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RESEARCH ARTICLE

Sub-Watershed Prioritization of Kariangote River in Kerala Based on Drainage Morphometry and Geomorphology – A Remote Sensing and GIS Approach

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Abstract

Objectives: This article examines the geohydrological behaviour of the Kariangote watershed and prioritizes its subwatersheds based on groundwater presence. **Methods:** Remote sensing and GIS techniques were used to study the morphometric and geomorphologic characteristic of the watershed. Six sub-watersheds were identified, and various morphometric and geomorphic parameters were calculated. Based on the relative importance to groundwater occurrence, sub-watersheds were prioritized by giving suitable weightage to morphometric and geomorphological units. **Findings:** Sub-watershed IV is the most deficit one and is given priority followed by III the next, V, II, I, and VI. Sub-watershed VI is with surplus groundwater and is given the last priority. **Novelty:** Higher priority should be given to conservation practices in sub-watersheds to prevent surface runoff and soil erosion and to increase groundwater levels. Sub-watersheds with highly permeable subsurface formation could be suggested for rainwater harvesting and artificial recharge of groundwater. Planning further groundwater development projects and managing watersheds would be aided by this study.

Keywords: Morphometry; Coastal Alluvium; Flood Plain; Groundwater; Prioritization

1 Introduction

Watershed is a region that provides runoff to rivers and their tributaries, and they are considered to be the basic unit of conservation. For developing a watershed management plan, watershed analysis and prioritization are the prerequisites. Researchers used several conventional methods to prioritize watersheds [1]. In recent years, Remote sensing (RS) and geographical information system (GIS) which are powerful and convenient tools for determining, interpreting, and analysing spatial information related to watersheds gained popularity among researchers [2]. RS and GIS techniques have proven useful for predicting and prioritizing groundwater potential in watersheds. They also provide insight into soil erosion and runoff in the region and help to suggest various soil and water conservation measures [3]. Several studies have been conducted on sub-watershed prioritization in the outer Himalayan region [4] and identified the tectonic and lithological control over the evolution of its drainage pattern. The Ghaghara River Basin of Himalaya was also studied and the role of neo-tectonic activities on the basin's development was identified [5]. In a similar way, Gautam et al. [6] examined the Sai River Basin in Uttar Pradesh and Dudhnai watershed in Meghalaya-Assam which is prone to both soil erosion and sedimentation [7].

Researchersbelieved an integrated approach would be more beneficial for the prioritization of watersheds [8]. Different methods such as SWAT model - soil and water assessment tool [9], FAHP - fuzzy analytical hierarchy process [10] land use/land cover and slope analysis [11], WEPP - water erosion prediction project [12] etc. were also taken up by various researchers. Recent research has shown that the prioritization of watersheds is an effective way of managing watersheds. As no previous studies have been conducted in the Kariangote watershed in Kerala, India, this study aims to prioritize sub-watersheds likely to contain surplus and deficit groundwater based on its morphometric and geomorphic characteristics.

1.1 Study area

Kariangote watershed (KWS) lies on the western flank of the Western Ghats in northern Kerala. The Kariangote River originates near Padinalkad Ghat Reserve forest in Kodagu district, Karnataka at an elevation of 1290m above MSL (mean sea level). It flows southwest for 93km, and joins the Arabian Sea at Padanna, Nileshwar. The main tributaries of the Kariangote River are Monachi hole, Malothipuzha, Pulingompuzha, Vannathipuzha, and Kavvayipuzha. The Kariangote watershed extends between 12°0'0" to 12°25'0" N latitudes and 75°6'5" to 75°33'3"E longitudes and occupies an area of 1262 km^2 (Figure 1)

