Comparative geomorphometric approach to understand the hydrological behaviour and identification of the Erosion prone areas of a coastal watershed using RS and GIS tools

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Abstract

Assessment of the geomorphometric parameters using Remote Sensing (RS) and Geographic Information System (GIS) tools forms an important part in routing the runoff and other hydrological processes. The current study uses a geospatial model based on geomorphometric parameters for the categorization of surface runoff and identification of the erosion-prone areas in the watershed of the Kuttiyadi River. The 4th order Kuttiyadi river is dominated by a dendritic to semi-dendritic drainage pattern in the subwatersheds. The linear aspect of the subwatersheds indicates towards the presence of permeable surface and subsurface materials with uniform lithology. The aerial and relief aspects of the subwatersheds shows fine drainage texture, gentle slopes, delayed peak flow, flatter hydrograph, and large concentration time which shows that subwatersheds are quite capable of managing flash floods during storm events. The estimated values of surface runoff (Q) and sediment production rate (SPR) are range from 2.13 to 32.88 km²-cm/km² and 0.0004–0.017 Ha-m/100km²/year respectively and suggest that Subwatershed 1 (SW₁) will generate more surface runoff and is prone to soil erosion followed by subwatershed 2 (SW₂) in comparison to other subwatersheds. This paper aims to fill the knowledge gap regarding categorization of flow and erosion dynamics in a coastal river watershed. We believe that our work may work help in providing the crucial information for decision-makers and policymakers responsible for establishing suitable policies and sustainable land use practices for the watershed.

Keywords Decision-makers · Erosion rate · Surface runoff · Remote sensing · Western ghats

Abbreviations

RS	Remote sensing
GIS	Geographic information system
MSL	Mean Sea Level
NE	North-East
SW	South-West
SRTM	Shuttle Radar Topography Mission
DEM	Digital Elevation Model
WGS	World Geodetic System
UTM	Universal Transverse Mercator
SPR	Sediment Production Rate

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SW ₁	Subwatershed 1
SW ₂	Subwatershed 2
SW ₃	Subwatershed 3
SW ₄	Subwatershed 4
SW ₅	Subwatershed 5
SW ₆	Subwatershed 6
SWAT-CUP	Soil and Water Assessment Tool–Calibration and Uncertainty Programme

1 Introduction

Rivers played a significant role in human civilization throughout the centuries [1]. As a result of their ecological and economic importance, hydrological processes have a great deal of interest among the public [2, 3]. Anthropogenic as well as natural factors influence hydrological processes such as shifting and intensity of rainfall occurring, sedimentation, consecutive droughts, and floods, etc. [4]. Changes in the climatic process in the watershed of spring/rain-fed rivers may lead to the drying up of sorings and can alter the land use. These changes impact the hydrological properties of soil, surface and sub-surface flow dynamics, and the frequency of floods [3, 5]. Urbanization exacerbates the problem by allowing less infiltration and intensifying surface runoff by decreasing the time lag between rainfall and surface runoff [6]. Streamflow and soil erosion are directly influenced by the intensity and amount of rainfall in a watershed which is further used to determine the sediment yield [7]. The sediment fluxes significantly affect the function of a river, as they affect the structure of channels, the development of deltas, the quality of water, geochemical cycles, and habitats in a river ecosystem [8, 9]. It is vital to understand how sediments are transported by rivers in relation to morphodynamics, hydrology, erosion rates, and sediment transfer dynamics within the specific watershed [10]. In several parts of the world, erosion rates have been accelerated because of anthropogenic changes at a global level. This has had a negative impact both on soil dynamics and sediment flow [11].

