



Morphometric analysis and prioritization of sub-watersheds in a hilly watershed using weighted sum approach

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Abstract

In this study, morphometric analysis of 14 hilly sub-watersheds (SWs) of Naula watershed located in upper Ramganga River basin, Uttarakhand State, India, was done using remote sensing (RS) and geographical information system (GIS). The morphometric parameters used for sub-watersheds prioritization were watershed area, perimeter, stream order, mean stream length, basin length, bifurcation ratio, drainage density, stream frequency, texture ratio, mean length of overland flow, form factor, circularity ratio, compactness coefficient, and elongation ratio. The cross-correlation analysis between morphometric parameters was performed and tested at 5% level of significance. The priority rank and category (very high, high, moderate, low, and very low) for each sub-watershed were assigned based on compound factor value. The value of compound factor for each sub-watershed was calculated using weighted sum approach (WSA). The results of this analysis illustrated that the 20.34% area under highly susceptible sub-watersheds (SW-5 and SW-10) needs appropriate soil and water conservation measures for its development and management.

Keywords Naula watershed · Prioritization · Morphometric · RS · GIS

Introduction

Morphometric analysis is important to understand the hydrological behavior of the watershed for development and management of natural resources. The rainfall–runoff transformation process at watershed scale is extremely complex phenomenon. However, hydrological behavior of a watershed and its runoff producing capacity can be related to its morphological characteristics (Kumar et al. 2012; Aher et al. 2014). The role of geological structures in the development of stream networks can be better understood by studying the nature and type of drainage pattern and quantitative morphometric analysis. The morphometric parameters of a watershed greatly reflect its hydrological response to help synthesize its

hydrological behavior. The analysis of watershed parameters together with soil and land use also plays a very important role in generating water resources action plan for locating recharge and discharge areas and subsequently the characterization and prioritization of the watersheds. A quantitative morphometric analysis of a watershed is considered to be the most satisfactory method because it enables understanding the relationship between different aspects of the drainage pattern of the watershed and also to make a comparative analysis of different watersheds developed in various geologic and climatic regimes (Kumar et al. 2012).

In recent years, several studies have been conducted on watershed prioritization based on morphometric (i.e., linear, areal, and shape) parameters determined using remote sensing and GIS techniques such as Nag (1998), Sidhu et al. (1998), Shrimali et al. (2001), Srinivasa et al. (2004), Nookaratnam et al. (2005), Jaiswal et al. (2007), Agarwal et al. (2011), Gajbhiye et al. (2013), Meshram and Sharma (2015), Sharma et al. (2015), Balasubramanian et al. (2017), Gaikwad and Bhagat (2018), and Meshram and Sharma (2018). Sidhu et al. (1998) used RS and GIS techniques for prioritization of sub-watersheds in upper Machkund watershed in Andhra Pradesh, India. Shrimali et al. (2001) introduced a contextual investigation of the Sukhana lake catchment in the Shiwalik hills for prioritizing the soil erosion

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zones using remote sensing and GIS techniques. Pandey et al. (2004) analyzed the morphological characteristics of Karso watershed in Hazaribagh, Jharkhand, and suggested management strategies for the watershed using GIS by integrating various thematic maps with morphometric parameters to delineate the areas suitable for adopting soil and water conservation measures. Srinivasa et al. (2004) utilized RS and GIS in morphometric parameters examination of sub-watersheds of Pawagada zone, Tumkur region, Karnataka. Chopra et al. (2005) completed morphometric analysis of Bhagra-Phungotri and Hara Maja sub-watersheds of Gurdaspur region, Panjab, India, using RS and GIS techniques. Nookaratnam et al. (2005) estimated sediment yield index and morphometric parameters utilizing remote sensing and GIS for locating check dam by prioritization of small scale watersheds. Thakkar and Dhiman (2007) used remote sensing and GIS techniques for morphometric analysis and prioritization of the eight mini-watersheds of Mohr watershed, located in Kheda district of Gujarat, India. Jaiswal et al. (2007) studied the quantitative morphometric analysis for linear and areal parameter for two watersheds in Madhya Pradesh, India. Gupta and Singh (2010) used the geomorphologic parameters for the development of a reliable response model for prediction of runoff and sediment yield from small watersheds of Mahi catchment in Gujarat, India. Agarwal et al. (2011) evaluated morphometric parameters and prioritized the sub-watersheds of Loni watershed in Uttar Pradesh, India, using RS and GIS techniques. Khan et al. (2011) utilized remote sensing and GIS for watershed prioritization in the Guhiya bowl watershed, India. Yasmin et al. (2012) conducted the study on morphometric parameter analysis of Milli watershed and suggested that GIS is skilled instrument for examination of morphometric parameters. Rao et al. (2013) portrayed the morphology of various order streams and studied alterations in cross sections of various order streams of Mahi river in Gujarat, India. Gajbhiye et al. (2013) used RS and GIS techniques for morphometric analysis and prioritization of 14 sub-watersheds of Manot River catchment, India. Aher et al. (2014) proposed weighted sum analysis method for prioritization of sub-watersheds of Pimpalgaon Ujjaini watershed located in Maharashtra, India. The quantitative analysis of morphometric parameters was done using remote sensing and GIS techniques. Meshram and Sharma (2015) utilized remote sensing and GIS for morphometric analysis and prioritization of the sub-watersheds of Shakkar River Catchment, India. Balasubramanian et al. (2017) analyzed morphometric characteristics of lower Bhavani basin, Tamil Nadu, using RS and GIS techniques, and prioritized the sub-watershed based on compound parameter. Gaikwad and Bhagat (2018) assessed morphometric parameters and prioritized sub-watersheds of Kas river basin, India, using RS and GIS techniques.