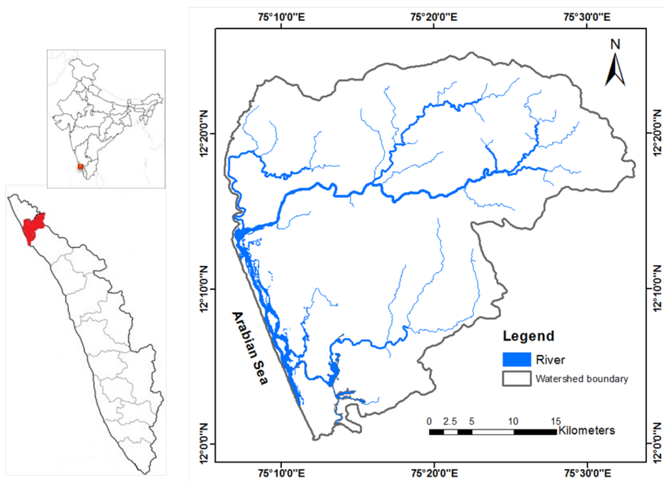

Fig 1. Study area map of Kariangote watershed

1.2 Physiography and climate

The Kariangote watershed is divided into three different physiographic units: coastal lowland to the west, the midlands, and highlands (malanad) to the east. The coastal lowland comprises straight and narrow beaches, islands, backwaters, and estuary. Lateritic plateaus with shallow valleys characterize the midland, and the highland is characterized by a steeply sloping continuous chain of hillocks forming the Western Ghats. The area experiences a warm, humid and tropical climate with heavy rainfall during SW monsoon (3500mm) and light showers during the NE monsoon. The temperature ranges from 19.7 to 33.4°C, and the humidity is high from June to October and gradually decreases as the monsoon recedes.

1.3 Geology and soil

The Kariangote watershed is occupied by charnockite (970km^2), anorthosite (26km^2), granitic gneiss (30km^2), and gabbro-granophyre (9.5km^2) of Archean to Proterozoic age (Figure 2 a). Along the coastal stretch, coastal or fluvial sediments (193km^2), sandstone (28km^2) and laterites (4.2km^2) of Tertiary and Quaternary age are observed [13]. The area is characterized by brown alluvial soil, hydromorphic soil, lateritic soil and forest loam [14]. The major hydrogeological units found in the watershed are alluvium, laterite, weathered and fractured crystalline rocks [14].

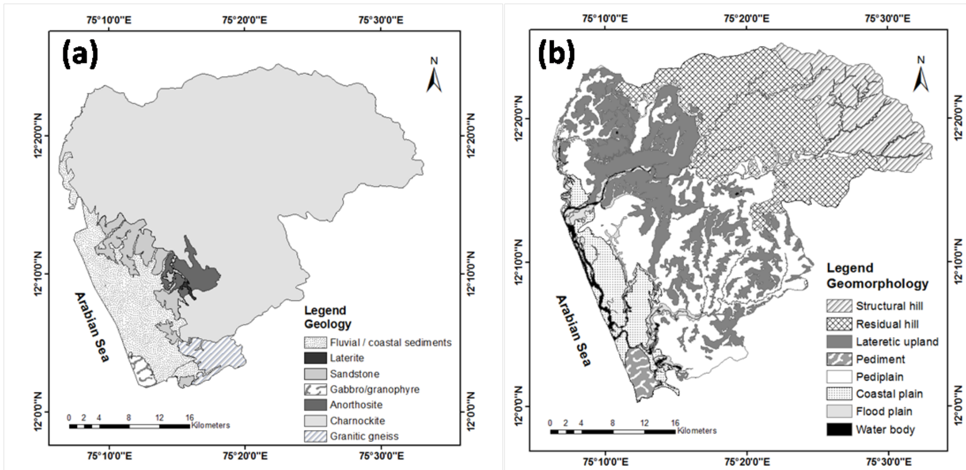

Fig 2. Map showing the geology (a) and geomorphology (b) of the Kariangote watershed

1.4 Drainage system

The Kariangote watershed is classified into six sub-watersheds (SW) based on the water divide concept, and each sub-watershed is named after one of the major rivers that drain the basin. The sub-watershed I is drained by Kariangote River, sub-watershed II by Monachi Hole, sub-watershed III by Malothi puzha, sub-watershed IV by Pulingom puzha, sub-watershed V by Vannathi puzha, and sub-watershed VI by Kavvayi puzha, respectively (Figure 3).

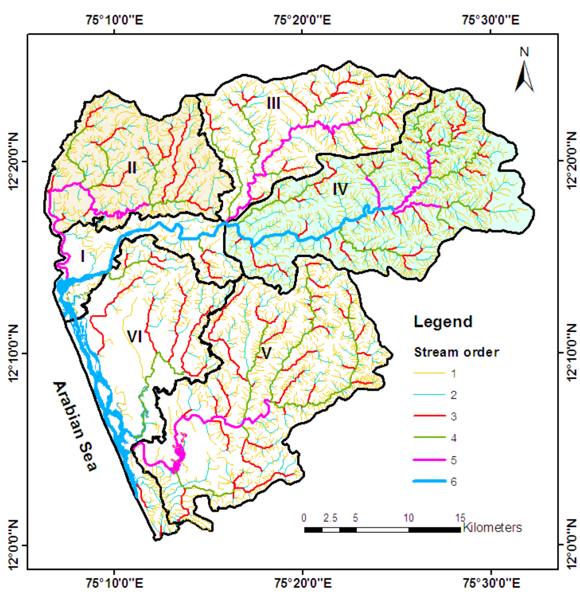

Fig 3. Map showing Kariangote sub-watersheds with their drainage network

2 Methodology

Watershed's hydrologic behaviour can be understood through morphometric analysis. It provides information about the geologic and geomorphic history of the watershed, as well as the area's groundwater potential.

