Prioritization of Sub-Watersheds of a Western Himalayan Catchment Employing Morphological Derived Compound Index and Sediment Production Rate

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A B S T R A C T

In the present paper, various morphological parameters representing one dimensional view via linear, two dimensional view via a real and three dimensional view via relief aspect of the catchment have been extracted in GIS environment by partitioning a Western Himalayan catchment from the Indian subcontinent into eight sub-watersheds (SW1 to SW8). The study catchment was found to be a sixth order drainage basin as per the Strahler stream ordering scheme. The catchment is dominated by the parallel and dendritic drainage patterns in different sub-watersheds. Higher bifurcation ratios between the first and second order streams imply the presence of active gullies in the catchment. Medium to high drainage densities, ranging 2.64 to 4.08 were found in the study area indicating the weak or impermeable subsurface material, high mountainous relief and fine drainage texture. Most of the sub-watersheds are characterized with high relief ratio, relative relief and average slope which are favorable to generate significant runoff even for a small volume of rainfall. In order to prioritize the catchment, a compound index was calculated by considering the individual rank assigned to all eight sub-watersheds based on 13 morphological parameters. To decide the quantum of conservation work required in each sub-watershed, the quantitative assessment of soil loss has been done using sediment production rate (SPR). Sediment production rate (SPR) of all sub-watersheds varies between 1.18 ha-m/100 sq.km/yr to 3.96 ha-m/100 sq.km/yr. These values are in concurrence with the design SPR values as adopted in most of the river valley projects constructed in the Western Himalayan region of India. SPR values estimated as well as compound ranking evaluated using morphological parameters in the present study may be helpful in identifying the critical areas in a un-gauged catchment and accordingly deciding the watershed treatment measures in volume and space.

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Introduction

Watershed planning and management schemes play a vital role in ensuring efficient use of land and water resources in terms of quantity and quality to meet the present and future demands for the stakeholder. The response to soil and water conservation measures for alleviating erosion would be different for different parts of a catchment due to their physiographical variability throughout the catchment or in other words exhibit different physiographical settings in the sub-watersheds of the same catchment. Thus, it is not only necessary to know the state of erosion of the watershed, but it is equally important to quantify the rate of erosion within the watershed to proportionately allocate the funds for their treatment for achieving the best output. In developing countries like India, observations of discharge and suspended sediment yield are usually gauged only at the outlet of large watersheds normally when these rivers enter the plain areas. However, the major sources of sediment are the upstream hilly areas and eroded soils from these areas are transported through small mountainous tributaries, unfortunately, which are un-gauged. The process of soil loss from a watershed is exclusively influenced by erosion, deposition and transportation sub-processes that continuously occur along the sediment flow path within the watershed (Merritt et al. 2003; Aksoy and Kavvas 2005; Rawat et al. 2016). Therefore, using sediment data from the outlet of a large watershed to identify the actual source areas of sediment within the watershed cannot be justified. To overcome this problem, various morphometric parameters (drainage density, drainage frequency, form factor, length of overland flow, elongation ratio, circularity ratio, compactness coefficient, drainage

texture, bifurcation ratio, etc.) have been correlated with surface and sub-surface features like slope, soil, rock resistance, structure and geological history of the watershed which are responsible for runoff and consequent erosion of the watershed. These morphometric parameters have been linked with hydrological behavior of an ungauged watershed through popular GIUH theory,(Rodriguez-Iturbeet al., 1979; Gupta et al., 1980), stream profile analysis (Hack, 1973), prioritization of sub-watersheds for their vulnerability of soil erosion (Mishra, 1980; Goel, 2003; Nookaratnam et al., 2005; Jaiswal et al., 2015; Grauso et al., 2008), estimation of sediment production rate (Jose and Das, 1982; Suresh et al., 2004; Grauso et al., 2008; Rymbai and Jha, 2012; Ahmed and Rao, 2015), identification of artificial recharge locations (Ghayoumian et al., 2005; Saraf and Chaudhary, 1998; Ghayoumian et al., 2005), permeability of underlying geological formation (Pakhmode et al., 2003; Anbazhagan et al., 2005) and many more.