Morphometry is the science of observing, measuring, and analyzing landform's dimensions based on the shape, size, and other features of the earth's surface [12, 13]. A geomorphometric analysis has been widely applied to understand the characteristic features of a watershed, such as drainage characteristics and quantitative morphological characteristics [14]. In terms of drainage watersheds and their connected drainage networks, morphometric parameters determine the form and its structure [15, 16]. The linear, aerial, and relief contributions can be determined via a measurement of the watershed and slope component [17]. Linear aspects of the Morphometric parameters, such as stream numbers, stream lengths, and stream patterns, are key components in comprehending a watershed's hydrological response [18]. A watershed is considered a fundamental conveyer of surface runoff and erosional landscape elements. Further, in the watershed continuous association of land units and water units takes place [19]. Hydrologists have utilized the watershed as a primary unit to study the hydrological response. In this regard, compared with individual channels or conflicting sections, geomorphometric investigations at the scale of the little watershed are more profitable [14]. The aerial aspect of the geomorphometric parameters has considerable influence on the surface runoff parameters such as travel time, concentration–time, time-lag, and intensity of land erosion cycles, which can be further anticipated with greater precision [20]. An investigation of geomorphometric features in river watersheds without gauges can provide insights into those variables that influence hydrological characteristics [21]. There are several factors influencing sediment transport in a watershed, such as relief, stream density, streamflow, terrain roughness, watershed shape, subsurface flow, rainfall, soil permeability, and water-holding capacity [22, 23]. Additionally, anthropogenic factors such as deforestation, afforestation, rapid urbanization, and inappropriate land use and management can also influence the hydrological response and erosion rate of a watershed [24]. Sedimentation and ecological degradation normally increase as a result of unsuitable land use and management practices [25]. It is therefore possible to quantify erosion rates in the watershed using sediment fluxes and other temporal features to understand erosion dynamics and assist in the development of river basins sustainably by monitoring these sediment fluxes over time.

Although in India, management of land and water resources on a watershed has been given top-most priority but still, most of the states of northern to southern regions of India are poorly managed to conserve water, soil, and the nutrient state as per watershed management plan [26, 27]. It is important to develop appropriate strategies and determine priorities for monitoring the watershed responses towards controlling soil erosion and flooding with some preliminary information about the spatio-temporal variations in the hydrological response dynamics of different subwatersheds [28]. The value of such conservation practices can be enhanced through the quantification of morphometric parameters

pertaining to a watershed. Remote Sensing (RS) tools along with Geographical Information System (GIS) provide a more accurate and more effective application to find out the hydrological response of a watershed [29, 30]. There have been numerous studies on erosion data at various scales in different parts of India, but no one has explored the hydrological behavior of a coastal watershed as well as identifying areas of high erosion by examining the sediment production rate and surface runoff. This study attempts to fill the research gap and will investigate hydrological behavior and identification of the zone of high erosion in the watershed by applying a mathematical model concerning the geo-morphometric analysis at three different aspects of a Kuttiyadi river watershed. In addition, the data will provide key information regarding sustainable resource management for public benefit.

2 Study area

Kuttiyadi River (Figs. 1 and 2) starts from the Narikota Ranges on the Western inclines near the hilly terrain of Waynad; which is a piece of Western Ghats, at a height of 1220 m over the mean sea level (MSL). The river moves along through Badagara, Qulandy, and Kozhikode Taluks in Kerala before it merges with the Arabian Sea at Kottakal. Kuttiyadi River and its tributaries drain an area of 436 km². The average annual precipitation received by the watershed is 5170 mm of which 30% of the average annual precipitation is received from the north-east (NE) monsoon and 60% of the average annual precipitation is received from the south-west (SW) monsoon [31]. The average ambient temperature in the Watershed ranges from 30 to 33.5 °C.

3 Methodology

Remote Sensing (RS) along with GIS tools have been widely used to determine the morphometric parameters of the Kuttiyadi River watershed. The watershed parameters are analyzed by digital imagery using ArcGIS 10.6.1. The data sets were used for the analysis as follows:

- i. Digital Elevation Model of SRTM 30 m spatial resolution.
- ii. Topographical maps of Kerala at 1: 2,50,000 scale.
- iii. Google base map.

The drainage generation categorization of the Kuttiyadi watershed was made up by using SRTM 30 m DEM (Fig. 3). The extraction of the watershed drainage map was prepared by the ArchHydro tool using ArcGIS 10.6.1 [67]. The drainage pattern was also digitized by using topographical maps and the satellite imagery overlapped with each other. Sinks in the Digital Elevation Model (DEM) were recognized and filled up by using the tool of fill sinks to identify and proper

Fig. 1 Location map of the study area

Fig. 2 **a** Flow direction map and **b** classification of the slope of the Kuttiyadi river watershed

Fig. 3 Methodology adopted for Prioritization of subwatersheds based on surface runoff and SPR

determination of the accumulation and direction of the flow. The watershed boundary was generated by defining the outlet point at the outlet. Similarly, the same process was repeated was for the sub-watershed of the Kuttiyadi watershed along the path of the main course. The raster datasets of the watershed and sub-watershed were converted into vector data sets in the form of polylines to polygon and projected into the WGS 1984 UTM Zone- 43 N for calculation of the watershed area, perimeter, and stream lengths. The other geo-morphometric parameters such as linear, relief, and aerial parameters are analyzed using the simple mathematical formulae (Table 1) [14, 32–36].

