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ORIGINAL ARTICLE

Prioritization of soil erosion prone sub-watersheds through morphometric analysis using geospatial and weighted sum approach: a case study of Boranakanive reservoir catchment in Tumkur district, Karnataka, India

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Abstract

The present study aims to prioritize the 18 sub-watersheds in the Boranakanive reservoir catchment for soil erosion-threat analysis based on morphometric analysis using the Geospatial and weighted sum approach (WSA). Due to the semi-arid climate of the study area, it is vital to understand the erosion state and drainage pattern for agricultural production. The Aster DEM with a resolution of 30 m were used to create drainage networks and delineate sub-watersheds using ArcGIS software. A matrix of linear, relief and areal parameters is generated based on previously developed standard formulas; these parameters are used to rank and prioritize sub-watersheds. Compound factor was calculated by cross-correlating 18 morphometric parameters and a weighted sum approach for each sub-watershed, and results show values ranging from 3.43 to 14.38. The sub-watershed with the most minimal compound factor value is assigned the highest priority inferring that SW2 is most sustainable and SW17 is most affected by soil erosion. Based on compound factor value, sub-watersheds are categorized into very good, good, moderate, low and very low. Results of this study show that SW17, SW18, and SW13 (160.61 km^2 area), highly prone to soil erosion, need adequate soil and water conservation practices for their management and development.

Keywords Drainage morphometry · Boranakanive catchment · Soil erosion · Watershed prioritization

Introduction

Morphometric analysis is essential for understanding watershed hydrological behavior, so that natural resources can be developed and managed effectively. Morphometric analysis is a study concerned with obtaining an accurate measurement of the earth's geometry, dimension, and shape (Clarke 1996; Agarwal 1998). Morphometric studies of a basin have been widely accepted as providing insights into changes in geomorphological and geological processes over time (Horton 1945; Strahler 1952, 1964; Muller 1968; Chorley et al. 1984). Physiographic parameters of a basin, such as shape, form, slope, density, size and length of the streams, and so on, can be linked to many hydrological phenomena (Rastogi and Sharma 1976; Magesh et al. 2012a; Arabameri et al. 2020; Hema et al 2021; Verma et al. 2022).

Hydrological behavior of catchment such as runoff, peak to discharge, soil erosion, pedology, sedimentation risks and environmental assessment are direct or inverse relationship with watershed morphometric parameters (Nookaratnam et al. 2005; Meshram and Sharma 2017; Doke et al. 2020; Rawat et al. 2021; Hema et al. 2021; Verma et al. 2022), and these are used to identify and prioritization of critical sub-watersheds. As early as the middle of the twentieth century, morphometric studies were initiated by manually analyzing topographic maps (Horton 1945; Strahler 1952, 1964; Schumm 1956). However, it is incredibly time-consuming and labour-intensive to analyze drainage morphometries conventionally. Despite of this, advances in geospatial and computational technologies have made it possible to perform more accurate and precise assessments than ever before. Compared to traditional techniques, geospatial techniques have excellent resources to tackle most of the difficulties in managing land and water resources (Rao et al. 2010).

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Satellite terrain data such as digital elevation model (DEM) may be used in cases, where there are no topographic maps available to determine morphometric parameters of watersheds. A DEM can easily be integrated into a GIS (Moore et al. 1991). Data from the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) has provided an accurate, quick, and low-cost technique to assess systemic hydrology (Smith and Sandwell 2003; Grohmann et al. 2007).

There are a direct correlation between soil erosion and land use and land cover (LULC) changes (Negash et al. 2021; Bou-imajjane et al. 2020; Olorunfemi et al. 2020). The problem of soil erosion is exacerbated by the degradation of the environment caused by the overexploitation of natural resources. Asfaw et al. (2020) describe soil erosion as a process in which water or wind loses topsoil and nutrients. Globally, soil erosion is becoming a severe environmental dilemma (Negash et al. 2021; Bou-imajjane et al. 2020; Aneseyee et al. 2020). The degradation of soil has a significant impact on agricultural productivity and food security. Inappropriate farming practices have a negative impact on agricultural production and the environment (Ahmad et al. 2020). Moreover, soil erosion poses a threat to land productivity (Benzougagh et al. 2022; Negash et al. 2021; Singh et al. 2021; Mengistu and Assefa 2020); as well as crop yields (Labriere et al. 2015; Meshesha et al. 2012).

When evaluating lands where soil erosion is the main threat to sustained agricultural production, it might be beneficial to assess erosion-prone sub-watersheds. Assessing soil erosion and mapping areas vulnerable to erosion provide information for conserving and management of soil (Sharma et al. 2012). In addition, information on soil erosion is needed to create effective land management plans for sustainable agricultural production (Bagherzadeh 2014). An analysis of the morphometry of a catchment is used to provide information on the drainage system arrangement, topographic surface pattern, dimensions and shapes of landforms, geological details, and the probability of soil erosion occurrence (Horton 1945; Smith 1950; Strahler 1957; Clarke 1996; Agarwal 1998; Negash et al. 2021; Bou-imajjane et al. 2020). Therefore, it is discovered that morphometry is an effective method for identifying and prioritizing erosion-prone locations in watersheds.

Prioritization involves identifying and ranking currently degraded sub-watersheds that require remediation to prevent further degradation. Morphometric basic, linear, aerial, and relief, parameters can facilitate the recognition of erosion-prone areas that merit prioritization. This information is crucial to prioritizing watersheds as it provides the most accurate quantitative data on drainage, slope, and relief characteristics. In the last four decades, geospatial technology and statistical tools have significantly accelerated morphometric and watershed prioritization studies. Numerous approaches have been proposed to prioritize sub-watersheds in recent years, including compound factor values (Abdeta et al. 2020), principal component analysis (PCA) (Arefin et al. 2020), multi-criteria decision-making and weighted sum approach (WSA) (Aher et al. 2014; Malik et al. 2019, Verma et al. 2022). Most studies used compound parameter values based on a simple arithmetic mean calculation to prioritize watersheds. It has been found that morphometric criteria have equal rank in identifying soil erosion-prone watersheds in these methods. However, this method may not be accurate due to the difficulty in identifying the significance of all the morphometric parameters within each sub watershed. In this study, the weighted sum method, based on a statistical correlation matrix, was used to prioritize watersheds. Compared with standard watershed prioritization techniques, this method is highly effective and dynamic. Accordingly, Aher et al. (2014), Kadam et al. (2017), Malik et al. (2019), Jothimani et al. (2020) and Omar et al. (2022) have used statistical correlation matrix-based weighted sum approaches to prioritize sub-watersheds. The present study aimed to prioritize sub-watersheds using the weighted sum approach, considering this background.

In contrast to the previous literature, the current study considers more morphometric parameters, relates stream order to stream number and stream length to stream order [coefficients of determination (R^2)] and employs a WSA for prioritization of soil erosion prone SW of the Boranakanive reservoir catchment. The study area has a semi-arid climate and groundwater levels have dropped to deeper depths due to erratic rainfall patterns and abandoned extraction. There is moderate to severe soil erosion in a significant part of the study area, which is a persistent and significant problem. As a result, it is Vital to comprehend the geomorphology, erosion state, and drainage pattern of the region to build a complete watershed development plan. As a consequence, the main Aim of this study is (1) to evaluate the hydrological characteristics of the Boranakanive reservoir catchment by determining sub-watershed morphometric parameters using ASTER DEM. (2) To identify significant sub-watersheds prone to soil erosion through prioritization using a WSA.

Study area

The Study Area Boranakanive Reservoir Catchment is bounded between authorizations 13° 42′ 18.86″ and 13° 16′ 13.72″ N and longitudes 75° 32′ 26.59″ and 76° 25′ 16.73″ E falling in Survey of India (SOI) topographic maps on the scale 1; 50,000 (57C/7, 8, 11, 12) and is located in Tumkur district. The covering an area of 970.54 km^2. The elevation varies from 978 to 585 m above mean sea level. The pre-monsoon period contributes a mean rainfall of 166 mm, the SW monsoon period contributes 417 mm, and the NE monsoon period contributes 197 mm. The study area covers different land use and land cover patterns representing Agriculture land, Scrub forest, degraded forest, and cultivated lands. Geomorphologically, the study area includes valley, valley fill, pediment, inselberg, shallow buried Pediplains, residual hill, and structural hill, etc. A structural hill is composed of schistose rocks in association with economic minerals, such as manganese, dolomite, and limestone deposits. Location map of the study area shown in Fig. 1.

Methodology

Pre-processed ASTER DEM used to derive drainage networks, delineate SW and calculate morphometric parameters using Arc GIS spatial analyst extension and Arc hydro tools in ArcGIS10.4. This drainage network is generated by filling the sinks with high elevations from the surrounding area. A set of eight-direction flow models is used to assign each grid cell the steepest downward slope from adjacent eight cells, ranging from 1, 2, 4, 8, 16, 32, 64 and 128. (Arabameri et al. 2020; Hema et al 2021). The drainage network is generated by calculating the flow accumulation based on the direction of water flow in the raster and using a different combination of pixels with a threshold value greater than 150. The workflow for delineating stream networks is illustrated in Fig. 2A. Pour points were used to define watershed and sub-watershed boundaries. These were cross verified through the SOI open series topographic maps, bearing the sheet no: (57C/7, 8, 11, 12) on 1:50,000 scale. To compute the morphometric parameters, the generated stream order will be converted to vector format. For this study, a number of the most critical quantitative morphometric parameters were chosen and analyzed, including linear, relief, and areal parameters are calculated using GIS software. Methodological flowchart used for watershed morphometric analysis shown in Fig. 2B. The derived parameters were calculated using the mathematical formulae and methods outlined in Table 1.