Since, most of the morphometric parameters are in the form of ratio, scale does not limit their application while comparing for different watersheds. Due to lack of observed data, these morphometric approaches are very popular in characterization of sub-watersheds in reference to their strong relationships with the factors responsible for soil erosion and transportation. Manual estimation of geomorphologic parameters is a tedious and cumbersome process and often discourages the field engineers from developing regional methodologies for solving various hydrological problems of un-gauged catchments or in limited data situations (Singh 1998; Kumar et al. 2001; Singh et al. 2003). With the advancement in the field of geo-spatial technologies like GIS and Remote Sensing (RS), geomorphological

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parameters can easily be extracted from the digitalized toposheets (Tarboton et al. 1991; Moore et al. 1992; Maathuis 2005; Hengl et al. 2006; Nookaratnam et al. 2005). Moreover, GIS tools are capable of handling spatial and temporal data, with the result that morphometric parameters can be updated whenever any change occurs (Apaydin et al. 2006).

Therefore, considering the strong interaction between the morphology and hydrologic response of the watershed, in the present study morphological characterization of eight sub-watersheds of Ujh catchment has been done using geospatial technique. The prioritization of sub-watersheds has been done through the compound index based on morphometric parameters. The sediment production rates (SPR) from different sub-watersheds have also been estimated using morphological parameters to help in deciding the amplitude of the treatment activities in different areas or sub-watersheds of Ujh catchment.

2.0 Study Area

In the present study Ujh river catchment located in district Kathua of Jammu and Kashmir State of India (Fig. 1) is selected for detail morphometric analysis. The Ujh catchment situated between 32.52 to 32.86 N latitude and 75.37 to 75.75 E longitudes. The river rises from the Domal Structure of Seojdhar of middle Himalayan ranges and the head waters of the river lie in the Kailash Mountains at an altitude of 4300 m near the Bhaderwah hill of Jammu province. River Ujh flows for a distance of nearly 100 km before it joins Ravi below Nainkot in West Pakistan. The water of Ujh River is mainly utilized for drinking purposes besides this the River also feeds a number of small canals and Khuls for irrigating the agriculture land of the district. The

catchment is hilly, mountainous and rugged, and sloping towards the south from the northern hilly terrain varying in altitude from 510 m to 4300 m. Areas having an altitude of 2000 m and above which constitute about 20% of the catchment are generally snow bound for most of the winter. The climatic conditions of the catchment vary from semi-arid to humid from south to north. The summer temperature rises as high as 48 ^{0}C in the plains and winter temperature in the upper hilly areas touches sub-zero. The mean annual temperature of the southern part of the catchment is 23 ^{0}C and that of the eastern portion of the catchment is 16 ^{0}C. The District experiences rainfall during winter and early summer primarily from western disturbances and monsoon rains from second week of July onwards. The annual rainfall in the entire district is about 1672 mm. About 85% of the total rainfall is received during monsoon season viz. July to September and rest occurs during December to February.
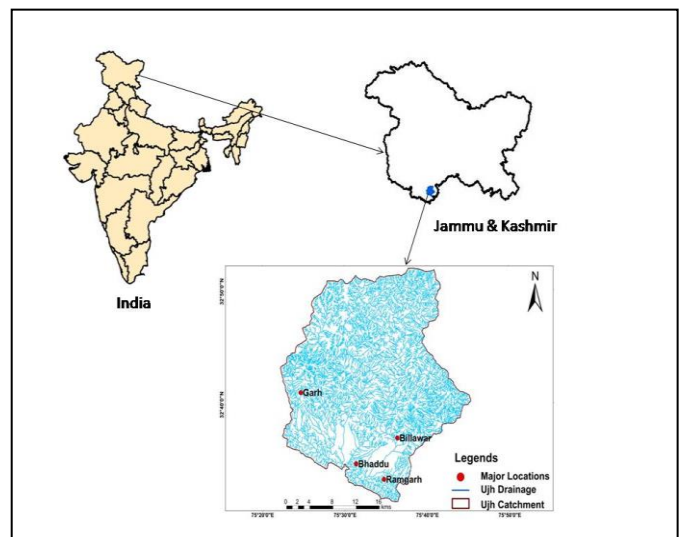