3.1 Geo-morphometric parameters

The analyzed geo-morphometric parameters of the Kuttiyadi watershed were categorized into three broad categories as follows:

- i. **Liner Aspects:** It includes all the linear Morphometric parameters of a basin such as stream nos. (N_u), length of streams (L_u), mean stream lengths (L_{sm}), stream length ratios (R_l), Bifurcation, and Mean Bifurcation ratio (R_b and R_{bm}).
- ii. **Relief Aspects:** It includes the parameters which are change with the elevation of a basin such as relative relief (R), relief ratio (R_p), and Ruggedness No. (R_n).
- iii. **Aerial Aspects:** It includes the parameters which are changes with the aerial distance of a basin such as a Drainage density (D_d), Texture ratio (T), Stream Frequency (F_s), Elongation ratio (R_e), Circularity ratio (R_c), Form factor (R_f), Rotundity Factor (R_r), Texture Ratio (T), Shape index (S_i), Length of overland flow (L_{of}), Constant Channel maintenance (C).

3.2 Watershed surface runoff sediment production rate

The Surface runoff and sediment production rate has been estimated for the categorization of the zones which convey high surface runoff to the watershed outlet. A similar approach was also used for the identification of the erosion-prone areas within the watershed. A mathematical model was used based on the Morphometric parameters

Table 1 Mathematical formulae for the geomorphometric parameters based on linear, relief and aerial aspects

S. No.		Morphometric parameters	Formule	References
1	Liner Parameters	Stream order (U)	Hierarchical rank	[38]
2		Stream length (L_u)	Length of stream	[39]
3		Mean stream length (L_{sm})	$L_{sm} = L_u / N_u$	[38]
4		Stream length ratio (R_L)	$R_L = L_u / L_{u-1}$	[39]
5		Bifurcation ratio (R_b)	$R_b = N_u / N_{u+1}$	[41]
6		Mean bifurcation ratio (R_{bm})	Average of bifurcation ratios of all orders	[37]
7	Relief Parameters	Watershed relief (W_h)	The vertical distance between the lowest and highest points of the watershed	[41]
8		Relief ratio (R_h)	$R_h = W_h / L_b$	[41]
9		Ruggedness number (R_n)	$R_n = W_h \times D_d$	[41]
10	Aerial Parameters	Drainage density (D_d)	$D = L_u / A$	[39]
11		Drainage Texture (R_t)	$R_t = N_u / P$	[42]
12		Stream frequency (F_s)	$F_s = N_u / A$	[39]
13		Length of overland flow (L_g)	$L_g = 1 / D_d \times 2$	[39]
14		Constant channel maintenance (C)	$C = 1 / D_d$	[41]
15		Elongation ratio (R_e)	$R_e = (2 / L_b) \times \text{sqrt}(A / \pi)$	[41]
16		Circulatory ratio (R_c)	$R_c = 4 \times \pi \times A / L_p^2$	[38]
17		Form factor (F_f)	$R_f = A / L_b^2$	[39]
18		Compactness Coefficient (C_c)	$C_c = 0.282 \times L_p / \text{sqrt}(A)$	[43]
19		Rotundity factor (R_f)	$R_f = L_b^2 / 4A$	[44]
20		Shape index (S_i)	$S_w = L_{bs}^2 / A$	[40]

where; L_u =Total stream length of order "u", N_u =Total no. of stream segments of order "u", R_L =Stream length ratio, $L_u - 1$ =The total stream length of its next lower order, R_b =Bifurcation ratio, $N_u + 1$ =Number of segments of the next higher order, W_h =Watershed relief (km), L_b =Watershed length (km), L_{bs} =Watershed length along the main stream (km), D_d =Drainage density (km^{-1}), A =Area of the Watershed (km^2), P =Perimeter (km), $\pi=3.14$

that have been applied to the subwatersheds for the quantification of runoff and sediment production rate [3, 45, 46].

