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RESEARCH PAPER

Prioritization of sub-watershed using geospatial techniques and WSPM model in Mandakini River basin, Uttarakhand, India

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Abstract
The integrity of a watershed is majorly contributed by soil and water; those are essential to thrive sustainably in a hilly area like Uttarakhand. With geoinformatics techniques mapping and estimation of hazard-prone areas can be done. The current study is based on the prioritization of sub-watersheds (SW) by using a correlation-based approach named the weighted sum priority model (WSPM) by utilizing Cartosat DEM. The Mandakini River Basin was delineated into 5 major sub-watersheds to study morphometric attributes, i.e., linear, areal, and relief parameters. The mean estimation of drainage density (Dd) is 2.51 and Stream frequency (Fs) is 4.46. Fs and Dd show positive correlation with other linear and areal parameters (0.83). Elongation Ratio (Re) values for SW 01 and SW05 shows oval shape of sub-watershed. The Form factor (Ff) value of SW 04 featuring a gradual rise and prolonged flow. The cumulative rank for all SW has been computed using the WSPM model, reveals the SW3 and SW4 have the highest priorities for soil erosion among all the rest of the sub-watersheds. This comparative study approaches planners and government officials to assist in decision-making for erosion conservation structures and also in the prediction of hazard-susceptible zones.

Keywords Sub-watershed (SW) · WSPM · Mandakini river basin · Soil erosion

Introduction

A watershed is a region that feeds water to a specific drainage system through surface or subsurface flow and channels into a single outlet. Watersheds are among the most fundamental parts of a landscape's natural organization, yet they contribute to the sustainability of the watershed with two major factors which are soil and water (Sharma and Mahajan 2020). The assessment and numerical analysis of our surface's shape and design, as well as the measurement of form and its landscape, is known as morphometry analysis (Clark 1996). Through morphometry analysis, data like hydrology, lithology infiltration capacity, and soil erosion were evaluated (Strahler 1964). Prior to the previous decades, the geometric analysis of basin was done with traditional measurements using maps and scales and nowadays, with geospatial tools and digital elevation models (DEM) were used to analyze the morphometry parameters of watersheds from geographical maps and field studies, It is an upgraded, faster way for analyzing watersheds (Gajbhiye et al 2014; Chandniha and Kansal 2017; Godif and Manjunatha 2022).

More recently, utilization of geospatial technology and gerographical information system (GIS) for calculating the morphometric attributes of various river watershed in India and ranked erosion prone zones in watershed (Agarwal et al 2011; Gajbhiye et al 2014; Chandniha and Kansal 2017; Malik et al 2019; Jothimani et al 2020). Malik et al (2019) used weighted sum approach (WSA) which is based on statistical correlation matrix for zonation of erosion susceptible area in watershed. WSA is authentic and dynamic approach over typical watershed prioritization models (Jothimani et al 2020).

The Mandakini River Watershed comprises of two major litho-stratigraphical group separated by Main Central Thrust (MCT) (Rawat et al. 2015). The history of the region indicates this region is prone to cloudbursts and flash floods which cause loss of natural resources and destruction of road network at various location due to landslides (Fig. 1), leads to multiple casualties in the area. The landslides are influenced by the degree of erosion and intense rainfall (Liu et al 2015). The heavy rainfall in the basin is responsible

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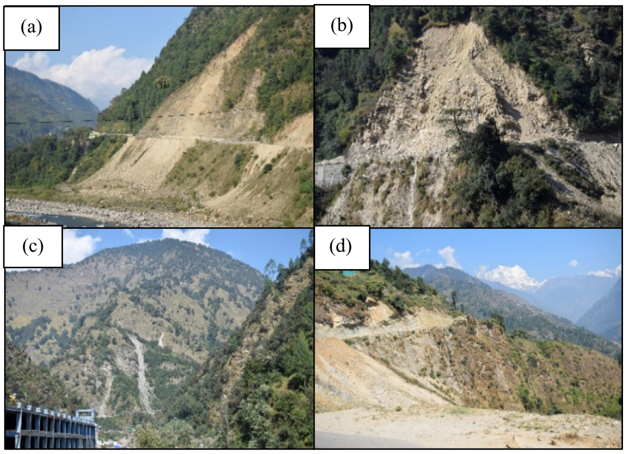


Fig. 1 Field photographs showing **a** Augustamuni **b** Badasu village **c** Sonprayag **d** Kalimath illustrating landslides in Mandakini River Watershed

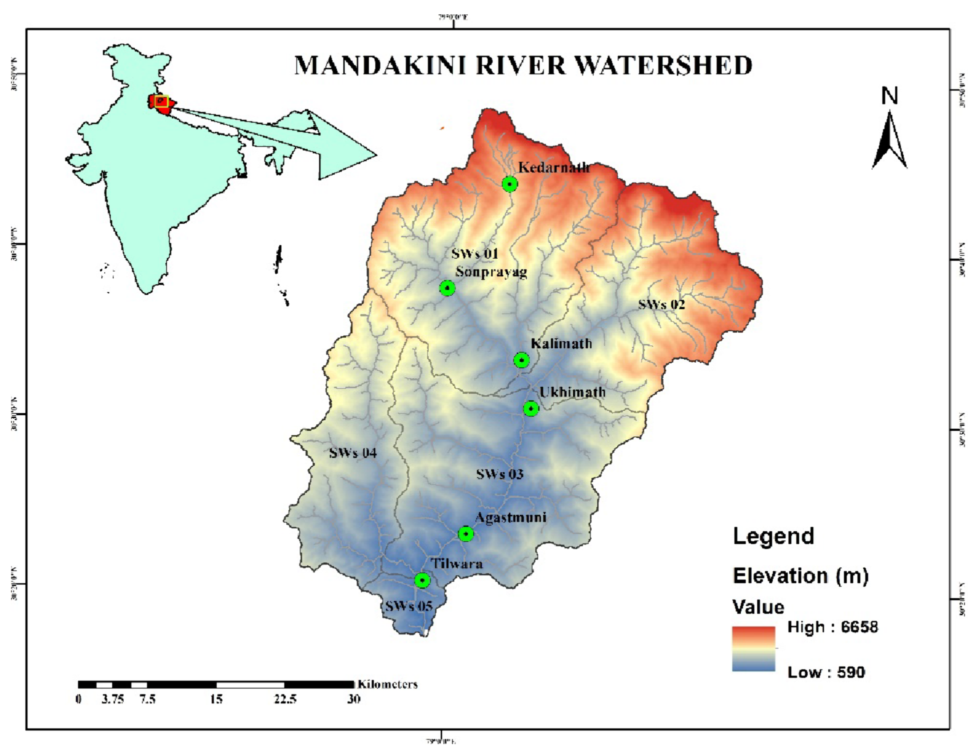
for rising water levels and intense flash floods which leads to erosion in the basin. Mahapatra et al. (2018) prepared a soil loss map of Uttarakhand, where the Mandakini river basin comes under the category of very severe due to the frequent downpours or cloudbursts in the basin. The soils are easily detached and migrate along the hillslope with the runoff, creating sheet erosion because the soils of the area has formed over layered, easily erodible sedimentary rocks from the tertiary period, making it vulnerable to soil erosion.