Figure 1: Location map of the Ujh catchment

3.0 Material and Methods
3.1 Data sources and analysis

In the present study, Ujh River catchment and its drainage network has been delineated from available Survey of India (SOI) topographic maps in the scale of 1:50000 and the attributes were assigned to create the digital database. The topographic maps were first Geo-referenced in ArcMap 10.3 software followed by digitization of drainage network. By following the Strahler (1964) method, stream ordering has been carried-out for the entire Ujh catchment and it was found to be sixth order catchment. According to the extracted drainage network, entire drainage area of 867.27 sq. km was subdivided into eight sub-watersheds (Fig. 2), having areas ranging from 30 sq. km (SW6) to 207 sq. km (SW1) for better understanding with morphometric parameters and finding their correlation with hydrological response and consequence soil erosion of the catchment. The drainage networks of eight different sub-watersheds were analyzed as per Horton's (1945) laws in ArcHydro module of ArcGIS. All sub-watersheds have been examined from all dimensional aspects i.e., linear aspect indicates one dimensional view of the watershed, aerial aspect shows two dimensional, however, relief aspect explored three dimensional characteristics of the watersheds. Linear aspect comprises the study of stream order (N_u), stream length (L), and bifurcation ratio (R_b) whereas aerial aspect deals with drainage density (D_d), stream frequency (F_s), texture (T), form factor (R_f), circulatory ratio (R_c), elongation ratio (R_e), compactness coefficient (C_c) and length of overland flow (L_o), however, total relief (H), relative relief (R_r), relief ratio (R_o) and average slope (S_a) was explored under the relief aspect of Ujh catchment. The formulae for computation of the morphometric parameters are shown in Table 1.
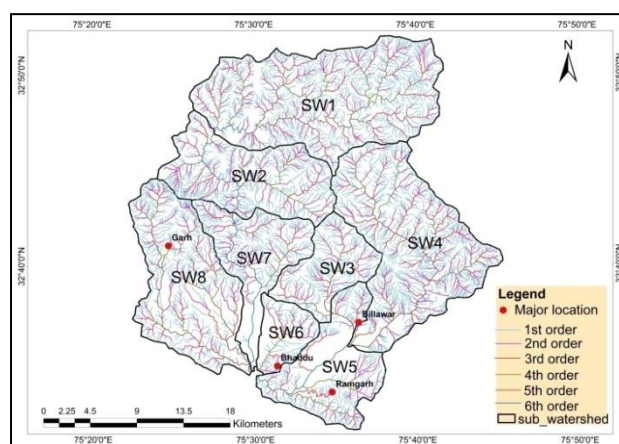

Figure 2. Delineated sub-watersheds of Ujh catchment and their drainage network according to stream order.

All thirteen morphological parameters pertaining to the one, two and three dimensional views of the watershed have been calculated for each sub-watershed of Ujh catchment. Keeping in view the nature of relationships (direct/inverse) of different morphological parameters with erodibility, each sub-watershed has been ranked 1 to 8 based upon thirteen morphological parameters. Rank 1 indicates most severe, whereas 8 denotes least severe with respect to soil erosion. Final prioritization was worked out by considering all ranks of a particular sub-watershed, which were assigned on the basis of thirteen geomorphological parameters considered in the study. The sub-watershed having lowest compound index value has given highest severity towards soil erosion and vice-versa.

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Table 1: Different morphometric parameters used in the Study and their standard formulae.

	Morphometric Parameter	Formula	Reference
	Stream order(u)	Hierarchical rank	Strahler(1964)
	Basin Length(L)	$L=1.312*A^{0.568}$ Where L=Basin length(km), A=Area of the basin (km^2)	Nookaratnam et al.(2005)
	Stream length(L_u)	Length of the stream	Horton (1945)
	Mean stream length(L_{sm})	$L_{sm}=L_u/N_u$ Where L_{sm}=Mean stream length L_u=Total stream length of order 'u', N_u=Total no. of stream segments of order 'u'	Strahler (1964)
	Bifurcation ratio (R_b)	$R_b=N_u/N_{u+1}$ Where, R_b=Bifurcation ratio N_u=Total no. of stream segments of order 'u', N_{u+1}=Number of segments of the next higher order	Schumm (1956)
Linear	Mean bifurcation ration (R_{bm})	R_{bm}=Average of bifurcation rations of all orders	Strahler(1957)
Areal	Drainage density (D_d)	$D_d=L_u/A$ where, D_d= drainage density, L_u= total stream length of all, A= Area of the basin	Horton(1945)
	Form factor(R_f)	$F_f=A/L^2$ Where F_f=Form factor A=Area of the basin(km^2), L=Basin length(km)	Horton(1932, 1945)
	Stream frequency (F_s)	$F_s=N_u/A$ where, F_s=stream frequency, N_u=total no. of streams of all orders, A=area of the basin	Horton(1945)

