Sigma L_u}{A}$ where ΣL_u is the total length of streams of all orders (u) within the drainage basin	km/km^2 or 1/km or km^{-1}	Horton (1932)
12	Stream frequency	F_s	$F_s = \frac{\Sigma N_u}{A}$ where ΣN_u is the total number of streams of all orders (u) within the drainage basin	1/km^2 or km^{-2}	Horton (1932)
13	Texture ratio	R_t	$R_t = \frac{N_1}{P}$ where N_1 = total number of first order streams	1/km or km^{-1}	Smith (1950); Reddy *et al.* (2004)
14	Length of overland flow	L_o	$L_o = \frac{1}{2D_d}$	km^2/km or km	Horton (1945)
15	Constant of channel maintenance	C	$C = \frac{1}{D_d}$	km^2/km or km	Schumm (1956)

Shape morphometric parameters					
16	Form factor	F_f	$F_f = \frac{A}{L_b^2}$ where $F_f < 1$	Dimensionless	Horton (1932)
17	Elongation ratio	R_e	$R_e = \frac{2}{L_b}\sqrt{\frac{A}{\pi}} = \frac{1.128A^{0.5}}{L_b}$ where $R_e \le 1$	Dimensionless	Schumm (1956)
18	Circularity ratio	R_c	$R_c = \frac{12.57A}{P^2}$ where $R_c \le 1$	Dimensionless	Miller (1953)
19	Compactness coefficient	C_c	$C_c = \frac{0.2821P}{A^{0.5}}$ where $C_c \ge 1$	Dimensionless	Gravelius (1914); Horton (1932); Strahler (1964)
20	Shape factor	B_s	$B_s = \frac{L_b^2}{A}$	Dimensionless	Horton (1945); Gregory and Walling (1973); Nooka Ratnam *et al.* (2005)
Relief morphometric parameters					
21	Relief ratio	R_h	$R_h = \frac{H}{L_b}$ where H and L_b are in same unit of measurement (*i.e.* km)	Dimensionless	Schumm (1956)
22	Relative relief	R_r	$R_r = \frac{100H}{P}$ where H and P are in same unit of measurement (*i.e.* km)	Dimensionless	Melton (1957)
23	Ruggedness number	R_N	$R_N = H \times D_d$ where H and D_d are in same unit of measurement (*i.e.* km)	dimensionless	Melton (1957)

Stream length (L_u)

Stream length refers to the length of the stream of a given order (u). The stream length of streams for all orders was determined using GIS environment and is illustrated in Table 4 for all sub-watersheds. It indicates that the total length of first-order streams in all sub-watersheds is highest among the remaining order streams. The drainage pattern of the Burhner river watershed showed absolute conformity with the Horton's law of stream number. In addition to it, the total length of streams gradually decreased with the subsequent order of streams (Mishra and Rai 2020).

Linear morphometric parameters

Bifurcation ratio (R_b)

As stated by Horton (1945), bifurcation ratio is defined as the ratio of number of streams of a given order (N_u) to the number of streams of the next higher order (N_{u+1}). It is mathematically denoted by R_b. The lower bifurcation ratio values are characteristics of the watershed, which has suffered fewer structural disturbances and the drainage pattern has not been distorted by structural disturbances (Nag and Chakraborty 2003).

Mean bifurcation ratio (R_{bm})

The mean bifurcation ratio (R_{bm}) is defined as the average of bifurcation ratio of all orders (Strahler, 1957). High R_{bm} indicates an early hydrograph peak with a potential of flash flooding during the storm events (Kumar *et al.* 2000). High values of R_{bm} are the characteristics of structurally more distributed watersheds with a prominent distortion in drainage patterns (Nag 1998). Table 5 shows the mean

Table 2: Details of basic morphometric parameters of 17 sub-watersheds of Burhner River watershed