Watershed conservation across the basin may not be achievable due to varied ownership and conflicting interests, hence the study region has been partitioned into numerous smaller components referred to sub-watersheds (SW) or micro-watersheds by considering its drainage network (Strahler 1964). The morphometric parameters computed for Mandakini River watershed and categorized basin into five major sub-watershed for prioritization on most to least eroded watershed using the weighted sum approach. This study includes specific objectives: (1) To calculate the morphometry parameters of sub-watersheds in GIS environment (2) To prioritize sub-watersheds using WSA and rank SW on least to most susceptible to erosion. Weighted sum priority model (WSPM) provide acknowledgement of erosion susceptible watershed on the foundation of morphometric factors and hypsometry analysis (Jothimani et al 2020; Shekar et al 2023) and take on better soil conservation technique for highly susceptible sub-watershed.

Description of study area

The Mandakini River basin (Fig. 2) lies between latitudinal extents of 30° 10′ 0″ N and 30° 50′ 0″ N, and longitudinal extents are 78° 50′ 0″E and 79° 20′ 0″ E. The altitude of whole watershed extends from 570 to 6658 m amsl. The study area is situated on a gradual to moderately sloping terrain, (0 to 17°) to (18 to 26°) respectively, while significant portion falls under moderately steep slope and a very

Fig. 2 Location map of study area



little section falls under very steep hillside in the northern direction. River Mandakini originates from glaciers north of Kedarnath valley named Chorabari glacier; its major tributaries include Vasuki Ganga, Sina Gad, Kali Ganga, Markanda Ganga, Kyar Gad, Mandani Ganga and Madhyamaheshwar Ganga. The Garhwal group and the Central Crystalline group and the two major litho-stratigraphical units are dominant in this region (Rawat et al. 2015). The Mandakini River watershed experienced maximum destruction caused by rainfall, around 1000–1800 mm of rainfall occurs there each year**.** The highest recorded rainfall during the monsoon season followed by landslides and flash floods.

Methodology and data used

The DEM data downloaded from tile number H44H and H44G of Cartosat DEM version 3R1 with a capture resolution of 1 arc second (~ 30 m) and a pixel resolution of 2.5 m. This satellite data is freely assessable on Bhuvan geo-portal of ISRO (https://bhuvan-app3.nrsc.gov.in/data/download/index.php). Mandakini River Watershed were verified by Survey of India (SOI) topo sheet numbers 53 J/15, 53N/3, 53N/7, 53 J/13, 53N/1, 53N/2, 53 J/14, and 53N/6 on a 1:50,000 scale. The application of Cartosat-DEM data involves the creation of terrain features such as slope, flow direction, drainage density, aspect relief, and elevation using Geographic Information Systems (GIS), notably utilizing the hydrology tools within the ArcGIS software. Dabrowski et al. (2008) conducted research showcasing the precision of stereo data generated by Cartosat-1, while Gajalakshmi and Anantharama (2015) and Agarwal et al. (2020) determined that Cartosat-DEM exhibits superior accuracy compared to SRTM-DEM regarding terrain characteristics. The DEM data undergone for catchment delineation and stream network generation from various hydrology tool and raster analysis tool (fill, flow direction, flow accumulation, raster calculator, pour point, watershed, Raster to polygon tool) of ArcMap version 10.8. Later, five major sub-watershed delineated in GIS environment for the morphometric analysis by using standardized morphometric equations and selecting erosion causing parameters for the prioritization of sub-watersheds (Fig. 3).