	Morphometric Parameter	Formula	Reference
	Drainage texture (T)	$T=N_u/L_p$, where N_u=total no. of streams of all orders, L_p=perimeter of the basin	Horton(1945)
	Elongation ratio(R_e)	$R_e =1.128xA^{0.5}/L$ A=Area of the basin (km^2), L=Basin length(km)	Schumm(1956)
	Circularity ratio(R_c)	$R_c=4\pi A/P^2$ Where R_c=Circularity ratio, A=Area of the basin (km^2), P=Perimeter(km)	Miller(1953), Strahler(1964)
	Compactness Coefficient (C_c)	$C_c=0.282L_p/A^{0.5}$, where L_p=perimeter of th basin, A=area of the basin	Horton(1945)
	Length of overland flow (L_o)	$L_g=1/(2XD_d)$, where D_d= drainage density	Horton(1945)
Relief	Total Relief (H)	H= Difference between maximum and minimum elevation of the watershed	Schumm(1956)
	Relative Relief (R_r)	$H_R=H/L_p$ where, H=total relief, L_p=basin perimeter	Schumm(1956)
	Relief Ratio (R_o)	$H_{RR}=H/L$ where, H=total relief, L=basin length	Schumm(1956)

3.2 Estimation of sediment production rate (SPR)

Prioritization discussed in the preceding section is only a qualitative representation of soil erosion severity problem faced by each sub-watershed. However, for planning the amplitude of conservation activities in any watershed, quantitative assessment of soil erosion from the area is indispensable. In the view of non-availability of observed data in the un-gauged watersheds/catchments, the actual estimation of soil erosion is almost impossible using traditional modeling approach. However, in such circumstances an alternative approach using Sediment Production Rate (SPR), which

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is the volume of sediment produced per unit watershed area per unit time, can be implemented to provide quantitative assessment of soil erosion. SPR is normally used in designing of the dead storage of a reservoir and hence imperative to decide the life of the reservoir. Morphological based approach for estimation of probable SPR from a watershed may be preferred in absence of observed sediment data. In the present study, the sediment production rate of different sub-watersheds of Ujh River catchment have been estimated by morphological method suggested by Jose and Das (1982) and is expressed by the following equation:

$$\text{Log(SPR)} = 4919.80 + 48.64\log(100 + R_t) - 1337.77\log(100 + R_c) - 1165.64\log(100 + Cc)\ldots(1)$$

where, SPR is sediment production rate in ha-m/100 sq. km./year, R_t is rotundity factor, R_c is circulatory ratio and Cc is compactness coefficient.

4.0 Results and Discussion

The various morphometric parameters of the Ujh river catchment in the present study are summarized in Tables 2 to 5. The basic parameters of all the sub-watersheds of Ujh catchment are shown in Table 2 and other parameters pertaining to linear aspects, areal aspects and relief aspects are described in subsequent sections.

Table 2. Basic Parameters of different sub-watersheds of Ujh River Catchment.

SW Name	Basin Area(km^2)	Perimeter(km)	Basin Length(km)
SW1	207.4	69.36	34.72
SW2	105.7	51.3	13.76
SW3	56.16	35.16	11.44
SW4	176.9	67.87	34.26
SW5	84.78	50.16	16.16
SW6	30.42	23.71	9.16
SW7	74.49	52.56	23.73
SW8	131.5	57.09	27.9

4.1 Linear aspects

Stream ordering

Stream ordering is the first step to extract the geomorphological parameters of a catchment. Ujh River basin was adjudged sixth order basin according to the Strahler (1964) hierarchical rank. The drainage map with stream order of the Ujh catchment is shown in Figure 2. As the stream order increases the total number of streams decreases as suggested by Strahler (1957) and shown in Table 3. The drainage pattern of an area reflects the nature of slope, geological structure and lithologic controls of the underlying rocks (Zernitz, 1932 and Easterbrook, 1969, Nag and Chakraborty, 2003).Ujh catchment comprises of two types of drainage pattern i.e parallel and dendritic. . In parallel drainage system primary and secondary streams flow parallel to each other and meet the main channel at about same angle. Such drainage pattern are pertaining the regional slope and normally start from the water divide of the

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watershed. In SW1, SW3, SW6 and SW7 sub-watersheds parallel drainage pattern is the dominant drainage pattern. However, dendritic drainage pattern is found frequently in SW2 and SW4 sub-watersheds and some parts of other sub-watersheds also. Dendritic type of drainage pattern refers to the homogeneity in texture, rock and lack of structural control.