$$\text{Log}Q = 2238.43 + 22.12\{\text{Log}(100 + R_f)\} - 608.28\{\text{Log}(100 + R_c)\} - 530.02\{\text{Log}(100 + C_c)\}$$

$$\text{LogSPR} = 4919.80 + 48.64\{\text{Log}(100 + R_f)\} - 1337.77\{\text{Log}(100 + R_c)\} - 1166.64\{\text{Log}(100 + C_c)\}$$

where; Q is watershed runoff ($\text{km}^2\text{-cm}/\text{km}^2$), SPR is the sediment production rate ($\text{Ha-m}/100\text{-km}^2/\text{year}$) for the unit area, R_f , R_c and C_c are the Rotundity factor, Circulatory ratio, and Compactness coefficient of the watershed respectively. The estimated runoff and the sediment production rate of the watersheds provided by the model are in the log scale. By taking the antilog of the estimated values, the actual runoff and sediment production rates of the watershed can be computed.

4 Results

4.1 Basic watershed parameters

The total 436 km^2 area of the upper Kuttiyadi river watershed is subdivided into 6 small subwatersheds along the main river (Table 2). The area and perimeter of subwatersheds range from 49.60 km^2 to 128.35 km^2 and 37.50 km to 115.4 km respectively (Table 2). The elevation of the basin ranges from 15 to 1542 m from amsl. A major area of this watershed is covered with flat topography and high plantations (Fig. 4c and d).

Table 2 Important watershed characteristics

S. No.	$E_{\min}$ (km)	$E_{\max}$ (km)	R_r	L_b (km)	A (km ²)	L_p (km)
SW ₁	0.017	0.563	0.546	16.96	128.35	60.78
SW ₂	0.017	1.038	1.021	14.87	97.07	56.82
SW ₃	0.038	1.291	1.253	13.04	49.6	45.4
SW ₄	0.033	1.542	1.509	17.92	68.12	115.4
SW ₅	0.015	0.692	0.677	19.03	61.97	88.64
SW ₆	0.015	0.027	0.012	9.25	31.03	37.5

4.2 Linear aspects

The 4th order Kuttiyadi river is made up of 96 different lower-order streams. The *highest stream order* among the 6 sub-watersheds is 4th shown by the 4 watersheds named SW₁, SW₂, SW₅, and SW₆ respectively, and while the remaining two watersheds have the highest stream of order 3rd named SW₃ and SW₄ (Table 3). The *stream length* (L_u) of the stream segments is maximum in the case of first-order streams and stream length decreases as the order of streams increases [48]. The *mean stream length* (L_{sm}) of any given order is greater than that of the lower order streams [39]. The higher stream length and mean stream length is shown by the SW₁ and SW₄ (Table 3). As a result, these two watersheds SW₄ are capable of conveying less surface runoff volume to the mainstream but due to high vegetal cover, uniform slope, and loamy soil, a large amount of surface runoff will infiltrate through cracks under the dry conditions of the soil. However, The lag time of the SW₆ has very little as compared to others because it has less watershed area and perimeter, and also the catchment has very few stream lengths (Table 3). *Stream length ratio* (R_l) is the ratio of the mean stream length of the individual stream segment to the next lower order stream segment [39]. A larger stream length ratio indicates a greater potential to carry a large volume of runoff [14]. This study showed that watershed uplift is negligible, with uniform lithology throughout the watershed. The *Mean bifurcation ratio* (R_{bm}) of the 6 subwatersheds of the Kuttiyadi river is 2.33, 2.13, 2.00, 3.28, 2.63, and 1.75 for SW₁, SW₂, SW₃, SW₄, SW₅, and SW₆ respectively (Table 3).

4.3 Relief aspects

In a watershed, *relief* indicates the difference between its maximum and minimum elevation. It is important for a watershed to examine its relief to investigate the behavior of surface runoff [51]. The results show the watershed relief of the SW₄ is quite high as compared to the others (Table 4). However, out of the total watershed area, 127.35 km² area falls under less than 15°, 73.20 km² area falls under 15–30° slope, 29.29 km² area falls under 30–45° slope and only 3.79 km² area falls under the greater than 45° slope (Fig. 2). The *ruggedness number* (R_n) indicates the structural complexity of the watershed terrain with the relief (W_h) and drainage density (D_d). It also describes the areas which are prone to soil erosion [65]. The computed values of R_n for the subwatersheds SW₁, SW₂, SW₃, SW₄, SW₅, and SW₆ are 0.08, 0.16, 0.23, 0.46, 0.14 and 0.04 respectively (Table 4).