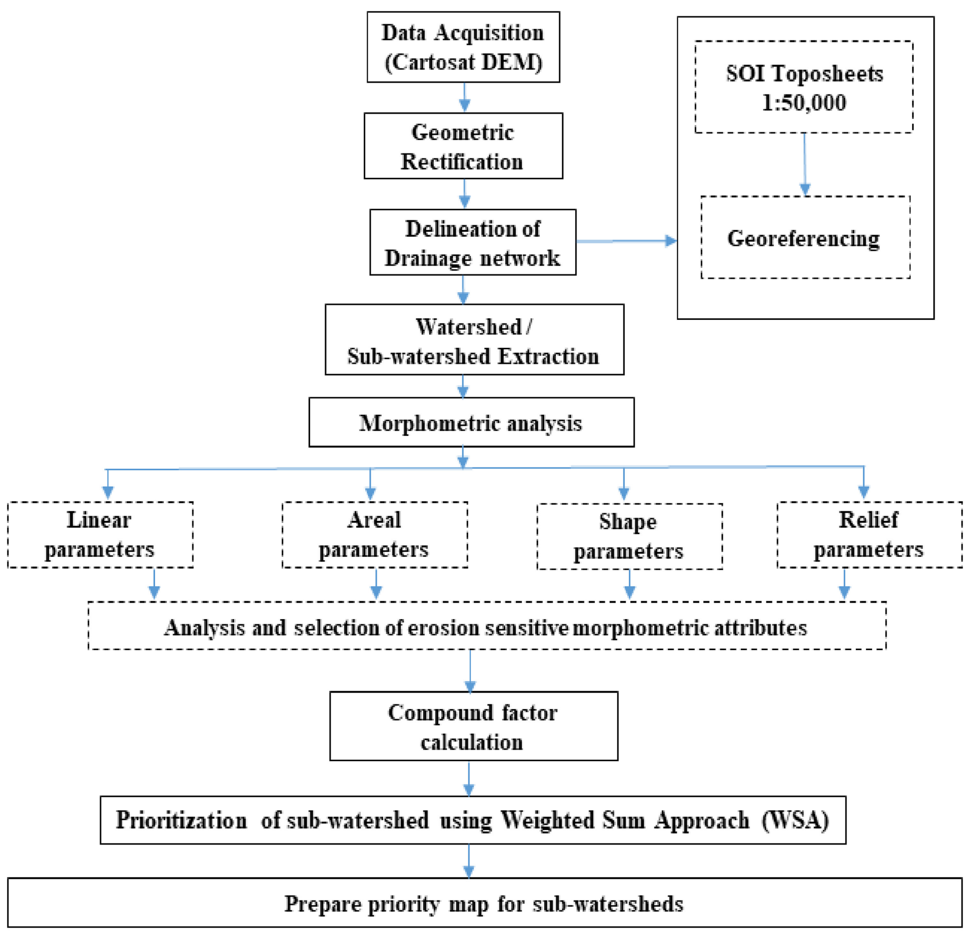


Fig. 3 Flowchart showing the methodology used for current study

Morphometry analysis and hypsometry analysis

The morphometric study is the analytical illustration of watershed which includes linear, areal, shape and relied characteristics of landform (Strahler 1964). In morphometric assessment, basin shape and stream network relation inferred the water and sediment yield of basin. The basic morphometric variable of sub-watershed such as Area (A), Perimeters (P), Basin Length (L_b), Basin Width (W_b), Minimum elevation (h) and Maximum elevation (H) profile were generated in ArcGIS version 10.8 (Table 1). The remaining morphometric attributes were calculated using standardized mathematical formulas and taking basic morphometric factors as input for computation of morphometric attributes (Table 2).

Table 1 Basic morphometric factors generated in GIS environment

Factors	SW 01	SW 02	SW 03	SW 04	SW 05
Area (A) (km^2)	512.59	378.685	455.84	259.29	39.46
Perimeter (P) (km)	143.11	136.85	153.16	125.29	38.46
Basin length (L_b) (km)	31.33	31.19	33.30	23.09	8.47
Basin width (W_b) (km)	29.48	20.59	23.67	12.25	7.16
Maximum elevation (H) (m)	6479	6658	3559	3736	1965
Minimum elevation (h) (m)	1102	1042	665	818	590

Hypsometry integral is dimensionless parameter and it is used to distinguish the different stage of erosion in a landscape. Where, Hypsometry curve goes in convex upward direction depicts basin youthful stage, concave upward curve represents peneplain and S-shaped curve reflects mature stage of basin (Strahler 1952; Schumm 1952). The hypsometry analysis generates hypsometry curve and hypsometry integral (HI) for evaluation of basin on the basis of the stage of erosional cycle of landforms (Ritter 1995). Pike and Wilson (1971) established the concept that HI is analogous to the elevation-relief ratio. This elevation-relief equation (Table 2) used for generating hypsometry curve which characterized the erosion profile and geologic stage of basin (Sharma and Mahajan 2020; Shekar et al 2023).

Prioritization of sub-watersheds using WSA

The initial step of this work is to find those morphometric parameters that contributes to soil erosion. The weighted sum approach (WSA) technique require correlation matrix, weightage assignation, compound factor generation and ranking of watershed (Jothimani et al 2020). The linear and relief morphometric attributes shows direct relation with soil erosion while few shape and areal parameters exhibit inverse relationship (Aher et al 2014). The higher value of linear and relief parameters assigned rank "1" and rank "2" for second highest value and so on. Whereas the smaller value of shape and areal attributes was symbolize as rank "1", next value

Table 2 Standardized equations for calculating morphometric factors

Sr. No	Morphometric factors	Formula	Reference
1	Stream order (U)	Hierarchical rank	Strahler (1964)
2	Stream number (Nu) (km)	$Nu = N1 + N2 + \ldots Nn$	Horton (1945)
3	Stream length (Lu) (km)	$Lu = L1 + L2 \ldots Lu$	Horton (1945)
4	Mean stream length (Lum)	$Lum = Lu/Nu$ nn	Strahler (1952)
5	Stream length ratio (Lur)	$Lur = Lu/L(u - 1)$	Strahler (1952)
6	Bifurcation ratio (Rb)	$Rb = Nu / (Nu + 1)$	Strahler (1952)
7	Form factor (Ff)	$Ff = A$ / 〖Lb〗 ^2	Horton (1932)
8	Elongation ratio (Re)	$Re = 2 / Lb \times (A$ / 〖3.14)〗 ^0.5	Schumm (1956)
9	Ciculatory ratio (Rc)	$Rc = 12.57 \times (A/P^2)$	Miller (1953)
10	Drainage texture (Dt)	$Dt = Nu/P$	Horton (1945)
11	Compactness coefficient (Cc)	$Cc = 0.284 \times P/A^{0.5}$	Gravelius (1914)
12	Stream frequency (Fs) ($1/km^2$)	$Fs = Nu/P$	Horton (1932)
13	Drainage density (Dd) (km/km^2)	$Dd = Lu/A$	Horton (1932)
14	Length of overland flow (Lo) (km)	$Lo = 1/(Dd \times 2)$	Horton (1945)
15	Basin relief (R)	$R = H - h$	Strahler (1952)
16	Relief ratio (Rr)	$Rh = R/Lb$	Schumm 1956)
17	Relative relief ratio (Rhp)	$Rhp = Rr \times 100/P$	Melton (1957)
18	Dissection index (Dis)	$Dis = (H - h)/H$	Gravelius (1941)
19	Ruggedness number (Rn)	$Rn = Dd \times (Rr/1000)$	Patton and Baker (1976)
20	Hypsometric integral (HI)	$HI = (Hmean - Hmin)/(Hmax - Hmin)$	Pike and Wilson (1971)