Sub-watersheds name	Sub-watersheds code	A (km^2)	P (km)	L_b (km)	H_{max} (m)	H_{min} (m)	H (m)
Sub-watershed 1	SW-1	59.777	50.220	13.397	754	393	361
Sub-watershed 2	SW-2	520.150	181.260	45.782	863	402	461
Sub-watershed 3	SW-3	116.186	73.320	19.541	825	402	423
Sub-watershed 4	SW-4	136.471	76.560	21.411	893	549	344
Sub-watershed 5	SW-5	431.808	162.540	41.189	954	549	405
Sub-watershed 6	SW-6	195.602	134.520	26.268	899	522	377
Sub-watershed 7	SW-7	457.402	166.260	42.558	849	432	417
Sub-watershed 8	SW-8	115.312	106.860	19.457	886	522	364
Sub-watershed 9	SW-9	146.117	88.200	22.258	885	548	337
Sub-watershed 10	SW-10	213.305	112.380	27.593	880	548	332
Sub-watershed 11	SW-11	102.316	71.280	18.179	859	592	267
Sub-watershed 12	SW-12	564.973	176.520	47.983	842	432	410
Sub-watershed 13	SW-13	238.841	135.240	29.424	885	592	293
Sub-watershed 14	SW-14	56.398	56.280	12.961	845	551	294
Sub-watershed 15	SW-15	150.529	87.240	22.637	831	565	266
Sub-watershed 16	SW-16	115.552	85.740	19.480	847	565	282
Sub-watershed 17	SW-17	339.074	171.720	35.904	858	551	307

where, A - sub-watershed area, P - perimeter of sub-watershed, L_b - basin length, H_{max} - maximum watershed relief in sub-watershed, H_{min} - minimum watershed relief in sub-watershed, H - total sub-watershed relief.

Table 3: Details of stream number and stream order of 17 sub-watersheds of Burhner river watershed

Sub-watersheds code	Stream numbers (N_u)								Total number of streams of all orders	Stream order
	N_1	N_2	N_3	N_4	N_5	N_6	N_7	N_8	$\sum N_u$	
SW-1	554	127	36	11	2	0	1	1	732	8th Order
SW-2	4628	1029	238	52	11	4	1	0	5963	7th Order
SW-3	1072	245	61	11	1	0	1	1	1392	8th Order
SW-4	1248	283	60	13	3	1	0	0	1608	6th Order
SW-5	4122	958	210	35	8	2	1	0	5336	7th Order
SW-6	1854	413	96	21	3	2	1	0	2390	7th Order
SW-7	4321	926	215	48	11	1	2	1	5525	8th Order
SW-8	1157	270	59	9	1	1	1	0	1498	7th Order
SW-9	1429	321	78	17	3	1	0	0	1849	6th Order
SW-10	1971	451	106	25	4	2	1	0	2560	7th Order
SW-11	999	240	62	15	2	1	0	0	1319	6th Order
SW-12	5314	1167	240	59	16	3	1	0	6800	7th Order
SW-13	2368	554	116	28	8	2	1	0	3077	7th Order
SW-14	515	116	27	6	1	2	1	0	668	7th Order
SW-15	1511	346	73	14	4	1	0	0	1949	6th Order
SW-16	1070	238	49	9	2	1	0	0	1369	6th Order
SW-17	3287	755	162	33	5	1	0	0	4243	6th Order

bifurcation ratio values of all 17-sub-watersheds of Burhner river watershed. In numeric terms, the mean bifurcation ratio varies between 2 in flat and rolling surface to 4 or 5 in mountainous or highly dissected drainage basins (Horton 1945). According to Strahler (1964), where the R_{bm} ranges between 3 and 5, geological structures do not hold a dominant control over the drainage basin. SW-17 indicated the highest value of R_{bm} (*i.e.* 5.105), specifying early hydrograph peak, less time of concentration and thus designating the region under higher risks of soil erosion induced from a high probability of flooding. On the contrary, the minimum value of R_{bm} was shown by SW-1 (*i.e.* 3.277), indicating flat topography and less susceptibility towards soil erosion than SW-17.