A set of morphometric parameters was determined (Table 1) by applying standard mathematical formulas and methods. The geological (Figure 2 a) and geomormorphological (Figure 2b) of the watershed was accessed from the geological survey of India

(GSI) https://bhukosh.gsi.gov.in website.

The study area consists of several geomorphic units, namely: structural hills, residual hills, lateritic uplands, pediments, pediplains, coastal plains, and flood plains. These geomorphic units were used to identify occurrences of groundwater and identify surplus/deficit zones. The digital elevation model (DEM), slope, aspect, and relief maps (Figure 4) were generated using the Shuttle Radar Topographic Mission (SRTM) (3 arc-seconds, filled, finished-A, WRS-2, Path-145, Row-051, 2000) from Global Land Cover Facility (GLCF). Morphometric and geomorphic units were analysed to evaluate the groundwater prospects of the area. Sub-watersheds of the Kariangote watershed were prioritized by assigning weights to morphometric parameters and geomorphic units and watersheds with the lowest ranking (deficit zones) are given priority.

Table 1. The formulas used for calculating various morphometric parameters.

S. no.	Parameter	Formula	
Linear aspects			
1	Stream order (U)	Hierarchical rank	15
2	Stream length (L_u)	Length of the stream	16
3	Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$	15
4	Stream length ratio (R_L)	$R_L = L_u/(L_{u-1})$	16
5	Bifurcation ratio (R_b)	$R_b = N_u/N_{u+1}$	17
6	Mean bifurcation ratio (R_{bm})	Average of bifurcation ratios of all order	18
Areal aspects			
7	Drainage density (D_d)	$D_d = \Sigma L_u/A$	16
8	Drainage texture (T)	$T = \Sigma N_u/P$	19
9	Stream frequency (F_s)	$F_s = \Sigma N_u/A$	16
10	Compactness co-efficient (C_c)	$C_c = 0.2821*(P/\sqrt{A})$	16
11	Elongation ratio (R_e)	$R_e = D/L = 1.128\sqrt{A}/L_b$	17
12	Form factor (F_f)	$F_f = A/L^2$	16, 20
13	Shape factor (B_s)	$B_s = L^2 /A$	20
14	Circularity ratio (R_c)	$R_c = 4\pi A/P^2$	15
15	Length of overland flow (L_o)	$L_o = 1/(D_d \text{ x } 2)$	16
16	Infiltration number (I_f)	$I_f = D_d \text{ x } F_s$	21
Relief aspects			
17	Basin relief (R)	$R= H - h$	22
18	Relief ratio (R_r)	$R_r = R/L_b$	23
19	Ruggedness Number (R_n)	$R_n = R \text{ x } D_d$	17

3 Results and Discussion

3.1 Slope, aspect and relief maps

The slope of a feature is a measure of its steepness or inclination. It is calculated as the maximum difference between a cell's elevations in comparison with eight of its neighbouring cells. According to Khan et al[15], slope analysis is an essential component of morphometric analysis, and both climatic and morphogenic processes influence it. In the Kariangote watershed, the slope ranges from 0° to 61° (Figure 4 a). The majority of the areas fall within a gentle slope of 0° to 12°, resulting in minimal erosion and slow surface runoff. The slopes on the eastern side of the watershed range from 21° to 61°, which are influenced by the Western Ghats. A mountain's aspect is basically the direction it faces the sun, 0° being true north, 90° being actual east, 180° being true south, and 270° being true west. The watershed consists primarily of south, north, and north-west facing slopes (Figure 4 b). According to the relief map (Figure 4 c), there is an increase in elevation perpendicular to the coast, with the highest elevation along the Western Ghats.