was assigned and so on (Godif and Manjuntha 2022; Shekar et al 2023). In WSPM, correlation matrix shows interrelation among erosion sensitive parameters. The sum of all selected morphometric parameter divided by grand total to weightage of morphometric attributes and using compound factor (CF) equation (Eq. 1) ranked the watershed accordingly (Aher et al 2014).

$$CF = \Sigma_{j=1}^{N} \Sigma_{i=1}^{M} (wj \times Ri) \quad (1)$$

where, 'N' depicts the total number of parameters, and 'M' indicates the sum total of ranks, Wj express as jth weightage of the parameters generated from the correlation matrix, Ri represents the ith rank of parameter allocated at the time of initial priority ranking.

Results and discussion

A total of five sub-watersheds was demarcated for conducting this study, and the linear, areal, shape and relief morphometric factors was calculated using WSPM ranking based on compound factor.

Linear morphometric parameter

This morphometric aspect incorporate 'Nu', 'Lu', 'Lur', and 'Rb' for quantification of all sub-watersheds (Table 3). The values generated for linear aspect denotes channel pattern of basin. Stream number (Nu) is the sum total of stream in one segment (Strahler 1957). The progressively decrease in number of stream as stream order increases (Horton 1945) (Fig. 4). SW 01 have a total number of stream (Nu) 2386 ranges to 171 in SW 05.

Stream length (Lu) generally, the summation of stream length segment in watershed as the basin having steeper slopes and fine textures possess smaller stream length (Horton 1945; Strahler 1954). The gradually decrease of stream length (Lu) as stream order (U) increases, (Fig. 5) validates the second law of stream length given by Horton (1945). The sum of stream length comes maximum in SW 01 and minimum in SW05.

Bifurcation ratio (Rb) initiated by Horton (1932). It is assumed to divaricate pattern of stream network and as explained by Schumm (1956) the proportion of number of stream order in one order to the number of stream order in next higher order. The computed 'Rb' ranges between 3.68 (SW 02) to 4.59 (SW 01) (Table 3), where the watershed with high bifurcation ratio with elongated basin expects hilly area yields to lesser but prolong peak flow and circular shape basin exhibit intense peak flow (Chitra et al 2011). SW 01 is highly susceptible to erosion due to extended peak flow in watershed.

Table 3 Calculated values of linear morphometric factors

Factors	SW 01	SW 02	SW 03	SW 04	SW 05
Stream number (Nu)					
Nu1	1843	1376	1539	848	134
Nu2	426	315	361	191	32
Nu3	97	74	77	45	5
Nu4	15	15	15	7	–
Nu5	4	3	4	2	–
Nu6	1	2	1	1	–
Nu7	–	1	1	–	1
Stream length (Lu)					
Lu1	759.92	601.02	643.27	354.81	49.19
Lu2	301.10	234.29	269.87	143.83	18.57
Lu3	144.09	113.5	91.97	69.43	14.26
Lu4	82.64	45.38	70.16	29.86	–
Lu5	37.35	24.32	23.88	30.81	–
Lu6	17.99	24.82	6.09	0.014	–
Lu7	–	0.02	28.37	–	8.00
Bifurcation ratio (Rb)					
Rb(1/2)	4.33	4.37	4.26	4.44	4.2
Rb(2/3)	4.39	4.26	4.69	4.24	6.4
Rb(3/4)	6.47	4.93	5.13	6.43	–
Rb(4/5)	3.75	5.00	3.75	3.50	–
Rb(5/6)	4.00	1.50	4.00	2.00	–
Rb(6/7)	–	2.00	1.00		5
Mean Rb	4.59	3.68	3.81	4.12	5.2

Areal morphometric parameter

The areal geometric factors are characterized by 'Rt', 'Fs', 'Dd' and 'Lo'. These morphometric parameters dominantly based on drainage distribution and frequency in the watershed. The calculated values of these attributes in (Table 4).

Stream frequency (Fs) describes the sum total of stream segments of all drainage order per unit area (Horton 1932; 1945). The estimated value of 'Fs' is highest 4.72 km^{-2} in SW 02 and lowest 4.22 km^{-2} in SW 04 (Table 4). This conclude that SW 04 have moderately porous sub-surface material then rest of sub-watersheds.

Drainage density (Dd) is sum length of drainage segments divided by drainage order of all given watershed area (Horton 1945). The 'Dd' explains the compactness of channels between each stream order and spacing of streams to describe the time taken by stream to travel in watershed (Dubey et al 2015). The minimum 'Dd' 2.26 km/km^2 in SW 05 and maximum is 2.75 km/km^2 in SW 02.