In previously reported studies, the prioritization of sub-watersheds was carried out on the basis of compound parameter value by taking simple arithmetic average of preliminary priority ranks for final prioritization of sub-watersheds. In previously used method, equal importance was given to all the morphometric parameters, which may not be true reality. In identification of highly susceptible areas for risk assessment and management, the importance of all the input constraints may not be equal as each sub-watershed has its own characteristics. So far, Aher et al. (2014) have proposed and used WSA for sub-watersheds prioritization of Pimpalgaon Ujjaini watershed located in Maharashtra, India. In this study, the similar approach has been used for prioritization of sub-watersheds in a hilly watershed located in Indian Himalayan region. In view of the above, this study was conducted with the specific objectives: (i) to compute the morphometric parameters of the sub-watersheds of Naula watershed using RS and GIS techniques and (ii) to prioritize sub-watersheds using weighted sum approach and fix their priority rank and category for conservation planning and management.

Materials and methods

Study area

The Naula watershed is located between 79° 10' 30" E to 79° 31' 30" E longitude and 29° 42' 0" N to 30° 3' 0" N latitude in the Ranikhet forest sub-division of Ramganga river catchment, Uttarakhand, India (Fig. 1). The boundary of Naula watershed spread in Chamoli, Bageshwar, Pauri Garhwal, and Almora districts and drains from North to South (outlet in Almora district). The shape of Naula watershed is nearly rectangular and comprises of 1071.26 km² area with the minimum and maximum elevations ranges from 724 to 3079 m, respectively. The rainfall in the watershed occurs mostly in the middle June to the end of September, with the mean annual rainfall of 1015 mm. The climate of watershed is sub-tropical to sub-temperate with an average annual temperature of 30 °C and a mean minimum temperature of 18 °C. The maximum area of Naula watershed was covered under forest and woodland followed by agriculture. The watershed has a hilly terrain with slopes ranging from relatively flat in narrow bands to steep slopes at the ridges. On the basis of terrain slopes, the land may be classified in three categories, i.e., (i) valley (slope vary from 8 to 10%) which is suitable for cultivation of crops, (ii) moderate hills (slope vary from 10 to 50%), and (iii) steep hills (slope more than 50%) which are generally near the hill tops where cultivation is not possible. The soil texture varies from loamy-sand to silt-loam with boulders and pebbles. The geological formation comprises mostly of granite with mica schist and patches of calcareous dolomite stones at some places.