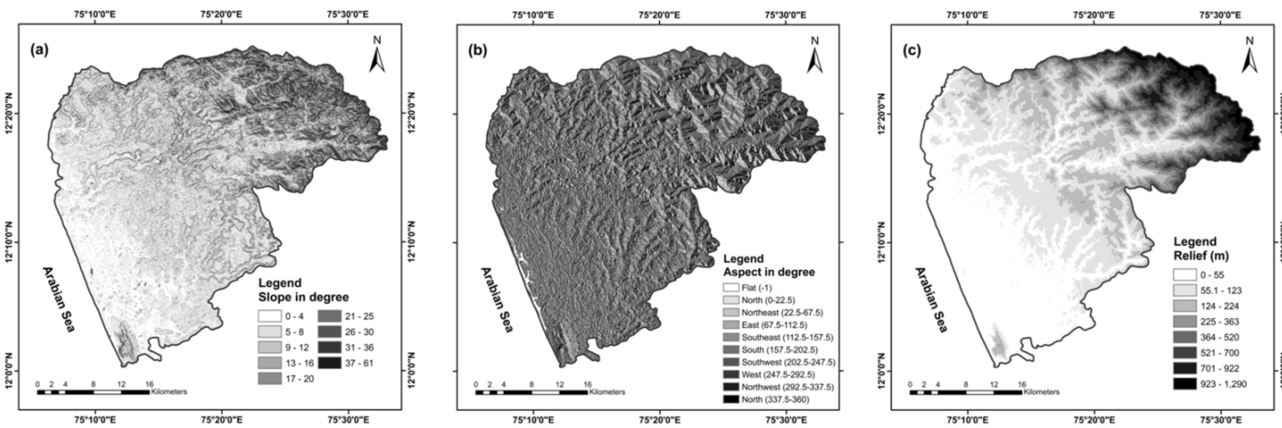

Fig 4. Slope (a), aspect (b) and relief map (c) of Kariangote watershed.

3.2 Morphometric parameters

A critical component of watershed management is the prioritization of sub-watersheds for groundwater prospecting. Based on prioritization, various water conservation plans can be developed. In order to determine the drainage characteristics, hydrogeological nature, and lithology of the area, morphometric and geomorphic parameters were studied. The morphometric and geomorphic aspects are discussed in the following section.

- **Linear morphometric parameters**

Stream ordering (Nu) is a method for arranging the streams in a basin according to their hierarchical positions in accordance with the Strahler's method [16]. A total of 4149 streams flow through the Kariangote watershed, which is categorised as a sixth-order watershed (Table 2). Out of 4149 streams, 3328 are Ist order streams, 644 are IInd order, 138 are IIIrd order, 29 are IVth order, 7 are Vth order, and three are VIth order streams. Detailed linear morphometric information is provided in Table 2. Sub-watersheds II, III, and V are of Vth order, and I, IV, and VI are of VIth order. Sub-watersheds III, IV, and V show a higher number of lower-order streams, indicating the area is highly prone to erosion. Lower order streams have the highest frequencies, and higher order streams have the lowest frequencies. Dendritic and sub-dendritic drainage patterns dominate the watershed, indicating more or less homogenous lithology.

Table 2. Linear morphometric parameters ofKariangote watershed and its sub-watersheds

Parameters	**SW I**	**SW II**	**SW III**	**SW IV**	**SW V**	**SW VI**	**KWS**
Watershed area (km^2)	80.51	168.18	186.30	304.61	329.29	193.47	1262.36
Watershed length (L_b) (km)	21.4	18.9	22.3	29.1	27.1	16.7	47.1
Perimeter (P) (km)	70.7	70.3	73.2	95.8	114.2	97.0	192.1
Number of streams of different order (N_u)							
I	100	441	522	1109	915	241	3328
II	17	78	101	232	168	48	644
III	2	15	26	47	37	11	138
IV	1	4	7	10	5	2	29
V	1	1	1	3	1	-	7
VI	1	-	-	1	-	1	3
Total number of streams (ΣN_u)	122	539	657	1402	1126	303	4149
Bifurcation Ratio (R_b)							
I/II	5.88	5.65	5.17	4.78	5.45	5.02	5.17
II/III	8.50	5.20	3.88	4.94	4.54	4.36	4.67

Continued on next page

Table 2 continued

III/IV	2.00	3.75	3.71	4.70	7.40	5.50	4.76
IV/V	1.00	4.00	7.00	3.33	5.00	-	4.14
V/VI	1.00	-	-	3.00	-	-	2.33
Mean bifurcation ratio (R_{bm})	3.68	4.65	4.94	4.15	5.60	4.96	4.21
Stream length (L_u) of different orders - km							
I	71.87	254.07	292.09	574.80	531.28	146.47	1870.58
II	21.48	75.32	74.06	170.58	126.50	50.30	518.25
III	5.48	43.12	38.61	65.45	86.36	46.64	285.67
IV	1.78	24.05	38.34	49.59	55.89	21.19	190.84
V	6.69	21.00	24.16	18.49	24.45	-	94.78
VI	25.68	-	-	21.78	-	18.49	65.95
Total length of stream (ΣL_u - km)	132.98	417.56	467.26	900.69	824.48	283.10	3026.08
Mean stream length ($L_{sm}= L_u/N_u$)							
I	0.72	0.58	0.56	0.52	0.58	0.61	0.56
II	1.26	0.97	0.73	0.74	0.75	1.05	0.80
III	2.74	2.87	1.48	1.39	2.33	4.24	2.07
IV	1.78	6.01	5.48	4.96	11.18	10.59	6.58
V	6.69	21.00	24.16	6.16	24.45	-	13.54
VI	25.68	-	-	21.78	-	18.49	21.98
Stream length ratio (R_L)							
II/I	0.30	0.30	0.25	0.30	0.24	0.34	0.28
III/II	0.26	0.57	0.52	0.38	0.68	0.93	0.55
IV/III	0.32	0.56	0.99	0.76	0.65	0.45	0.67
V/IV	3.76	0.87	0.63	0.37	0.44	-	0.50
VI/V	3.84	-	-	1.18	-	-	0.70