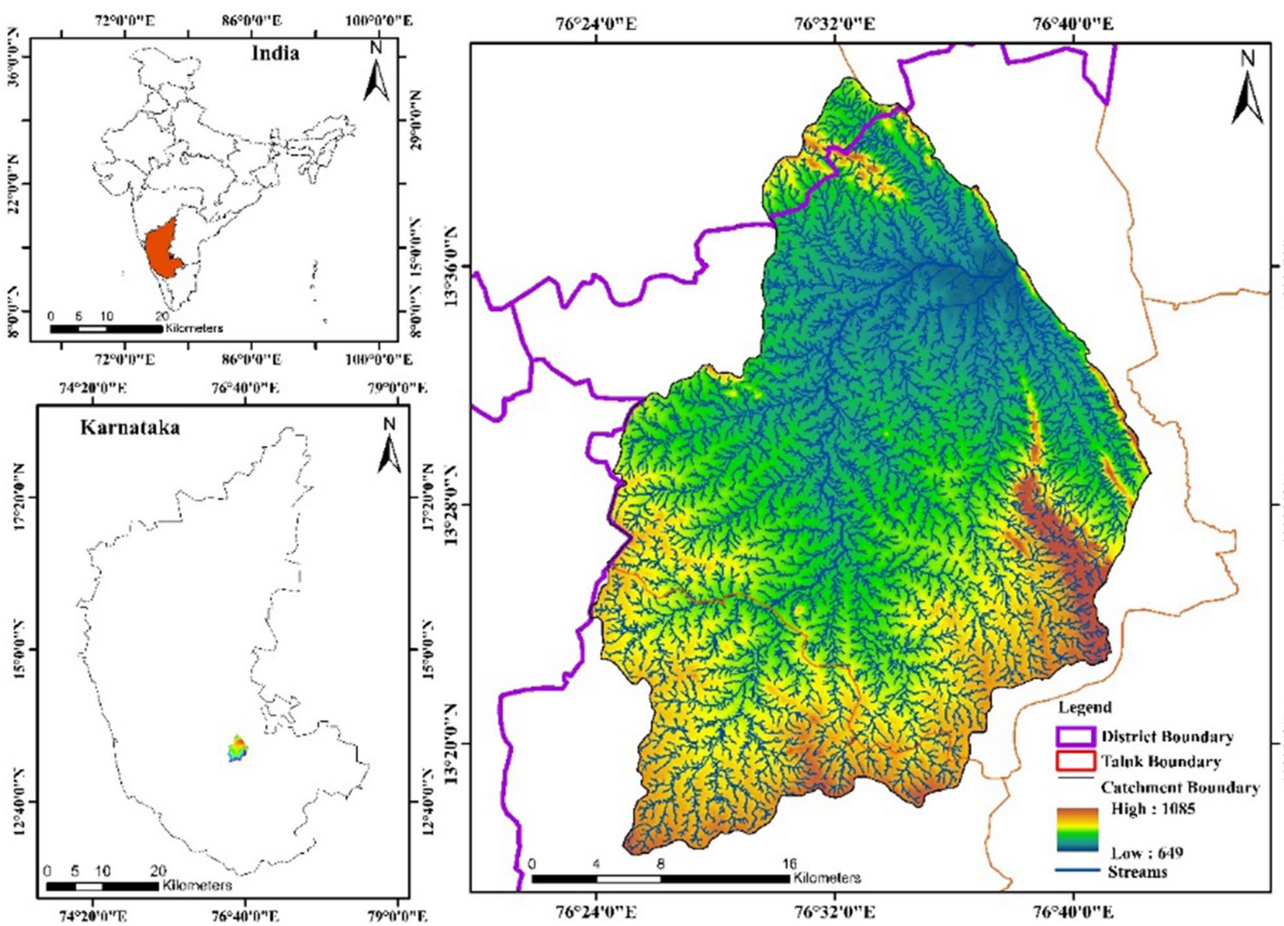

Fig. 1 Location map of the study area

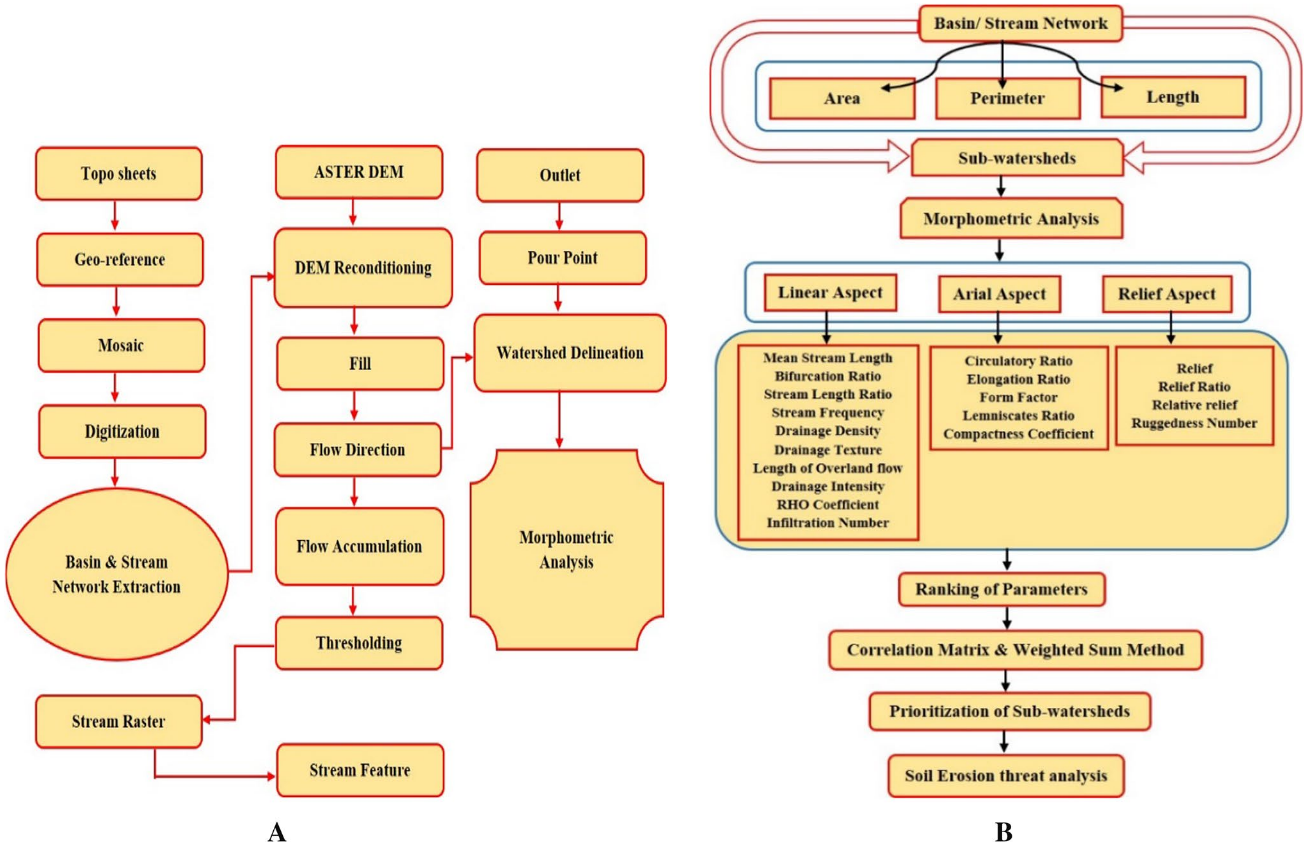

Fig. 2 **A** Workflow drainage network extraction from ASTER DEM for the study area. **B** Methodological flowchart used for watershed morphometric analysis

Preliminary priority ranking (PPR) of sub-watersheds

Assigned the preliminary ranking of sub-watersheds in terms of priority was based on their morphological characteristics, which are in accordance with (1) linear aspects including bifurcation ratio, stream length ratio, stream frequency, drainage density, length of overland flow, drainage intensity, RHO coefficient, and infiltration number. (2) areal aspects includes circulatory ratio, elongation ratio, form factor, lemniscate ratio and compactness coefficient, and (3) relief aspects includes relief, relief ratio, relative relief and ruggedness number. The potential for soil erosion and runoff intensity in a specific basin are directly related to linear and relief factors (Nookaratnam et al. 2005; Abdeta et al. 2020; Hema et al. 2021). As a result, linear and relief parameters have been ranked first, in those parameters the most significant higher value has been considered first, and the least significant value has been ranked last. In contrast, areal and form parameters exhibit an anti-correlation with soil erodibility (Raja et al. 2017), with the lowest significant values indicating susceptible soil erosion areas in a watershed. The lowest area/shape parameter value ranked first, followed by the next lowest value ranked second, and so on until the greatest value ranked last. Because all morphometric factors would have equal weight for the final ranking.

Weighted sum approach (WSA)

Sub-watershed rankings are determined by the compound factor (CF) value, calculated by multiplying the preliminary rankings derived from morphometric analysis and the weights determined through cross-correlation analysis (Aher et al. 2014). The compound factor's mathematical formula:

$$CF = PPR_{MP} \times W_{MP}, \quad (1)$$

where W_{MP} is the weighted morphometric parameter is calculated using cross-correlation analysis, PPR_{MP} is the preliminary priority rank derived from morphometric parameters, and CF is the compound factor.