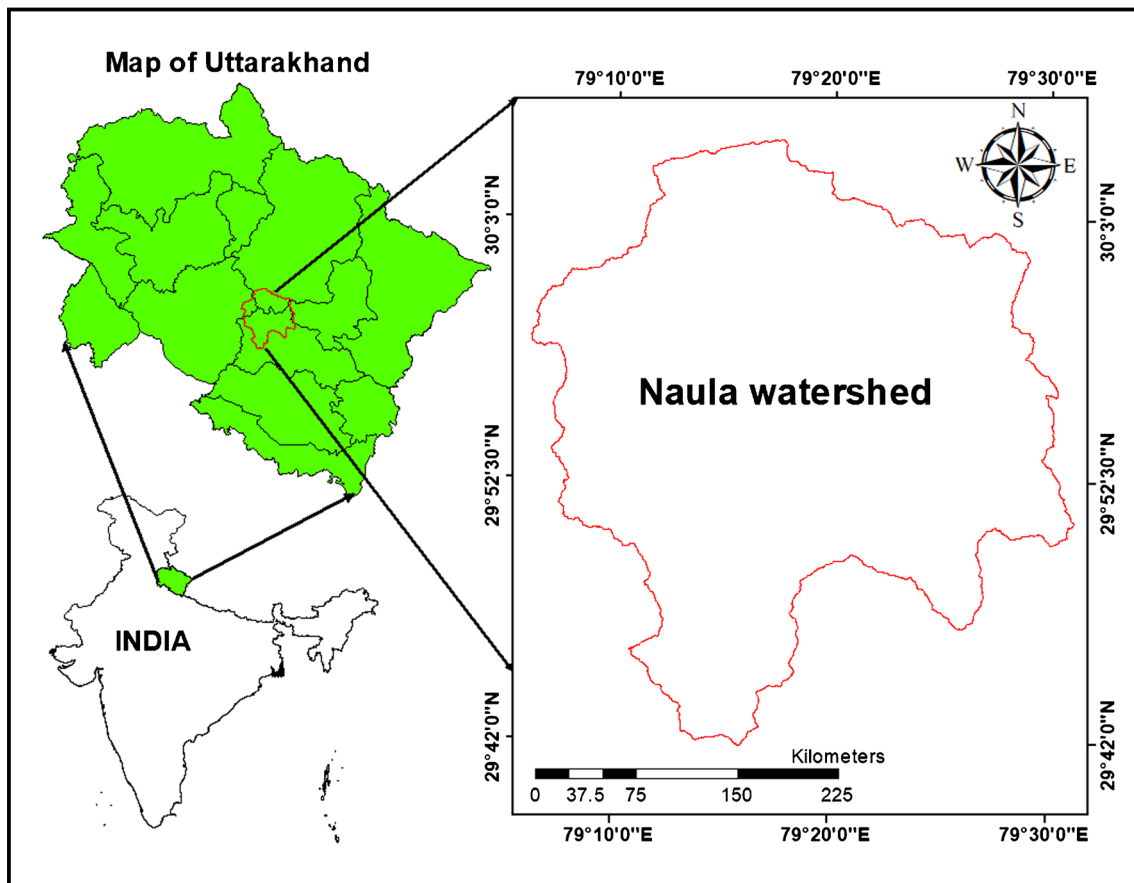


Fig. 1 Location map of study area

Data collection and methodology

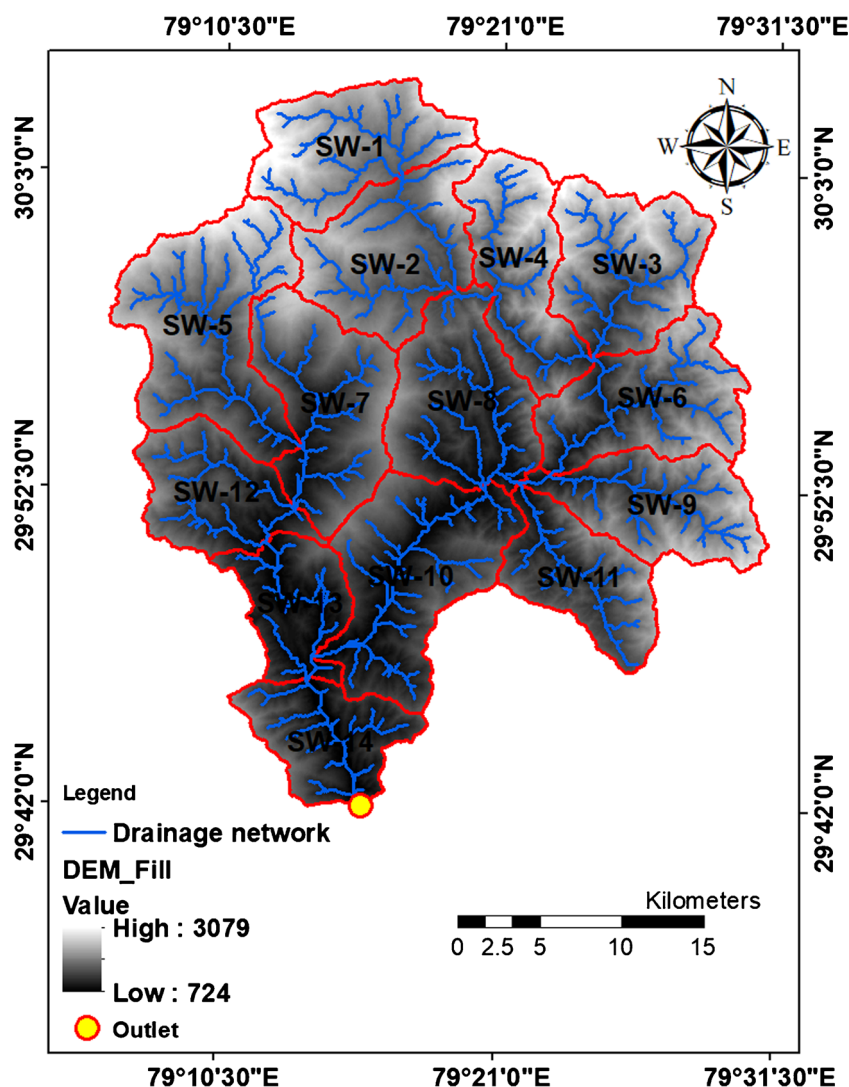
In this study, the base map of catchment was prepared using Survey of India (SOI) toposheet Nos. 53 N/4, 53 N/8, 53 O/1, 53 O/5, 53 O/6, 53 O/9, and 53 O/10 on 1:50000 scale. The digital elevation model (DEM) of Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) of 30 m \times 30 m resolution (downloaded from <https://earthexplorer.usgs.gov>) was used to delineate the boundary and stream of the watershed and further sub-divided into 14 sub-watersheds (Fig. 2) using ArcGIS 10.2 software.

Morphometric analysis

The morphometric analysis is the systematic description of watershed geometry, stream, and its measurement to understand the linear aspects of drainage network, areal aspects of watershed, and relief aspects of stream network (Strahler 1964). In morphometric analysis of watershed, the stream ordering (u) is the primary process. Stream ordering is a kind of designation allotted to the streams existing within the watershed boundary. For stream ordering, Horton (1945) and Strahler (1952) introduced a

system, in which stream networks of watershed are clearly demarcated on the topographic map of the watershed along with the denoting the outlet. The morphometric parameters directly or indirectly reflect the causative factors affecting surface runoff and sediment loss from the watershed. The morphometric parameters such as area (A), perimeter (P), stream order (u), stream length (L_u), mean stream length (\bar{L}_u), basin length (L_b), bifurcation ratio (R_b), drainage density (D_d), stream frequency (F_s), texture ratio (R_t), mean length of overland flow (L_{om}), form factor (F_f), circularity ratio (R_c), compactness coefficient (C_c), and elongation ratio (R_e) were calculated using the standard formulas given in Table 1. Form factor (F_f) is defined as the ratio of the axial width to axial length of the watershed or basin area to the square of axial (maximum) length of the watershed (Horton 1932). Rai et al. (2014) suggested that the value of form factor greater than 0.7854 indicates that basin is circular, while lower value indicates elongated basin. Drainage density (D_d) is defined as the ratio the total length of stream of all orders in a watershed to the total area of the watershed (Horton 1932). The smaller value of drainage density indicates that overland flow predominates in the basin, while higher

Fig. 2 DEM and drainage network map of 14 sub-watersheds of Naula watershed



value of drainage density indicates that channel flow predominates in the basin. Suresh (2007) stated that the less value of drainage density indicates highly permeable sub-surface material and land covered with dense vegetation of low relief, while higher value of drainage density indicates impermeable sub-surface material with sparse vegetation and high relief. Kumar et al. (2012) found that the drainage density indicates channel development in watershed and closeness of the channel spacing. The lithology, compactness of sub-surface, vegetation cover, and relief control the drainage density. Stream frequency (F_s) also known as channel frequency is defined as the total number of stream segment for all stream order per unit area of the basin (Horton 1932). Circularity ratio (R_c) is defined as the ratio of the watershed area to the area of circle that has the same perimeter as the watershed (Miller 1953). The value of circularity ratio ranges from 0.2 to 0.8 or ≤ 1 . The higher value (>0.5) indicates more circularity and more homogeneity in the geological material. The lower value (<0.5) indicates elongated shape of

watershed. Compactness coefficient (C_c) is defined as the ratio of the perimeter of the watershed to the perimeter of the equivalent circular area of the watershed (Strahler 1964). In general, the value of compactness coefficient is always ≥ 1 and also known as Gravelius index. Elongation ratio (R_e) is defined as the ratio between the diameter of a circle having the same area as that of the basin and the maximum length of the basin (Schumm 1956). In general, the value of elongation ratio ranges from 0.4 to 1.0 or ≤ 1.0 for a wide range of climatic and geologic conditions. If the value of elongation ratio is approximately 1.0, it indicates region of very low relief, while value of elongation ratio 0.4 to 0.8 indicates region of very high relief and steep ground slope. Texture ratio (R_t) also called drainage texture and defined as the total number of stream segments of all orders to the perimeter of the basin (Horton 1945). Smith (1950) classified the drainage density into five different classes of textures such as (i) very coarse (<2), (ii) coarse (2 to 4), (iii) moderate (4 to 6), (iv) fine (6 to 8), and (v) very fine (>8).

