Morphometric analysis for prioritizing sub-watersheds of Murredu River basin, Telangana State, India, using a geographical information system

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Abstract

The Murredu watershed in Telangana State was chosen for the morphometric and land use/land cover (LULC) analysis in this current study. Geographical information system (GIS) and remote sensing (RS) techniques can estimate the morphometric features and LULC analysis of a catchment. A total of fourteen sub-watersheds (SWs) were created from the watershed (SW 1 to SW 14), and sub-watersheds were prioritized based on morphometric and LULC features. Evaluation of various morphometric characteristics such as linear aspects, relief aspects, and aerial aspects has been carried out for every sub-watershed to prefer ranking. Four parameters were utilized for the LULC analysis to rank and prioritize sub-watersheds. The sub-watersheds were categorized into three groups as low, medium, and high, for soil and water conservation priority based on morphometric and LULC analysis. Using morphometric analysis, higher priorities have been assigned to SW 12 and SW 1, while using LULC analysis, higher priorities have been assigned to SW 9 and SW 11. SW 10 and SW 13 are the most common sub-watersheds that fall within the same priority while using morphometric and LULC analysis. The coefficient of regression results reveals that stream length and stream order, and also stream number and stream order, have a strong association. The deployment of soil and water conservation measures may be conducted in the high-priority sub-watersheds.

Keywords: Morphometric analysis, LULC analysis, Prioritization, Murredu watershed

Introduction

Morphometric characteristics are a mathematical and quantitative study of the Earth's surface arrangement, as well as the shape and magnitude of its landforms [3, 10, 34]. A watershed is a section of land where rainwater contributes to a common location [11]. The study of watersheds is crucial for preventing soil erosion, conserving water, and ensuring long-term growth. Techniques like geographical information system (GIS) and remote sensing are powerful tools for analyzing the river basin's hydraulic process [57].

The size, drainage, shape, and land use pattern of a watershed determine its classification. The many forms of watersheds are mini-watersheds (one to hundred hectares), micro-watersheds (hundred to thousand hectares), milli-watersheds (thousand to ten thousand hectares), sub-watersheds (ten thousand to fifty thousand hectares), and macro-watersheds (greater than fifty thousand hectares). Morphometric characteristics are a helpful process for analyzing watersheds as it shows the relationship among many features of a catchment like a stream order, stream length, etc. Watershed protection has drawn attention towards the safety of natural resources such as soil and water [14].

Various scientists have used traditional methods to analyze various watershed characteristics [13, 16–18, 45, 50, 52–54], and nowadays, remote sensing and GIS tools have been widely used for watershed analysis [2, 7, 4–6, 21, 32, 36, 37, 41, 43, 44, 47, 49, 51, 58]. Morphometric characteristics provide a quantitative catchment report, which is valuable in studies like watershed prioritization, hydrologic modeling, natural resource conservation, etc. [49].

Extracting drainage features from the shuttle radar topography mission (SRTM) digital elevation model (DEM) has become a more popular, accurate, faster, and cost-effective way of conducting catchment studies [22, 31]. Morphometric analysis is a quantitative catchment analysis that reveals the drainage features and development of soil erosion, surface runoff, groundwater infiltration capacity, groundwater potential, etc. [42].

A systematic analysis is essential for the configuration of a catchment, and its stream courses involve relief aspects, linear aspects, and aerial or shape aspects of the catchment [54]. Linear aspects involve the stream length, the number of streams, the bifurcation ratio, the mean stream length ratio, the stream frequency, the stream length ratio, the stream density, the drainage texture, the drainage intensity, the length of the overland flow, and the RHO coefficient. Relief features contain watershed relief, relief ratio, relief relative, ruggedness number, maximum elevation, and minimum elevation. Also, the areal features consist of circulation ratio, watershed area, perimeter, form factor ratio, basin length, elongation ratio, lemniscate ratio, and compactness coefficient [54].

According to scientific studies, morphometric features of a river basin play a significant role in prioritizing sub-watersheds [24]. Sediments, nutrients, and pollutants will be deposited and collected by the water flowing into and out of the basin [35]. They can have a significant impact on the river basin's onsite and offsite ecosystem. As a result, studying the drainage basin process has the potential to help for a better understanding of how water moves through the hydrologic cycle. Implementing watershed management is crucial for achieving sustainable land and water resource use, as well as mitigating increasing pollutants' impacts [18, 40, 38]. For the present study, the most relevant quantitative morphometric characteristics have been chosen and applied. Morphometric characteristics can be divided into three categories such as linear, relief, and areal aspects. These have been utilized to prioritize more susceptible sub-watersheds since they have a direct or indirect relationship with peak flow, runoff, and soil erosion hazards [33, 18, 48, 46, 41].

The status of the catchment's land use/land cover (LULC) is another crucial factor to consider when prioritizing sub-watersheds [18, 19, 39]. The most influential factor and indicator of environmental degradation, including a catchment, is LULC changes.

Several researchers have explored and used LULC analysis in catchment prioritizing [25, 55]. Increased slope gradient irregularly enhanced soil erosion rates under various LULC scenarios, which were determined to be greatest at a particular critical degree of slope [59]. Changes in the catchment's LULC have been recognized as the principal cause of environmental change, resulting in accelerated soil erosion, and are primarily anthropogenic [25]. RS and GIS techniques can represent various LULC categories through classification procedures [1, 9, 12, 15, 20, 23, 26, 29, 56]. RS and GIS techniques have been used in catchment prioritizing [28], which is a basic prerequisite for planners and policymakers to design management schemes that consider the immensity of the catchment area [19].

The objectives of the current study are to prioritize sub-watersheds depending on the morphometric characteristics of each sub-watersheds and also to prioritize sub-watersheds using LULC analysis of each sub-watersheds. Also, the study aims to locate the most common sub-watersheds that fall within the same priority by utilizing both morphometric and LULC analyses.

Study area

Murredu catchment is located in Telangana State. Murredu River is the sub-tributary of the Godavari River, as shown in Fig. 1. Murredu watershed is located between longitudes 80° 20′ 0″ and 80° 50′ 0″ East and latitudes 17° 10′ 0″ and 17° 50′ 0″ North. It has a total area of 1593.33 km^2. The hottest months of the year are usually March to June. The watershed's rainy season is from July to September. In November, the weather turns cool and stays that way until February. The monsoon arrives in June and lasts until September. The Murredu River basin's altitude ranges from 57 to 784 m above sea level, according to the SRTM digital elevation model.

**Fig. 1** Geographical map of the Murredu River basin
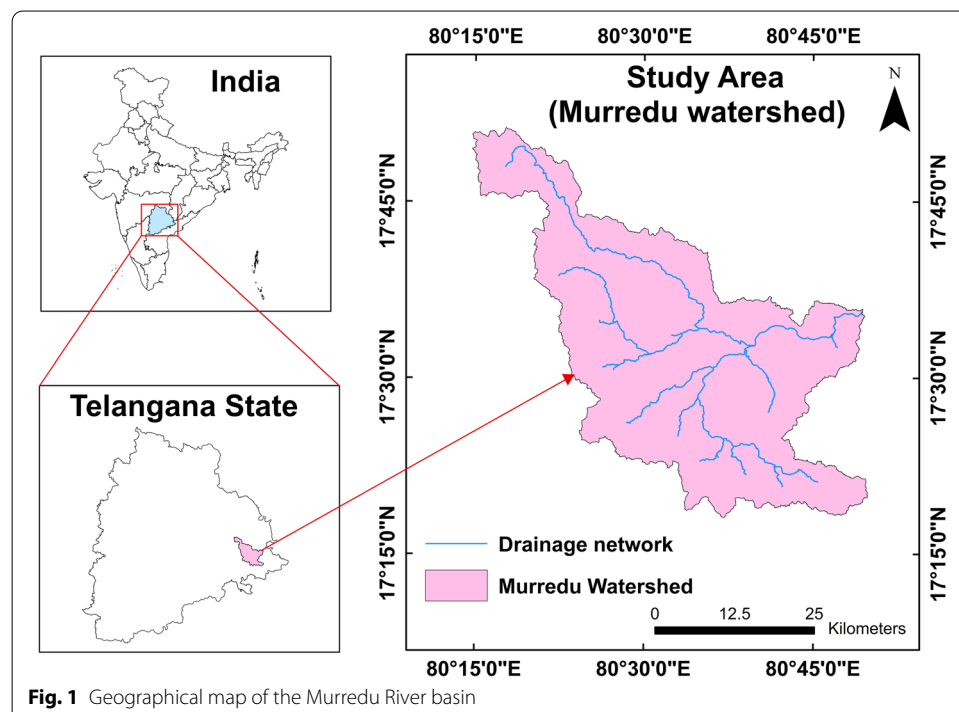
Geology

According to the World Geologic Maps of the United States Geological Survey (USGS), the study area has two types of significant rocks. Lower Triassic to Upper Carboniferous and undivided Precambrian are the geological age of two rocks. Sedimentary (Lower Triassic to Upper Carboniferous) and metamorphic rocks (undivided Precambrian) are the type of rocks that were observed in the research area. The undivided Precambrian-Metamorphic Rock occupies the majority of the current study's area. The drainage pattern of the catchment is dendritic to sub-dendritic. The geological and drainage network of the study area is shown in Fig. 2.

Methods

The SRTM DEM was used for the watershed delineation in this current study. It can be downloaded from USGS Earth Explorer. DEM has a resolution of 30 m. The quantitative morphometric characteristics were performed to examine fourteen sub-watersheds of the Murredu catchment. Table 1 shows the data that was used in this research.