Table 1 Formulae and methods adopted to compute watershed morphometric parameters

Parameters and aspects	Formulae/ methods	Units	References
Basic parameters			
Area (A)	GIS software analysis	km^2	
Perimeter (P)	"	Km	
Maximum elevation (H)	"	M	
Minimum elevation (h)	"	"	
Length	"	"	
Stream order (U)	Hierarchical rank	Dimensionless	Nookaratnam et al. (2005)
Stream number (N_u)	$N_u = N_{u1} + N_{u2} + \ldots\ldots + N_{un}$	"	Strahler (1964)
Stream length (L_u)	$L_u = L_{u1} + L_{u2} + \ldots\ldots + L_{un}$	km	Horton (1945)
Derived parameters			
Linear aspects			
Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$	km	Horton (1945)
Bifurcation ratio (R_b)	$R_b = N_u/(N_u + 1)$	Dimensionless	Schumm (1956)
Stream length ratio (R_L)	$R_L = L_u/(L_u - 1)$	"	Horton (1945)
Mean bifurcation ratio (R_{bm})	R_{bm} = average of bifurcation ratios of all orders	"	Schumm (1956)
Mean stream length ration (R_{lm})	R_{lm} = average of stream length ratios of all orders	"	Schumm (1956)
Stream frequency (F_s)	$F_s = N_u/A$	km^{-2}	Schumm (1956)
Drainage density (D_d)	$D_d = L_u/A$	"	Schumm (1956)
Drainage texture (D_t)	$D_t = Nu/\rho$	km^{-1}	Schumm (1956)
Length of overland flow (L_o)	$L_o = 1/2D_d$	Km	Schumm (1956)
Drainage intensity (D_i)	$D_i = F_s/D_d$	km^{-1}	Faniran (1968)
RHO coefficient (ρ)	$\rho = R_{lm}/R_h$		Horton (1945)
Infiltration number (I_f)	$I_f = F_s/D_d$	km^{-3}	Faniran (1968)
Relief aspects			
Relief (B_h)	$B_h = H–h$	km	Strahler (1952)
Relief ratio (R_h)	$R_h = H/L_b$	Dimensionless	Schumm (1956)
Relative relief (R_{hp})	$R_{hp} = H \times 100/P$	"	Melton (1957)
Ruggedness number (R_n)	$R_n = R \times D_d$	"	Strahler (1954)
Areal/shape aspects			
Circulatory ratio (R_c)	$R_c = 4\Pi A/P^2$	Dimensionless	Miller (1953)
Elongation ratio (R_e)	$R_e = 2/L_b \times A^{0.5}/\Pi$	"	Schumm (1956)
Form factor (F_f)	$F_f = A/L_b^{\ 2}$	"	Horton (1945)
Lemniscates ratio (K)	$K = L_b^{\ 2}/4A$	"	Chorley et al. (1957)
Compactness coefficient (C_c)	$C_c = P/2(\Pi A)^{0.5}$	"	Horton (1945)

L_{sm} mean stream length, L_u total stream length of order "u", R_b bifurcation ratio, N_u total number of stream strengths of order "u", $N_u + 1$ number of segments of the next higher order, R_L stream length ratio, $L_u - 1$ the total stream length of its next lower order, F_s stream frequency, A area of the basin, D_d drainage density, D_t drainage texture, ρ RHO coefficient, L_o length of overland flow, D_i drainage intensity, R_{lm} average of stream length ratios of all orders, R_b bifurcation ratio, I_f infiltration number, B_h relief, H maximum elevation, h minimum elevation, Rh relief ratio, H total relief (relative relief) of the basin (km), L_b basin length, R_{hp} relative relief, P perimeter, R basin relief, R_c circulatory ratio, Π 3.14, P^2 square of the perimeter, R_e elongation ratio, F_f form factor, K lemniscates ratio, C_c compactness coefficient

Results and discussion

The study area consists of 18 sub-watersheds coded SW1 to SW18. There is typically a dendritic or sub-dendritic drainage pattern. DEM and 18 Subwatersheds and drainage network of the study area shown in Figs. 3 and 4, which results in lithology characteristics, soil types, and several morphometric parameters directly or inversely related to soil erosion that are explained below.

Basic parameters

Watershed area (A) It is the major significant watershed characteristic as it directly represents the volume of water in a watershed. Therefore, the total area of the watershed projected on the horizontal plane is expressed as the watershed area (A). In this study, Total area of the Boranakanive reservoir catchment is 970.54 km^2 and sub watersheds area ranges from 35.90(SW5) to 75.85(SW10) km^2.The areas of each sub watershed shown in Table 2.

The watershed perimeter (P) is the length of the depicted boundary, representing the watershed's size. In this study, sub watershed perimeter lengths range from 29.63 (SW3-shortest) to 55.16 km (SW2-longest). The perimeter of each sub watershed shown in Table 2

Watershed length (L_b) indicates the length of a basin that is contiguous to a drainage channel (Schumm 1956). It represents the central channel of the watershed through which most water flows. In the present study, among the eighteen sub watershed, where 16.68 km (SW16) is the longest and 9.42 km (SW2) is the shortest watershed length. The L_b of each sub watershed shown in Table 2

Watershed relief (B_h) The height between the outlet and the highest elevation point on a watershed is known as watershed relief (B_h). Here, the study area elevation ranges from 582 to 976 m above mean sea level.

Stream order (U) The location of a stream in the hierarchy of tributaries is determined by stream order (U). In this study, the number and kind of tributary junctions are used to categorize the streams, which is the first stage in the morphometric analysis. The streams are ordered according to Strahler's (1964) method. First-stream orders consist of minor fingers type and non-branched tributaries; second-stream orders result from meeting two first-stream orders; third-stream orders result from meeting two second-stream orders, and so forth. Due to the geomorphology of the watershed, it increases upstream to downstream. A stream of the highest order is the primary pathway through which all discharges, runoffs, and sediments pass (Chandniha and Kansal 2017). In the present study, the highest stream order found in SW2, SW11, SW12 SW13, and SW17 exhibits the 7th and 6th order, whereas other Sub watersheds show the 5th order.

Stream number (N_u) The stream segments in each order are known as the stream number (N_u). An inverse geometric series is formed by connecting the stream numbers of a particular order (Horton 1945); it provides information on the characteristics of runoff and erosion. In the present study, the stream number is greatest at 528 (SW16) and smallest at 265 (SW3), respectively.

Stream length (L_u) In drainage networks, stream length (L_u) refers to the linear properties of the drainage system, which are used to measure the length of a channel in a given order. L_u of a given order is calculated by the sum of the length of all streams of order to the total number of streams contained in that order. The growth of L_u in first-order is most prominent; it increases with increasing stream order (Horton 1945). Shorter L_u are found in areas with steeper slopes and more refined textures, whereas longer ones are located in areas with nearly level-gentle slopes and coarser textures (Strahler 1964). It also assesses the area's hydrological parameters and bedrock formation. As a result of relatively permeable bedrock and a well-drained watershed, stream length was shortened (Sethupathi et al. 2011). In this study, 237.16 km (SW16) and 106.8 km (SW5) had the longest and shortest L_u, respectively, as shown in Table 2.

The mean stream length (L_{sm}) The characteristic size of drainage network components, i.e., a channel's dimensional attribute and contribution to watershed surfaces, is revealed as L_{sm} (Strahler 1964). In general, the L_{sm} of a higher order is more significant than the lower order. Validation of Horton's law of 'N_u' and 'L_u' strongly supports the connection of the geometry hypothesis often observed in a watershed with increasing stream order (Strahler 1953), as shown in Table 2.

Stream length ratio (R_L) In consonance with Horton's law (1945), stream length ratio is defined as the ratio of the mean length of one order to that of the next lower order. In the case of a significant change in value from one order to another, it indicates that the geomorphic development is at a late youth to mature stage. This phenomenon frequently occurs on hilly terrain due to high erosion rates (Singh and Singh 1997; Hema and Govindaiah 2012). The R_L has a direct influence in relation to the surface flow discharge and erosional stage of a basin. Low values of R_L indicate higher discharge with high erosion rates and vice versa (Sreedevi et al. 2009).

In a drainage basin, two fundamental laws are pertinent to the number and length of streams of different orders (Horton 1945).

1. Stream numbers are expressed as an inverse geometric progression based on the bifurcation ratio, which relates the number of streams of a specific order to stream order. It was observed that the results of this rule are consistent with Horton's law of stream numbers for all sub-watersheds. Figure 5 shows the relationship between stream order and stream number. A strong inverse relationship exists between stream order and stream number, with coefficients of determination (R^2) ranging from 0.86 (SW2) to 0.99 (SW12).
2. The law of stream lengths is a direct geometric series that describes the average length of streams of a particular order, the average length of streams of 1st order, and the stream length ratio. All sub-watersheds were tested for the existence of this rule, and the results differed from Horton's law L_u. Figure 6 shows the relationship between stream order and stream length, which showed a weak correlation between L_u and U, with coefficients of determination (R^2) ranging from 0.71 (SW17) to 0.99 (SW3, SW5, SW7).The deviation and variances across sub-watersheds might imply that the sub-watersheds differ in bedrock and the existence of geological control and other environmental elements, such as erosion processes.