Areal morphometric parameters

Drainage density (D_d)

As stated by Horton (1945), drainage density (D_d) is the average length of streams within the basin per unit area. In mathematical terms, drainage density can be defined as the ratio of the total length of streams of all orders to the area of a basin with km/km^2 or 1/km as its unit of measurement. D_d aids in analyzing the measurement of landscape dissection and run-off potential (Reddy *et al.* 2004). If D_d is nearly zero, it specifies a permeable basin with high infiltration rates and high groundwater potential. High D_d indicates impermeable rocks with sparse vegetation and a hilly relief region (Horton 1945). High D_d is observed in weak and impermeable sub-surface materials and sparse vegetation with mountainous relief (Nag 1998).

In contrast, low and moderate values of D_d reveal permeable subsurface materials, good vegetation cover and low relief values as the primary characteristics (Nag and Chakraborty 2003). Higher D_d values clearly illustrate less time of concentration, low opportunity time for infiltration suggesting higher risks of soil erosion induced from significant surface runoff. A close observation of obtained numeric values of D_d for all sub-watersheds indicated high values. Such higher D_d values among all sub-watersheds were due to the predominance of a higher number of first and second order streams, thus increasing the overall length of streams of all orders. Among all the 17 sub-watersheds, SW-16 specified highest values of D_d (*i.e.* 4.425 km/km^2), indicating higher susceptibility to soil erosion as compared to SW-2 with least values of D_d (*i.e.* 4.031 km/km^2).

Stream frequency (F_s)

Stream frequency is defined as the ratio of a total number of streams of all orders to the area of the basin. High stream frequencies are indicative of regions with greater surface runoff and steep ground slopes (Horton 1932; 1945). The F_s value of watersheds is indicative of permeability, infiltration capacity and relief of watersheds (Montgomery and Dietrich, 1989; 1992). High values of F_s among all sub-watersheds clearly illustrate a high number

Table 4: Details of stream length of 17 sub-watersheds of Burhner river watershed

Sub-watersheds code	Stream length (L_u)								Total stream length
	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	$\sum L_u$
	(km)								
SW-1	129.538	58.654	32.304	17.733	5.967	0.000	0.015	8.932	253.143
SW-2	1114.600	503.354	236.045	106.009	67.350	28.614	40.708	0.000	2096.680
SW-3	254.695	121.439	59.648	15.866	9.407	0.000	0.034	26.562	487.651
SW-4	306.929	146.401	73.752	32.269	19.313	5.527	0.000	0.000	584.191
SW-5	960.427	426.409	211.634	98.841	44.051	23.753	21.372	0.000	1786.487
SW-6	431.336	209.090	101.174	41.920	9.546	26.359	13.600	0.000	833.025
SW-7	1025.022	452.307	222.327	95.920	49.156	1.279	0.030	62.492	1908.533
SW-8	273.767	123.104	58.097	23.111	23.020	0.016	7.051	0.000	508.166
SW-9	336.681	154.110	74.689	39.464	7.899	22.248	0.000	0.000	635.091
SW-10	475.228	232.612	105.545	45.811	25.021	0.048	29.429	0.000	913.694
SW-11	246.301	106.876	45.759	26.563	23.640	1.619	0.000	0.000	450.758
SW-12	1249.208	578.697	287.928	117.753	67.382	11.446	64.058	0.000	2376.472
SW-13	517.179	251.097	113.198	56.897	32.722	14.783	10.943	0.000	996.819
SW-14	119.251	63.496	24.081	9.769	9.294	0.040	6.486	0.000	232.417
SW-15	369.429	164.938	59.694	29.265	18.137	22.759	0.000	0.000	664.222
SW-16	281.208	127.362	52.829	18.596	25.129	6.195	0.000	0.000	511.319
SW-17	779.668	345.337	173.208	85.835	17.998	47.579	0.000	0.000	1449.625