Figure 3 shows the processing of DEM, including fill, flow direction, flow accumulation, stream definition, stream to features, etc. Using ArcGIS 10.4.1 software, sub-watersheds (SW 1 to SW 14) are categorized based on the length of the stream, stream order, stream number, etc. Three groups of morphometric features were studied and categorized; they were linear, relief aspect, and aerial aspect. These features are determined using various empirical methods shown in Table 2. Linear parameters of the Murredu river basin (SW 1 to SW 14) were calculated and presented in Table 3. After getting all the morphometric values, the next step is to find the rank of individual parameters in each sub-watershed. The sub-watershed having the maximum value in the relief and linear characteristics has been ranked as first, while the second maximum value has been ranked as second, the third maximum value has been ranked as third, and so on. The sub-watershed having the minimum value in the areal or shape characteristics has been ranked as first, while the second minimum value has been ranked as second, the third

Fig. 2 Geological and drainage network of the study area
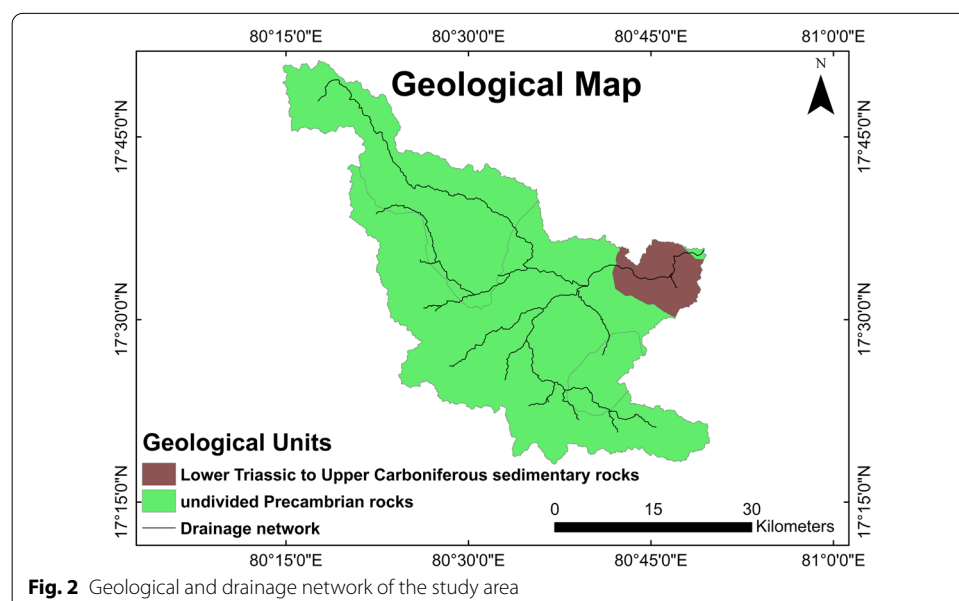
Table 1 Remote sensing data used for the current study

Sl. No	Data	Source
1	SRTM DEM	USGS Earth Explorer
2	Sentinel-2 (LULC)	Environmental Systems Research Institute (ESRI) 2020 Land Cover
3	World Geologic Maps	USGS

Fig. 3 Methodology of the morphometric analysis
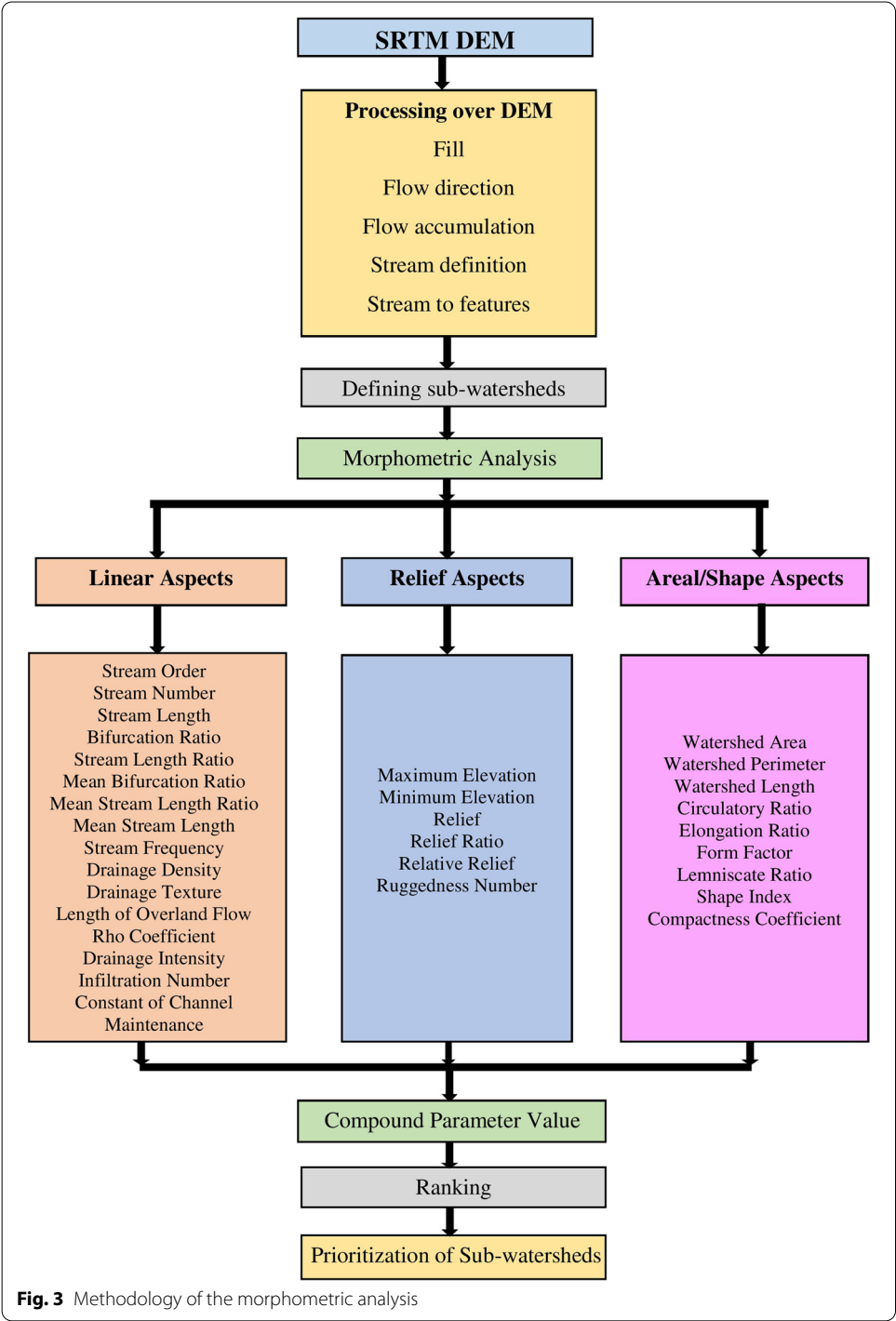
Table 2 Morphometric parameters of the Murredu watershed

Parameters	Formulae/methods	Units	References
Linear aspects			
Stream order (U)	Hierarchical rank	Dimensionless	[54]
Stream length (L_u)	$L_u = L_{u1} + L_{u2} + L_{u3} \cdots + L_{un}$	Kilometer (km)	[17]
Stream number (N_u)	$N_u = N_{u1} + N_{u2} + N_{u3} \cdots + N_{un}$	Dimensionless	[17]
Stream length ratio (R_l)	$R_l = L_u/L_u - 1$	Dimensionless	[17]
Bifurcation ratio (R_b)	$R_b = N_u/N_u + 1$	Dimensionless	[45]
Mean bifurcation ratio (R_{bm})	Average of bifurcation ratio of all orders	Dimensionless	[53]
Mean stream length (L_{sm})	$L_{sm} = (L_u/N_u)$	Kilometer	[17]
Mean stream length ratio (R_{lm})	Average of the steam length ratio of all orders	Dimensionless	[45]
Stream frequency (F_s)	$F_s = (\sum N_u)/A$	km^{-2}	[45]
Drainage density (D_d)	$D_d = (\sum L_u)/A$	km/km^2	[45]
Drainage texture (D_t)	$D_t = (\sum N_u)/P$	km^{-1}	[45]
Length of overland flow (L_o)	$L_o = (1/(2D_d))$	Kilometer	[45]
RHO coefficient (ρ)	$\rho = R_{lm}/R_{bm}$	Dimensionless	[17]
Drainage intensity (D_i)	$D_i = F_s/D_d$	km^{-1}	[13]
Infiltration number (I_f)	$I_f = F_s \times D_d$	km^{-3}	[13]
Constant of channel maintenance (C_{cm})	$C_{cm} = 1/D_d$	km^2/km	[45]
Relief aspects			
Maximum elevation (H)	GIS analysis	Meter	
Minimum elevation (h)	GIS analysis	Meter	
Relief (B_h)	$B_h = H - h$	Kilometer	[52]
Relief ratio (R_h)	$R_h = B_h/L_b$	Dimensionless	[45]
Relative relief (R_{hp})	$R_{hp} = H \times 100/P$	Dimensionless	[27]
Ruggedness number (R_n)	$R_n = B_h \times D_d$	Dimensionless	[53]
Areal/shape aspects			
Area of the watershed (A)	GIS analysis	Km^2	
Perimeter of the watershed (P)	GIS analysis	Kilometer	
Basin length (L_b)	$L_b = 1.312 \times A^{0.568}$	Kilometer	[33]
Circulatory ratio (R_c)	$R_c = 4\pi A/P^2$; where $\pi = 3.14$	Dimensionless	[30]
Elongation ratio (R_e)	$R_e = (2 (A/\pi)^{0.5})/(L_b)$	Dimensionless	[45]
Form factor (F_f)	$F_f = (A/L_b^2)$	Dimensionless	[17]
Lemniscate ratio (K)	$K = (L_b^2/4A)$	Dimensionless	[8]
Shape index (S_b)	$S_b = 1/F_f$	Dimensionless	[16]
Compactness coefficient (C_c)	$C_c = (P/2(\pi A)^{0.5})$	Dimensionless	[17]

minimum value has been ranked as third, and so on. After getting all ranks for individual parameters in each sub-watershed, the next step is to find the compound parameter value for each sub-watershed. To arrive at the compound parameter value, all the ranks in SW1 are added together and divided by the number of characteristics (the present study area consists of 20 characteristics) and repeat the procedure for other sub-watersheds. Following the calculation of compound values, the sub-watersheds were categorized into three classes high, medium, and low. The high priority has been given to the sub-watersheds with the very low compound value, denoted by the number 1 (high). The medium priority has been given to the sub-watershed with the next low compound parameter value, denoted by the number 2 (medium). The low priority has been given to

Table 3 Linear parameters of the Murredu River basin (SW 1 to SW 14)