Table 3: Extracted stream of different orders and their bifurcation ratios

Sub-watershed	Parameter	Stream Order						Mean Bifurcation ratio (R_b)
		I	II	III	IV	V	VI	
SW1	No. of Stream	1053	209	49	8	2	1	4.28
	Stream Length(km)	517.56	123.94	70.41	41.39	22.69	6.63	
	Bifurcation ratio	5.04	4.26	6.12	4.00	2	-	
SW2	No. of Stream	500	96	26	5	1	1	4.02
	Stream Length(km)	272.59	70.99	31.41	14.71	3.33	11.9	
	Bifurcation ratio	5.21	3.69	5.2	5	1	-	
SW3	No. of Stream	204	47	9	3	1	-	3.89
	Stream Length(km)	135.71	32.20	16.58	8.09	4.46	-	
	Bifurcation ratio	4.34	5.22	3.00	3.00	-	-	
SW4	No. of Stream	880	187	40	8	3	1	3.51
	Stream Length(km)	492.04	114.24	60.63	25.62	28.80	0.38	
	Bifurcation ratio	4.71	4.68	5.00	2.67	3.00	1.00	
SW5	No. of Stream	26	62	15	3	1	1	3.49
	Stream	7						
	Stream Length(km)	145.87	42.46	24.80	14.76	3.26	12.15	
	Bifurcation ratio	4.31	4.13	5.00	3.00	1.00	-	
SW6	No. of Stream	90	21	7	1	-	-	4.76
	Stream Length(km)	49.210	12.18	12.83	6.15	-	-	
	Bifurcation ratio	4.28	3.00	7.00	-	-	-	
SW7	No. of Stream	268	58	14	2	1	1	3.75
	Stream Length(km)	153.76	41.11	17.35	7.22	0.11	20.05	
	Bifurcation ratio	4.62	4.14	7.00	2.00	1.00	-	
SW8	No. of Stream	505	111	29	7	2	-	
	Stream Length(km)	279.22	69.97	42.25	18.70	32.74	-	4.01
	Bifurcation ratio	4.55	3.83	4.14	3.5	-	-	

Stream Length

Numbers of stream of various orders in all sub-watersheds were counted and their lengths from mouth to drainage divide were measured with the help of GIS software and depicted in Table 3. Generally, the total lengths of stream segments are highest in first order streams and decreases as the stream order increases (Table 3). However, in case of SW1, SW4, and SW8 sub-watersheds the stream segments of first orders are proportionately very high as compare to general observation (Table 3). This change may indicate flowing of streams from high altitude, lithological variation and converging terrain (Singh and Singh, 1997).

Bifurcation Ratio (R_b)

Abnormally high value of R_b might be expected in region of steeply dipping rock strata. The value of R_b is also indicative of shape of the basin. An elongated basin is likely to have high R_b, where as a circular basin is likely to have a low R_b. In the study area, the values of R_b are in the middle range and vary from 3.5 to 4.8 (Table 3). The minimum and maximum value was found to be 3.51 and 4.76 for sub-watershed SW4 and SW6, respectively. It can be witnessed from Table 3, the bifurcation ratios between the first order, second order and third order streams are higher than the other higher orders in all sub micro-watersheds indicating that the catchment falls under areas of active gullies and ravines, hence, higher erosion rates.

4.2 Areal Aspects

Areal aspects include different morphometric parameters, like drainage density (D_d), stream frequency (F_s), drainage texture (T), form factor (R_f), infiltration number (I), circulatory ratio (R_c), elongation ratio (R_e) and length of the overland flow (L_o) and compactness coefficient (C_c). The values of these parameters were calculated and results have been given in Table 4.

Drainage Density (D_d)

Drainage basin with high D_d indicates that a large proportion of the precipitation is run-off. The drainage density, expressed in km/km^2, indicates closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. Further, it also gives an idea of the physical properties of the underlying rocks. Low drainage density occurs in regions of highly resistant and permeable sub soil materials with dense vegetation and low relief, whereas high drainage density is prevalent in region of

weak, impermeable sub-surface material which is sparsely vegetated and has high relief (Strahler1964). Drainage density in the study area varies between 2.64 (SW6) and 4.08 (SW4) indicating medium to high drainage density (Table 4). High drainage density of 4.08 in SW4 sub-watershed may be resultant of weak or impermeable subsurface material, high mountainous relief and fine drainage texture. However, low drainage density in SW6, SW5 and SW2 sub-watersheds indicate areas of highly resistant on permeable subsoil material, low relief and coarse drainage texture.

Stream Frequency /Drainage Frequency (F_s)

It mainly depends upon the lithology of the basin and reflects the texture of the drainage network. Stream frequency of Ujh sub-watersheds varies from 3.91 to 6.37. Sub-watershed SW1, SW2, SW4 and SW8 associated with high stream frequency while sub-watersheds SW6 having low stream frequency. Drainage density and stream frequency has a similar measure of stream network of a drainage basin. Table 4 shows close correlation between drainage frequency with drainage density indicating the increase in stream population with respect to increase in drainage density.