Table 5: Details of linear and areal morphometric parameters of 17 sub-watersheds of Burhner river watershed

Sub-watersheds code	Linear morphometric parameters	Areal morphometric parameters				
	R_{bm}	D_d	F_s	R_t	L_o	C
	(Dimensionless)	(km/km²) or (1/km)	(1/km²)	(1/km)	(km)	(km)
SW-1	3.277	4.235	12.246	11.031	0.118	0.236
SW-2	4.146	4.031	11.464	25.532	0.124	0.248
SW-3	4.490	4.197	11.981	14.621	0.119	0.238
SW-4	4.215	4.281	11.783	16.301	0.117	0.234
SW-5	4.207	4.137	12.357	25.360	0.121	0.242
SW-6	3.977	4.259	12.219	13.782	0.117	0.235
SW-7	4.474	4.173	12.079	25.989	0.120	0.240
SW-8	4.403	4.407	12.991	10.827	0.113	0.227
SW-9	4.364	4.346	12.654	16.202	0.115	0.230
SW-10	3.853	4.284	12.002	17.539	0.117	0.233
SW-11	4.333	4.406	12.891	14.015	0.113	0.227
SW-12	4.251	4.206	12.036	30.104	0.119	0.238
SW-13	3.782	4.174	12.883	17.510	0.120	0.240
SW-14	3.623	4.121	11.844	9.151	0.121	0.243
SW-15	4.364	4.413	12.948	17.320	0.113	0.227
SW-16	4.259	4.425	11.847	12.480	0.113	0.226
SW-17	5.105	4.275	12.513	19.142	0.117	0.234

where R_{bm} - mean bifurcation ratio, D_d - drainage density, F_s - stream frequency, R_t - texture ratio, L_o - length of overland flow, C - constant of channel maintenance.

Table 6: Details of shape morphometric parameters of 17 sub-watersheds of Burhner river watershed

Sub-watersheds code	Shape morphometric parameters				
	F_f	R_c	R_e	C_c	B_s
	(Dimensionless)	(Dimensionless)	(Dimensionless)	(Dimensionless)	(Dimensionless)
SW-1	0.333	0.298	0.651	1.832	3.002
SW-2	0.248	0.199	0.562	2.242	4.030
SW-3	0.304	0.272	0.622	1.919	3.286
SW-4	0.298	0.293	0.616	1.849	3.359
SW-5	0.255	0.205	0.569	2.207	3.929
SW-6	0.283	0.136	0.601	2.713	3.528
SW-7	0.253	0.208	0.567	2.193	3.960
SW-8	0.305	0.127	0.623	2.807	3.283
SW-9	0.295	0.236	0.613	2.058	3.391
SW-10	0.280	0.212	0.597	2.171	3.570
SW-11	0.310	0.253	0.628	1.988	3.230
SW-12	0.245	0.228	0.559	2.095	4.075
SW-13	0.276	0.164	0.593	2.469	3.625
SW-14	0.336	0.224	0.654	2.114	2.979
SW-15	0.294	0.249	0.612	2.006	3.404
SW-16	0.305	0.198	0.623	2.250	3.284
SW-17	0.263	0.145	0.579	2.631	3.802

where F_f - form factor, R_c - circularity ratio, R_e - elongation ratio, C_c - compactness coefficient, B_s - shape factor.

of streams in the sub-watersheds indicative of early hydrograph peak, less time of concentration designating greater risks of soil erosion resulting from a high-intensity rainfall event.

In the present study, SW-2 showed the least F_s (as 11.464 km^{-2}) whereas SW-8 showed the highest F_s (as 12.991 km^{-2}), which represent the highest susceptibility of soil erosion in SW-8 and least in SW-2 as compared to all other sub-watersheds.