Sub-watersheds	Stream order	Stream number (Nu)	$Log_{10}(Nu)$	Stream length (Lu)	$Log_{10}(Lu)$	Mean stream length	Bifurcation ratio (R_b)	Steam length ratio (R_l)
SW 1	1	70	1.85	64	1.81	0.91	No	No
	2	16	1.20	39	1.59	2.44	4.38	0.61
	3	3	0.48	20	1.30	6.67	5.33	0.51
	4	1	0.00	5	0.70	5.00	3.00	0.25
		$\sum N_u = 90$		$\sum L_u = 128$			$\sum R_b = 12.71$	$\sum R_l = 1.37$
							$\sum R_{bm} = 3.18$	$\sum R_{lm} = 0.34$
SW 2	1	16	1.20	14	1.15	0.88	No	No
	2	3	0.48	7	0.85	2.33	5.33	0.50
	3	1	0.00	7	0.85	7.00	3.00	1.00
		$\sum N_u = 20$		$\sum L_u = 28$			$\sum R_b = 8.33$	$\sum R_l = 1.50$
							$\sum R_{bm} = 4.17$	$\sum R_{lm} = 0.75$
SW 3	1	57	1.76	62	1.79	1.09	No	No
	2	12	1.08	30	1.48	2.50	4.75	0.48
	3	4	0.60	9	0.95	2.25	3.00	0.30
	4	1	0.00	11	1.04	11.00	4.00	1.22
		$\sum N_u = 74$		$\sum L_u = 112$			$\sum R_b = 11.75$	$\sum R_l = 2.01$
							$\sum R_{bm} = 3.92$	$\sum R_{lm} = 0.67$
SW 4	1	41	1.61	39	1.59	0.95	No	No
	2	12	1.08	12	1.08	1.00	3.42	0.31
	3	2	0.30	9	0.95	4.50	6.00	0.75
	4	1	0	9	0.95	9.00	2.00	1.00
		$\sum N_u = 56$		$\sum L_u = 69$			$\sum R_b = 11.42$	$\sum R_l = 2.06$
							$\sum R_{bm} = 3.81$	$\sum R_{lm} = 0.69$
SW 5	1	67	1.83	71	1.85	1.06	No	No
	2	15	1.18	29	1.59	1.93	4.47	0.41
	3	5	0.70	17	1.18	3.40	3.00	0.59
	4	1	0.00	10	0.78	10.00	5.00	0.59
		$\sum N_u = 88$		$\sum L_u = 127$			$\sum R_b = 12.47$	$\sum R_l = 1.58$
							$\sum R_{bm} = 4.16$	$\sum R_{lm} = 0.53$
SW 6	1	71	1.85	55	1.74	0.77	No	No
	2	16	1.20	39	1.59	2.44	4.44	0.71
	3	4	0.60	15	1.18	3.75	4.00	0.38
	4	1	0.00	6	0.78	6.00	4.00	0.40
		$\sum N_u = 92$		$\sum L_u = 115$			$\sum R_b = 12.44$	$\sum R_l = 1.49$
							$\sum R_{bm} = 4.15$	$\sum R_{lm} = 0.50$
SW 7	1	46	1.66	71	1.85	1.54	No	No
	2	13	1.11	33	1.52	2.54	3.54	0.46
	3	4	0.60	19	1.28	4.75	3.25	0.58
	4	2	0.30	9	0.95	4.50	2.00	0.47
		$\sum N_u = 65$		$\sum L_u = 132$			$\sum R_b = 8.79$	$\sum R_l = 1.51$
							$\sum R_{bm} = 2.93$	$\sum R_{lm} = 0.50$
SW 8	1	55	1.74	86	1.93	1.56	No	No
	2	11	1.04	31	1.49	2.82	5.00	0.36
	3	4	0.60	25	1.40	6.25	2.75	0.81
	4	1	0.00	1	0.00	1.00	4.00	0.04
		$\sum N_u = 71$		$\sum L_u = 143$			$\sum R_b = 11.75$	$\sum R_l = 1.21$
							$\sum R_{bm} = 3.92$	$\sum R_{lm} = 0.40$

Table 3 (continued)

Sub-watersheds	Stream order	Stream number (Nu)	$Log_{10}(Nu)$	Stream length (Lu)	$Log_{10}(Lu)$	Mean stream length	Bifurcation ratio (R_b)	Steam length ratio (R_l)
SW 9	1	198	2.29	35	1.54	0.18	No	No
	2	44	1.64	18	1.26	0.41	4.5	0.51
	3	11	1.04	7	0.85	0.64	4	0.39
	4	2	0.30	1	0.00	0.50	5.5	0.14
	5	1	0.00	2	0.30	2.00	2	2.00
		$\sum N_u = 256$		$\sum L_u = 63$			$\sum R_b = 16$	$\sum R_l = 3.05$
							$\sum R_{bm} = 4$	$\sum R_{lm} = 0.76$
SW 10	1	70	1.85	90	1.95	1.29	No	No
	2	11	1.04	31	1.49	2.82	6.36	0.34
	3	3	0.48	11	1.04	3.67	3.67	0.35
	4	1	0.00	12	1.07	12.00	3.00	1.09
		$\sum N_u = 85$		$\sum L_u = 144$			$\sum R_b = 13.03$	$\sum R_l = 1.79$
							$\sum R_{bm} = 4.34$	$\sum R_{lm} = 0.60$
SW 11	1	81	1.91	71	1.85	0.88	No	No
	2	19	1.28	33	1.51	1.74	4.26	0.46
	3	6	0.78	21	1.32	3.50	3.17	0.64
	4	2	0.30	8	0.90	4.00	3.00	0.38
	5	1	0.00	6	0.78	6.00	2.00	0.75
		$\sum N_u = 109$		$\sum L_u = 139$			$\sum R_b = 12.43$	$\sum R_l = 2.23$
							$\sum R_{bm} = 3.11$	$\sum R_{lm} = 0.56$
SW 12	1	75	1.87	62	1.792	0.83	No	No
	2	17	1.23	28	1.44	1.65	4.41	0.45
	3	6	0.778	15	1.176	2.50	2.83	0.54
	4	1	0	16	1.2	16	6.00	1.07
		$\sum N_u = 99$		$\sum L_u = 121$			$\sum R_b = 13.25$	$\sum R_l = 2.05$
							$\sum R_{bm} = 4.42$	$\sum R_{lm} = 0.68$
SW 13	1	62	1.79	84	1.92	1.35	No	No
	2	14	1.14	45	1.65	3.21	4.43	0.54
	3	5	0.70	23	1.36	4.60	2.80	0.51
	4	2	0.30	5	0.70	2.50	2.50	0.22
	5	1	0.00	3	0.48	3	2.00	0.60
		$\sum N_u = 84$		$\sum L_u = 160$			$\sum R_b = 11.73$	$\sum R_l = 1.86$
							$\sum R_{bm} = 2.93$	$\sum R_{lm} = 0.47$
SW 14	1	22	1.34	22	1.34	1.00	No	No
	2	4	0.60	15	1.18	3.75	5.50	0.68
	3	1	0.00	16	1.20	16.00	4.00	1.07
		$\sum N_u = 27$		$\sum L_u = 53$			$\sum R_b = 9.50$	$\sum R_l = 1.75$
							$\sum R_{bm} = 3.17$	$\sum R_{lm} = 0.58$

the sub-watershed with the lowest compound parameter value, denoted by the number 3 (low). The high priority signifies the sub-watershed having the highest risk of runoff, peak flow, and soil erosion [18, 33].

Results and discussion

The quantitative morphometric measurements give information on the catchment's hydrological features. There are fourteen sub-watersheds in the Murredu catchment. By examining multiple criteria like the basin's linear aspect, aerial aspect, and relief aspect,

the morphometric analysis was utilized to prioritize sub-watersheds (Murredu). The details of various parameters are discussed below.

Basic parameters of river basin

Area of the watershed (A)

The area of the watershed can directly reflect the overall volume of water. It is one of the important parameters because a watershed's overall area is projected into the horizontal plane. It is denoted by "A." The overall area of the watershed is 1593.33 km^2. In the present study, the largest and smallest sub-watershed areas are 230.95 km^2 (SW 8) and 25.79 km^2 (SW 2), respectively.

The perimeter of a watershed (P)

Watershed's outer boundary that encloses its area is defined as the watershed perimeter [21] and is designated by *P*. The total perimeter of the watershed is 314 km. Out of the fourteen Murredu basins, the largest and smallest sub-watershed perimeters are 164.32 km (SW 8) and 45.46 km (SW 9), respectively.

Watershed length (L_b)

The major dimension among the essential parameters of the major drainage channel is the watershed length [33]. It is denoted by L_b. In the current research, the longest length of the sub-watersheds is at SW 8 (and is 28.87 km), while the shortest is at SW 2 (8.31 km).

Relief (B_h)

Catchment relief is described as the elevation variation between the maximum value and outlet value on the perimeter of the catchment and is denoted by B_h [52]. In this current study, SW 13 has the maximum relief (0.66), and SW 9 has the minimum relief (0.13).

Stream order (U)

According to Strahler [54], the order of stream is termed as the calculation of the position of a stream in the hierarchy of streams. The smallest finger type, as well as any unbranched tributaries, is termed first stream order. Two first stream orders are combined to generate a second stream order. Following that, the second stream order combines the third, and so on. The letter U is used to represent stream order. Figure 4 depicts the representation of each sub-watershed and its drainage network. The Murredu catchment consists of fourteen sub-watersheds, in that 5th order for SW 9, SW11, and SW13; 4th order for SW 1, SW 3, SW 4, SW 5, SW 6, SW 7, S.W 8, SW 10, and SW 12; and 3rd order for SW 2 and SW 14. The catchment has a dendritic to sub-dendritic drainage structure.

Stream number (N_u)

In a given catchment, the number of streams is defined as the number of streams in each sequence of that catchment [17] and is denoted by the symbol N_u. SW 9 (256) and SW 2 (20), respectively, have the highest and lowest stream numbers in this study.
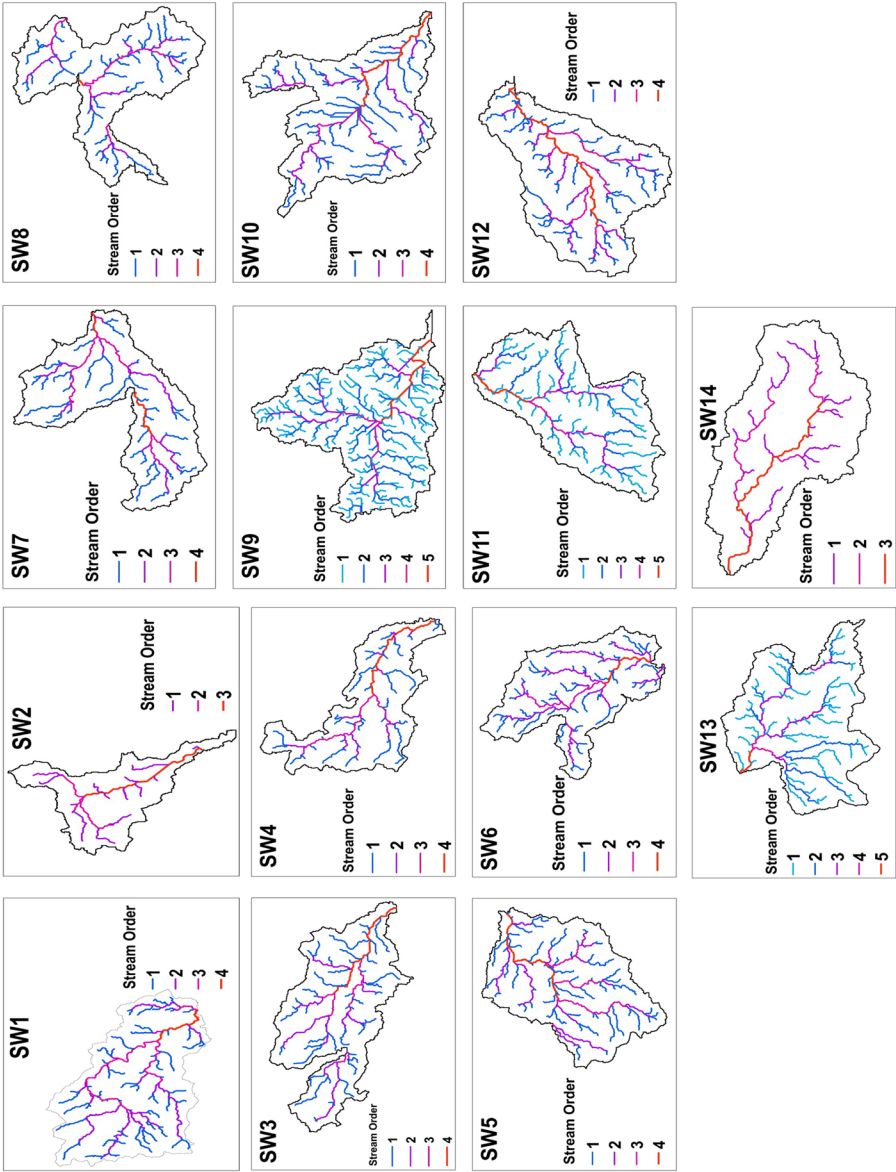
Fig. 4 Sub-watersheds and drainage networks