Table 1 Formula used for computation of linear, areal, and shape morphometric parameters

Morphologic parameters	Formula	References
Linear parameters		
Basin area (<i>A</i>)	Area of watershed (km ²)	
Basin perimeter (<i>P</i>)	Perimeter of watershed (km)	
Stream order (<i>u</i>)	Hierarchical rank	Horton (1945)
Stream length (<i>L_u</i>)	Length of stream (km)	Horton (1945)
Mean stream length (\bar{L}_u)	$\bar{L}_u = \frac{L_u}{N_u}$ where \bar{L}_u is the mean stream length (km), <i>L_u</i> is the total length of stream of order <i>u</i> , <i>N_u</i> is the total number of stream of order <i>u</i>	Strahler (1964)
Basin length (<i>L_b</i>)	$L_b = 1.312 \times A^{0.568}$, (km)	Schumm (1956)
Bifurcation ratio (<i>R_b</i>)	$R_b = \frac{N_u}{N_{u+1}}$ where <i>N_{u+1}</i> is the number of stream segments of (<i>u</i> + 1)th order	Schumm (1956)
Areal parameters		
Drainage density (<i>D_d</i>)	$D_d = \frac{\sum L_u}{A}$, (km/km ²) where, $\sum L_u$ is the total length of stream of all orders (km)	Horton (1932)
Stream frequency (<i>F_s</i>)	$F_s = \frac{\sum N_u}{A}$, (1/km ²)	Horton (1932)
Texture ratio (<i>R_t</i>)	$R_t = \frac{\sum N_u}{P}$, (1/km)	Horton (1945)
Mean length of overland flow	$L_{om} = \frac{1}{2D_d}$ where <i>L_{om}</i> is the mean length of overland flow (km)	Horton (1945)
Shape parameters		
Form factor (<i>F_f</i>)	$F_f = \frac{A}{L_b^2}$, (<i>F_f</i> < 1)	Horton (1932)
Circularity ratio (<i>R_c</i>)	$R_c = \frac{12.57 A}{P^2}$, (<i>R_c</i> ≤ 1)	Miller (1953)
Compactness coefficient (<i>C_c</i>)	$C_c = \frac{0.2821 P}{A^{0.5}}$, (<i>C_c</i> ≥ 1)	Strahler (1964)
Elongation ratio (<i>R_e</i>)	$R_e = \frac{1.128 A^{0.5}}{L_b}$, (<i>R_e</i> ≤ 1)	Schumm (1956)

Table 2 Details of linear parameters of 14 sub-watersheds of Naula watershed

Sub-watershed (SW) name	Linear parameters										
	<i>A</i> (km ²)	<i>P</i> (km)	Streams order (<i>u</i>)					<i>N_u</i>	<i>L_u</i> (km)	\bar{L}_u (km)	<i>L_b</i> (km)
			1	2	3	4	5				
SW-1	75.677	44.764	22	12	8	0	0	42	50.686	1.207	15.317
SW-2	85.087	50.712	23	8	7	9	0	47	58.301	1.240	16.372
SW-3	78.537	43.440	28	14	7	6	0	55	55.215	1.004	15.644
SW-4	68.851	47.953	23	8	6	9	0	46	46.824	1.018	14.517
SW-5	112.988	63.049	35	14	8	12	0	69	80.799	1.171	19.233
SW-6	80.708	50.189	25	12	4	2	1	44	56.781	1.290	15.888
SW-7	87.639	49.739	28	17	5	7	0	57	54.788	0.961	16.649
SW-8	85.156	46.319	24	9	12	4	1	50	60.492	1.209	16.379
SW-9	69.007	45.986	26	11	6	8	1	52	51.228	0.985	14.535
SW-10	104.872	56.905	37	16	2	0	1	56	80.299	1.434	18.436
SW-11	58.809	40.235	20	7	11	0	0	38	41.474	1.091	13.273
SW-12	59.402	41.856	19	11	4	4	0	38	40.408	1.063	13.349
SW-13	47.959	40.468	16	3	1	13	1	34	38.902	1.144	11.821
SW-14	56.567	40.785	18	8	0	0	1	27	42.886	1.588	12.983

Table 3 Linear, areal and shape parameters of 14 sub-watersheds of Naula watershed

SW name	Sub-watershed wise morphometric parameters								
	Linear	Areal				Shape			
	R_b	D_d (km/km ²)	F_s (km ⁻²)	R_t (km ⁻¹)	L_{om} (km)	F_f	R_c	C_c	R_e
SW-1	1.658	0.670	0.555	0.938	0.335	0.323	0.475	1.452	0.641
SW-2	1.343	0.685	0.552	0.927	0.343	0.317	0.416	1.551	0.636
SW-3	1.701	0.703	0.700	1.266	0.352	0.321	0.523	1.383	0.639
SW-4	1.364	0.680	0.668	0.959	0.340	0.327	0.376	1.630	0.645
SW-5	1.458	0.715	0.611	1.094	0.358	0.305	0.357	1.673	0.623
SW-6	2.277	0.704	0.545	0.877	0.352	0.320	0.403	1.576	0.638
SW-7	1.713	0.625	0.650	1.146	0.313	0.316	0.445	1.499	0.634
SW-8	2.048	0.710	0.587	1.079	0.355	0.317	0.499	1.416	0.636
SW-9	1.981	0.742	0.754	1.131	0.371	0.327	0.410	1.562	0.645
SW-10	2.559	0.766	0.534	0.984	0.383	0.309	0.407	1.568	0.627
SW-11	1.348	0.705	0.646	0.944	0.353	0.334	0.457	1.480	0.652
SW-12	1.766	0.680	0.640	0.908	0.340	0.333	0.426	1.532	0.651
SW-13	1.503	0.811	0.709	0.840	0.406	0.343	0.368	1.648	0.661
SW-14	2.046	0.758	0.477	0.662	0.379	0.336	0.427	1.530	0.653