Texture ratio (R_t)

Texture ratio is defined as the ratio of a total number of first-order streams to the perimeter of the watershed (Smith 1950; Nooka Ratnam *et al.* 2005). Texture ratio depends on the underlying geology, infiltration capacity of bedrock and relief aspects of the basin (Reddy *et al.* 2004). Higher number of first-order streams per unit perimeter of watershed clearly indicates higher susceptibility towards soil erosion due to less soil resistance and high reliefs (Altin and Altin 2011). The highest value of R_t was detected in SW-12 (*i.e.* R_t = 30.104 km^{-1}), illustrating greater risk from soil erosion, whereas it was lowest in the case of SW-14 ((*i.e.* R_t = 9.151 km^{-1}), indicating a comparatively lesser risk from soil erosion with reference to SW-12.

Length of overland flow (L_o)

The term "length of overland flow" expressed as L_o is used to describe the length of the flow of water over the ground before it becomes concentrated in definite stream channels (Horton 1945). In a watershed, the overland flow and channel flow are the two common types of flow prominent due to rainfall. The overland flow is distinguished by a thin layer of water flowing over a wide surface, which occurs at the upper reaches of the flow before the flow terminates into a channel (Suresh 2012). Length of overland flow is defined as half of the reciprocal of drainage density (Horton 1945; Schumm 1956). As the name suggests, the unit of measurement of L_o is in km.

Lower values of L_o for all sub-watersheds as shown in Table 5, clearly illustrate that channel flow dominates in the watershed due to the large watershed area and high values of stream frequencies. From Table 5, it is observed that SW-8, SW-11, SW-15 and SW-16 indicate lower values of L_o (*i.e.* L_o = 0.113 km) and SW-2 indicates the highest value of L_o among all the 17 sub-watersheds (*i.e.* L_o = 0.124 km).

Constant of channel maintenance (C)

Schumm (1956) has defined constant of channel maintenance as the reciprocal of drainage density (D_d). Its unit of measurement is km^2/km. Half of the constant of channel maintenance equals the length of overland flow (Chow, 1965). Constant of channel maintenance signifies how much area is required to maintain a unit length of channel (Shulits 1968). The value of C depends upon not only on the rock type and permeability, climatic regime, vegetation cover and relief but also on the duration of erosion and climatic history (Nag and Chakraborty 2003). Lower values of C interpret weak or low resistance soils, sparse vegetation and mountainous terrain (Shulits 1968). Table 5 shows the values of C for all 17 sub-watersheds of Burhner river watershed. It is visible from Table 5 that SW-16 indicates the lowest value of C (*i.e.* C = 0.226 km^2/km), specifying a greater level of risk from soil erosion, whereas SW-2 posses' highest value of C (*i.e.* C = 0.248 km^2/km) representing a comparatively lower risk from soil erosion.

Shape morphometric parameters

Form factor (F_f)

Horton (1932) defined the form factor as the ratio of basin area (A) to the square of the basin length (L_b). In case of perfectly squared basins, the value of F_f should always be less than 0.7854 (Nautiyal 1994). The smaller the value of F_f, the more elongated is the basin (Nag and Chakraborty 2003). The basins with high F_f have a high rate of peak flows for a shorter duration, whereas elongated basins with low F_f have a lower peak of flows for a longer duration (Nautiyal 1994). Among all the 17 sub-watersheds of Burhner river watershed (Table 6), SW-12 illustrated the least value of F_f (*i.e.* F_f = 0.245) and on the contrary, SW-14 indicated the highest value of F_f (*i.e.* F_f = 0.336), which clearly states that SW-12 is at the highest level of risk from soil erosion.