4.4 Aerial aspects

The *drainage density* (D_d) of the subwatersheds of the Kuttiyadi river is 0.145, 0.154, 0.182, 0.307, 0.282, and 0.194 for SW₁, SW₂, SW₃, SW₄, SW₅, and SW₆ respectively (Table 5). The *drainage texture* (R_t) of the subwatersheds of the Kuttiyadi river is 0.119, 0.079, 0.066, 0.069, 0.051, and 0.077 for the subwatersheds SW₁, SW₂, SW₃, SW₄, SW₅, and SW₆ respectively (Table 5) and indicates a very fine drainage texture. Stream frequency is defined as the total number of streams of all orders per unit watershed area. The *stream frequency* (F_s) is related to the watershed infiltration rate and capacity, permeability, and relief [14, 18]. The result shows that the SW₂ watershed has the minimum stream frequency among all the subwatersheds. This might be due to the fact that the watershed has a high relative relief and it contains some rocky terrain as well (Tables 1 and 5). The SW₄ shows high stream frequency as compared to other watersheds. This may be due to the watershed having comparatively low relief and having more vegetation as compared to the others (Tables 1 and 5). *Length of overland flow* (L_g) is one of the most independent parameters which affect both hydrological and hydrographical development of the watersheds [40, 59]. The computed values of L_g for

Fig. 4 **a** Drainage map, **b** Soil map, **c** Elevation profile, and **d** land use pattern of the Kuttiyadi river watershed

Fig. 4 (continued)

Table 3 Computed values of the Linear aspect of the geomorphometric parameters for the sub-watershed of the Kuttiyadi river

S. No.	U	N _u	L _u (km)	L _{sm} (km)	R _L	R _b	R _{bm}
SW ₁	1	20	40	2	1	3.33	2.33
	2	6	19.72	3.29	0.493	3	
	3	2	7.61	3.81	0.39	2	
	4	1	6.87	6.87	0.90	1	
SW ₂	1	12	29.68	2.47	1	4	2.13
	2	3	21.59	7.20	0.73	1.5	
	3	2	3.84	1.92	0.18	2	
	4	1	4.52	4.52	1.18	1	
SW ₃	1	6	16.66	2.78	1	3	2.00
	2	2	10.21	5.11	0.61	2	
	3	1	0.27	0.27	0.02	1	
	4	–	–	–	–	–	
SW ₄	1	17	37.95	2.23	1	2.83	3.28
	2	6	10.5	1.75	0.27	6	
	3	1	14.23	14.23	1.36	1	
	4	–	–	–	–	–	
SW ₅	1	13	26.7	2.05	1	6.5	2.63
	2	2	2.97	1.49	0.11	1	
	3	2	16.15	8.08	5.43	2	
	4	1	5.86	5.86	0.36	1	
SW ₆	1	6	11.83	1.97	1	3	1.75
	2	2	6.7	3.35	0.57		
	3	2	3.21	1.60	0.48		
	4	1	2.39	2.39	0.75		

Table 4 Computed values of the Relief aspect of the geomorphometric parameters for the sub-watershed of the Kuttiyadi river

S. No.	W _h	R _h	R _n
SW ₁	546	0.03	0.08
SW ₂	1021	0.07	0.16
SW ₃	1253	0.10	0.23
SW ₄	1509	0.08	0.46
SW ₅	677	0.04	0.14
SW ₆	192	0.02	0.04

Table 5 Computed values of the aerial aspect of the geomorphometric parameters for the sub-watershed of Kuttiyadi river