Length of overland flow (Lo) expressed as the half the reciprocal of drainage density (Horton 1945). A minimal rainfall is sufficient to generate a large amount of surface runoff in the watershed which having smaller value of

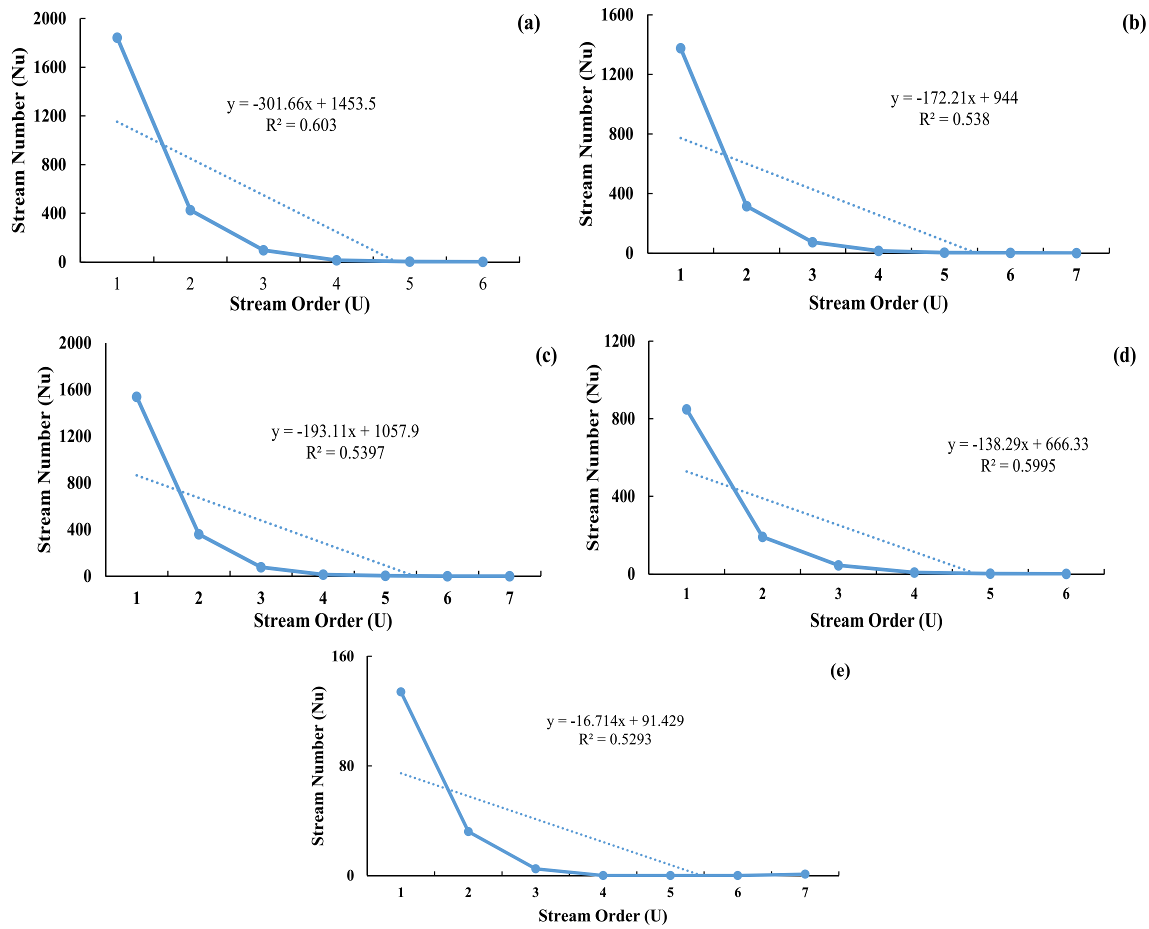


Fig. 4 Relationship between Nu and U. **a** SW01, **b** SW02, **c** SW03, **d** SW04, **e** SW05

overland flow so, it predicts the occurrence of flooding in watershed (Prabhakaran and Jawahar Raj 2018). The ‘Lo’ value for SW 02 is 0.73, significantly low and 0.88 is highest in SW 05.

Shape morphometric parameter

The Shape morphometric parameters are comprises of Form factor (Ff), Circulatory ratio (Rc), Compactness coefficient (Cc) and Elongation ratio (Re) and these factors are able to characterized the shape of watershed. As shape of basin affects from peak flow of stream these parameters are sensitive for flooding and soil erosion (Gajbhiye et al 2014; Godif and Manjunatha 2022).

Form factor (Ff) can able to quantify the configuration of basin. It describes that the values ranges from less than < 0.785 (Circular) and values less than < 0.78 denotes the elongated shape of watershed (Waikar and Nilawar 2014). The watershed characterized by higher value tends to witness more peak flow over shorter periods, while basin with minimal value of ‘Ff’ exhibits shorter peak flow that extends over longer duration. The computed value shows 0.52 and 0.55 for SW 01 and SW 05 indicating circular basin with intense peak flow. These sub-watershed SW 04 have 0.24 value depicts elongated shape sub-watershed with gentle peak flow over longer period.

Circulatory factor (Rc) is a measure that can identify the extent of circularity form of the river basin. The watershed with high value likely to have more efficient stream pattern, faster runoff flow and shorter peak flow period (Waikar and Nilawar 2014). The development stage of watershed can be identified from this factor where, ‘Rc’ can classified in three types i.e., younger stage have low value, medium value represents mature stage and watershed with higher values depicts the older stage (Bharath et al 2021). The calculated value of the ‘Rc’ ranges from 0.21 (SW 04) to 0.33 (SW 05) denotes moderate level of circularity.

Elongated ratio (Re) can predict the elongated form of watershed (Schumm 1956). The ‘Re’ value classified into three distinct categories: firstly, highly circular (>0.9); secondly oval range (0.8–0.9) and elongated shape (< 0.7) (Gajbhiye et al 2014; Waikar and Nilawar 2014). The SW