Circularity ratio (R_c)

Miller (1953) stated circularity ratio as the ratio between the area of the basin and the area of the

Table 7: Details of relief morphometric parameters of 17 sub-watersheds of Burhner river watershed

Sub-watersheds Code	Relief morphometric parameters		
	R_h (Dimensionless)	R_r (Dimensionless)	R_N (Dimensionless)
SW-1	0.027	0.719	1.529
SW-2	0.010	0.254	1.858
SW-3	0.022	0.577	1.775
SW-4	0.016	0.449	1.473
SW-5	0.010	0.249	1.676
SW-6	0.014	0.280	1.606
SW-7	0.010	0.251	1.740
SW-8	0.019	0.341	1.604
SW-9	0.015	0.382	1.465
SW-10	0.012	0.295	1.422
SW-11	0.015	0.375	1.176
SW-12	0.009	0.232	1.725
SW-13	0.010	0.217	1.223
SW-14	0.023	0.522	1.212
SW-15	0.012	0.305	1.174
SW-16	0.014	0.329	1.248
SW-17	0.009	0.179	1.313

where R_h - relief ratio, R_r - relative relief and R_N - ruggedness number.

circle having same perimeter to that of the basin. The circularity ratio makes a comparative evaluation between the area of the drainage basin (A) to the area of a circle (A_c) having the same circumference (Miller, 1953). In general, watersheds with lower values of R_c (*i.e.* R_c= 0.4) are more elongated in shape and are likely controlled by geologic settings and structure (Chow, 1965). More round basins have R_c ranging from 0.6 to 0.7 (Fryirs and Brierley, 2013). The value of R_c ranged from 0.127 to 0.298 for all the sub-watersheds with the highest values in the case of SW-1 (*i.e.* R_c = 0.298) and lowest in the case of SW-8 (*i.e.* 0.127). Such values evidently illustrate the higher level of susceptibility associated with soil erosion in SW-8.

Elongation ratio (R_e)

Elongation ratio is the ratio of the diameter of a circle having the same area (as that of the basin) and the maximum length of the basin (Schumm 1956). The value of elongation ratio ranges from 0.4 to 1.0 or ≤ 1 over a wide range of geologic and climatic conditions. Value of R_e closer to 1 is indicative of very low relief, while R_e value ranging between 0.4 to 0.8 shows regions of very high reliefs and steep ground slopes (Malik *et al.* 2019). The least value of R_e was indicated by SW-12 (*i.e.* R_e = 0.559) while it was highest for SW-14 (*i.e.* R_e = 0.654) which stated that SW-12 is highly susceptible to soil erosion and SW-14 is at lowest risk from soil erosion.

Compactness coefficient (C_c)

Compactness coefficient (C_c) is defined as the ratio of the perimeter of the watershed to the perimeter of an equivalent circular area of a watershed (Horton 1945; Strahler 1964). The compactness coefficient is also known as Gravelius Index and its value is always ≥ 1. A circular basin yields the shortest time of concentration before peak flow occurs in the basin with C_C = 1, for C_C = 1.28, watersheds are square-shaped and for C_C value greater than 3.0 watersheds are varying in their shape (Zavoianu 1985; Altaf *et al.* 2013). Large deviation of C_C values from unity is indicative of the large time of concentration, whereas closeness of C_C to unity directs circular behavior of the basin (Mokarram and Sathyamoorthy 2015). The value of C_C in 17 sub-watersheds (Table 6) ranges from 1.832 to 2.807 with highest value for SW-8 (*i.e.* C_C = 2.807) and lowest value for SW-1 (*i.e.* C_C = 1.832) indicating greater levels of susceptibility towards soil erosion in SW-1 among all other sub-watersheds and least susceptibility in case of SW-8.

Shape factor (B_s)

Shape factor is defined as the ratio of square of the a basin length (L_b) to the area of basin (A) (Nooka Ratnam *et al.* 2005). High values of shape factors reveals high basin length which specifies high time of concentration and longer basin lag time whereas lower value of B_s shows low time of concentration and shorter basin lag time. In the present study, the value of B_s ranged between 2.979 to 4.075 (Table 6) illustrating highest value for SW-12 (*i.e.* B_s = 4.075) whereas least value for SW-14 (*i.e.* B_s = 2.979) thus designating SW-14 at greater risk of soil erosion and SW-12 at least risk.