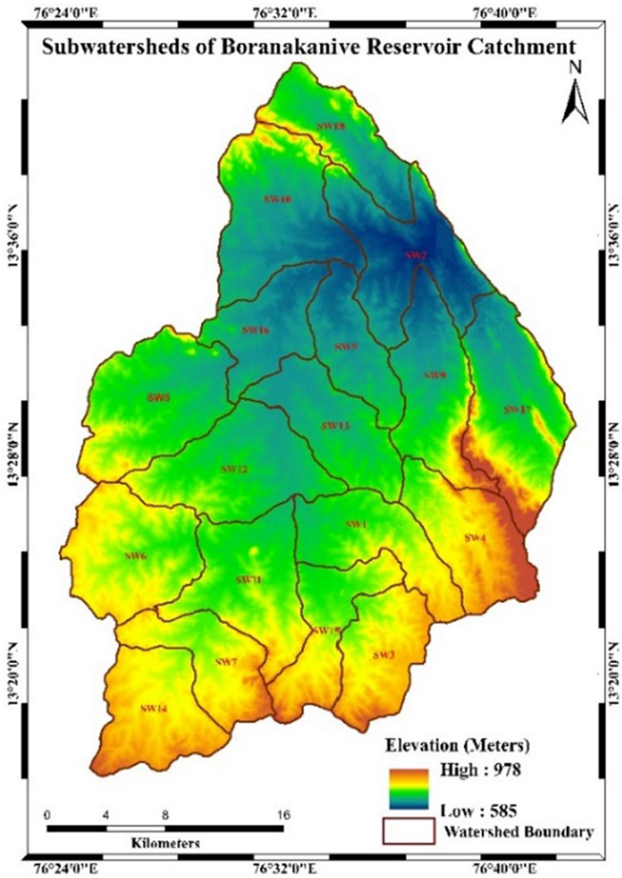

Fig. 3 DEM and 18 subwatersheds of the study area

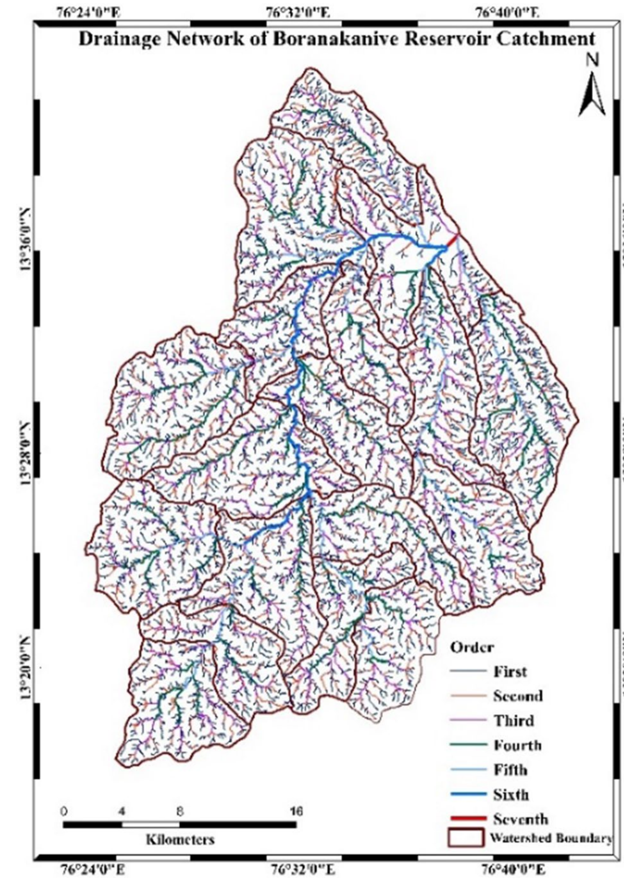

Fig. 4 Drainage network of the study area

The bifurcation ratio (R_b) To calculate it, a stream segments number is divided by the number of stream segments of the next higher order (Schumn 1956). The amount of integration between streams of different orders is indicated by the schema of branching of a drainage network (Horton 1945). Strahler (1957) proved that the R_b has a moderate range of variance for different places unless strong geological impact predominates. Table 2 results of morphometric Analysis of 18 Subwatersheds shows that R_b values do not remain constant from one order to the next order, these anomalies are determined by the watershed geological and lithological evolution (Strahler 1964). Lower R_b values are associated with sub-watersheds with fewer physiographic interventions (Strahler 1964) and whose drainage patterns have not been changed due to these interventions (Nag 1998). Higher R_b values suggest substantial structural control over the drainage pattern. In the present study, the highest and lowest R_b values were found at 23.94 (SW1) and 15.68 (SW15) accordingly. As a result, SW1, SW11, and SW2 are more interventions and SW15, SW17, and SW3 are more sustainable sub-watersheds. The mean value of the R_b of all orders is the mean R_b (R_{bm}). In this study, R_{bm} values range from 3.29(SW2) to 5.98 (SW1).

Derived parameters

Linear parameters

Stream frequency (F_s) The total number of streams per unit area is known as stream frequency (F_s) (Horton 1945). It is theoretically conceivable to have basins with the same D_d but different stream frequencies, as well as basins with the same F_s but different D_d, because D_d and F_s vary with the size of the drainage area, they are not directly comparable for small and large drainage basins. However, F_s has a positive association with D_d, indicating that F_s and D_d increase simultaneously (Abdeta et al. 2020; Hema et al 2021). According to Reddy et al. (2004), low values of F_s are simply the existence of underlying permeable material and intense relief. An increase in F_s values indicates a high rate of erosion. In this study, F_s is higher at 8.48 (SW17), and lower at 5.67 (SW2). Due to its impermeable subsurface material, sparse vegetation, high relief, and low infiltration rate, SW 17 is subject to rapid soil erosion compared to other sub watersheds. Accordingly, SW17 is assigned rank 1, which is the most vulnerable to erosion, and the

Table 2 Results of morphometric analysis of 18 subwatersheds

	Stream orders	Code of watersheds																	
		SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11	SW12	SW13	SW14	SW15	SW16	SW17	SW18
1	Number of the stream (N_u)	356	359	265	352	275	455	268	483	372	509	455	476	397	338	287	528	336	331
	1st order (N_{u1})	280	277	208	270	198	353	208	370	288	386	357	361	299	261	224	395	246	244
	2nd order (N_{u2})	60	62	45	63	54	78	48	89	65	94	81	81	67	59	48	101	69	68
	3rd order (N_{u3})	14	12	8	13	20	19	9	20	13	19	12	23	23	13	11	24	14	16
	4th order (N_{u4})	1	2	3	5	2	4	2	3	5	6	2	8	5	4	3	7	4	2
	5th order (N_{u5})	1	3	1	1	1	1	1	1	1	3	2	2	2	1	1	1	2	1
	6th order (N_{u6})	–	2	–	–	–	–	–	–	–	1	1	1	1	–	–	–	1	–
	7th order (N_{u7})	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2	Length of the stream (L_u)	142.8	166.3	116.9	157.0	106.8	185.4	126.2	213.7	173.6	220.8	189.5	207.6	153.1	152.7	129.6	237.1	134.5	144.1
	1st order (L_{u1})	70.04	78.71	59.01	75.22	52.59	97.58	66.17	107.29	85.91	111.31	96.18	101.14	74.90	78.42	63.98	126.98	70.38	78.60
	2nd order (L_{u2})	32.38	34.88	30.90	41.02	28.29	43.21	30.76	57.42	38.36	51.87	47.75	49.22	37.68	34.66	32.18	48.13	31.18	33.39
	3rd order (L_{u3})	20.69	29.69	16.15	23.83	13.32	24.61	18.79	25.60	27.07	23.55	19.15	27.93	15.95	23.20	14.46	22.52	12.91	17.72
	4th order (L_{u4})	13.91	5.67	6.68	6.44	9.35	14.8	6.69	19.27	6.04	16.83	11.47	17.94	9.26	11.23	12.25	27.83	5.56	7.87
	5th order (L_{u5})	5.82	7.80	4.22	10.41	4.29	5.11	3.76	4.17	16.29	14.73	8.21	3.38	11.14	4.63	6.76	11.67	4.97	6.59
	6th order (L_{u6})	–	8.38	–	–	–	–	–	–	–	2.50	6.76	7.96	4.22	–	–	–	9.55	–
	7th order (L_{u7})	–	1.20	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
3	Bifurcation ratio (R_b)	23.94	19.78	15.91	16.72	18.36	17.37	16.16	18.26	17.03	17.21	20.15	16.84	16.47	16.2	15.68	18.53	15.98	17.83
	N_{u1}/N_{u2} (R_{b1})	4.66	4.46	4.62	4.28	3.66	4.52	4.33	4.15	4.63	4.10	4.40	4.45	4.46	4.42	4.66	3.91	3.56	3.58
	N_{u2}/N_{u3} (R_{b2})	4.28	5.11	5.62	4.84	2.7	4.10	5.33	4.45	5	4.94	6.75	3.52	2.91	4.53	4.36	4.20	4.92	4.25
	N_{u3}/N_{u4} (R_{b3})	14	6	2.66	2.6	10	4.75	4.5	6.76	2.8	3.16	6	2.87	4.6	3.25	3.66	3.42	3.5	8
	N_{u4}/N_{u5} (R_{b4})	1	0.66	3	5	2	4	2	3	5	2	1	4	2.5	4	3	7	2	2
	N_{u5}/N_{u6}(R_{b5})	–	1.5	–	–	–	–	–	–	–	3	2	2	2	–	–	–	2	–
	N_{u6}/N_{u7}(R_{b6})	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
4	Stream length ratio (R_l)	2.19	4.07	2.09	3.01	2.18	1.94	1.95	1.99	4.07	2.67	3.03	4.93	3.08	2.0	2.33	2.5	4.10	2.22
	L_{u2}/L_{u1} (R_{l1})	0.48	0.44	0.52	0.54	0.53	0.46	0.43	0.56	0.46	0.46	0.49	0.48	0.50	0.44	0.50	0.37	0.44	0.42
	L_{u3}/L_{u2} (R_{l2})	0.63	0.85	0.52	0.58	0.43	0.56	0.61	0.47	0.70	0.45	0.40	0.56	0.42	0.66	0.44	0.46	0.41	0.53
	L_{u4}/L_{u3} (R_{l3})	0.67	0.19	0.42	0.27	0.75	0.60	0.35	0.75	0.24	0.73	0.49	0.64	0.58	0.48	0.84	1.23	0.43	0.44
	L_{u5}/L_{u4} (R_{l4})	0.41	1.38	0.63	1.62	0.45	0.34	0.56	0.21	2.69	0.87	0.61	0.88	1.20	0.41	0.55	0.41	0.89	0.83
	L_{u6}/L_{u5} (R_{l5})	–	1.07	–	–	–	–	–	–	–	0.16	0.82	2.35	0.37	–	–	–	1.91	–
	Lu_7/L_{u6} (R_{l6})	–	0.14	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Parameters	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11	SW12	SW13	SW14	SW15	SW16	SW17	SW18
1	(A)	48.05	63.22	42.81	51.22	35.90	61.78	41.28	71.00	54.88	75.85	60.78	66.62	47.18	51.68	41.73	73.82	39.61	43.13
2	(P)	38.08	55.16	29.63	33.07	29.90	33.72	33.64	37.61	42.00	46.82	42.87	39.59	34.35	32.48	39.30	41.05	34.19	34.19
3	(H)	780	753	827	978	699	769	815	783	905	789	803	749	715	819	845	978	733	798
4	(h)	585	585	687	671	597	673	686	628	588	594	642	628	621	696	664	601	601	598