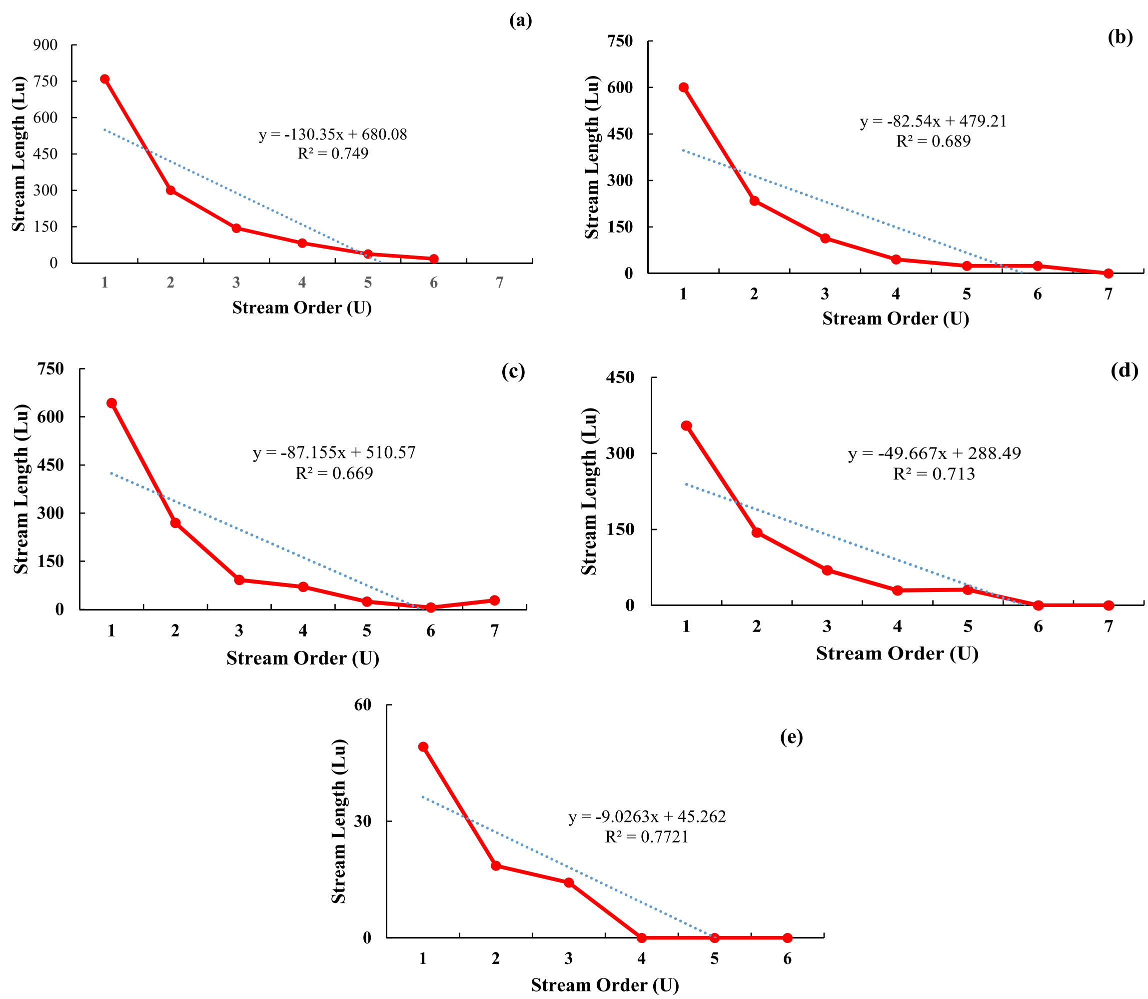


Fig. 5 Relationship between Lu and U. **a** SW01, **b** SW02, **c** SW03, **d** SW04, **e** SW05

Table 4 Calculated values of areal and shape morphometric factors

Factors	SW 01	SW 02	SW 03	SW 04	SW 05	Mean value
Stream frequency (Fs)	4.65	4.72	4.38	4.22	4.36	4.466
Drainage density (Dd)	2.62	2.75	2.49	2.43	2.28	2.514
Length of overland flow (Lo)	0.76	0.73	0.80	0.82	0.88	0.798
Form factor (Ff)	0.52	0.39	0.41	0.24	0.55	0.422
Elongation ratio (Re)	0.82	0.70	0.72	0.55	0.84	0.726
Circulatory ratio (Rc)	0.31	0.25	0.24	0.21	0.33	0.268
Compactness coefficient (Cc)	1.8	2	2.04	2.21	1.76	1.962

04 computed value is 0.72 shows elongated shape of sub-watershed and SW 01 and SW 05 value ranges from 0.82 to 0.84 reveals oval shape of sub-watersheds. This factor is crucial for predicting flood and soil erosion.

Compactness coefficient (Cc) can serves as a metric to evaluate the shape of watershed. low values of 'Cc' expresses circular watershed and vice versa. The computed value of SW 01 and SW 05 shows circular shape watershed (Table 4).

Relief morphometric parameters

These relief morphometric factors describes the terrain features of watershed. The potential energy of stream can significantly accelerated in hilly landscape (Strahler 1964; Dubey et al 2015). The relief attributes include Basin relief (R), Relief ratio (Rr), Dissection index (Dis), Ruggedness number (Rn) and Hypsometric integral (HI) (Table 5).

Table 5 Quantified values of relief morphometric factors

Factors	SW 01	SW 02	SW 03	SW 04	SW 05	Mean value
Basin relief (R)	5377	5616	2894	2918	1375	3636
Relief ratio (Rr)	171.62	189.06	86.91	88.64	162.34	139.71
Dissection index (Dis)	1.92	2.01	1.03	1.04	0.49	1.298
Ruggedness number (Rn)	14.09	15.47	7.2	7.08	3.14	9.39
Hypsometric integral (HI)	0.50	0.49	0.49	0.49	0.49	0.49

Basin relief (R) is the range of elevation between the highest and lowest point of the watershed floor this reveals basin relief. The SW 01 has highest 5377 m basin relief and lowest is 1375 m in SW 05. These values predict that high 'R' value region are more vulnerable to soil loss (Godif and Manjuntha 2022).

Relief ratio (Rr) computed value for SW 02 is 189.06 which is highest reveals as watershed at high risk of erosion. The SW 01 shows high value of Ruggedness number indicates steep slopes and erosion susceptible sub-watershed (Sujatha et al 2013; Bharatha et al 2013) where, SW 05 least prone to erosion.