Stream length (*L*$_u$)

Stream length is defined as the mean length of the stream of each of the dissimilar orders in a catchment. As a result, the length of the stream is greater in a first-order stream, and also it increases as stream order increases [17]. It is designated by *L*$_u$. In the present research, the lengths of the largest and smallest of the stream are SW 13 (160 km) and SW (28 km), respectively.

Linear aspects

Bifurcation ratio (*R*$_b$)

According to Schumm [45], the bifurcation ratio is termed as the proportion of the number of streams of any given order to the number of streams of the next higher order. It was indicated by *R*$_b$. In the current study, SW 9 (16) has the maximum bifurcation ratio, and SW 2 has the minimum (8.33).

Mean stream length (*L*$_{sm}$)

It is defined as the ratio of the length of the stream to the number of streams [17] and is denoted by *L*$_{sm}$. In the current study, the maximum (20.97) and minimum (3.72) mean stream lengths are SW 12 and SW 9, respectively.

Stream length ratio (*R*$_l$)

It is defined as the ratio of the given order's average stream length to the next smaller order's mean stream length [17]. *R*$_l$ is the symbol for it. SW 9 (3.05) and SW 2 (1.5) had the highest and lowest stream length ratio values, respectively, in the current study.

According to Horton [17], the stream length and number of unique orders in a drainage basin are linked by two fundamental rules. The foremost is the law of stream numbers that describes the link between the given order's stream number and its stream order in terms of an inverted geometric series with the bifurcation ratio as the base. Figure 5 shows a strong correlation between stream order and stream number with better coefficients of determination ranging from SW 4 (0.975) to SW 6 (0.999).

The second is the law of stream length, which is the mean length of a particular order in terms of stream order, the average length of first-order streams, and stream length ratio. This rule is expressed as a direct geometric series. Figure 6 shows a strong correlation between stream order and stream length with coefficients of determination ranging from SW 14 (0.603) to SW 7 (0.996).

Mean bifurcation ratio

Strahler [53] utilized a weighted average ratio of bifurcation generated by multiplying the ratio of bifurcation for every consecutive set of patterns by the overall number of streams occupied in the ratio and taking the average of the combination of these results to arrive at a more representative bifurcation number. SW 1 has the highest value, whereas SW 13 has the lowest value in this study.
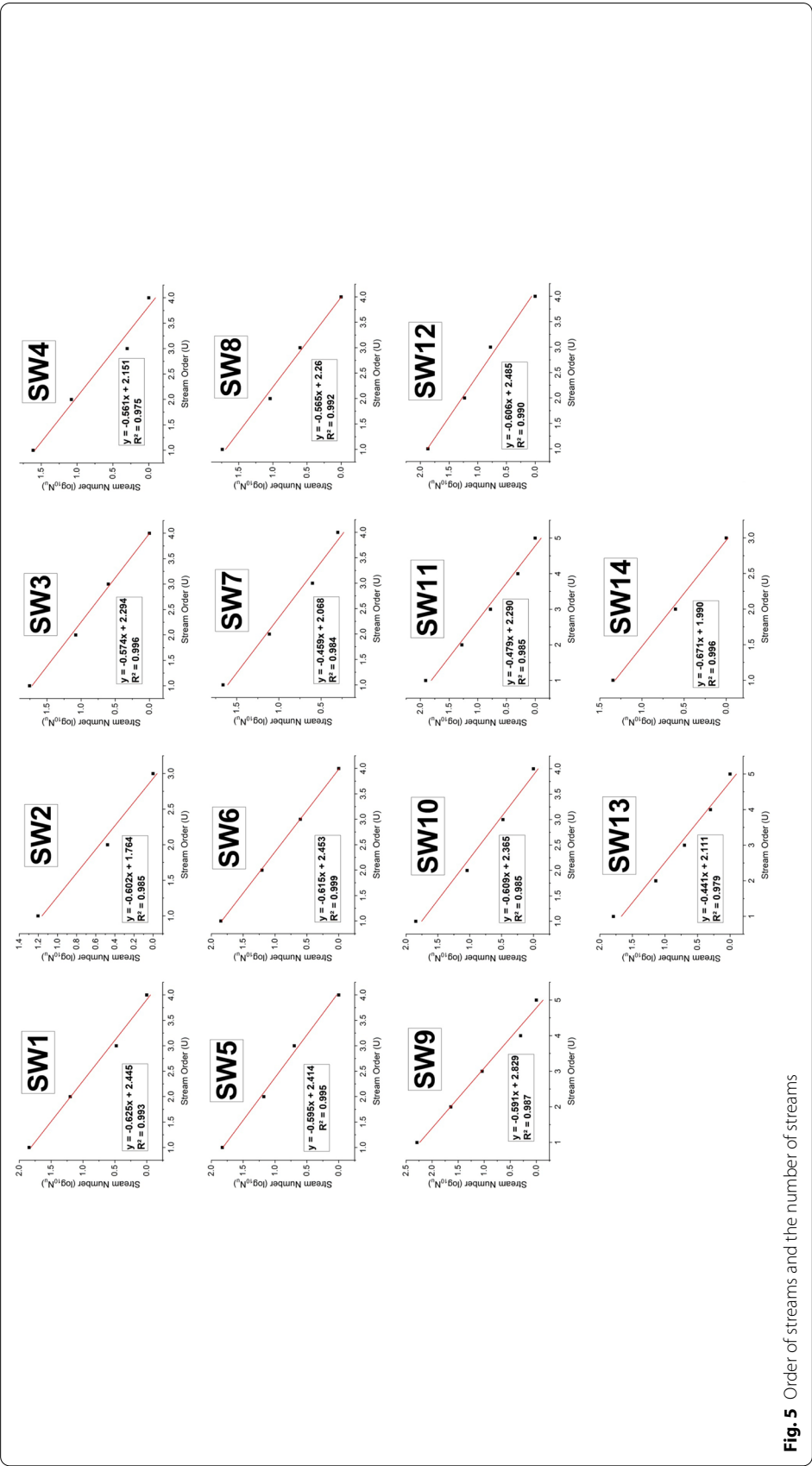
Fig. 5 Order of streams and the number of streams
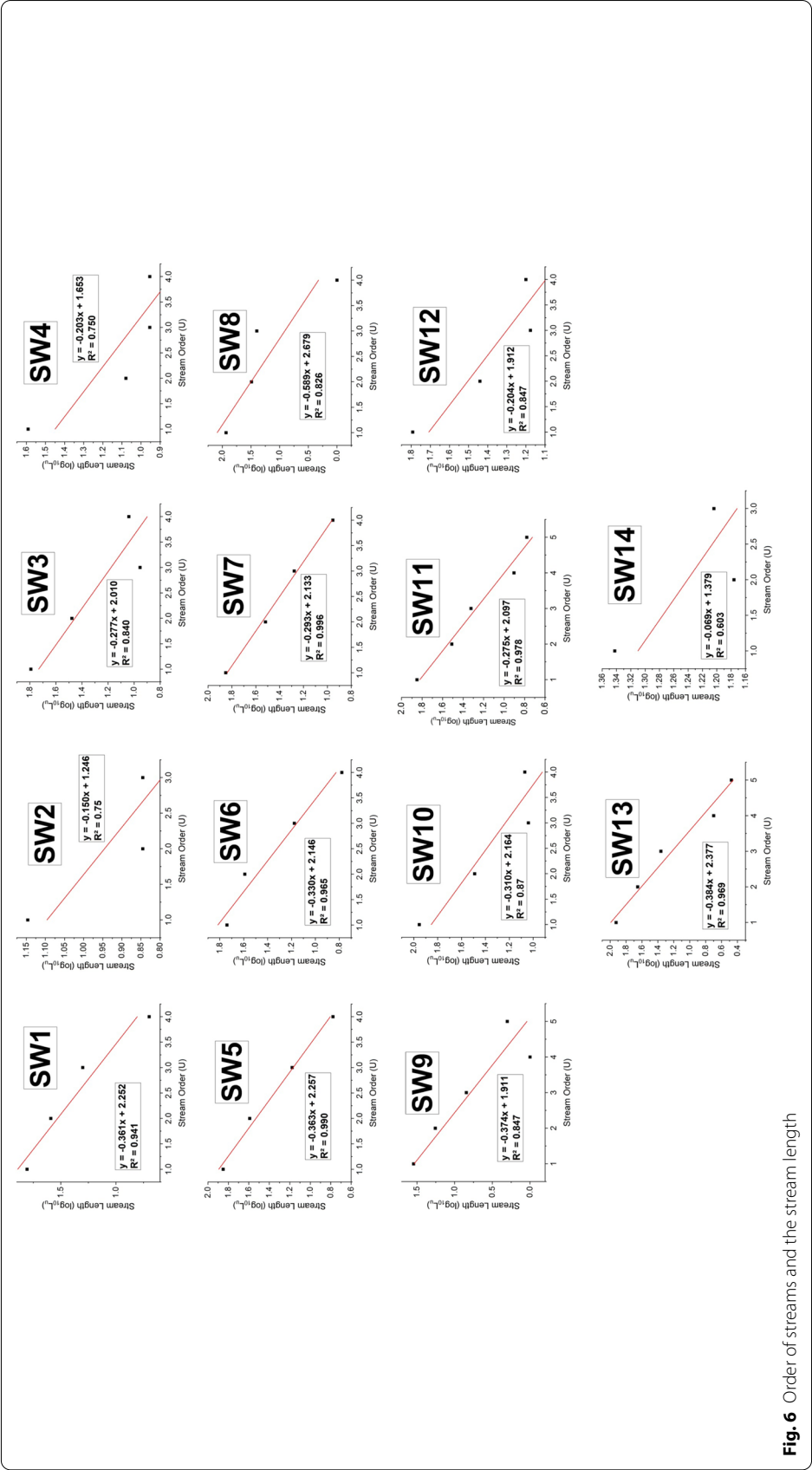
Fig. 6 Order of streams and the stream length
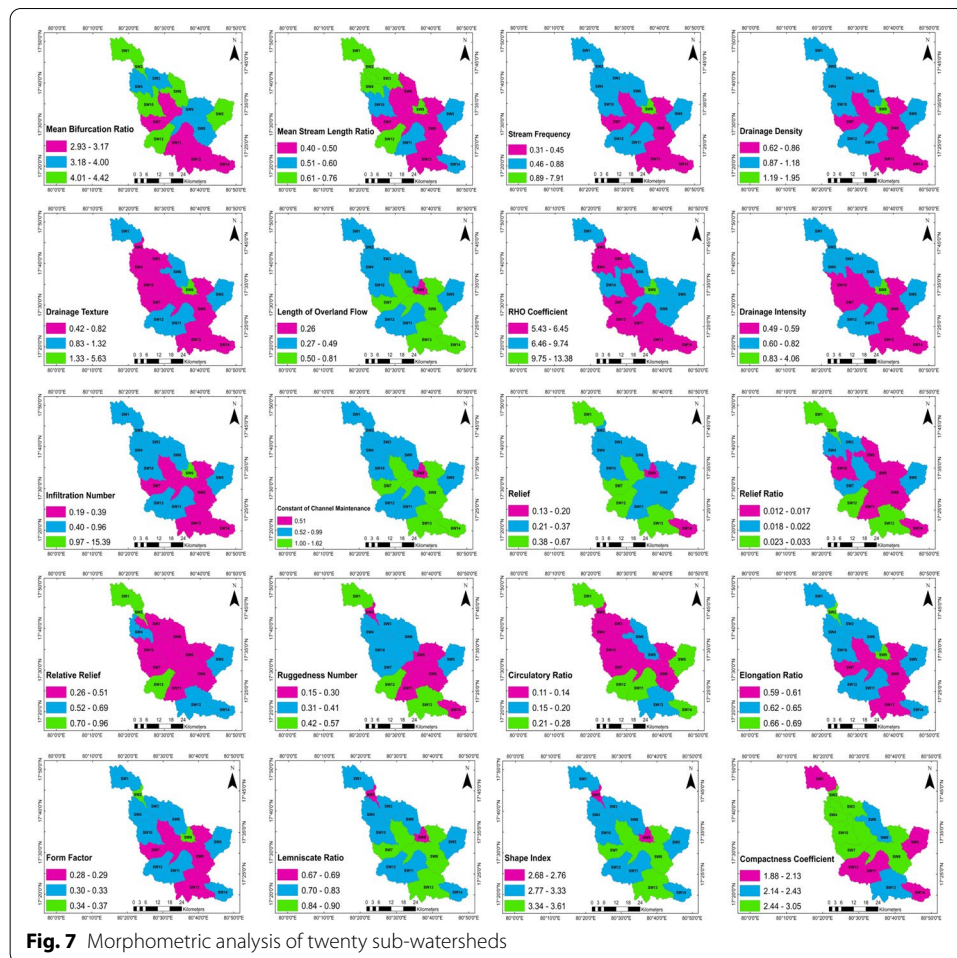
Fig. 7 Morphometric analysis of twenty sub-watersheds