Table 2 (continued)

	Parameters	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11	SW12	SW13	SW14	SW15	SW16	SW17	SW18
5	(L_b)	13.86	9.42	10.41	12.79	12.07	10.06	10.95	12.84	15.28	12.96	13.01	15.19	12.30	10.34	13.53	16.68	11.62	13.28
6	(U)	V	VII	V	V	V	V	V	V	V	VI	VI	VI	VI	V	V	V	VI	V
7	(N_u)	356	359	265	352	275	455	268	483	372	509	455	476	397	338	287	528	336	331
8	(L_u)	142.83	166.37	116.98	157.00	106.86	185.43	126.20	213.78	173.67	220.80	189.54	207.60	153.18	152.17	129.65	237.16	134.581	144.182
9	(L_{sm})	0.401	0.463	0.441	0.446	0.388	0.407	0.470	0.442	0.466	0.433	0.416	0.436	0.385	0.450	0.451	0.449	0.400	0.435
10	(R_b)	23.94	19.78	15.91	16.72	18.36	17.37	16.16	18.26	17.03	17.21	20.15	16.84	16.47	16.2	15.68	18.53	15.98	17.83
11	(R_l)	2.19	4.07	2.09	3.01	2.18	1.95	1.99	1.94	4.07	2.67	3.03	4.93	3.08	2.00	2.33	2.5	4.10	2.23
12	(R_{bm})	5.98	3.29	3.97	4.18	4.59	4.34	4.04	4.56	4.25	3.44	4.03	3.36	3.29	4.05	3.92	4.63	3.19	4.45
13	(R_{lm})	0.54	0.67	0.52	0.75	0.54	0.48	0.49	0.48	1.01	0.53	0.60	0.98	0.61	0.50	0.58	0.62	0.82	0.55
14	(F_S)	7.40	5.67	6.18	6.87	7.65	7.36	6.49	6.80	6.77	6.71	7.48	7.14	8.41	6.53	6.87	7.15	8.48	7.67
15	(D_d)	2.97	2.63	2.73	3.06	2.97	3.00	3.05	3.01	3.16	2.91	3.11	3.11	3.24	2.94	3.10	3.21	3.39	3.34
16	(D_t)	9.34	6.50	8.94	10.64	9.19	13.49	7.96	12.84	8.85	10.86	10.61	12.02	11.55	10.40	7.30	12.86	9.82	9.68
17	(L_o)	0.1682	0.1900	0.1830	0.1631	0.1680	0.1666	0.1635	0.1661	0.1580	0.1718	0.1603	0.1604	0.1540	0.1700	0.1609	0.1556	0.1471	0.1496
18	(D_i)	2.49	2.15	2.26	2.24	2.57	2.45	2.12	2.25	2.14	2.30	2.40	2.29	2.59	2.22	2.21	2.22	2.49	2.29
19	(p)	0.091	0.206	0.131	0.179	0.119	0.112	0.123	0.106	0.239	0.155	0.150	0.292	0.187	0.123	0.148	0.134	0.257	0.125
20	(I_f)	22.01	14.93	16.90	21.05	22.76	22.08	19.84	20.47	21.44	19.52	23.33	22.263	27.311	19.198	21.356	22.97	28.80	25.64
21	(B_h)	195	168	140	307	102	96	129	155	317	195	161	121	94	123	181	377	132	200
22	(R_h)	0.056	0.079	0.079	0.076	0.057	0.076	0.074	0.060	0.059	0.060	0.061	0.049	0.058	0.079	0.062	0.058	0.063	0.060
23	(R_{hp})	2.048	1.365	2.790	2.956	2.337	2.280	2.422	2.081	2.154	1.684	1.872	1.891	2.081	2.521	2.149	2.382	2.143	2.33
24	(R_n)	0.5790	0.442	0.382	0.940	0.303	0.288	0.394	0.466	1.002	0.567	0.501	0.377	0.305	0.361	0.562	1.21	0.448	0.668
25	(R_c)	0.416	0.261	0.612	0.588	0.504	0.682	0.458	0.630	0.390	0.434	0.415	0.534	0.502	0.615	0.339	0.550	0.425	0.463
26	(R_e)	0.564	0.951	0.708	0.631	0.559	0.880	0.661	0.740	0.546	0.758	0.675	0.605	0.629	0.784	0.538	0.581	0.610	0.557
27	(F_t)	0.249	0.711	0.394	0.312	0.246	0.609	0.343	0.430	0.234	0.451	0.358	0.288	0.311	0.483	0.227	0.265	0.293	0.244
28	(K)	4.001	1.406	2.534	3.195	4.062	1.639	2.908	2.321	4.25	2.214	2.786	3.466	3.208	2.069	4.387	3.768	3.411	4.091
29	(C_c)	1.549	1.956	1.277	1.303	1.407	1.210	1.476	1.259	1.599	1.516	1.551	1.368	1.410	1.274	1.715	1.347	1.532	1.468

sub-watershed with the lowest F_s (5.87) is assigned rank 17, i.e., SW2.

Drainage density (D_d) refers to the total length of streams per unit area (Horton 1945). It depicts the growth of channels and the proximity of their spacing in a watershed. In soil erosion calculations, drainage density is a sensitive indicator, as it indicates the effect of topographic factors on the outflow. It has been shown that D_d is greatly influenced by the dimensions of the watershed, relief, climate, vegetation (Moglen et al. 1998), and soil and rock characteristics (Kelson and Wells 1989), as well as the processes of landscape development. In a basin with sparse vegetation and significant relief, the D_d will be greater if the underlying material is soft and impervious. Low D_d and coarse D_t are directly correlated, whereas high D_d leads to fine D_t, excessive runoff, and erosion potential (Strahler 1964). This study found a higher D_d of 3.39 (SW17) and 2.63 (SW2) had a D_d. According to the values, the underlying material in SW 17 is soft and impervious, sparsely vegetated, and has significant relief, resulting in a higher level of soil erosion than in other sub watersheds. Accordingly, SW17 is assigned rank 1, which is the most vulnerable to erosion, and the sub-watershed with the lowest D_d (2.63) is assigned rank 17, i.e., SW2.

Drainage texture (D_t) is the total number of streams of all orders per perimeter of the basin (Horton 1945). In impermeable terrain, drainage lines are closer together than in permeable areas (Smith 1950), D_t is categorized into five distinct textures: 0–2 specifies extremely coarse, 2–4 medium, 4–6 moderate, 6–8 fine, and > 8 specifies very fine D_t. Vegetation cover is also essential when it comes to drainage texture, because a more delicate texture was predicted in areas of soft rock that were not shielded by vegetation, and coarse D_t results in resistant rocks. In the current study values of D_t of 13.49(SW6), 12.84(SW8) are higher and 6.50(SW2), 7.30(SW15) are lower. In our study, we found that sub watersheds varied in drainage texture from very fine to fine. In general, a high texture ratio is associated with a high erosion rate. The result is that SW6 has the highest erosion ranking of 1, while SW2 has the lowest erosion ranking of 17, which is the least susceptible to erosion among different sub watersheds.

Length of overland flow (L_o) it refers to the amount of time that water flows over the land before being concentrated in defined stream courses. It is half of the reciprocal of D_d (Horton 1945). In the present study, the L_o is greater in 0.190(SW2), 0.183(SW3), and shorter in 0.147(SW17), (0.149) SW18 among eighteen sub-watersheds. The higher the L_o value, the greater the surface area for surface run-off, and therefore, the greater the possibility for water infiltration and less erosion. Therefore, the highest ranking is assigned to SW17, whereas the lowest ranking is assigned to SW2.

Drainage intensity (D_i) the ratio of F_s to D_d is known as drainage intensity (D_i) (Faniran 1968). Flooding, erosion, and landslides are all vulnerable in a watershed with low D_d, D_t, and D_i. In the current study, among eighteen sub-watersheds, the drainage intensity of 2.59 (SW13) and 2.57 (SW5) are higher, whereas 2.12(SW7), and 2.14(SW9), are lower. According to the values, SW7 and SW9 have the highest levels of soil erosion compared to the other sub-watersheds. Therefore, the highest ranking is assigned to SW7, whereas the lowest ranking is assigned to SW13.

The rho coefficient (ρ) is the proportion of L_u to R_b (Horton 1945). The ρ is an essential metric that links D_d to physiographic development, making it easier to assess the drainage network's dimension of storage (Horton 1945). In this present study, the Rho coefficient is greater 0.292 (SW12), 0.239(SW9), whereas 0.091(SW1), 0.123 (SW14), are lower. This indicates that SW12 has the maximum dimension of storage during floods and the greatest erosion intensification under high discharge.

The infiltration number (If) is obtained by the D_d and F_s product. An inverse relationship exists between this parameter and the infiltration capacity of a basin. A higher value suggests limited infiltration and heavy runoff, whereas a lower value indicates very low runoff and strong infiltration capacity (Faniran 1968). In this present study, the infiltration numbers 28.80 (SW17), 27.31(SW13), are higher, whereas 14.93(SW2), 16.90(SW3), are lower. According to this results, SW17 and SW13 have the highest levels of soil erosion compared to the other sub-watersheds. Therefore, the highest ranking is assigned to SW17, whereas the lowest ranking is assigned to SW2.