Hypsometry integral (HI) values ranges to 0.49 to 0.50, which classify the sub-watershed in dominantly mature to young stage of basin development (Fig. 6). The mature stage of sub-watershed denotes the susceptibility of sub-watershed to active soil degradation (Sharma and Mahajan 2020). As $\leq 50\%$ sub-watersheds area of its mass near to denudation stage.

Sub-watershed prioritization

Based on morphometry analysis of five watersheds the factor mainly contribute to soil erosion are bifurcation ration (Rb), form factor (Ff), elongation ratio (Re), Circulatory ratio (Rc), compactness coefficient (Cc), drainage texture (Dt), stream frequency (Fs), Drainage density (Dd), length of overland flow (Lo), Relief ratio (Rr), ruggedness number (Rn) and hypsometry intergral (HI). These parameters were taken for ranking of sub-watersheds using WSA approach and the correlation matrix shows the relationship among the selected morphometric factors (Table 6).

The correlation matrix depicts that bifurcation ration (Rb) has positive correlation with form factor (Ff), elongation ratio (Re), circulatory ratio (Rc), and length of overlan flow (Lo). Further, the bifurcation ratio (Rb) has negative correlation with compactness coefficient (Cc), drainage texture (Dt), stream frequency (Fs) and ruggedness number (Rn). Drainage density (Dd) shows inverse relationship with bifurcation ratio, form factor, elongation ratio and circulatory ratio but it shows positive correlation with drainage texture and stream frequency. The weightage of selected morphometric parameters are obtained through the division of the total correlation coefficient sum with grand total of all parameters (Table 7). The form factor has the maximum weightage (0.17) among all selected morphometric factors followed by stream frequency (0.16) show strong impact on soil erosion and minimum weightage assigned to compactness coefficient (−0.03) and length of overland flow (−0.03) both factors indicates the inverse relation with soil susceptibility.

Fig. 6 Hypsometric curve of sub-watersheds (SW 01 to SW 05)

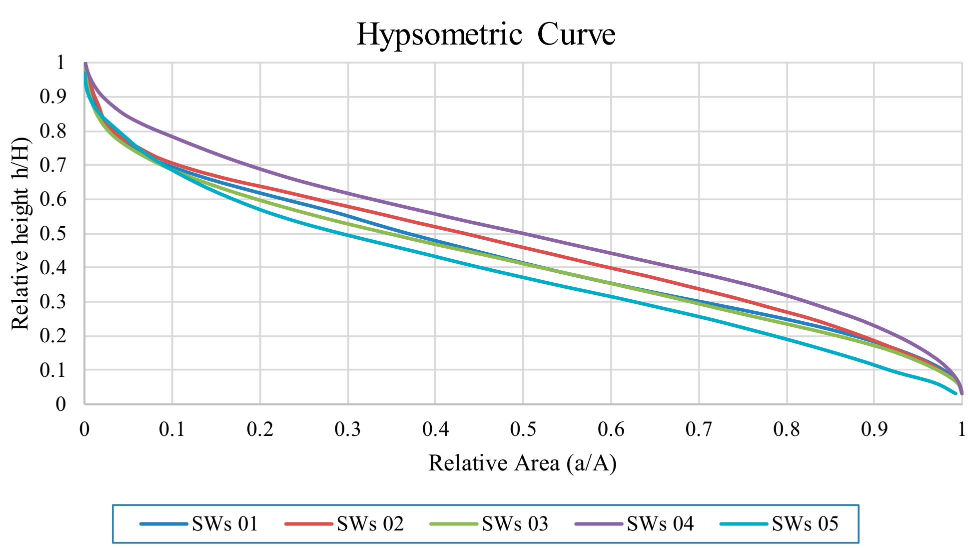


Table 6 Correlation matrix of selected erosion sensitive morphometric factors

	Rb	Ff	Re	Rc	Cc	Rt	Fs	Dd	Lo	Rr	Rn	HI
Rb	1.00											
Ff	0.66	1.00										
Re	0.63	1.00	1.00									
Rc	0.83	0.95	0.94	1.00								
Cc	−0.73	−0.98	−0.98	−0.99	1.00							
Rt	−0.56	0.00	0.04	−0.19	0.07	1.00						
Fs	−0.22	0.41	0.44	0.31	−0.43	0.57	1.00					
Dd	−0.67	−0.13	−0.10	−0.24	0.12	0.74	0.84	1.00				
Lo	0.70	0.17	0.14	0.29	−0.17	−0.80	−0.79	−0.99	1.00			
Rr	0.28	0.61	0.61	0.65	−0.69	0.02	0.81	0.44	−0.35	1.00		
Rn	−0.51	−0.03	0.00	−0.10	0.00	0.72	0.87	0.97	−0.97	0.54	1.00	
HI	0.28	0.45	0.45	0.47	−0.49	0.57	0.49	0.33	−0.37	0.37	0.50	1.00
Sum	1.69	3.44	2.54	1.20	−0.59	2.82	3.22	1.75	−0.69	1.91	1.50	1.00
Grand total	19.79	19.79	19.79	19.79	19.79	19.79	19.79	19.79	19.79	19.79	19.79	19.79

Table 7 Weightage of morphometric factors

Factors	Rb	Ff	Re	Rc	Cc	Rt	Fs	Dd	Lo	Rr	Rn	HI
Weightage	0.09	0.17	0.13	0.06	−0.03	0.14	0.16	0.09	−0.03	0.10	0.08	0.05

$$\begin{aligned}\text{WSPM} = {} & (0.09 * Rb) + (0.17 * Ff) + (0.13 * Re) \\ & + (0.06 * Rc) - (0.03 * Cc) + (0.14 * Rt) \\ & + (0.16 * Fs) + (0.09 * Dd) - (0.03 * Lo) \\ & + (0.10 * Rr) + (0.08 * Rn) + (0.05 * Hi)\end{aligned} \tag{2}$$

Using the Eq. (1) estimation of compound factor (Cf) can be done, by taking weightage value (Table 7) which are same for all SW, while the input value of geometric attributes will be change for individual SW (Eq. 2). The computed value of 'Cf' ranges from 11.9 (SW 04) to 22.23 (SW 02). The sub-watershed having maximum value of 'Cf' will receive rank '1', followed by next maximum value and so on. Which depicts the higher 'Cf' value of sub-watershed considered as more susceptible to soil erosion. Whereas, the highest 'Cf' value shows the less stable sub-watershed with more prone to erosion (Gajbhiye et al 2014; Jothimani et al 2020; Bharath et al 2021; Omar et al 2022). The SW 02 has maximum 'Cf' value with priority rank first followed by SW 01 and the SW 04 has minimum 'Cf' value show more stable sub-watershed as compared to other sub-watershed in terms of soil erosion (Table 8).