Preliminary priority ranking of sub-watersheds

The preliminary priority ranking of sub-watersheds was done on the basis of morphological characteristics which were assessed according to (i) linear parameters including bifurcation ratio (R_b); (ii) areal parameters including drainage density (D_d), stream frequency (F_s), texture ratio (R_t), and mean length of overland flow (L_{om}); and (iii) shape parameters including form factor (F_f), circularity ratio (R_c), compactness coefficient

(C_c), and elongation ratio (R_e). Since linear and aerial parameters are directly related to soil erodibility (Biswas et al. 1999; Nookaratnam et al. 2005; Thakkar and Dhiman 2007; Gajbhiye et al. 2013), the larger the value of these parameters, the more is the erodibility potential. The largest value of linear and aerial parameters was given the highest priority ranking of 1, the second highest value was given rank 2, and so on for all the 14 sub-watersheds. The shape parameters of a sub-watershed have an inverse relationship to soil erodibility, i.e., the lower the value, the more is the erodibility potential. Hence, the sub-watersheds with the lowest value of shape parameters were given the rank 1, next lower value was ranked 2, and so on for all the 14 sub-watersheds (Nookaratnam et al. 2005; Thakkar and Dhiman 2007; Patel et al. 2012; Gajbhiye et al. 2013). If two sub-watersheds have same values of linear, areal, and shape parameters, equal rank was assigned to such sub-watersheds (Kandpal et al. 2017).

Table 4 Preliminary priority ranking of linear, areal and shape parameters of 14 sub-watersheds

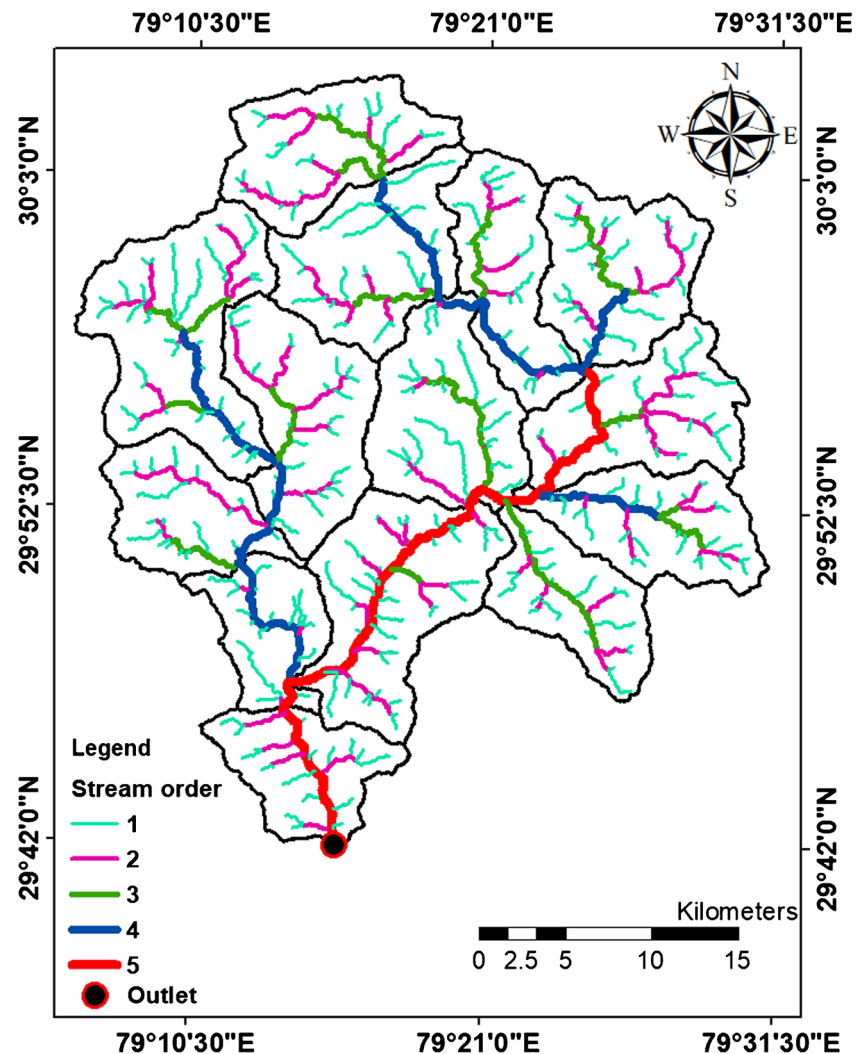
SW name	Linear	Areal				Shape			
	R_b	D_d	F_s	R_t	L_{om}	F_f	R_c	C_c	R_e
SW-1	9	13	10	9	13	8	12	3	8
SW-2	14	10	11	10	10	4.5	7	8	4.5
SW-3	8	9	3	1	8.5	7	14	1	7
SW-4	12	11.5	4	7	11.5	9.5	3	12	9.5
SW-5	11	5	8	4	5	1	1	14	1
SW-6	2	8	12	12	8.5	6	4	11	6
SW-7	7	14	5	2	14	3	10	5	3
SW-8	3	6	9	5	6	4.5	13	2	4.5
SW-9	5	4	1	3	4	9.5	6	9	9.5
SW-10	1	2	13	6	2	2	5	10	2
SW-11	13	7	6	8	7	14	11	4	12
SW-12	6	11.5	7	11	11.5	11	8	7	11
SW-13	10	1	2	13	1	12	2	13	14
SW-14	4	3	14	14	3	13	9	6	13