Drainage Texture (T)

Drainage texture is the ratio of the total number of stream segments of all orders to the perimeter of that area (Horton, 1945). Smith (1939) classified five different categories of D_t namely very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8).The drainage texture of entire 8 sub-watersheds are of coarse to very fine. The sub-watershed located in the downstream of Ujh catchment (SW5, SW6, SW7, and SW8) consist coarse drainage texture however, sub-

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watersheds of upstream part or hilly region (SW1, SW3 and SW4), comprise moderate to very fine texture. More finer is the texture more will be dissection and leads more erosion.

Form Factor (Rf)

It is dimensionless property and is used as a quantitative expression of the shape of basin form. The values of form factor of the sub-watersheds in the present case are in between 0.13-0.56. According to form factor SW1, SW4, SW7 and SW8 are relatively more elongated due to low values of form factor. However, SW2, SW3, SW5 and SW6 are relatively having high values of form factor and hence less elongated. The basins with high form factors, have high peak flows of shorter duration, whereas, elongated drainage basin with low form factors have lower peak flow of longer duration.

Infiltration Number (I)

The infiltration Number is defined as the product of Drainage Density (D_d) and Drainage Frequency (F_s). Sub-watershed SW6 has the low infiltration 10.34 and the sub-watershed SW4 has the higher infiltration number of 25.81. Higher the infiltration number lower will be infiltration and consequently higher will be run off. It gives an idea about the infiltration characteristics which play vital role in transformation of rainfall into the runoff. High value of infiltration number SW1, SW2 and SW4 reveal that the sub-watersheds are impermeable lithology and higher relief.

Circulatory Ratio (Rc)

The circulatory ratio is a similar measure as elongation ratio, originally defined by Miller (1953), as the ratio of the area of the basin to the area of the circle having same circumference as the basin perimeter. The value of circularity ratio varies from 0 (in line) to 1 (in a circle). The Circulatory ratio for all sub-watersheds is in the range of 0.34 to 0.68. It is clear from the Fig. 2 that SW7 is elongated and hence attributed to low value of circulatory ratio (0.34), however, SW6 is circularin nature and associated with higher value of circulatory ratio (0.68).

Elongation Ratio (Re)

It is defined as the ratio between the diameter of a circle with the same area that of the basin to the maximum length of the basin. The elongation ratio ranges from 0.0 to 1.0 over a wide variety of climatic and geological environments. High Value (nearing 1) of elongation ratio is typical of regions of low relief, whereas low values are generally associated with strong relief and steep ground slopes. In Ujh catchment area SW1, SW4, SW7, SW8 are having high relief (consisting high average slope) and hence associated with low values of elongation ratio.

Length of Overland Flow (Lo)

The term length of overland flow is used to describe the length of flow of water over the ground before it becomes concentrated in definite stream channels. Horton (1945) expressed it as equal to half of the reciprocal of drainage density (D_d). This factor relates inversely to the average slope of the channel and is quite synonymous with the length of sheet flow at a large degree. Overland flow lengths are ranging from 122.56 meter to 189.22 meter in Ujh sub-watersheds. SW4 has highest relief among all sub-watersheds and hence has low length of overland flow i.e. 122.56 meter. However, Smaller the value of overland flow the quicker surface

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runoff will enter the streams represents well developed drainage network with higher slope. In such watersheds a significant amount of surface runoff is to be contributed in the stream discharge for even a low amount of rainfall.

Compactness constant (C_c)

Compactness coefficient is used to express the relationship of a hydrologic basin with that of a circular basin having the same area as the hydrologic basin. A circular basin is the most hazardous from as drainage stand point because it will yield the shortest time of concentration before peak flow occurs in the basin. The values of C_c in the eight sub-watersheds of Ujh catchment varies from 1.21 to 1.72 showing variations across the watersheds. It can be shown from the Fig 2 that SW6 is somewhat circular in shape which tends to low value of compactness coefficient (close to unity). However, SW5 and SW7 having higher values of Cc due to their elongated shape.

Table 4: Aerial Aspect of the Ujh River Catchment

Sub-Watershed	D_d (km/km²)	F_s (no./km²)	I	R_c	R_f	R_e	T	L_o (m)	C_c
SW1	3.77	6.37	240	0.51	0.0	0.4	19	1325	1.3
SW2	3.83	5.95	229	0.5	0.5	0.9	122	1305	1.4
SW 3	3.51	4.70	164	0.5	0.4	0.7	230	1425	1.3
SW4	4.08	6.33	259	0.4	0.1	0.4	326	1225	1.4
SW5	2.87	4.12	118	0.4	0.3	0.6	6.96	1742	1.5
SW6	2.64	3.91	103	0.6	0.3	0.6	5.02	1892	1.2
SW7	3.22	4.62	149	0.3	0.1	0.4	6.54	1554	1.7
SW8	3.37	4.97	16.75	0.51	0.17	0.46	11.46	148.46	1.40

4.3 Relief Aspects

Relief aspects of drainage basin relate to the three dimensional features of the basin involving area, volume and altitude of vertical dimension of landforms wherein different morphometric methods are used to analyze terrain characteristics. Because many landscape processes are driven by gravity and relief properties are frequently used as indicators of erosion potential and denudation rates. In this study, thus, relief aspect includes the analysis of total relief, relief ratio, relative relief and average slope of all seven sub-watersheds of the Ujh catchment.