The Bifurcation ratio (R_b) shows how different order streams are integrated in a drainage basin. It represents the ratio between the number of streams in a particular order (N_u) and the number of streams of the next higher order (N_u+1) [17]. R_b varies from 2.33 to 5.17 for the Kariangote watershed and from 1 to 8.5 in various sub-watersheds (Table 2). R_{bm} is 4.21 for the Kariangote watershed, and it is from 3.68 to 5.60 for various sub-watersheds.

Stream length (L_u) is the length of a stream in each order [18] and it represents the hydrologic properties of the bedrock. L_u is highest for the lower order streams (1870.58km for Ist order and 518.25km for IInd order) and lowest for the higher order streams (Table 2). The longest segment of stream ($\sum L_u$) is found in sub-watershed IV, while the shortest segment is found in sub-watershed I.

The mean stream length (L_{sm}) of an order is determined by dividing the total stream length of an order 'u' by the number of streams (N_u) segments in the order [16]. It varies from 0.56 to 21.98 for the Kariangote watershed and 0.52 to 25.68 for various sub-watersheds (Table 2). The L_{sm} of a watershed depends on its size and topography [16].

The stream length ratio (R_L) is calculated by dividing the mean length of a stream of one order (L_u1) by the mean length of the stream of the next lower order (L_u-1). Within the Kariangote watershed, stream length ratios range from 0.28 to 0.70. As slope and topography change from one sub-watershed to the next, the R_L also vary (0.24 to 3.76).

- **Areal and relief morphometric parameters**

The drainage density (D_d) of a watershed is the ratio of the total length of the stream (ΣL_u) to the total area of the basin [18]. D_d is 2.40km/km^2 for the Kariangote watershed and varies from 1.46 to 2.96km/km^2 for various sub-watersheds (Table 3). A relatively low D_d is found in sub-watersheds I and VI, which indicates the rainfall is mostly absorbed through infiltration and very little surface runoff occurs in these sub-watersheds [19]. Sub-watersheds III, IV, and V have higher D_d, indicating impervious subsurface formation leading to higher runoff.

Drainage texture (T) is the total number of stream segments of all orders in a river basin to the perimeter of the basin and it is determined by number of factors, including the soil type, rock type, the kind of vegetation, rainfall, and climate. Smith [20] classified drainage textures as coarse (<4/km), intermediate (4-10/km), fine (10-15/km) and very fine (>15/km). The drainage texture of the Kariangote watershed is 21.60/km, and it varies from 1.73 to 14.63/km for sub-watersheds (Table 3). The sub-watersheds I and VI are coarsely textured, whereas the II, III, and V are intermediately textured, and IV is fine textured. The fine

Table 3. An analysis of theareal and relief morphometric parameters of the Kariangote watershed and its sub-watersheds

Parameters	SW I	SW II	SW III	SW IV	SW V	SW VI	KWS
Drainage texture (T) (km^{-1})	1.73	7.67	8.97	14.63	9.86	3.12	21.60
Drainage density (D_d) (km/km^2)	1.65	2.48	2.51	2.96	2.50	1.46	2.40
Stream frequency (F_s) (km^{-2})	1.52	3.20	3.53	4.60	3.42	1.57	3.29
Infiltration number (I_f)	2.50	7.96	8.85	13.61	8.56	2.29	7.88
Form factor (F_f)	0.18	0.47	0.37	0.36	0.45	0.69	0.57
Elongation ratio (R_e)	0.47	0.77	0.69	0.68	0.76	0.94	0.85
Circulatory ratio (R_c)	0.20	0.43	0.44	0.42	0.32	0.26	0.43
Compactness Coefficient (C_c)	2.22	1.53	1.51	1.55	1.78	1.97	1.53
Length of over land flow (L_o) (km^2/km)	0.30	0.20	0.20	0.17	0.20	0.34	0.21
Shape factor (Bs)	5.66	2.13	2.67	2.79	2.23	1.44	1.76
Minimum elevation (m)	0	0	7	4	0	0	0
Maximum elevation (m)	145	568	1205	1298	351	253	1298
Basin relief (R) (km)	0.15	0.57	1.20	1.29	0.35	0.25	1.29
Relief ratio (R_r)	0.007	0.030	0.054	0.044	0.013	0.015	0.028
Basin slope (S_b)	0.01	0.03	0.05	0.04	0.01	0.02	0.03
Ruggedness Number (R_n)	0.24	1.41	3.00	3.83	0.88	0.37	3.11

texture signifies little groundwater recharge and the coarse texture indicate higher infiltration and lower runoff, contributing significantly to aquifer recharge[16].