Relief morphometric parameters

Relief ratio (R_h)

Relief ratio is defined as the ratio between total relief of a basin (elevation difference of lowest and highest points of a basin) and the longest dimension of the basin (L_b) parallel to the main drainage line (Schumm 1956). Field studies conducted by Hadley and Schumm (1961) reveal that residuals or abnormally high points on the divide should be ignored when obtaining total relief values of the basin. On a quantitative basis, it is the measurement of the overall steepness of the drainage basin (Altaf *et al.* 2013). In addition to it, R_h is an indicator of the intensity of erosion processes operating on the basin slopes (Dodov and Foufoula-Georgiou 2005). R_h holds an inverse relationship with drainage basin area typically. A close inspection of R_h values in Table 7 illustrates that SW-1 holds highest R_h value (*i.e.* R_h = 0.027), indicating potential threat from soil erosion in SW-1 whereas SW-12 and SW-17 hold the lowest value (*i.e.* R_h = 0.009), thus representing its status as least susceptible to soil erosion.

Relative relief (R_r)

Relative relief is defined as the ratio of the basin relief to the basin's perimeter. (Melton 1957). The best advantage of relative relief (R_r) over relief ratio (R_h) is that for determining the value of R_r both the values of basin area (A) and perimeter of the basin (P) are readily available as such values are used for computation of other morphometric parameters. From Table 7, it is clear that SW-1 holds the highest value of R_r (*i.e.* R_r = 0.719). In contrast, it is least for SW-17 (*i.e.* R_r = 0.179), thus indicating that SW-1 is highly susceptible to soil erosion among all the sub-watersheds, whereas SW-17 is least affected by soil erosion.

Ruggedness number (R_N)

Ruggedness number is the product of maximum basin relief to the drainage density in the same unit of measurement (Melton 1957). Higher basin relief and high drainage density are indicative of a steep slope which directly raises the values of R_N (Hema *et al.* 2021). From Table 7, it is clear that SW-15 indicates the lowest value of R_N (*i.e.* R_N = 1.174) and SW-2 indicates the highest value of R_N (*i.e.* R_N = 1.858), which clearly states that SW-2 is highly susceptible to soil erosion as compared to all other sub-watersheds whereas SW-15 is at least risk among all the sub-watersheds.

CONCLUSION

Remote sensing and GIS have proved to be effective in morphometric studies of watersheds. The present study attempts to understand the hydrological behaviors of sub-watersheds inherent in Burhner river watershed. Among the 17 delineated sub-watersheds of Burhner river watershed, three sub-watersheds were of 8th order, eight sub-watersheds were of 7th order and six sub-watersheds were of 6th order revealing dendritic to sub-dendritic drainage patterns. Basic morphometric parameters were calculated using GIS environment and standard formulas at the initial level. Based on the obtained values of basic morphometric parameters, linear, areal, shape and relief morphometric parameters were assessed using the standard formulas. Among all the sub-watersheds, the number of first order streams and the overall total length of first order streams were highest. High mean bifurcation ratio (R_{bm}) values indicated geomorphological control over the sub-watersheds. High values of areal parameters such as drainage density (D_d), stream frequency(F_s), texture ratio (R_t) indicated channel flow as the dominating flow in the sub-watersheds with lower numeric values of length of overland flow (L_o) supporting it. Beside it, the lower value of the constant channel maintenance (C) indicated weak or low resistance soils. Smaller form factor values (F_f) stated the elongated shape of the sub-watersheds. Lower values of circularity ratio (R_c) also supported that shape of sub-watersheds is elongated with elongation ratio (R_e), indicating mountainous relief in the sub-watersheds. Higher values of compactness coefficient (C_c) and shape factor (B_s) illustrated a large time of concentration in the sub-watersheds. Besides the linear, areal and shape morphometric parameters, higher values of relief morphometric parameters such as relief ratio (R_h), relative relief (R_r) and ruggedness number (R_N) specified the risks associated with high relief and large D_d of sub-watersheds.

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