Weighted sum approach

The final priority ranking and related categorization were made on the basis of the compound factor value, which was computed by multiplying the ranks from morphometric analysis and their weights obtained using cross-correlation analysis of these parameters to give compound factor for final prioritization of sub-watersheds. The mathematical expression for compound factor is written as follows (Aher et al. 2014):

$$CF = PPR_{MP} \times W_{MP} \tag{1}$$

Fig. 3 Stream order map of 14 sub-watersheds of Naula watershed



where CF is the compound factor, PPR_{MP} is the preliminary priority rank based on morphometric parameter, and W_{MP} is the weight of morphometric parameter obtained using cross-correlation analysis. The final ranking was made on the basis of compound factor in such a way that the lowest value of compound factor was given the priority rank 1, next lower value was given priority rank of 2, and so on for all the 14 sub-watersheds.

Results and discussion

The morphometric analysis was conducted for 14 sub-watersheds of Naula watershed to assess the characteristics and properties of the drainage networks. These parameters were classified into linear parameters (basin area, perimeter, stream order, stream length, mean stream length, basin length, and bifurcation ratio), areal parameters (drainage density, stream frequency, texture ratio and mean length of overland

flow), and shape parameters (form factor, circularity ratio, compactness coefficient, and elongation ratio). The quantitative value of linear, areal, and shape parameters are given in Tables 2 and 3. After morphometric analysis, the preliminary priority rank was assigned for 14 sub-watersheds as given in Table 4.

Linear morphometric parameters

The drainage network pattern of Naula watershed indicates that it is a 5th-order watershed consisting of the streams of various orders as shown in Fig. 3. The detail of all the stream orders of 14 sub-watershed is given in Table 2. It was observed from Table 2 the area of sub-watershed varies from 47.959 km² (SW-13) to 112.988 km² (SW-5), while perimeter varies from 40.235 km (SW-11) to 63.049 km (SW-5). Figure 3 and Table 2 reveal that there are 344 streams of 1st-order, 150 of 2nd-order, 81 of 3rd-order, 74 of 4th-order, and 6 of 5th-order streams. It also seen from Table 2 that the highest

Table 5 Cross-correlation matrix between linear, areal, and shape parameters

Morphometric parameters	R_b	D_d	F_s	R_t	L_{om}	F_f	R_c	C_c	R_c
R_b	1.000	0.310	-0.367	-0.002	0.297	0.196	-0.103	0.103	0.170
D_d	0.310	1.000	-0.079	-0.200	0.999*	-0.118	0.378	-0.378	-0.171
F_s	-0.367	-0.079	1.000	0.451	-0.059	-0.269	0.042	-0.042	-0.304
R_t	-0.002	-0.200	0.451	1.000	-0.176	0.524	-0.270	0.270	0.568*
L_{om}	0.297	0.999*	-0.059	-0.176	1.000	-0.120	0.357	-0.357	-0.173
F_f	0.196	-0.118	-0.269	0.524	-0.120	1.000	0.132	-0.132	0.982*
R_c	-0.103	0.378	0.042	-0.270	0.357	0.132	1.000	-1.000*	0.053
C_c	0.103	-0.378	-0.042	0.270	-0.357	-0.132	-1.000*	1.000	-0.053
R_c	0.170	-0.171	-0.304	0.568*	-0.173	0.982*	0.053	-0.053	1.000
Sum of correlation	1.604	1.741	0.372	2.164	1.767	2.196	0.588	-0.588	2.072
Grand total	11.916	11.916	11.916	11.916	11.916	11.916	11.916	11.916	11.916
Weight	0.135	0.146	0.031	0.182	0.148	0.184	0.049	-0.049	0.174

*Significant at 5% level of significance

stream segments were found in SW-5 (69) and the lowest stream segments were found in SW-14 (27).

In this study, stream length of 1st- to 5th-order streams of 14 sub-watersheds were measured using GIS technique as given in Table 2 which indicates the total length of all the streams is found to vary from the minimum of 38.902 km (SW-13) to the maximum of 80.799 km (SW-5) and total length of all streams for the watershed is 759.083 km. The mean stream length for sub-watersheds varies from 0.961 km (SW-7) to 1.588 km (SW-14). The basin length varies from 11.821 km (SW-13) to 19.233 km (SW-5), and the total length of basin is 214.396 km. The value of bifurcation ratio for 14 sub-watersheds is given in Table 3, which indicates that the bifurcation ratio varies from 1.343 (SW-2) to

2.559 (SW-10). The more the value of bifurcation ratio is, the more will be the soil erosion.

Areal morphometric parameters

In the present study, the values of drainage density of 14 sub-watersheds (Table 3) vary from 0.625 km/km² (SW-7) to 0.811 km/km² (SW-13). The low value of drainage density for SW-7 indicates highly permeable sub-surface under vegetative cover with low relief, whereas higher value of drainage density for SW-13 indicates a well-developed efficient drainage network with impermeable sub-surface materials with less vegetative cover and high relief.

The values of stream frequency of 14 sub-watersheds are given in Table 3, which indicates that the stream frequency varies from 0.477 km⁻² (SW-14) to 0.709 km⁻² (SW-13). A low value of stream frequency indicates low runoff and higher value indicates more runoff in the region. The value of texture ratio of 14 sub-watersheds (Table 3) varies from 0.622 km⁻¹ (SW-14) to 1.266 km⁻¹ (SW-3). According to the classification, all sub-watersheds fall in very coarse category of drainage texture. The value of mean length of overland flow of 14 sub-watersheds varies from 0.313 to 0.406 km in the watershed.