Areal parameter

The circularity ratio (R_c) is the ratio of the area of a watershed to the area of a circle with the same circumference as the watershed's perimeter (Miller 1953). Various factors influence the R_c, including stream length, frequency and geological formations, land use/land cover, climate, terrain, and basin slope. Therefore, it is an important ratio reflects a watershed's development stage. There are young, mature, old stages of watershed development represented by R_c values of a low, medium, and high (Wilson and Ch 2012). The R_c value describes the basin's shape; as the R_c value rises, the basin's shape becomes more rounded, permeable strata and the short flow duration increases the risk of flooding at the outflow point (Bogale 2021). Lower R_c values indicates elongated shape and impermeable surface. The circulatory ratio in the present study is lower 0.261(SW2), 0.390(SW9), and higher 0.682(SW6), 0.630(SW8) among eighteen sub-watersheds. According to the results, SW2 and SW9 with impermeable strata at a youth stage of watershed

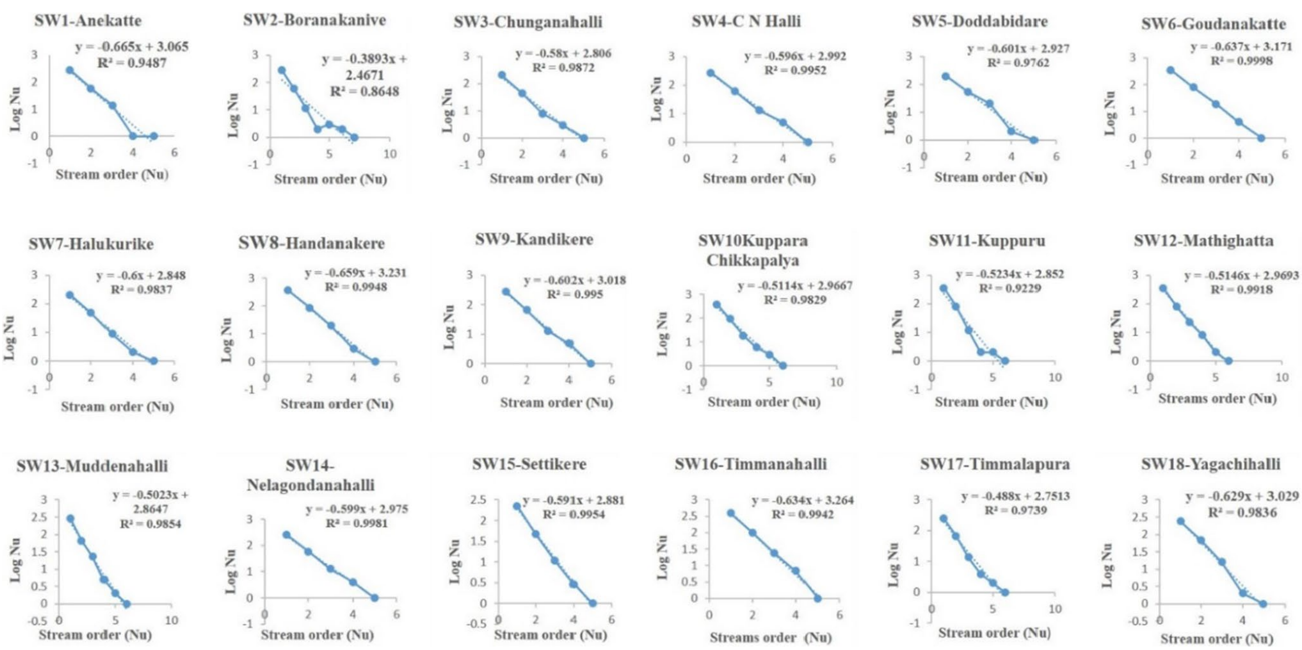

Fig. 5 Relationship between stream order and stream number

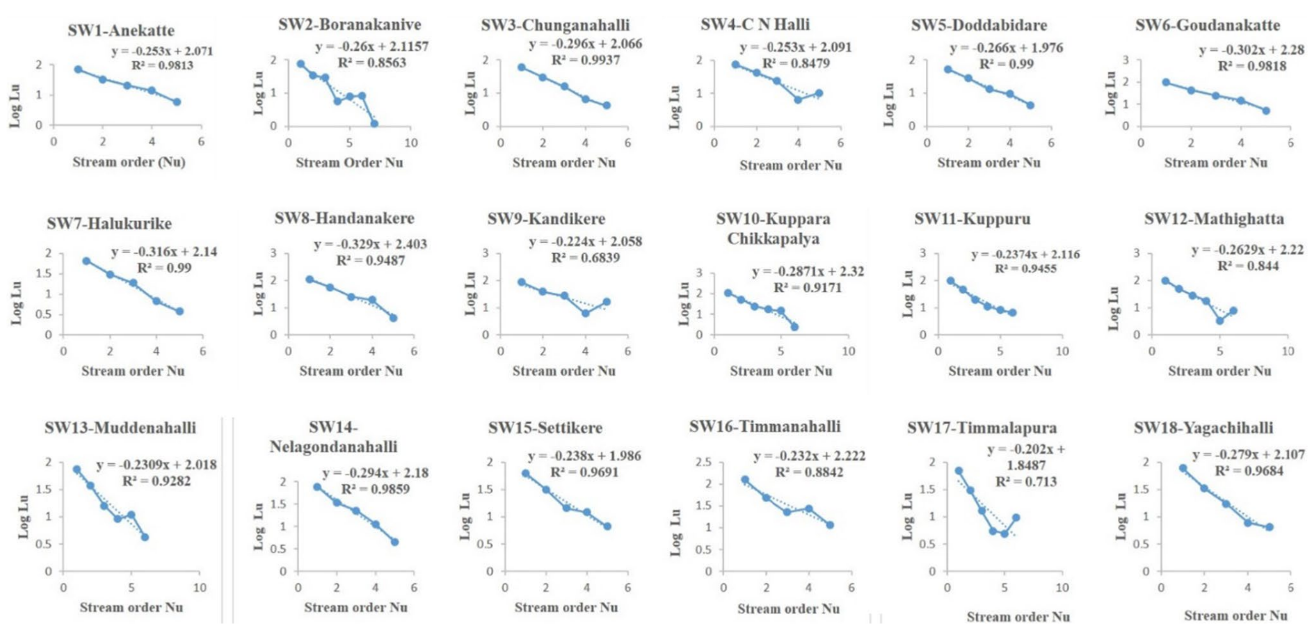

Fig. 6 Relationship between stream order and stream length

development, whereas SW6 and SW8 are with permeable strata at an older stage of watershed development.

The elongation ratio (R_e) A watershed's elongation ratio (R_e) is defined as the ratio between the diameter of the circle and the maximum length of the watershed (Schumm 1956). R_e values range from 0.52 to 0.75 under a wide range of climatic and geologic conditions. Closer to 1.0 indicates minimal amount of relief and values between 0.6 and 0.8 indicate substantial relief and steep land slope (Strahler 1964). These numbers classified into three groups: (a) circular (> 0.9), (b) oval (0.9 to 0.8), and (c) less elongated (0.7). Compared to an elongated basin, a circular basin efficiently discharges run-off (Singh and Singh 1997). In the present study 0.538(SW15), 0.546(SW9) had lower R_e values and 0.951 (SW2), 0.880(SW6) have higher R_e values. The study's results indicate that the sub-watersheds in the study area are oval or less elongated and that soil erosion and runoff intensities differ depending on the shape of the sub-watersheds. For example, SW2 and SW6 have oval shapes, and SW15 and SW9 have less elongated shapes.

Form factor (F_f) The ratio of the watershed area (A) to watershed length squared (L_b) is called form factor (Strahler 1964). According to the preponderance of researchers, for a perfectly circular basin, the value of the F_f would always be more than 0.78 (Abdeta et al. 2020; Hema et al 2021). If the form factor is smaller; a low runoff will create a prolonged runoff duration. However, a rounded-shaped watershed with a high form factor value experiences high runoff with a short concentration time, which is highly susceptible to floods. The maximum form factor threshold value for this rounded shape watershed should be less than 0.7854 (Waikar and Nilawar 2014). In this study, the value of F_f is lower at 0.227 (SW15), 0.234 (SW9), whereas 0.711(SW2), 0.609(SW6), have greater form factors. A maximum value of 0.711 is observed in SW2, which shows low erosion susceptibility and a minimum value of 0.227 is observed in SW15, which indicates high erosion susceptibility.

The Lemniscate's ratio (K) evaluates the watershed's gradient (Chorley et al. 1957). In this study 1.406 (SW2), 1.639(SW6) have lower K values, whereas 4.387(SW15), 4.25(SW9), have higher K values.

The compactness coefficient (C_c) also known as Gravelius indexes (GI), are calculated by dividing a basin's perimeter by its circumference to equal its area (Horton 1945). The C_c is unaffected by watershed size and is only influenced by the slope. Lower values suggest more basin elongation and less erosion, whereas higher values indicate less elongation and more erosion. In this study, the compactness coefficient of 1.210(SW6), 1.259(SW8), is lower, but 1.956 (SW2), 1.715(SW15) are significantly higher. It was found that the value of C_c in this study is lower at 1.210 (SW6) and 1.259 (SW8), while it is higher at 1.956 (SW2) and 1.715 (SW6). Observed values of SW2 are 1.956, indicating a low erosion susceptibility, and SW6 value of 1.210, which indicates a high erosion susceptibility.

Relief parameter

A relief ratio (R_h) it is defined as a ratio of the maximum relief of a watershed to its maximum length, which is parallel to the principal drainage line. It is an indicator of erosion process and intensity on watershed slopes, it measures the overall steepness of a watershed (Schumm 1956).The conversion rate of potential to the kinetic energy of water flowing through the basin is controlled by the relief ratio. There is a general consensus that high values of R_h represent the attributes of elevated regions, whereas low values represent the attributes of valleys and Pediplains (Asode et al. 2016). Steeper basins with high R_h value indicate quicker run-off and more peaked basin discharge and potent erosive force (Abdeta et al. 2020). In this study, 0.079(SW14) and 0.079(SW2), have higher R_h values, whereas 0.049(SW12) and 0.056(SW1) have lower R_h values.

Relative relief (R_{hp}) is determined through perimeter and watershed relief (Melton 1957). Defining R_{hp} as a morphometric quantity is used to examine the morphological characteristics of any terrain. In this study, 2.956(SW4), 2.790(SW3) had greater relative relief values, whereas 1.356(SW2), 1.684(SW10) have lower values.