Total Relief (H)

It is the maximum vertical distance between the lowest and highest point of the watershed. It is also known as maximum watershed relief. Watershed relief controls the gradient of drainage lines within the watershed and hence significantly influences the soil erosion of the watershed (Patton et al., 1988 and Ozdemir and Bird, 2009). SW1 is attributed by high relief i.e. 3164 m and SW2, SW3, SW4, SW5, SW7 and SW8 comprise medium to high relief i.e. 1809 m, 1514 m, 2623 m 1033 m, 1472 m, and 1667 m respectively. However, SW6 is attributed to low relief i.e. 425 m. Most of the watersheds are associated with medium to high range relief and hence prone to generation of significant runoff and consequent soil erosion.

Relief Ratio (R_h)

The relief ratio defined as the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line (Schumm,1956). The advantage of relief ratio over the total watershed relief as it removes the size effect by dividing the total relief by

the basin length. In Ujh watershed relief ratio varies from 46.397 m/km (SW6) to 132.343 m/km (SW3)(Table 5). Significant high relief ratio especially in SW3 indicates the steepness of the principal flow path which eventually severally eroded the bank of the stream.

Relative Relief (R_r)

It is the ratio of the maximum watershed relief to the perimeter of the watershed. Relative relief represents actual variation of altitude in a unit area with respect to its local base level. It enumerates that the steeper the slope the higher is the surface above its base. The values of the relative reliefs for 8 Sub-Watersheds of Ujh catchment vary from17.925 m/km (SW6) to 45.617m/km (SW1), indicating the terrain of Ujh catchment is highly undulating. High values of R_r for SW1 and SW3 sub-watershed indicates that these are highly susceptible to soil erosion.

Average Slope (S_a)

Average slope of the watershed, S_a has direct influence on the erodibility of the watershed. It has been proved by researcher that more the percentage of slopes more are the erosion, if other factors remain unchanged. The average slope for different sub-watersheds varies between 12.379% (SW6) to 48.126 % (SW1) (Table 5). It was observed that high relief ratio and relative relief sub-watersheds are characterized by high slopes and vice versa.

Table 5. Relief Aspect of the Ujh River Catchment

Sub-Watershed	H (m)	R_h (m/km)	R_r (m/km)	S_a (%)
SW1	3164	91.129	45.617	48.126
SW2	1809	131.468	35.263	40.891
SW 3	1514	132.343	43.060	31.945
SW4	2623	76.562	38.647	40.586
SW5	1033	63.923	20.594	16.013
SW6	425	46.397	17.925	12.379
SW7	1472	62.031	28.006	33.861
SW8	1667	59.749	29.200	23.422

4.4 Prioritization of Sub-watersheds using Morphological Parameters

Morphological parameters (linear, aerial and relief) for all sub-watersheds were calculated separately and shown in Table 2-5. For prioritization, all eight sub-watersheds are ranked based upon their corresponding morphological parameters value. Morphological parameters like drainage density, stream frequency, bifurcation ratio, infiltration number and texture ratio have direct relationship with erosivity. Therefore, the sub-watershed having highest numerical value of these individual parameters was assigned ranked first and next higher was second and so on. Similarly, aerial parameters like elongation ratio, circulatory ratio, form factor and compactness coefficient having the inverse relationship with erosivity. Therefore, the sub-watershed having lowest value of these individual parameters was assigned rank first and next lower was second and so on. Similarly, sub-watersheds are ranked according to relief aspect as it has direct relationship with the erosivity.

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Finally, based upon all individual ranking, a compound ranking was calculated for each sub-watershed and depicted in Table 6. It is evident from the Table 6 that SW1 has the first priority (lowest value of compound parameter i.e. 3.1) and SW6 has the least priority (highest value of compound parameter i.e. 6.1). The highest priority indicates the greater degree of erosion in the particular sub-watershed and it becomes a potential candidate for applying soil conservation measures. Thus, in order to check soil erosion, treatment has to be started from SW1 and then to others depending on their priority. The priority map of Ujh catchment is shown in Figure 3.