A stream frequency (F_s) measures the number of stream segments per unit area. According to Horton[16, 20] [18], higher the F_s, steeper the gradient and greater surface runoff. F_s of the Kariangote watershed is 3.29/$km^2$and for sub-watersheds it varies from 1.52 to 4.60/km^2 (Table 3). Sub-watershed I and VI shows the lowest Fs as a result of gentle gradient, low surface runoff, high permeability and high infiltration. Sub-watersheds II, III, IV and V has the highest F_s resulting from steep gradient, greater surface runoff and less infiltration.

Infiltration number (I_f) is the product of stream frequency (F_s) and drainage density (D_d). This is inversely proportional to watershed's infiltration capacity[21]. I_f is 7.88 for the Kariangote watershed and it varies from 2.29 to 13.61 for various sub-watershed s (Table 3). The higher the infiltration number (sub-watersheds II, III, IV and V) the lower will be the infiltration capacity resulting in high surface runoff.

A form factor (F_f) is the ratio of the area of a watershed to the square of its length[16,18,20]. It ranges from zero to one (elongated to circular). For the Kariangote watershed, it is 0.57and it ranges between 0.18 and 0.69 for various sub-watersheds (Table 3).

Circularity ratio (R_c) is the ratio of the area of the basin to that of the circle whose circumference matches the perimeter of the basin. R_c for the watershed is 0.43 and it ranges from 0.20 to 0.44 for various sub-watersheds (Table 3). R_c mainly concerns with the frequency and length of the stream, as well as the gradient of stream and its tributaries in the watershed[16].

The elongation ratio (R_e) is the ratio of the diameter of a circle with the same area as the basin to the length of the basin [17]. According to Gayen et al. [22], it is a measure of the shape of a watershed, and its shape is influenced by geology and climatic conditions. R_e varies between zero (elongated) and one (circular), and is close to one if geomorphology has the least influence on watershed development [16]. R_e of the Kariangote watershed is 0.85 and for sub-watersheds it ranges from 0.47 to 0.94 (Table 3). Bali et al. [23] stated that higher R_e indicate higher infiltration capacity and lower surface runoff, while lower R_e indicates steeper slopes and higher relief. Higher R_e may also mean an active denudation process is underway.

Compactness Coefficient (C_c) is the ratio of the perimeter of the basin to the circumference of the circular area, which equals the basin area [19] . For a perfectly circular basin, C_c is one. It is 1.53 for the Kariangote watershed and ranges from 1.51 to 2.22

for various sub-watersheds (Table 3).

Length of overland flow (L_o) is the distance over which water flows before it is confined to a specific channel[18]. L_o is 0.21 for the Kariangote watershed and it varies from 0.17 to 0.34 km^2/km for various sub-watersheds (Table 3). The lower value of sub-watershed IV suggest short flow path with a steep ground slope resulting in quick surface runoff and less infiltration. Sub-watershed VI shows a relatively higher value (0.34km^2/km), representing a long flow path with a gentle slope, slow surface runoff, and high infiltration. The drainage network is sparsely developed in this case.

A watershed's relief (R) refers to the height difference between the highest and lowest points of the watershed and it is one of the factors that determines the amount of surface runoff, sedimentation, and flood pattern in the watershed. The maximum relief of the Kariangote watershed is 1.29km, and it is 0.15km, 0.57km, 1.20km, 1.29km, 0.35km, and 0.25km, respectively, for various sub-watersheds (Table 3). The eastern part of the study area shows the highest relief and steep slope, and the south-western part shows low relief and moderate slope resulting in better infiltration (Figure 4).

A relief ratio (R_r) is the ratio between the length (L) and relief (R) of the watershed, and it indicates the intensity of erosion on the slope of the watershed. R_r for the Kariangote watershed is 0.028, and it ranges from 0.007 to 0.054 for various sub-watersheds (Table 3). Sub-watershed III and IV have the highest ratio indicating a higher gradient, and sub-watershed I and V have the lowest R_r indicating the lower gradient of pediplain and valleys. Understanding slope patterns in this region would help the administrators to plan the settlements, irrigation structures, and its possibilities. In order to reduce soil erosion, bench-like cultivation pattern can be preferred in sub-watershed III and IV. In these areas, afforestation can be planned according to the R_r . For all developmental activities, relief ratio can be considered as the primary factor.