Stream frequency (F_s)

Stream frequency is defined as the number of stream segments of all orders per unit catchment area, according to Schumm [45]. It is denoted by F_s. In the current study, the higher stream frequency is at SW 9 and the lower stream frequency is at SW 8.

Drainage density (D_d)

According to Schumm [45], drainage density is defined as the proportion of the overall length of the stream segments of all orders to the catchment area projected on the horizontal surface. It is indicated by D_d. In this study, drainage density is higher at SW 9 and lower at SW 8.

Drainage texture (D_t)

It is defined as the total number of streams per perimeter of the catchment, according to Schumm [45], and is denoted by the symbol D_t. In the current study, drainage texture is maximum at SW 9 and is minimum at SW 2.

Length of the overland flow (L_o)

The highest value of the length of the overland flow indicates greater surface runoff and the lowest value of the length of the overland flow indicates shorter surface run-off, according to Schumm [45]. It is denoted by L_o. The length of the overland flow is higher at SW 8 and lower at SW 9.

Drainage intensity (D_i)

According to Faniren [13], drainage intensity is defined as the ratio of stream frequency to drainage density. It is denoted by D_i. In this current study, the drainage intensity is higher and lower at SW 9 and SW 7, respectively, and shown in Fig. 7.

RHO coefficient (ρ)

RHO coefficient is a proportion between the stream length ratio and the bifurcation ratio, according to Horton [17]. It is designated by ρ. In this current study, the RHO coefficient is higher and lower at SW 9 and SW 14, respectively.

Infiltration number (I_f)

It is defined as the combination of stream frequency and drainage density, according to Faniran [13], and is denoted by I_f. In the current study, SW 9 has a higher infiltration number and SW 8 has a lower infiltration number.

Constant of channel maintenance (c_{cm})

This property defines the number of units of catchment surface needed to support one unit of route length. In other terms, it is the number of square kilometers of catchment surface area required to support one linear kilometer of stream segment. It was first proposed by Schumm in 1956 [45], who defined the channel maintenance constant as the reverse of drainage density. In the current study, SW 8 has a higher constant of channel maintenance and SW 9 has a lower constant of channel maintenance.

Areal aspect

Circulatory ratio (R_c)

According to Miller [30], it is termed as the proportion of the area of a catchment to the area of the circle with an equal circumference as the catchment's perimeter. It is indicated as R_c. Its ratio indicates the shape of the catchment. In the current study, SW 5 has a higher circulatory ratio and SW 8 has a lower circulatory ratio.

Elongation ratio (R_e)

It is defined as the proportion of the diameter of a circle covering the equal area as the catchment to the minimum length of the catchment, as per Schumm [45]. It is denoted by R_e. In this current study, SW 2 has a higher elongation ratio and SW 8 has a lower elongation ratio.

Form factor (F_f)

Form factor is defined as the proportion of catchment area to the square of catchment length, according to Horton [17]. It is denoted by F_f. In this present study, SW 2 has a higher form factor and SW 8 has a lower form factor.

Lemniscate ratio (K)

It is used to calculate the catchment's slope [8]. It is denoted by K. In this present study, SW 8 has a higher lemniscate ratio and SW 2 has a lower lemniscate ratio.

Shape index (S_b)

The shape index is the reciprocal of the form factor. It was first proposed by Horton [16]. It is denoted by the symbol S_b. In this present study, SW 8 has a higher shape index and SW 2 has a lower shape index.

Compactness coefficient (C_c)

According to Horton [17], the compactness coefficient is termed as the proportion of the catchment's perimeter to the circumference of an equivalent circular area and is indicated as C_c. In this present study, SW 8 has a higher compactness coefficient and SW 5 has a lower compactness coefficient.

Relief aspect

Relief ratio (R_h)

According to Schumm [45], the relief ratio is termed as the proportion of the maximum catchment relief (B_h) to the minimum catchment length which is parallel to the primary catchment line and is denoted by R_h. In this current study, the higher value of the relief ratio is at SW 2 and the lower value of the relief ratio is at SW 13.

Relative relief (R_hp)

The perimeter and watershed are used to determine relative relief [27]. R_{hp} is the symbol for it. SW 2 has the higher value, whereas SW 8 has the lower value in this study.

Ruggedness ratio (R_n)

According to Strahler [53], the ruggedness ratio is used to measure the surface unevenness or roughness. It is the combination of drainage density and maximum catchment relief and is denoted by R_n. In this study, the higher value and lower value have been identified at SW 13 and SW 14, respectively.

Hypsometric analysis

The relative proportion of the catchment areas below or above a specific height is represented by the hypsometric curve for a catchment. The hypsometric integral is defined as the area below the hypsometric curve [52, 45], and it has been used to determine the stage of development of a catchment, along with the hypsometric curve. The catchment is split into three phases such as old, mature, and young. The value of the hypsometric integral in the old stage is less than 0.3, the mature stage is between 0.3 and 0.6, and the youthful stage is greater than 0.6. The hypsometric integral is shown in Table 4.