Shape morphometric parameters

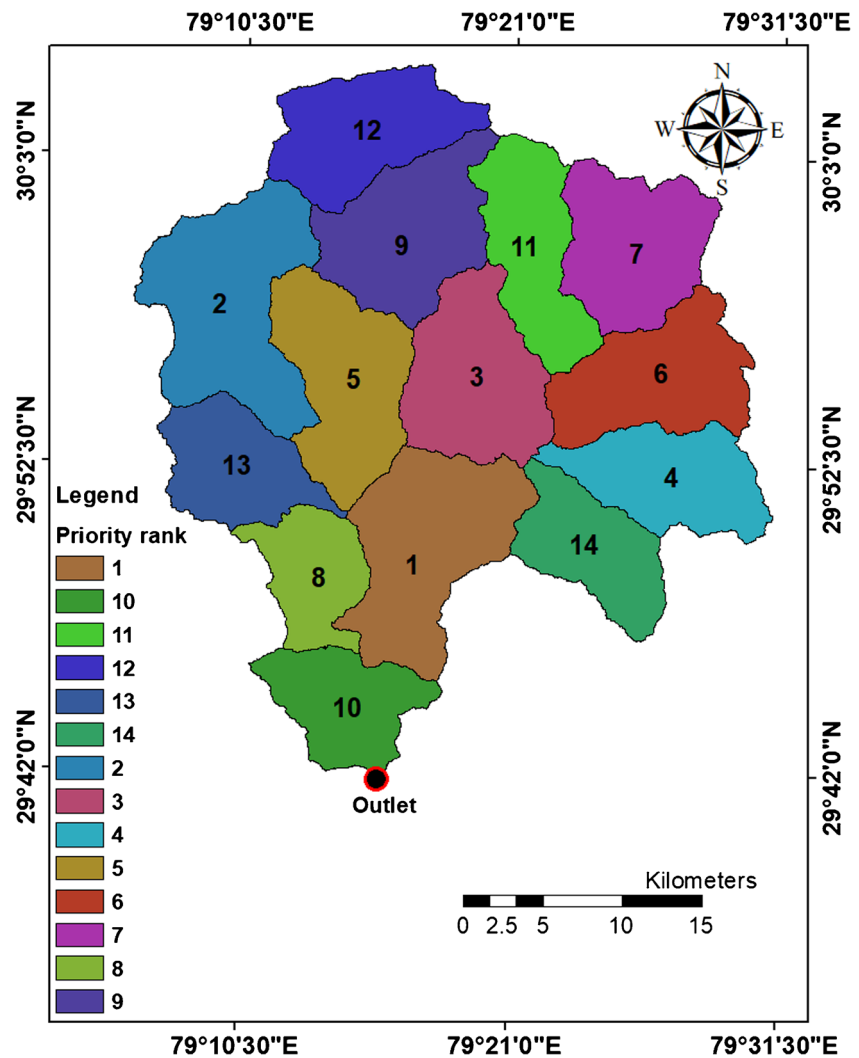
The value of form factor of 14 sub-watersheds is given in Table 3, which indicates that the form factor varies from 0.305 to 0.343. Based on the value of form factor, all the 14 sub-watersheds represented elongated shape with lower peak flow for longer duration.

The values of circularity ratio for 14 sub-watersheds (Table 3) vary from 0.357 to 0.523. It is also indicating that SW-3 has circular shape, while the remaining SW-1, SW-2, and SW-4 to SW-14 are of elongated shape. The calculated values of

Table 6 Final priority ranking of 14 sub-watersheds based on compound factor value

SW name	Compound factor	Prioritized ranks
SW-1	10.295	12
SW-2	8.550	9
SW-3	7.076	7
SW-4	9.355	11
SW-5	3.645	2
SW-6	7.056	6
SW-7	6.904	5
SW-8	5.514	3
SW-9	5.681	4
SW-10	2.689	1
SW-11	10.463	14
SW-12	10.399	13
SW-13	8.167	8
SW-14	9.206	10

Fig. 4 Final priority ranks map of 14 sub-watersheds of Naula watershed



compactness coefficient for 14 sub-watersheds (Table 3) range from 1.383 to 1.673. A high value (> 1) of compactness coefficient indicates more compact sub-watersheds. The values of elongation ratio for 14 sub-watersheds (Table 3) range from 0.623 to 0.661, which indicates that all the sub-watersheds are of high relief and steep ground slope.

Prioritization of sub-watershed based on weighted sum approach

The cross-correlation analysis among linear, areal, and shape parameters (Table 5) was performed and tested at 5% level of significance. It was observed from Table 5 that the combination D_d and L_{om} , R_t and R_e , and F_f and R_c has significant positive correlation, while R_c and C_c have significant negative correlation at 5% level of significance. The priority ranks of sub-watersheds were determined on the basis of compound factor (Table 6), which was calculated using Eq. 1. The value of weights assigned to a morphometric parameter was calculated by dividing the sum of correlation coefficient of each parameter by the grand total of

correlations (Table 5). By assigning the weights to different parameters, a model was formulated to assess the final priority ranking. The compound factor for watershed prioritization was computed as follows:

$$\begin{aligned} \text{Compound factor} = & (0.135 \times \text{PPR of } R_b) + (0.146 \times \text{PPR of } D_d) \quad (2) \\ & + (0.031 \times \text{PPR of } F_s) + (0.182 \times \text{PPR of } R_t) \\ & + (0.148 \times \text{PPR of } L_{om}) + (0.184 \times \text{PPR of } F_f) \\ & + (0.049 \times \text{PPR of } R_c) - (0.049 \times \text{PPR of } C_c) \\ & + (0.174 \times \text{PPR of } R_e) \end{aligned}$$

The final priority ranking was made in such a way that the lowest value of compound factor was given the priority rank of 1, the next lower value was given priority rank of 2, and so on for all the 14 sub-watersheds. As observed from Table 6, the highest priority rank (1) was assigned to SW-10 followed in order by SW-5, SW-8, SW-9, SW-7, SW-6, SW-3, SW-13, SW-2, SW-14, SW-4, SW-1, SW-12, and SW-11. Figure 4 shows the final priority ranking map of 14 sub-watersheds under study.