Ruggedness number (R_n) is the product of drainage density and maximum basin relief. It is 3.11 for the Kariangote watershed and 0.24 to 3.83 for various sub-watersheds (Table 3). The slope of the basin is steeper and longer when R_n is high. Sub-watershed IV and III show the highest number, indicating high dissection, higher drainage frequency, and higher channel gradient leading to more erosion. Most of the topographic features of these basins are high, relative to their mean elevation, and hence down cutting is more. Sub-watershed I and VI have the lowest R_n indicating lower drainage frequency and lower channel gradient leading to less erosion.

Table 4. Areal coverage of geomorphic units in various sub-watersheds with their groundwater prospect

Geomorphic units	Ground water prospect	Total areal extent Km^2	SW I (%)	SW II (%)	SW III (%)	SW IV (%)	SW V (%)	SW VI (%)
Structural hill	Poor	144.1	-	-	15.74	37.69	-	-
Residual hill	Poor	309.2	-	8.62	76.77	46.31	3.21	-
Lateretic upland	Moderate	279.6	46.64	57.02	4.85	2.43	27.52	20.24
Pediment	Poor	18.0	-	-	-	-	2.28	5.04
Pediplain	Good	376.2	20.04	30.99	1.99	12.45	57.27	40.18
Flood plain	Excellent	46.4	21.08	3.26	0.65	1.12	5.55	9.81
Coastal plain	Good	88.9	12.24	0.12	-	-	6.46	29.78

3.3 Geomorphology

Various geomorphic units of the study area include residual hills, structural hills, lateritic uplands, pediments, pediplains, coastal plains, and floodplains (Figure 2 b). The areal coverage of these geomorphic units in various sub-watersheds with their groundwater prospects is expressed in Table 4. A structural hill formed by tectonic forces occupies much of the NE part of the study area. They are highly deformed rocks covering an area of 144.1km^2. They occupy some parts of sub-watershed III (15.74%) and sub-watershed IV (37.69%). Groundwater prospect is poor for this unit due to its steep slopes[24,25]. A residual hill is formed as a result of the weathering and erosion of pre-existing hill ranges. It covers an area of 309.2km^2 and the major part of sub-watershed III (76.77%) and IV (46.31%) are covered by this unit. Lateretic uplands are developed on the charnockite, granitic gneiss, and anorthosite basement rocks (279.6km^2). This unit is characterized by moderate groundwater prospects. Pediments are gently sloping bedrock surfaces with a thin layer of topsoil resulting in poor groundwater prospect and a pediplain is a highly eroded, loose alluvial surface which is good for the groundwater prospect. Pediplain covers an area of 376.2km^2, and 57.27% is distributed in sub-watershed V, 30.99% in sub-watershed II, and 20.04% in sub-watershed I. A flood plain is an area that is prone to flooding, and it covers an area of 46.4km^2 and occupies 21.08% of the sub-watershed I and 9.81% of sub-watershed VI. This unit act as an excellent site for the groundwater prospect. The western part of the watershed comprises the coastal plain with recent marine and fluvial deposits. It covers an area of 88.9km^2 of which 29.78% is in sub-watershed VI, 12.24% is in sub-watershed I, and 6.46% is in sub-watershed V.

Table 5. Prioritization of sub-watersheds based on morphometric and geomorphic units

Morphometric and geomorphic units	SW I	SW II	SW III	SW IV	SW V	SW VI
Mean bifurcation ratio (R_{bm})	6	4	3	5	1	2
Drainage texture (T) (km^{-1})	6	4	3	1	2	5
Stream frequency (F_s) (km^{-2})	6	4	2	1	3	5
Drainage density (D_d) (km/km^2)	5	4	2	1	3	6
Form factor (F_f)	1	5	3	2	4	6
Circulatory ratio (R_c)	1	5	6	4	3	2
Elongation ratio (R_e)	1	5	3	2	4	6
Shape factor (B_s)	6	2	4	5	3	1
Compound value (C_m)	4.00	4.13	3.25	2.63	2.88	4.13
Structural hill	3	3	2	1	3	3
Residual hill	5	3	1	2	4	5
Lateretic upland	2	1	5	6	3	4
Pediplain	3	4	1	2	6	5
Pediment	3	3	3	3	2	1
Flood plain	6	3	1	2	4	5
Coastal Plain	4	2	1	1	3	5
Compound value (C_g)	3.71	2.71	2.00	2.43	3.57	4.00
Total compound value (C_m+C_g)	**7.71**	**6.84**	**5.25**	**5.05**	**6.45**	**8.13**
Final Priority	**5**	**4**	**2**	**1**	**3**	**6**

3.4 Identification and prioritization of sub-watersheds

An integration of morphometric and geomorphic parameters would be helpful to ascertain the groundwater potential of any region. Morphometric parameters provide insight into the lithologic and hydrological nature of the basin and geomorphic parameters provide information about the groundwater occurrence, movement, and storage of an area. A combination of these two parameters would help to prioritize the drainage basin in terms of groundwater availability.