S. No.	D _d	F _s	T	L _g	C	S _i	F _f	C _c	R _e	R _c	R _f
SW ₁	0.145	0.056	0.119	3.46	6.92	1.762	0.446	1.513	0.754	0.436	0.560
SW ₂	0.154	0.046	0.079	3.26	6.51	2.272	0.439	1.626	0.747	0.378	0.569
SW ₃	0.182	0.06	0.066	2.74	5.48	2.480	0.292	1.818	0.609	0.302	0.857
SW ₄	0.307	0.117	0.069	1.63	3.26	3.457	0.212	3.942	0.520	0.064	1.178
SW ₅	0.208	0.073	0.051	2.40	4.80	3.563	0.171	3.175	0.467	0.099	0.984
SW ₆	0.194	0.089	0.077	2.57	5.14	2.698	0.363	1.798	0.679	0.309	0.689

the subwatersheds SW₁, SW₂, SW₃, SW₄, SW₅, and SW₆ are 3.46, 3.26, 2.47, 1.63, 2.40, and 5.57 respectively (Table 5). *Constant channel maintenance* (C) which is reciprocal of the *Drainage density* (D_d) indicates how much watershed drainage area is required to maintain a unit length of a channel [60]. The computed values of C for the subwatersheds SW₁, SW₂, SW₃, SW₄, SW₅, and SW₆ are 6.92, 6.51, 5.48, 3.26, 4.80, and 5.14 respectively (Table 5).

The *elongation ratio* (R_e) depends on a wide variety of climate, geology, and relief of a watershed. If R_e is greater than 0.9 then the watershed lies in the category of the circular watershed, if R_e lies in between 0.9 and 0.7 then it is categorized under an oval watershed and if R_e lies less than 0.7 then the watershed is called elongated in shape [14]. The *form factor* (F_f) of a watershed indicates the duration of runoff to reach the outlet. The high values of form factors indicate high peak flows with shorter duration whereas the low form factor indicates the lower peak flow with longer duration [61]. The form factor of the subwatersheds of the Kuttiyadi river is 0.446, 0.439, 0.292, 0.212, 0.171, and 0.363 for the watersheds SW_1 , SW_2 , SW_3 , SW_4 , SW_5 , and SW_6 respectively (Table 5). The *compactness coefficient* (C_c) expresses the relationship of a watershed with that of a circular watershed having the same area. A drainage channel in the circular watershed drains the water in the shortest period as compared to the other shapes to the outlet i.e., the peak of a hydrograph will occur in the shortest period after a storm event [62, 63]. If C_c approaches unity, the watershed behaves like a completely circular watershed and if C_c is greater than 1 watershed shows more deviation from its circular shape [64]. The computed values of C_c are greater than one suggesting that all the watersheds deviate from the circular shape and show some elongation.

The *circulatory Ratio* (R_c) of the watershed influences the frequency and length of the streams, geological structures, LULC, relief, climate, and slope [53]. The computed values of R_c for the subwatersheds SW_1 , SW_2 , SW_3 , SW_4 , SW_5 , and SW_6 ranges from 0.064 to 0.436 (Table 5). Generally for any watershed, if the value of the *Rotundity factor* (R_f) approaches unity it indicates the perfectly circular watershed [46]. The computed value of the R_f ranges from 0.56 to 1.17 which indicates all the subwatersheds are elongated in shape (Table 5). The rate of flow and the erosion rate of a watershed along with the main river is largely affected by the *shape index* (S_i) [40, 54]. It depends on the relief and length of the watershed. If a computed value of the shape index approaches to unity, the watersheds show maximum erosion rate. The computed values of S_i are 1.72, 2.272, 2.480, 3.457, 3.563, and 2.698 for the subwatersheds SW_1 , SW_2 , SW_3 , SW_4 , SW_5 , and SW_6 respectively (Table 5).

4.5 Surface runoff and sediment production rate

From the analysis of the aerial aspect of geo-morphometric parameters, the volume of surface runoff per unit area of the subwatersheds are found as 32.88, 26.02, 16.15, 2.13, 7.42, and 16.57 $\text{km}^2\text{-cm}/\text{km}^2$ for SW_1 , SW_2 , SW_3 , SW_4 , SW_5 , and SW_6 respectively (Fig. 5). The subwatersheds were categorized as a zone of low runoff to high runoff based on the estimated surface runoff values (Fig. 6a). The Sediment production rate of the subwatersheds of the Kuttiyadi river are estimated as 0.017, 0.010, 0.0036, 0.0004, 0.0006 and, 0.0038 ($\text{Ha-m}/100.\text{km}^2/\text{year}$) for SW_1 , SW_2 , SW_3 , SW_4 , SW_5 , and SW_6 respectively (Fig. 5). The categorization of the SPR shows SW_1 is more prone to soil erosion followed by SW_2 whereas, SW_3 , SW_4 , SW_5 , and SW_6 are less prone to soil erosion (Fig. 6b).