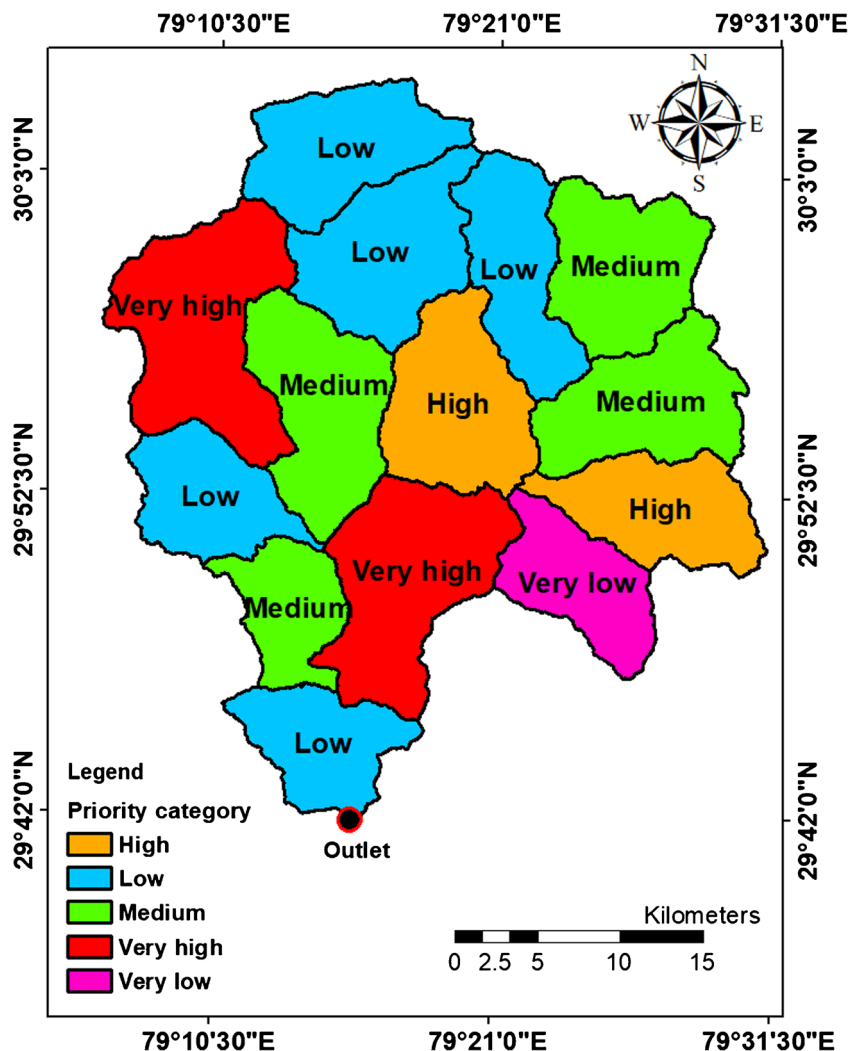
Table 7 Priority category of 14 sub-watersheds based on compound factor value (Aher et al. 2014)

Sr. no.	Priority level	Priority category	SW name	Percentage of area
1	2.689 to ≤ 4.617	Very high	SW-5, SW-10	20.34
2	4.617 to ≤ 6.545	High	SW-8, SW-9	14.39
3	6.545 to ≤ 8.473	Medium	SW-3, SW-6, SW-7, SW-13	27.52
4	8.473 to ≤ 10.401	Low	SW-1, SW-2, SW-4, SW-12, SW-14	32.26
5	> 10.401	Very low	SW-11	5.49

Based on the compound factor value, all the 14 sub-watersheds of Ramganga River basin were classified into five priority categories (Aher et al. 2014) such as (i) very high (2.689 to ≤ 4.617), (ii) high (4.617 to ≤ 6.545), (iii) medium (6.545 to ≤ 8.473), (iv) low (8.473 to ≤ 10.401), and (v) very low (> 10.401) as given in Table 7. It was observed from Table 7 that the two sub-watersheds (SW-5 and SW-10) were under very high category, two sub-watersheds (SW-8 and SW-9) under high category, four sub-watersheds (SW-3, SW-6, SW-7, SW-13) under medium, five sub-watersheds (SW-1,

SW-2, SW-4, SW-12, SW-14) under low category, and one sub-watershed (SW-11) was under very low category. The final priority category map of 14 sub-watersheds is shown in Fig. 5, which reveals that the percentage of area of sub-watersheds under very high category is 20.34%, high category is 14.39%, medium category is 27.52%, low category is 32.26%, and very low category is 5.49%. This information is very useful for implementation of watershed management techniques in terms of soil and water conservation measures in the study area.

Fig. 5 Final priority category map of 14 sub-watersheds of Naula watershed



Conclusion

The prioritization of watershed is the most critical part of making arrangements for execution of its improvement and administration programs. In this study, the morphometric analysis of 14 sub-watersheds of Naula watershed was done for understating the hydrological behavior for efficient watershed management planning. The morphometric parameters (linear, areal, and shape) of 14 sub-watersheds were estimated using RS and GIS techniques. The prioritization of 14 sub-watersheds was done using weighted sum approach. The morphometric investigation demonstrated that sub-watershed SW-5 and SW-10 have very high vulnerability to soil erosion followed by SW-8 and SW-9 in the study area. Hence, the appropriate conservation measures are required in these sub-watersheds to safeguard against the land and water degradation. These results are also expected to help decision makers in identifying priority sub-watersheds which need instant adaptation of proper soil conservation and land management practices in the study region.

The weighted sum approach is a dynamic, effective, and sustainable method over traditional or ordinary watershed prioritization methods in which significance of several characterization parameters was considered. The application of weighted sum approach in sub-watershed prioritization would be helpful in better decision-making for water resources management and adoption of conservation measures.

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