The Kariangote sub-watersheds were prioritized for groundwater prospects based on the hydrological factors, drainage characteristics, and geomorphology. The extent and impact of each factor on groundwater recharge was analyzed, and each unit was rated as excellent, good, moderate, or poor. The linear/aerial morphometric (drainage texture, stream frequency, drainage density, and bifurcation ratio) and shape morphometric parameters (form factor, circularity ratio, elongation ratio, and shape factor) were used to calculate sub-watershed's groundwater infiltration capacities and classify them into surplus or deficit areas. For each of the six sub-watersheds, the highest value of linear/aerial morphometric parameters was ranked as 1, the next as 2, and so on until the lowest value was ranked last. Shape aspects are ranked from lowest to highest among the six sub-watersheds, with the lowest value ranked as 1, the next as 2, so that the highest value is the last. Compound morphometric values (C_m) are calculated as the average of all ranked values (Table 5).

Furthermore, the geomorphic units were ranked based on their groundwater potential and area coverage. The geomorphic units with good to excellent groundwater prospects and lower area coverage ranked first, the next as second, and so forth. The most extensive geomorphic units with poor to moderate groundwater prospects were ranked as 1, followed by 2 and 3. Compounded geomorphic values (C_g) are calculated from the ranked values of each sub-watershed. The total compound value (C_t) is determined as the sum of C_m and C_g. The lowest total compound value (C_t) will be the most deficit sub-watershed for the groundwater prospect, followed by the next highest C_t and then the highest C_t will be the most surplus sub-watershed. The sub-watershed IV is deficit of groundwater and given the top priority, followed by III, V, II, and I (Figure 5). Sub-watershed VI has the most surplus groundwater, and given the least priority.

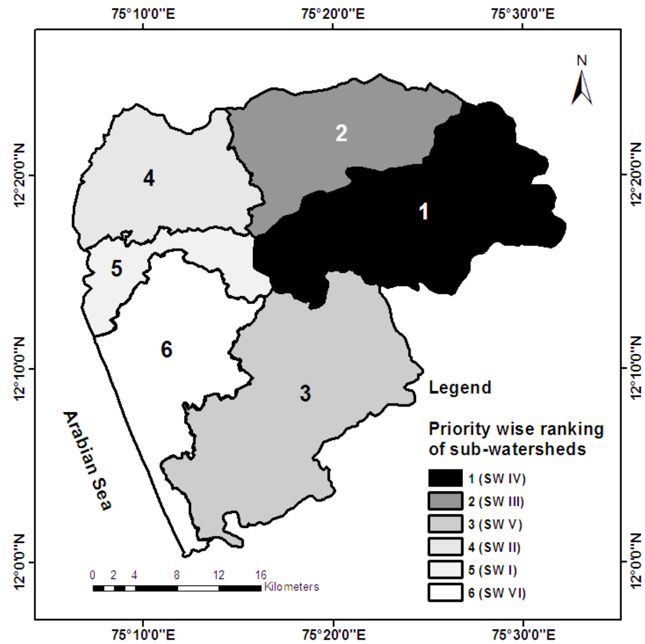

Fig 5. Priority wise ranking of the Kariangote River sub-watersheds

4 Conclusion

The study summarizes the sub-watershed prioritization of the less studied Kariangote River based on morphometric and geomorphic parameters. The sub-watersheds with deficit or surplus of groundwater is identified. In this study, various morphometric and geomorphic parameters were calculated and compound morphometric (C_m) and compound geomorphic (C_g) values were determined based on the weightage of each parameter, and the total compound value (C_t) was calculated. Accordingly, the sub-watershed IV with the lowest C_t is identified as the groundwater deficit one and is given the highest priority. The next value represents the next priority. The sub-watershed VI with highest C_t reflects the most surplus sub-watershed and given the lowest priority. In terms of water conservation, the sub-watersheds with high priority (IV and III) can be addressed immediately. In these sub-watersheds, water harvesting structures, such as check dams, percolation tanks, recharge pits, nala bunds, etc. can be recommended to increase the infiltration capacity and to reduce the surface runoff. Additionally, this study would allow planners to prioritize resources across various sub-watersheds.

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