5 Discussion

To assess flow and erosion dynamics of the subwatersheds in the Kuttiyadi river, the current study was conducted with the objective of calculating various morphometric parameters of the river and calculating runoff and SPR.

Fig. 5 Estimated values of surface runoff and sediment production rate of the different sub-watershed of the Kuttiyadi river

Fig. 6 Classification and prioritization of the zones (a) surface runoff and (b) Erosion prone area of the different sub-watershed of the Kuttiyadi river

5.1 Linear aspects

The discharge carrying capacity of a stream and the flowing velocity increase with the *stream order*. In addition to contributing to greater sediment loads to the river, higher velocity and discharge exacerbate the erosion of the river bed and banks [47]. Additionally, it is observed that the number of stream segments decreases as the stream order increases and vice versa [39]. There is a possibility in the watershed that the mean *Bifurcation ratio* may not remain constant from one order to the next because of variations in geometry and lithology [49]. The low Rbm indicates the delay in the peak of hydrograph i.e., the time of concentration is more and the high Rbm indicates the early rise in the hydrograph i.e., the time of concentration is less so that the Rbm is used to identifying the watersheds which are responsible for flash flooding [14, 50]. Overall the Rbm of the subwatersheds is less showing the delayed peak in the hydrographs. The linear aspect of geo-morphometric parameters demonstrates that the watershed area depends on the drainage characteristics for the runoff movement.

5.2 Relief aspects

In the Kuttiyadi river watershed, there is a lot of variation between maximum and minimum elevation. This may happen if the watershed is elongated enough or the watershed is having very steep slopes. An elongated watershed shows a delayed hydrograph peak with a larger time of concentration [14]. The maximum area of the watershed lies under the low relief and less slope. The basins relief aspects indicate that the study area has been no probable uplift due to the uniform geology and lithology [1]. Quantitatively, the *relief ratio* of a watershed measures the overall steepness [51]. Also, it is a primary indicator of erosion intensity which operates on the mountainous slopes [52]. Relief ratio increases with decreasing the area and size of a watershed [53]. The computed value of the subwatersheds shows very low values of relief ratio, thus are less prone to erosion. The subwatersheds have relatively very low erosion based on the minor change in R_h . The lesser values of the R_n indicate the subwatersheds are less prone to the soil erosion due to low drainage density, low relief, and gentle slopes (Figs. 2a and 4b).

5.3 Aerial aspects

In a drainage watershed the factors affecting the *drainage density* are the length of the streams, climate, weathering, and permeability, etc.; [54]. The drainage density also affects the travel time of runoff in the watershed [55]. The results show that low drainage density which might be due to the impermeable surface or subsurface materials with high vegetation cover and low catchment relief (Fig. 4c). The *drainage texture* indicates the subwatersheds have a very fine drainage texture so that all the subwatersheds show a longer duration to the peak runoff. The results also show that watershed has very low relief with a low drainage density [42]. The *stream frequency* of the watershed is low because the watershed

of the Kuttiyadi river is covered by adequate vegetation and loamy soil leading to higher infiltration rate and infiltration capacity. So, the early rise in the hydrograph peak is not possible due to the low stream frequency of the watershed i.e., the runoff will take more time to reach the watershed outlet [56–58]. Among all the subwatersheds, SW₂ has higher vegetation and presence of loamy soil. During the study we found that all the subwatersheds shows higher values of *overland flow* which indicates that watershed has gentle slopes with longer flow paths for the runoff. In addition the larger values of the *constant channel maintainance* indicate that the watershed has high resistive soils, with rich vegetation and a flat area indicative of subwatersheds being less prone to erosion (Fig. 4b and d). As a result the concentration time of the surface runoff is higher.