Table 4 Morphometric results of the Murredu catchment

Sl.No.	Parameters	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11	SW12	SW13	SW14
1	Stream order	4	3	4	4	4	4	4	4	5	4	5	4	5	3
2	Stream number	99	20	74	56	88	92	65	71	256	85	109	99	84	27
3	Stream length	121	28	112	69	127	115	132	143	63	144	139	121	160	53
4	Bifurcation ratio	13.25	8.33	11.75	11.42	12.47	12.44	8.79	11.75	16	13.03	12.43	13.25	11.73	9.5
5	Stream length ratio	2.05	1.5	2.01	2.06	1.58	1.49	1.51	1.21	3.05	1.79	2.23	2.05	1.86	1.75
6	Mean stream length	15.02	10.21	16.84	15.45	16.39	12.96	13.33	11.63	3.72	19.77	16.11	20.97	14.67	20.75
7	Mean bifurcation ratio	4.42	4.17	3.92	3.81	4.16	4.15	2.93	3.92	4	4.34	3.11	4.42	2.93	3.17
8	Mean steam length ratio	0.68	0.75	0.67	0.69	0.53	0.5	0.5	0.4	0.76	0.6	0.56	0.68	0.47	0.58
9	Stream frequency	0.74	0.78	0.74	0.82	0.74	0.84	0.39	0.31	7.91	0.69	0.85	0.88	0.45	0.38
10	Drainage density	1.05	1.09	1.12	1.01	1.06	1.05	0.80	0.62	1.95	1.18	1.08	1.08	0.86	0.74
11	Drainage texture	1.16	0.42	0.76	0.71	1.21	1.02	0.54	0.43	5.63	0.82	1.28	1.32	0.74	0.44
12	Length of overland flow	0.47	0.46	0.45	0.49	0.47	0.47	0.63	0.81	0.26	0.42	0.46	0.46	0.58	0.68
13	RHO coefficient	9.26	5.56	5.86	5.55	7.88	8.33	5.80	9.74	13.38	7.28	5.57	6.45	6.29	5.43
14	Drainage intensity	0.70	0.71	0.66	0.81	0.69	0.80	0.49	0.50	4.06	0.59	0.78	0.82	0.53	0.51
15	Infiltration number	0.78	0.84	0.83	0.83	0.79	0.89	0.31	0.19	15.39	0.82	0.92	0.96	0.39	0.28
16	Constant of channel maintenance	0.95	0.92	0.89	0.99	0.94	0.95	1.25	1.62	0.51	0.85	0.92	0.93	1.17	1.35
17	Maximum elevation	745	456	468	469	430	413	616	429	217	446	350	624	784	345
18	Minimum elevation	228	184	134	163	57	100	100	73	86	125	97	116	118	146
19	Relief	0.52	0.27	0.33	0.31	0.37	0.31	0.52	0.36	0.13	0.32	0.25	0.51	0.67	0.20
20	Relief ratio	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.01	0.03	0.03	0.01
21	Relative relief	0.96	0.96	0.48	0.59	0.59	0.46	0.51	0.26	0.48	0.43	0.41	0.83	0.69	0.57
22	Ruggedness number	0.54	0.30	0.37	0.31	0.40	0.33	0.41	0.22	0.25	0.38	0.27	0.55	0.57	0.15
23	Watershed area	121.50	25.79	100.08	68.24	119.26	109.21	165.12	230.95	32.37	122.31	128.13	111.94	186.74	71.69
24	Watershed perimeter	77.69	47.39	96.83	79.08	72.92	90.07	120.67	164.32	45.46	103.35	85.36	74.91	114.21	60.85

Table 4 (continued)

Sl.No.	Parameters	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW 9	SW10	SW11	SW12	SW13	SW 14
25	Basin length	19.13	8.31	17.95	14.44	19.83	18.87	23.86	28.87	9.46	20.12	20.66	19.13	25.59	14.85
26	Circulatory ratio	0.25	0.14	0.13	0.14	0.28	0.17	0.14	0.11	0.20	0.14	0.22	0.25	0.18	0.24
27	Elongation ratio	0.62	0.69	0.63	0.65	0.62	0.63	0.61	0.59	0.68	0.62	0.62	0.62	0.60	0.64
28	Form factor	0.30	0.37	0.31	0.33	0.30	0.31	0.29	0.28	0.36	0.30	0.30	0.31	0.29	0.32
29	Lemniscate ratio	0.83	0.67	0.81	0.76	0.82	0.81	0.86	0.90	0.69	0.83	0.83	0.82	0.88	0.77
30	Shape index	3.31	2.68	3.22	3.06	3.30	3.26	3.45	3.61	2.76	3.31	3.33	3.27	3.51	3.08
31	Compactness coefficient	1.99	2.63	2.73	2.70	1.88	2.43	2.65	3.05	2.25	2.64	2.13	2.00	2.36	2.03
32	Hypsometric integral	0.4	0.33	0.33	0.35	0.29	0.28	0.23	0.26	0.35	0.32	0.25	0.24	0.2	0.36

Table 5 Twenty parameters and ranking for different sub-watersheds

Parameters	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW 10	SW 11	SW 12	SW 13	SW 14
Mean bifurcation ratio	4.42 [1]	4.17 [4]	3.92 [8]	3.81 [10]	4.16 [5]	4.15 [6]	2.93 [13]	3.92 [9]	4.00 [7]	4.34 [3]	3.11 [12]	4.42 [2]	2.93 [14]	3.17 [11]
Mean steam length ratio	0.68 [4]	0.75 [2]	0.67 [6]	0.69 [3]	0.53 [10]	0.5 [11]	0.5 [12]	0.4 [14]	0.76 [1]	0.6 [7]	0.56 [9]	0.68 [5]	0.47 [13]	0.58 [8]
Stream frequency	0.74 [7]	0.77 [6]	0.73 [8]	0.82 [5]	0.73 [9]	0.84 [4]	0.39 [12]	0.30 [14]	7.90 [1]	0.69 [10]	0.85 [3]	0.88 [2]	0.44 [11]	0.37 [13]
Drainage density	1.05 [8]	1.08 [4]	1.11 [3]	1.01 [10]	1.06 [7]	1.05 [9]	0.79 [12]	0.61 [14]	1.94 [1]	1.17 [2]	1.08 [5]	1.08 [6]	0.85 [11]	0.73 [13]
Drainage texture	1.15 [5]	0.42 [14]	0.76 [8]	0.70 [10]	1.20 [4]	1.02 [6]	0.53 [11]	0.43 [13]	5.63 [1]	0.82 [7]	1.27 [3]	1.32 [2]	0.73 [9]	0.44 [12]
Length of overland flow	0.47 [7]	0.46 [11]	0.44 [12]	0.49 [5]	0.46 [8]	0.47 [6]	0.62 [3]	0.80 [1]	0.25 [14]	0.42 [13]	0.46 [10]	0.46 [9]	0.58 [4]	0.67 [2]
RHO coefficient	9.26 [3]	5.55 [12]	5.85 [9]	5.54 [13]	7.87 [5]	8.32 [4]	5.80 [10]	9.73 [2]	13.3 [1]	7.27 [6]	5.56 [11]	6.44 [7]	6.29 [8]	5.43 [14]
Drainage intensity	0.70 [7]	0.71 [6]	0.66 [9]	0.81 [3]	0.69 [8]	0.8 [4]	0.49 [14]	0.49 [13]	4.06 [1]	0.59 [10]	0.78 [5]	0.81 [2]	0.52 [11]	0.50 [12]
Infiltration number	0.78 [10]	0.84 [5]	0.82 [7]	0.82 [6]	0.78 [9]	0.88 [4]	0.31 [12]	0.19 [14]	15.3 [1]	0.81 [8]	0.92 [3]	0.95 [2]	0.38 [11]	0.27 [13]
Constant of channel maintenance	0.94 [7]	0.92 [11]	0.89 [12]	0.98 [5]	0.93 [8]	0.94 [6]	1.25 [3]	1.61 [1]	0.51 [14]	0.84 [13]	0.92 [10]	0.92 [9]	1.16 [4]	1.35 [2]
Relief	0.51 [2]	0.27 [11]	0.33 [7]	0.30 [10]	0.37 [5]	0.31 [9]	0.51 [3]	0.35 [6]	0.13 [14]	0.32 [8]	0.25 [12]	0.50 [4]	0.66 [1]	0.19 [13]
Relief ratio	0.02 [4]	0.03 [1]	0.01 [8]	0.02 [6]	0.01 [7]	0.01 [9]	0.02 [5]	0.01 [13]	0.01 [11]	0.01 [10]	0.01 [14]	0.02 [2]	0.02 [3]	0.01 [12]
Relative ratio	0.95 [2]	0.96 [1]	0.48 [9]	0.59 [5]	0.58 [6]	0.45 [11]	0.51 [8]	0.26 [14]	0.47 [10]	0.43 [12]	0.41 [13]	0.83 [3]	0.68 [4]	0.56 [7]
Ruggedness number	0.54 [3]	0.29 [10]	0.37 [7]	0.30 [9]	0.39 [5]	0.32 [8]	0.41 [4]	0.22 [13]	0.25 [12]	0.37 [6]	0.27 [11]	0.54 [2]	0.57 [1]	0.14 [14]
Circulatory ratio	0.25 [13]	0.14 [6]	0.13 [2]	0.13 [3]	0.28 [14]	0.16 [7]	0.14 [4]	0.10 [1]	0.19 [9]	0.14 [5]	0.22 [10]	0.25 [12]	0.17 [8]	0.24 [11]
Elongation ratio	0.62 [6]	0.68 [14]	0.62 [10]	0.64 [12]	0.62 [7]	0.62 [9]	0.60 [3]	0.59 [1]	0.67 [13]	0.62 [5]	0.61 [4]	0.62 [8]	0.60 [2]	0.64 [11]
Form factor	0.30 [6]	0.37 [14]	0.31 [10]	0.32 [12]	0.30 [7]	0.30 [9]	0.29 [3]	0.27 [1]	0.36 [13]	0.30 [5]	0.30 [4]	0.30 [8]	0.28 [2]	0.32 [11]
Lemniscate ratio	0.82 [9]	0.66 [1]	0.80 [5]	0.76 [3]	0.82 [8]	0.81 [6]	0.86 [12]	0.90 [14]	0.69 [2]	0.82 [10]	0.83 [11]	0.81 [7]	0.87 [13]	0.76 [4]
Shape index	3.30 [9]	2.67 [1]	3.22 [5]	3.05 [3]	3.29 [8]	3.25 [6]	3.44 [12]	3.60 [14]	2.76 [2]	3.30 [10]	3.33 [11]	3.26 [7]	3.50 [13]	3.07 [4]
Compactness coefficient	1.98 [2]	2.63 [9]	2.73 [13]	2.70 [12]	1.88 [1]	2.43 [8]	2.64 [11]	3.05 [14]	2.25 [6]	2.63 [10]	2.12 [5]	1.99 [3]	2.35 [7]	2.02 [4]

Morphometric sub-watershed prioritization and ranking

For this analysis, the most relevant quantitative morphometric characteristics are chosen and applied. Morphometric characteristics can be divided into three categories (linear features, relief features, and areal features). These have been utilized to prioritize more susceptible sub-watersheds since they have a direct or indirect relationship with peak flow, runoff, and risk of soil erosion [17, 18, 48, 46].

Soil erosion is directly relevant to the linear and relief characteristics such as mean bifurcation ratio, drainage density, stream frequency, drainage texture, relief, ruggedness number, and so on [18, 33]. The maximum value of linear and relief characteristics in a catchment indicates the most erodible soil. Consequently, the sub-watershed with the maximum value in the relief and linear characteristics is ranked first, while the second maximum value is ranked as second, the third maximum value is ranked as third, and so on.

The areal characteristics such as circularity ratio, shape index, compactness coefficient, elongation ratio, form factor, and lemniscate ratio have an indirect relationship with soil erosion [18, 33]. The most erodible soil in a catchment is the soil with the minimum areal characteristic value. Hence, sub-watershed having the lowest areal characteristics values will be ranked first, the second lowest areal characteristic values will be ranked as second, the third lowest areal characteristic values will be ranked as third, and so on.