Table 6: Prioritization of Sub-watersheds of Ujh catchment according to morphological parameters.

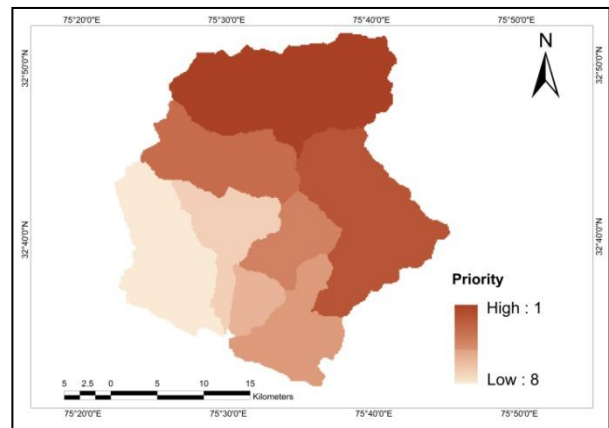| Sub-Watershed No.	Morphological Parameter													Compound Parameter	Final Ranking
	R_b	D_d	F_s	I	R_c	R_f	R_e	T	C_c	H	R_h	R_r	S_a		
SW1	3	3	8	2	6	3	4	3	3	1	3	1	1	3.1538	1
SW2	4	2	6	3	4	8	8	4	5	3	2	4	2	4.2308	3
SW3	5	4	4	5	7	7	7	2	2	5	1	2	5	4.3077	4
SW4	6	1	7	1	3	2	2	1	6	2	4	3	3	3.1538	2
SW5	8	7	2	7	2	5	5	6	7	7	5	7	7	5.7692	7
SW6	1	8	1	8	8	6	6	8	1	8	8	8	8	6.0769	8
SW7	7	6	3	6	1	1	1	7	8	6	6	6	4	4.7692	6
SW8	2	5	5	4	5	4	3	5	4	4	7	5	6	4.5385	5

Figure 3: Sub-watershed wise priority map of Ujh catchment.

4.5 Estimation of Sediment Production Rate (SPR) using morphological parameters

Sediment production rate (SPR) for various sub-watersheds was estimated using Eq. 1. and tabulated in Table 7. From this analysis, the highest SPR was found to be 3.96 ha-m/100 sq.km/yr for SW1, indicates that the watershed produces significant amount of sediment load annually. Estimated SPR value is also close to the design SPR values (4.3 ha-m/100 sq.km/yr) for major river valley projects in Western Himalayan region viz. Beas in Himachal Pradesh, Bhakra-Nangal on Satluj and Ramganga in Uttarakhand. . It was found that the SPRs estimated for different sub-watersheds using Eq.1 have concurrence to the priority as listed in Table 6. Sediment Production Rate (SPR) calculated in this study for an un-gauged catchment not only plays a key role in fixing the priority of watershed but it is vital important in deciding the volume of the conservation measures to reduce the SPR at certain level. Moreover, priority classification based on standardized SPR gave a better distribution of sub-watersheds between various priority categories.

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Table 7: Estimated sediment production rate (SPR) for different sub-watersheds of Ujh catchment.

Particulars	Sub-watershed of Ujh catchment							
	S W1	S W2	S W3	S W4	S W5	S W6	S W7	S W8
SPR	3.96	2.28	2.65	3.79	1.78	2.34	1.18	3.77

5. Conclusion

Prioritization is to be the first and primary step for any watershed management and planning project and the success of project depends upon the accuracy in prioritization at large extent. In developing country like India where availability of data is a major constraint, to prepare a fruitful project plan, such morphological parameters based methodology as discussed in this paper has high practical utility. The proposed methodology for prioritization of a catchment using morphological parameters in GIS environment is easy to use and very useful for an un-gauged catchment. Since, most of data used in the study are freely available; the proposed approach is parsimonious in terms of funds and also time saving. Once identify the criticality of these watersheds using morphological based approach would help in facilitating investment decision and making best use of the available resources. The proposed approach is not only fixing the priority but it also quantifies the erosivity, in terms of SPR values, with in the catchment which is also helpful to divide the treatment activities in proportionate to the erosivity. Moreover, it can be helpful to allocate the budget for treatment in different watersheds within the catchment. In the present study, rainfall intensity and volume and its variation within the watershed has not considered, therefore, sediment production rate (SPR) estimated for different sub-watersheds of Ujh catchment cannot be compared quantitatively with the sediment yield data at the watershed outlet.

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