The SW₄ has a larger *elongation ratio* and *compactness coefficient* among all the subwatersheds as compared to other watersheds (Table 5). The sub-watershed having a weak stratum and permeable surface and sub-surface material allows infiltration of the water and approaches to a flatter hydrograph with a high time of concentration. Similarly the lower values of the *form factors* and *Circulatory ratio* shows that the surface runoff will take a large time to reach the outlet of the watershed. As a result, the subwatersheds are well elongated in shape and they are quite capable to manage flood flows as compared to circular watersheds [1]. Also, the permeability of the SW₁, SW₂, SW₃, and SW₆ is relatively high as compared to the SW₄ and SW₅ which allows infiltration and contributes to the base flow. The *shape index* of SW₁ and SW₂ shows a higher erosion rate with very little time of concentration and SW₄ and SW₅ shows less erosion rate and larger concentration–time as compared to other subwatersheds [46]. From the data, it is clearly seen that low shape index is responsible for the higher erosion of the watershed.

5.4 Runoff and sediment production rate

Runoff from the surface of a watershed is dependent on several hydrological parameters, including precipitation, evaporation, infiltration, and transpiration, which are themselves related to climatic conditions, lithology, structure, relief, and slopes [3]. The SW₄, SW₅, and SW₆, SW₃ will be categorized under the zone of low and medium surface runoff respectively which may be due to the elongation of watersheds, low drainage density, and reasonable geological control over the surface runoff pattern. SW₁ and SW₂ were categorized under the zone of high surface runoff which may be due to the less elongation, high drainage density, and absence of geological control over the subwatersheds surface runoff. The accumulated estimated surface runoff at the watershed outlet is 1019.7 mm which is nearly equal to the measured surface runoff as 944.03 mm for the Kuttiyadi watershed computed by the SCS-CN method and further routed and calibrated with the help of Soil and Water Assessment Tool–Calibration and Uncertainty Programme (SWAT-CUP) [66]. The high erosion rate of the sub-watershed was due to the combination of steep slopes, the presence of sandy loam and clay loam soils, and low forest cover. The subwatersheds which are less prone to soil erosion have adequate high forest cover and gentle slope over the watersheds. The findings demonstrate a strong relationship between the geo-morphometric parameters and terrain slope in the watershed which is sensitive for the generation of surface runoff and sediment production. As a result, it is vital to emphasize on these parameters to develop regional systems intended to manage, protect, and develop land resources. According to the numerical model used in this study, the drainage characteristics of basins have a direct influence on erosion rates and sediment yield. Despite the fact that the effect of land use on the overall sediment yields of rivers around the world is less clear, as there have been some instances reporting both increase and decrease in sediment yields. Understanding the role of sediment production rate within a drainage basin inevitably means understanding the linkages between land use, erosion, and sediment yield within a river basin.

6 Conclusion

The Remote Sensing (RS) along with Geographic Information System (GIS) tools are the most reliable and convenient tools for computing the geo-morphometric parameters. Geomorphological parameters are considered to be the preliminary indicator of geology, relief, slope, climate, and hydrodynamics of a river system. In watershed management, the determination of the behavior of stream networks and their interactions are crucial factors. In this study geo-morphometric analysis of the linear, aerial, and relief aspects of subwatersheds has been performed. According to the study, it is concluded that the hydrologic response of the sub-watershed of the Kuttiyadi river can be categorized as semi-dendritic to dendritic with the highest order of 4th. The analysis of the linear aspects of the subwatersheds shows that the hydrological response of the subwatersheds is a primary function of the topographic and geomorphologic parameters and the vegetation cover. The mathematical model demonstrates that SW₁ can be categorized under the zone of high surface

runoff and is more prone to soil erosion followed by SW₂ while SW₄ and SW₅ are categorized under the zone of less surface runoff and low soil erosion. Therefore, preventing further erosion of the land in these watersheds is necessary for the preservation of the ecological environment and development of the area. This primary investigation can potentially play an important role in flood vulnerability and risk assessments in the downstream regions of the Kuttiyadi river. It will also supply provide the information and basic knowledge to the decision and policymakers to develop the pre-assessment for peak flooding and sustainable land-use policies.

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Authors’ contributions Kuldeep Singh Rautela led the development and design of the manuscript, Varun Khjuria analyzed the parameters and writing under the supervision of Prof. Mohit Kumar and Dr. M.A. Alam. All authors read and approved the final manuscript.

Data availability All data generated or analysed during this study are included in this article (and its supplementary information files).

Declarations

Competing interests The authors declare that there is no conflict of interest in this study.

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