Ruggedness number (R_n) is the product of the maximum basin relief (H) and the D_d. The R_n shows the terrain's structural complexity and it rises when the H and D_d are high, and the slope is steep (Strahler 1956). In contrast, a high ruggedness number indicates that the area is highly susceptible to soil erosion, while a low ruggedness number suggests that the area is less prone to soil erosion. In this study, the R_n values are higher 1.21(SW16), 1.002(SW9), and lower at 0.288(SW6), 0.305 (SW13) (Table 3).

Prioritization of sub watershed based on weighted sum approach (WSA)

Prioritization of watersheds is an integral part of watershed management by assigning ranks to distinct watersheds in a catchment in priority of various treatments (Pandey et al. 2011). It may not be possible to complete the watershed development program entirely at the same time due to a lack of resources and economic restrictions. As a result, High-risk erosion regions are defined and determined using morphometric analysis (Choudhari et al. 2018; Verma et al. 2022). This study focuses on the prioritization of sub-watersheds for soil erosion threats. The cross-correlation analysis performed for the linear, areal, and shape parameters, as shown in Table 4, D_d and R_{lm}, R_{bm} and F_s, D_t, D_i, ρ, B_h, R_{hp}, R_n, R_c, K, and I_f and C_c has a substantial positive connection, but F_f and R_e, L_o and R_h have a significant negative association. CF was calculated using Eq. 2 to determine the priority rank of sub-watersheds. Next, the attribution of weights to morphometric parameters are computed by dividing the total correlations by the sum of the correlation coefficients

Table 3 Preliminary priority ranking of linear, areal, and shape parameters of 18 sub-watersheds

Sl. no.	Parameters	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11	SW12	SW13	SW14	SW15	SW16	SW17	SW18
Linear parameters																			
1	Mean Bifurcation ratio (R_{bm})	1	17	12	8	3	6	10	4	7	14	11	15	16	9	13	2	18	5
2	Mean Stream length ratio (R_{lm})	11	5	14	4	12	17	16	18	1	13	8	2	7	15	9	6	3	10
3	Stream Frequency (F_S)	6	18	17	10	4	7	16	11	12	13	5	10	2	14	9	8	1	3
4	Drainage density (D_d)	14	18	17	9	13	12	10	11	5	16	6	7	3	15	8	4	1	2
5	Drainage texture (D_t)	12	18	13	7	14	1	15	3	15	6	8	4	5	9	17	2	10	11
6	Length of overland flow (L_o)	5	1	2	10	6	7	9	8	14	3	13	12	16	4	11	15	18	17
7	Drainage intensity (D_i)	4	16	10	13	2	5	18	11	17	7	6	9	1	14	15	12	3	8
8	RHO coefficient (p)	18	4	11	6	15	16	14	17	3	7	8	1	5	13	9	10	2	12
9	Infiltration number (I_f)	9	18	17	12	6	8	14	13	10	15	4	7	2	16	11	5	1	3
Relief parameters																			
10	Relief (B_h)	6	8	11	3	16	17	13	10	2	5	9	15	18	14	7	1	12	4
11	Relief ratio (R_h)	17	2	3	4	16	5	6	12	13	11	9	18	14	1	8	15	7	10
12	Relative relief (R_{hp})	14	18	2	1	6	8	4	13	9	17	16	15	12	3	10	5	11	7
13	Ruggedness number (R_n)	5	11	13	3	17	18	12	10	2	6	8	14	16	15	7	1	9	4
Areal parameters																			
14	Circulatory ratio (R_c)	5	1	15	14	11	18	8	17	3	7	4	12	10	16	2	13	6	9
15	Elongation ratio (R_e)	5	18	13	10	4	17	11	14	2	15	12	7	9	16	1	6	8	3
16	Form factor (F_f)	5	18	13	10	4	17	11	14	2	15	12	7	9	16	1	6	8	3
17	Lemniscate ratio (K)	14	1	6	9	15	2	8	5	17	4	7	12	10	3	18	13	11	16
18	Compactness coefficient (C_c)	14	18	4	5	8	1	11	2	16	12	15	7	9	3	17	6	9	10

Table 4 Cross-correlation matrix between linear, aerial, and relief parameters. Correlation between each morphometric parameters based on possitive and negative values colour is varied

	(Rbm)	(Rlm)	(FS)	(Dd)	(Dt)	(Lo)	(Di)	(p)	(If)	(Bh)	(Rh)	(Rhp)	(Rn)	(Rc)	(Re)	(Ff)	(K)	(Cc)
(Rbm)	1	-0.335	0.023	-0.078	0.044	0.039	0.15	-0.661	-0.047	0.143	-0.115	0.27	0.134	0.163	-0.271	-0.263	0.304	-0.193
(Rlm)	-0.335	1	0.118	0.329	-0.025	-0.311	-0.137	0.913	0.216	0.297	-0.334	-0.167	0.318	-0.29	-0.312	-0.293	0.344	0.252
(FS)	0.023	0.118	1	0.793	0.403	-0.787	0.814	0.137	0.971	-0.247	-0.54	0.03	-0.154	0.07	-0.484	-0.489	0.435	-0.201
(Dd)	-0.078	0.329	0.793	1	0.221	-0.996	0.294	0.292	0.912	0.105	-0.527	0.144	0.216	-0.012	-0.648	-0.654	0.598	-0.139
(Dt)	0.044	-0.025	0.403	0.221	1	-0.249	0.432	-0.017	0.336	-0.387	-0.153	0.047	-0.359	0.65	0.199	0.156	-0.306	-0.654
(Lo)	0.039	-0.311	-0.787	-0.996	-0.249	1	-0.293	-0.258	-0.902	-0.116	0.547	-0.166	-0.227	-0.025	0.666	0.675	-0.611	0.18
(Di)	0.15	-0.137	0.814	0.294	0.432	-0.293	1	-0.089	0.653	-0.476	-0.364	-0.071	-0.435	0.14	-0.167	-0.169	0.137	-0.206
(p)	-0.661	0.913	0.137	0.292	-0.017	-0.258	-0.089	1	0.228	0.101	-0.256	-0.302	0.121	-0.313	-0.124	-0.111	0.136	0.295
(If)	-0.047	0.216	0.971	0.912	0.336	-0.902	0.653	0.228	1	-0.132	-0.547	0.058	-0.028	0.02	-0.554	-0.558	0.504	-0.16
(Bh)	0.143	0.297	-0.247	0.105	-0.387	-0.116	-0.476	0.101	-0.132	1	-0.121	0.192	0.993	-0.129	-0.334	-0.321	0.369	0.1
(Rh)	-0.115	-0.334	-0.54	-0.527	-0.153	0.547	-0.364	-0.256	-0.547	-0.121	1	0.353	-0.179	0.206	0.659	0.652	-0.65	-0.059
(Rhp)	0.27	-0.167	0.03	0.144	0.047	-0.166	-0.071	-0.302	0.058	0.192	0.353	1	0.213	0.632	-0.314	-0.343	0.223	-0.668
(Rn)	0.134	0.318	-0.154	0.216	-0.359	-0.227	-0.435	0.121	-0.028	0.993	-0.179	0.213	1	-0.114	-0.402	-0.39	0.432	0.069
(Rc)	0.163	-0.29	0.07	-0.012	0.65	-0.025	0.14	-0.313	0.02	-0.129	0.206	0.632	-0.114	1	0.147	0.1	-0.268	-0.973
(Re)	-0.271	-0.312	-0.484	-0.648	0.199	0.666	-0.167	-0.124	-0.554	-0.334	0.659	-0.314	-0.402	0.147	1	0.996	-0.971	0.038
(Ff)	-0.263	-0.293	-0.489	-0.654	0.156	0.675	-0.169	-0.111	-0.558	-0.321	0.652	-0.343	-0.39	0.1	0.996	1	-0.948	0.092
(K)	0.304	0.344	0.435	0.598	-0.306	-0.611	0.137	0.136	0.504	0.369	-0.65	0.223	0.432	-0.268	-0.971	-0.948	1	0.109
(Cc)	-0.193	0.252	-0.201	-0.139	-0.654	0.18	-0.206	0.295	-0.16	0.1	-0.059	-0.668	0.069	-0.973	0.038	0.092	0.109	1
Sum of correlation	0.305	1.583	1.892	1.851	1.338	-1.833	1.214	1.092	1.971	1.037	-0.426	1.129	1.208	1.003	-0.874	-0.869	0.839	1
Grand total	13.461	13.461	13.461	13.461	13.461	13.461	13.461	13.461	13.461	13.461	13.461	13.461	13.461	13.461	13.461	13.461	13.461	13.461
Weight	0.0227	0.117628	0.140546	0.137498	0.099416	-0.136165	0.0902	0.081143	0.1464	0.07706	-0.0317	0.0838	0.08975	0.07451	-0.065	-0.065	0.06231	0.0743

assigned to each parameter, as shown in Table 4. Finally, a model was formulated to assess the final priority ranking by attribution of weights to different parameters. The CF for watershed prioritization was computed as follows:

$$\begin{aligned}\text{Compound factor (CF)} = {} & \left(0.023 \times \text{PPR of } R_{\text{bm}}\right) + \left(0.1176 \times \text{PPR of } R_{\text{lm}}\right) + \left(0.1405 \times \text{PPR of } F_{\text{s}}\right) \\ & + \left(0.1375 \times \text{ PPR of } D_{\text{d}}\right) + \left(0.0994 \times \text{PPR of } D_{\text{t}}\right) - \left(0.1361 \times \text{ PPR } L_{\text{o}}\right) \\ & + \left(0.092 \times \text{PPR of } D_{\text{i}}\right) + (0.0811 \times \text{ PPR of } \rho) + \left(0.146 \times \text{ PPR of } I_{\text{f}}\right) \\ & + \left(0.0771 \times \text{PPR of } B_{\text{h}}\right) - \left(0.032 \times \text{PPR of } R_{\text{h}}\right) + \left(0.084 \times \text{PPR of } R_{\text{hp}}\right) \\ & + \left(0.0898 \times \text{PPR of } R_{\text{n}}\right) + \left(0.075 \times \text{PPR of } R_{\text{c}}\right) - \left(0.06 \times \text{PPR of } R_{\text{e}}\right) \\ & - \left(0.06 \times \text{PPR of } F_{\text{f}}\right) + (0.0623 \times \text{PPR of } K) + \left(0.074 \times \text{PPR of } C_{\text{c}}\right),\end{aligned} \tag{2}$$

This equation will have the same weighted factor for all sub-watersheds but different values for morphometric parameters. Similarly, WSA values have been calculated for each of the 18 sub-watersheds.

where PPR is the preliminary priority ranking, R_{bm} is the mean bifurcation ratio, R_{lm} is the mean stream length ratio, F_{s} is the stream frequency, D_{d} is the drainage density, D_{t} is the drainage texture, L_{o} is the length of overland flow, D_{i} is the drainage intensity, ρ is the RHO coefficient, I_{f} is the infiltration number, B_{h} is the relief, R_{h} is the relief ratio, R_{hp} is the relative relief, R_{n} is the ruggedness number, R_{c} is the circulatory ratio, R_{e} is the elongation ratio, F_{f} is the form factor, K is the lemniscates ratio, C_{c} is the compactness coefficient.