For linear and relief parameters, the maximum value is given a ranking of 1, and the next maximum value is given a ranking of 2, and so on. In the case of areal parameters, the minimum value was given a ranking of 1, followed by the next minimum value is given a ranking of 2, and so on.
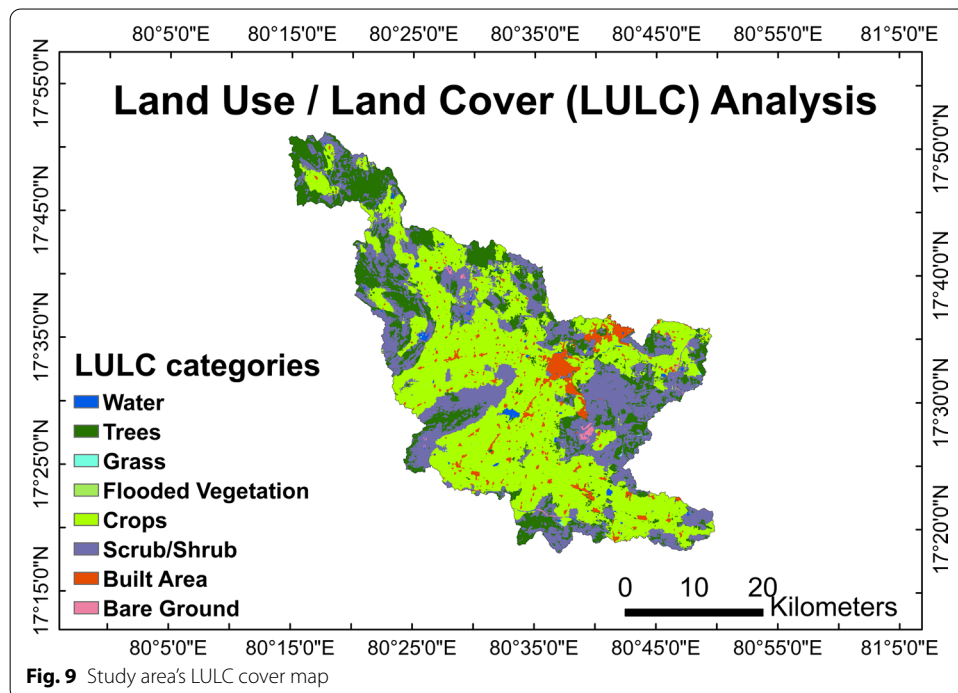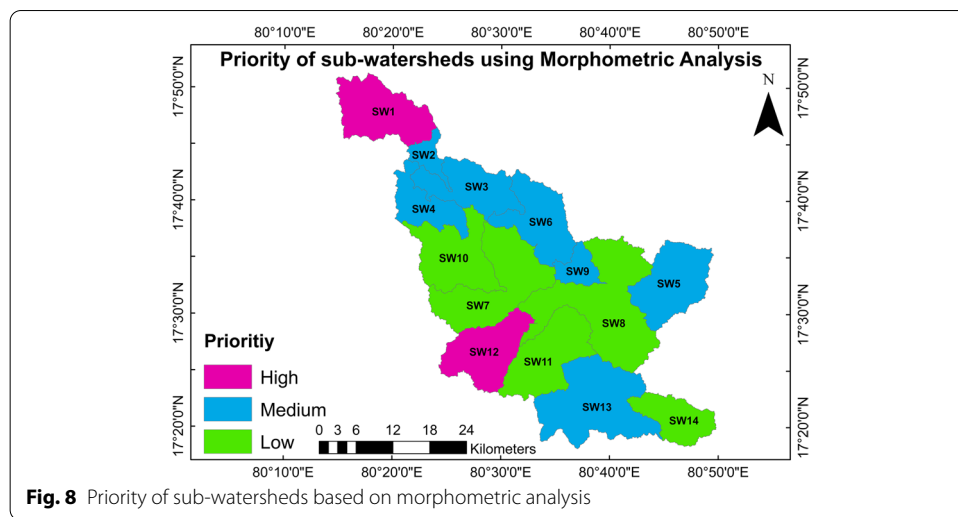
After assigning a ranking based on each parameter, the ranking values for all fourteen sub-watersheds were averaged to arrive at a compound parameter value. Table 5 shows the results of ranking for all fourteen sub-watersheds. Sub-watershed 1 has a compound value of 5.75 if all the ranks in SW1 are added together and divided by 20 characteristics. The procedure has been repeated for other sub-watersheds (from SW 2 to SW 14) and presented in Table 6.

Following the calculation of compound values, the sub-watersheds were categorized into three groups, high ($\geq$ 5.05 to < 6.5), medium ($\geq$ 6.5 to < 8), and low ($\geq$ 8 to < 9.5). The sub-watershed with the minimum compound value represents as rank 1 category, SW having the next minimum compound value represents as rank 2 category, and so on. The sub-watersheds with the compound value in the range of $\geq$ 5.05 to < 6.5 have been specified as high priority. The sub-watershed with the compound value in the range of $\geq$ 6.5 to < 8 has been chosen as a medium priority. The sub-watersheds with the compound value in the range of $\geq$ 8 to < 9.5 have been specified as a slow priority. Among 14 sub-watersheds, SW 12 and SW 1 are falling within high priority; SW 2, SW 3, SW 4, SW 5, SW 6, SW 9, and SW 13 fall within a medium priority; and SW 7, SW 8, SW 10, SW 11, and SW 14 fall within a low priority. This means that the sub-watersheds with the highest priority have the greatest danger of runoff, peak flow, and soil erosion risk [18, 33].

The final priority map of sub-watersheds in the Murredu catchment is shown in Fig. 8. SW 12 and SW 1 are the most vulnerable sub-watersheds to land degradation,

Table 6 Calculation of compound parameters, prioritization, and ranking

Parameters	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW 10	SW11	SW12	SW13	SW14
Mean bifurcation ratio	1	4	8	10	5	6	13	9	7	3	12	2	14	11
Mean steam length ratio	4	2	6	3	10	11	12	14	1	7	9	5	13	8
Stream frequency	7	6	8	5	9	4	12	14	1	10	3	2	11	13
Drainage density	8	4	3	10	7	9	12	14	1	2	5	6	11	13
Drainage texture	5	14	8	10	4	6	11	13	1	7	3	2	9	12
Length of overland flow	7	11	12	5	8	6	3	1	14	13	10	9	4	2
RHO coefficient	3	12	9	13	5	4	10	2	1	6	11	7	8	14
Drainage intensity	7	6	9	3	8	4	14	13	1	10	5	2	11	12
Infiltration number	10	5	7	6	9	4	12	14	1	8	3	2	11	13
Constant of channel maintenance	7	11	12	5	8	6	3	1	14	13	10	9	4	2
Relief	2	11	7	10	5	9	3	6	14	8	12	4	1	13
Relief ratio	4	1	8	6	7	9	5	13	11	10	14	2	3	12
Relative ratio	2	1	9	5	6	11	8	14	10	12	13	3	4	7
Ruggedness number	3	10	7	9	5	8	4	13	12	6	11	2	1	14
Circulatory ratio	13	6	2	3	14	7	4	1	9	5	10	12	8	11
Elongation ratio	6	14	10	12	7	9	3	1	13	5	4	8	2	11
Form factor	6	14	10	12	7	9	3	1	13	5	4	8	2	11
Lemniscate ratio	9	1	5	3	8	6	12	14	2	10	11	7	13	4
Shape index	9	1	5	3	8	6	12	14	2	10	11	7	13	4
Compactness coefficient	2	9	13	12	1	8	11	14	6	10	5	3	7	4
Sum of rankings (x)	115	143	158	145	141	142	167	186	134	160	166	102	150	191
Total number of parameters (y)	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Compound parameter (x/y)	5.75	7.15	7.9	7.25	7.05	7.1	8.35	9.3	6.7	8	8.3	5.1	7.5	9.55
Ranking	2	6	9	7	4	5	12	13	3	10	11	1	8	14
Final priority	High	Medium	Medium	Medium	Medium	Medium	Low	Low	Medium	Low	Low	High	Medium	Low

Fig. 8 Priority of sub-watersheds based on morphometric analysis

Fig. 9 Study area's LULC cover map

and they are more vulnerable to soil erosion and runoff. As a result, the findings will help in better planning and the management of the Murredu catchment.

Land Use/Land Cover (LULC) analysis

Prioritization of LULC of sub-watersheds was based on LULC data of the year 2020 from Sentinel-2 imagery. LULC has a resolution of 10 m. LULC categories include eight primary classes such as grass, flooded vegetation, water, trees, crops, scrub/shrub, built-up area, and bare ground. Figure 9 depicts the LULC map of the research area. Table 7 shows the details of the various LULC categories.

Table 7 LULC results of the Murredu catchment

LULC category	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11	SW12	SW13	SW14
Water (km^2)	0.44	0.19	0.56	0.12	1.03	0.62	0.75	2.54	0.21	1.30	0.70	0.93	1.60	0.31
Trees (km^2)	67.40	2.81	24.51	29.03	26.56	27.47	8.92	30.26	5.46	18.42	9.35	13.50	28.83	5.61
Grass (km^2)	0.05	0	0.06	0	0.19	0.10	0.03	0.32	0.01	0.07	0.05	0.10	0.23	0
Flooded vegetation (km^2)	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0
Crops (km^2)	22.13	13.06	46.34	18.36	38.98	45.99	108.71	79.50	10.35	63.38	102.46	63.82	106.26	44.04
Scrub/shrub (km^2)	30.98	9.57	26.81	20.49	49.52	33.97	42.64	89.93	8.00	36.27	9.78	30.20	42.66	19.24
Built area (km^2)	0.49	0.16	0.95	0.21	1.96	0.99	4.07	25.84	8.35	2.84	5.71	3.12	6.43	2.37
Bare ground (km^2)	0	0	0.85	0	1.00	0.08	0	2.53	0	0	0.07	0.28	0.73	0.10
Total area (km^2)	121.50	25.79	100.09	68.21	119.25	109.21	165.12	230.92	32.38	122.33	128.13	111.95	186.74	71.69
Water (%)	0.37	0.75	0.56	0.17	0.87	0.57	0.45	1.10	0.64	1.06	0.55	0.83	0.86	0.43
Trees (%)	55.48	10.90	24.49	42.56	22.27	25.15	5.40	13.11	16.87	15.06	7.30	12.06	15.44	7.83
Grass (%)	0.05	0	0.06	0	0.16	0.09	0.02	0.14	0.02	0.06	0.04	0.09	0.12	0
Flooded vegetation (%)	0	0	0	0	0	0	0	0	0	0.04	0	0	0	0
Crops (%)	18.22	50.66	46.30	26.92	32.69	42.11	65.84	34.43	31.95	51.81	79.97	57.00	56.90	61.44
Scrub/shrub (%)	25.49	37.09	26.78	30.04	41.53	31.11	25.82	38.95	24.72	29.65	7.63	26.97	22.85	26.84
Built-up area (%)	0.40	0.60	0.95	0.31	1.65	0.90	2.46	11.19	25.80	2.32	4.46	2.79	3.44	3.31
Bare ground (%)	0	0	0.85	0	0.84	0.07	0	1.09	0	0	0.06	0.25	0.39	0.15
Total area (%)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 8 Four parameters and ranking for different sub-watersheds