The current study classified the sub-watershed on five major category which shows that a total 54% of sub-watershed (SW 03, SW 04) come under low to very low category and 45.85% of sub-watershed falls in high, very high and moderate class of soil erosion susceptible area (Table 8), while these erosion prone sub-watershed require efficient soil conservation measures (Fig. 7)

Table 8 Ranking of sub-watersheds and erosion area coverage (%)

SW	WSPM	Final priority order	Erosion status	Area coverage %
1	20.95	2	High	31.14
2	22.23	1	Very high	23.01
3	11.93	4	Low	27.70
4	11.37	5	Very low	15.75
5	17.89	3	Medium	2.40

Conclusion

This study attempted a weighted sum approach on Mandakini River Watershed using compounds factor of morphometric attributes for five sub-watersheds. The SW 01 and SW 02 are affected by most with an area comprising of 455.85 km^2 (15.75%) and 259.29 km^2 (27.70%) comes in very high to high erosion category, SW 05 contains an area of 39.46 km^2 (2.40%) covers the moderate erosion class, the SW 03, SW 04 shows the erosion status of very low, low class comprises the area respectively, 512.59 km^2 (31.14%) and 378.69 km^2 (23.01%). In general, Patel (2012) suggests that the accuracy of Cartosat DEM is adequate for fulfilling the needs of water resource management. This research exclusively examines five major sub-watersheds, yet further watershed classification could enhance the accuracy of predicting erosion-prone

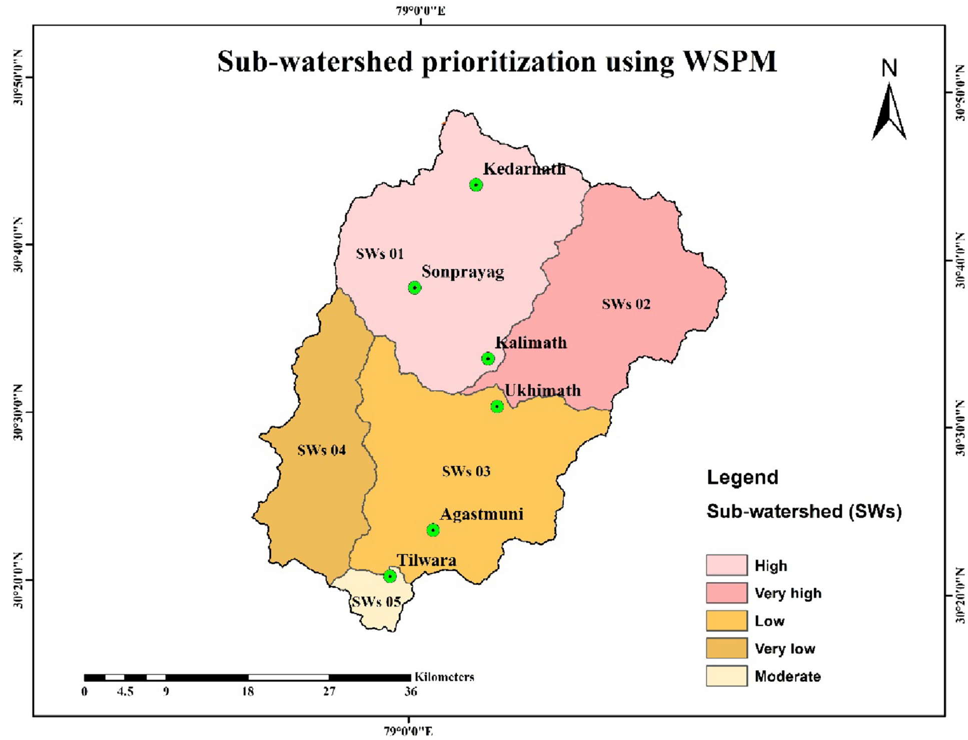


Fig. 7 Sub-watershed prioritization map using compound factor

zones. Overall, the analysis of watershed ranking using morphometric parameters yields satisfactory results in this study. GIS tools offer detailed analyses of basin characteristics, predicting hazard-prone areas, and erosion susceptibility (Bohat and Joshi 2023). Malik et al. (2019) proposed that the application of WSA in sub-watershed prioritization could enhance decision-making in water resources management and facilitate the adoption of conservation measures. This approach can serve as a valuable decision-making tool for watershed management and prioritize identification for effective watershed management, as suggested by Rai et al. 2018; Obeidat 2021. Such findings provide an additional avenue for erosion mitigation measures and offer valuable insights for watershed management authorities to aid decision-makers in erosion control strategies. Implementing development structures like check dams, contour trenches, gabion structures, and plant-based bioengineering methods can effectively reduce soil degradation rates within the watershed.

As the research area is already vulnerable to landslides and flash floods then there is urgent need to adopt the mitigation measures. From this study a good referenced gap can be taken up for conducting further analysis on micro-watershed level using spectral datasets and models i.e., RUSLE model, SWAT can be applicable.

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Data Availability The datasets generated during the current study are available from the corresponding author upon reasonable request.

Competing interests The authors declare that they have no competing interests.

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