Under diverse terrain and climatic circumstances, the interaction between morphometric factors varies from one sub-watershed to another. Accordingly, the sub-watershed exhibiting the lowest CF has been assigned the highest priority and is denoted by number 1. There follows the sub-watershed with the next highest CF value, and so on, until the sub-watershed with the lowest CF is assigned the lowest priority (Ayele et al. 2017; Sheikh

Table 5 Final priority ranking of 18 sub watersheds based on compound factor value

Prioritized rank	Compound factor	Sub watershed name	Prioritized rank	Compound factor	Sub watershed name
1	3.43675	SW-17 Timmalapura	10	9.7789	SW-6 Goudanakatte
2	4.8192	SW-16 Timmanahalli	11	10.9524	SW-1 Anekatte
3	5.3315	SW-13 Muddenahalli	12	11.1027	SW-8 Handanakere
4	5.8815	SW-18 Yagachihalli	13	11.31335	SW-10 Kuppara Chikkapalya
5	6.3913	SW-11 Kuppuru	14	11.75515	SW-15 Settikere
6	7.2751	SW-4 C N Halli	15	13.332	SW-14 Nelagondanahalli
7	8.0459	SW-12 Mathighatta	16	13.6099	SW-7 Halukurike
8	8.3673	SW-9 Kandikere	17	14.2593	SW-3 Chunganahalli
9	9.13339	SW-5 Doddabidare	18	14.3833	SW-2 Boranakanive

et al. 2017). Consequently, runoff and soil erosion are the greatest threats in the sub-watershed with the highest priority. Made the final priority ranking such that gave the lowest CF value as priority rank 1, the next lower value was given a priority rank of 2, and so on for all the 18 sub-watersheds.

As observed in Final priority ranking of 18 sub watersheds based on Compound factor value shown in Table 5, the highest priority rank (1) was assigned to SW-17, followed in order by SW-16, SW-13, SW-18, SW-11, SW-4, SW-12, SW-9, SW-5, SW-6, SW-1, SW-8, SW-19, SW-15, SW-14, SW-7, SW-3, and SW-2. The SW17, SW16, and

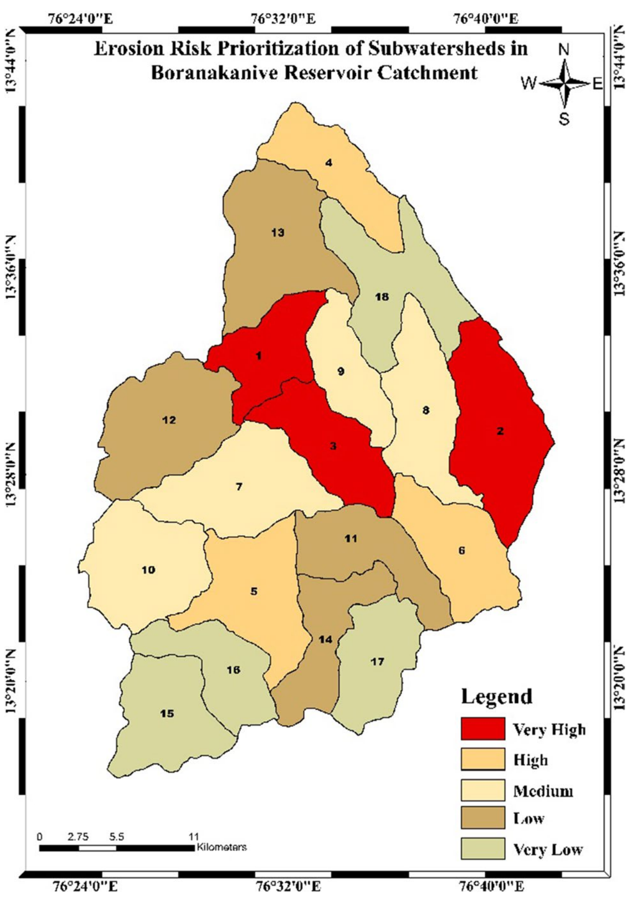

Fig. 7 Erosion risk prioritization map of Boranakanive Reservoir Catchment

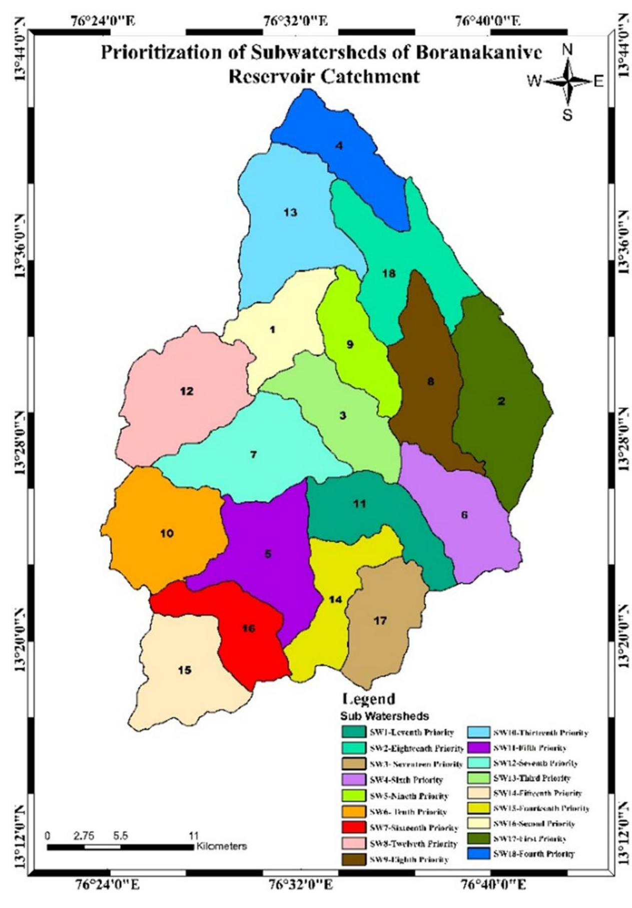

Fig. 8 Final prioritization map of 18 sub watershed

SW13 are the most anxiety to land deterioration and soil erosion. Because of their intrinsic geomorphometric properties, they require prompt attention to the prioritized soil and water conservation measures or practices. All sub watersheds classified into five categories of soil erosion prone areas such as very high, high, moderate, poor and very poor based on compound factor values. Very high covers 160.61 km^2, high covers 155.13 km^2, moderate covers 219.18 km^2, poor covers 236.63 km^2 and very poor covers 198.99 km^2. Figure 7 Shows erosion risk prioritization map of the study area. It has been found that high and very high soil erosion-prone sub-watersheds have higher linear relief and lower aerial aspect values, which positively impact soil erosion. Conversely, moderate regions have moderate relief linear and aerial aspect values. In comparison, low and very low regions have low values of relief and linear aspect and higher values of aerial aspect. It was concluded from the study above that proper land and water management practices should be planned based on the sensitivity rank of each sub-watershed. Figure 8 shows the final prioritization map of 18 sub-watersheds.

Conclusion

A quantitative morphometric analysis using a geospatial and weighted sum approach was conducted for 18 sub-watersheds within the Boranakanive Reservoir catchment. All sub-watersheds have drainage density values below 5, indicating porous and coarse strata. An analysis of the sub-watersheds morphometric characteristics reveals dendritic to sub-dendritic drainage patterns and their relative characteristics in regard to the catchment's hydrologic response. The variation in stream ratio could be the result of changes in slope and topography in the study area. Different topographies and geometric developments explain the disparities in bifurcation ratios between sub-watersheds. In addition, all sub-watersheds within the study area showed a positive correlation between stream frequencies and drainage density, indicating an increase in stream numbers. The texture of the drainage is fine to very fine. Elongation ratios indicate the existence of elongated patterns within a certain sub-watershed. The present study used a statistical correlation-based weighted sum approach to assess prioritization. A statistical correlation-based weighted sum approach is a sustainable and dynamic method over conventional watershed ranking methods, whose compound factors range from 3.43 to 14.38 and are used to prioritize soil erosion threats for 18 sub watersheds. A comprehensive analysis of the present study reveals that SWS-17, SWS-16, and SWS-13 are more prone to soil erosion. Consequently, appropriate soil erosion management methods are needed in these sub watersheds. It is imperative that decision makers allocate resources to essential sub-watersheds in a cost-effective and technical manner. In addition, it must be monitored and evaluated in terms of its environmental safety, economic viability, and social acceptability.

Author contributions CJR—devised the study, implemented the methodology, and wrote the original draft. SL and AKK—conceptualization, validation, GR—supervision, writing, review and editing. All authors participated in formulating the idea and discussing the proposed approach and results. In the final version of the manuscript, all authors have read and approved it.

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Data availability To obtain related information, data and materials, please contact the corresponding author.

Declarations

Conflict of interest It should be noted that there is no conflict of interest regarding the publication of this paper.

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