LULC category	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11	SW12	SW13	SW14
Trees (%)	55.47 [14]	10.90 [4]	24.48 [11]	42.55 [13]	22.27 [10]	25.14 [12]	5.403 [1]	13.10 [6]	16.87 [9]	15.05 [7]	7.299 [2]	12.05 [5]	15.43 [8]	7.826 [3]
Crops (%)	18.21 [1]	50.65 [8]	46.29 [7]	26.91 [2]	32.69 [4]	42.10 [6]	65.84 [13]	34.42 [5]	31.95 [3]	51.81 [9]	79.96 [14]	57.00 [11]	56.89 [10]	61.44 [12]
Scrub/shrub (%)	25.49 [4]	37.09 [12]	26.78 [6]	30.03 [10]	41.52 [14]	31.11 [11]	25.82 [5]	38.94 [13]	24.71 [3]	29.64 [9]	7.634 [1]	26.97 [8]	22.84 [2]	26.83 [7]
Built-up area (%)	0.40 [13]	0.60 [12]	0.95 [10]	0.31 [14]	1.64 [9]	0.90 [11]	2.46 [7]	11.1 [2]	25.7 [1]	2.31 [8]	4.45 [3]	2.79 [6]	3.44 [4]	3.31 [5]

Table 9 Calculation of compound parameters, prioritization, and ranking

LULC category	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	SW11	SW12	SW13	SW14
Trees (%)	14	4	11	13	10	12	1	6	9	7	2	5	8	3
Crops (%)	1	8	7	2	4	6	13	5	3	9	14	11	10	12
Scrub/shrub (%)	4	12	6	10	14	11	5	13	3	9	1	8	2	7
Built-up area (%)	13	12	10	14	9	11	7	2	1	8	3	6	4	5
Sum of rankings (x)	32	36	34	39	37	40	26	26	16	33	20	30	24	27
Total number of parameters (y)	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Compound parameter (x/y)	8	9	8.5	9.75	9.25	10	6.5	6.5	4	8.25	5	7.5	6	6.75
Ranking	8	11	10	13	12	14	4	5	1	9	2	7	3	6
Final priority	Low	Low	Low	Low	Low	Low	Medium	Medium	High	Low	High	Medium	Medium	Medium

The following classes are the LULC criteria that were considered for prioritizing sub-watersheds.

Trees

SW 14 has the highest percentage of land with trees (55.48%), while SW 7 has the lowest percentage of trees (5.40%). Sub-watersheds with a smaller percentage of trees have been given a high rank, while those with a higher percentage of trees have been given a low rank.

Crops

SW 11 has the highest percentage of land with crops (79.97%), while SW 1 has the lowest percentage of crops (18.22%). Sub-watersheds with a small percentage of crops were given a high rank, while those with a high percentage of crops were given a low rank.

Scrub/shrub

SW 5 has the highest percentage of scrub/shrub (41.53%), while SW 11 has the lowest percentage of scrub (7.63%). Sub-watersheds with a lower percentage of scrub/shrub have a high rank, whereas those with a larger percentage of scrub/shrub have a low rank.

Built-up area

SW 9 has the highest percentage of land with the built-up area (25.80%), while SW 4 has the lowest percentage of built-up area (0.31%). Sub-watersheds with a larger percentage of the constructed area have a low rank, while sub-watersheds with a smaller percentage of the built-up area have a high rank.

Fig. 10 Priority of sub-watersheds based on LULC analysis
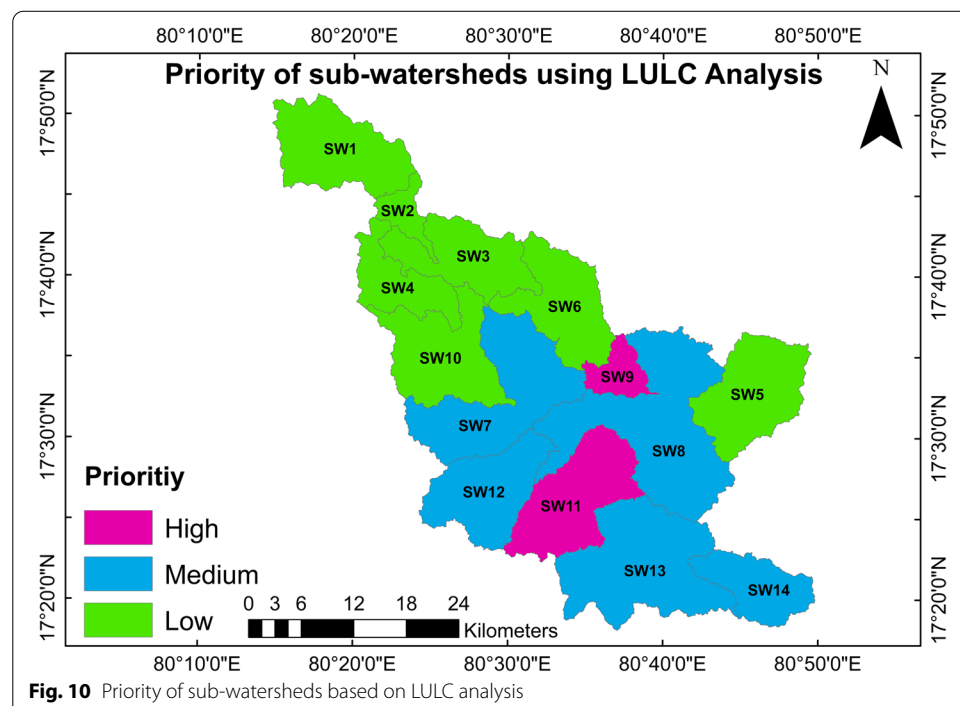
For the built-up area parameter, the maximum value was given a ranking of 1, and the next maximum value was given a ranking of 2, and so on. In the case of trees, crops, and scrub/shrub parameters, the minimum value was given a ranking of 1, followed by the next minimum value is given a ranking of 2, and so on.

The compound parameter method of averaging values was applied for sub-watershed prioritization. Table 8 shows the results of the ranking of all fourteen sub-watersheds. All the ranks in SW1 are added together and divided by four characteristics, and then the compound parameter has been computed as 8. The procedure has been repeated for the remaining sub-watersheds from SW 2 to sw14, as shown in Table 9.

Following the calculation of compound values, the sub-watersheds were categorized into three groups, high ($\geq$ 4 to < 6), medium ($\geq$ 6 to < 8), and low ($\geq$ 8 to < 10). The sub-watershed with the minimum compound value represents as rank 1 category, SW having the next minimum compound value represents as rank 2 category, and so on. The sub-watersheds with the compound value in the range of $\geq$ 4 to < 6 have been specified as a high priority. The sub-watershed with the compound value in the range of $\geq$ 6 to < 8 has been chosen as a medium priority. The sub-watersheds with the compound value in the range of $\geq$ 8 to < 10 have been specified as low priority. Among four sub-watersheds, SW 9 and SW11 are falling within a high priority; SW 7, SW 8, SW 12, SW 13, and SW 14 fall within a medium priority; and SW 1, SW 2, SW 3, SW 4, SW 5, SW 6, and SW 10 fall within a low priority. Figure 10 shows the priority of sub-watersheds based on LULC analysis.

The quantitative analysis of morphometric factors will be used in the development of catchment, river basin prioritizing for soil conservation, and also for water conservation. Morphometric descriptors are simple techniques for defining catchment processes that can be used to compare catchment characteristics and for a better understanding of the geological history of the catchment. According to the data, SW 9 and SW11 have the highest priority, and SW 1, SW 2, SW 3, SW 4, SW 5, SW 6, and SW 10 have the lowest priority among sub-watersheds. The results of morphometric and LULC analysis were compared to determine the most common sub-watersheds associated with each priority. According to morphometric study and LULC analysis, two sub-watersheds, SW 10 and SW 13, are the common sub-watersheds that fall within a low and medium priority, respectively.

Conclusions

GIS and remote sensing approaches have been used for morphometric and LULC research over the Murredu catchment area. Twenty parameters of morphometric and four parameters of LULC have been calculated and scientifically analyzed in this current study. The results of morphometric analysis-based prioritization showed that the SW 12 and SW 1 sub-watersheds are of high priority. The results of the LULC analysis-based prioritizing showed that the SW 9 and SW11 sub-watersheds are of high priority. Comparing morphometric and LULC analysis, the common sub-watersheds falling within the same priority are SW 10 and SW 13. The deployment of soil and water conservation measures may be conducted in the high-priority sub-watersheds. As a result, effective land and water management strategies should be planned for each sub-watershed based on their sensitivity rankings.

Abbreviations

LULC: Land use/land cover; SWs: Sub-watersheds; GIS: Geographical information system; RS: Remote sensing; SRTM: Shuttle radar topography mission; DEM: Digital elevation model; USGS: United States Geological Survey; ESRI: Environmental Systems Research Institute; U: Stream order; L_u: Stream length; N_u: Stream number; R_l: Stream length ratio; R_b: Bifurcation ratio; R_{bm}: Mean bifurcation ratio; L_{sm}: Mean stream length; R_{lm}: Mean stream length ratio; F_s: Stream frequency; D_d: Drainage density; D_t: Drainage texture; L_o: Length of overland flow; ρ: RHO coefficient; D_i: Drainage intensity; I_f: Infiltration number; C_{cm}: Constant of channel maintenance; H: Maximum elevation; h: Minimum elevation; B_h: Relief; R_h: Relief ratio; R_{hp}: Relative relief; R_n: Ruggedness number; A: Area of watershed; P: Perimeter of watershed; L_b: Basin length; R_c: Circulatory ratio; R_e: Elongation ratio; F_f: Form factor; K: Lemniscate ratio; S_b: Shape index; C_c: Compactness coefficient; x: Sum of rankings; y: Total number of parameters; x/y: Compound parameter.

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Authors' contributions

PRS: conceptualization, methodology, software, data curation, and writing—original draft preparation; AM: supervision, visualization, and investigation writing—reviewing and editing. The authors read and approved the final manuscript.

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Availability of data and materials

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests

The authors declare that they have no competing interests.

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