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Prioritization of watershed susceptible to erosion using morphometric indices and GIS techniques, in Béré Region, Côte d'Ivoire

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Abstract

The discipline of geomorphometry is concerned with the measurement and the mathematical analysis of the Earth's surface, including its dimensions. It is particularly useful for characterizing watersheds when field data is not readily available. In this study, SRTM imagery and the GIS are used to identify erosion-prone areas and to assess their groundwater potential within the Béré region sub-catchment. Morphometric parameters, including bifurcation ratio, drainage density, flow frequency, drainage texture, basin length, form factor, circulatory ratio, elongation ratio, surface flow length, basin form factor, and compactness coefficient, were used to prioritize sub-catchments and identify areas with high groundwater potential and areas susceptible to erosion. Consequently, the lowest corresponding compound parameter (Cp) was considered as one for the final priority ranking (Rp), then the second lowest value as two, and so on. In terms of water and soil conservation, SW09 is of high priority while SW15 is of low priority. In terms of groundwater potential, SW09 has the lowest amount of groundwater while SW15 has the highest. Morphometric analysis is useful for water and soil conservation practices in areas where groundwater and relevant data sets are unavailable.

Keywords: GIS; Remote Sensing; Morphometric Analysis; SRTM DEM; Béré Region

1. Introduction

The development of a drainage system in space and time is influenced by several variables such as geology, geomorphology, soil, climate and vegetation of the area through which it flows. This information is vital for water resource management and soil conservation. Good quality climatic and geospatial data, such as precipitation, temperature, topography, land use and soil maps, are the basic building blocks of hydrological modeling [1]. However, in most African countries, there are difficulties in accessing data because they are generally expensive, or not very accurate, or chronologically irregular. In Côte d'Ivoire, the collection of data in various measurement places of the country was hindered by the socio-political crises from 1999 to 2010 [2].

When hydrological data is unavailable, geomorphological parameters can be used to describe the watershed in relation to its climate [3], [4]. Most studies conducted in Côte d'Ivoire [5], [6], [7], [8], [9], have primarily focused on the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith in 1978 to assess soil erosion by water. As for groundwater, most research relies on piezometric and borehole data to identify areas of high-water potential. Piezometric data are often unavailable or difficult to access. It would be interesting to explore other types of data.

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Indeed, few studies seem to have been devoted to the use of morphometric parameters of the watersheds for the prevention of erosion and the determination of areas with productive aquifers in Côte d'Ivoire. The morphometric parameters mentioned are essential for hydrological studies, such as groundwater management, basin management, water and soil conservation, and environmental assessment [10], [11], [12]. Analysis of morphometric parameters is significant in identifying and determining groundwater zones and areas at high risk of erosion [13].

Numerous basins and sub watersheds around the world have been morphometrically characterized using conventional techniques [14], [15], [16], [17], [18]. Geomatics has significantly simplified the assessment of drainage basin morphometry. The use of geospatial techniques has enabled the measurement of watershed morphometric parameters on a large scale with greater reliability, accuracy, and cost-effectiveness [19], [3].

This paper presents a study that utilizes SRTM and GIS imagery to map the prioritization of erosion-prone and high groundwater potential areas in the sub-watersheds of the Béré region.

The specific objectives of this study are outlined below

- Extract the drainage network, physical characteristics of the watershed and morphometric parameters from SRTM DEM.
- Analyze the morphometry of the drainage network.
- Prioritize the sub-watersheds based on their susceptibility to erosion and high groundwater potential.

2. Site description

The Béré region is 500 km from Abidjan, the economic capital of Côte d'Ivoire. It lies between longitudes 5 and 6 West and latitudes 7 and 9 North (Fig. 1). It covers an area of 19,122 km2.

The region is in the middle-north of Côte d'Ivoire. It is part of the Woroba District. The region is characterised by the pervasive Sudanese climate. This climate is a tropical regime of transition between the sub-Saharan semi-arid zones and the tropical zones of the Gulf of Guinea. The topography of the investigated area is clearly defined by a series of plateaus that fall moderately from north to south. The altitude ranges from 400 to 300 metres.

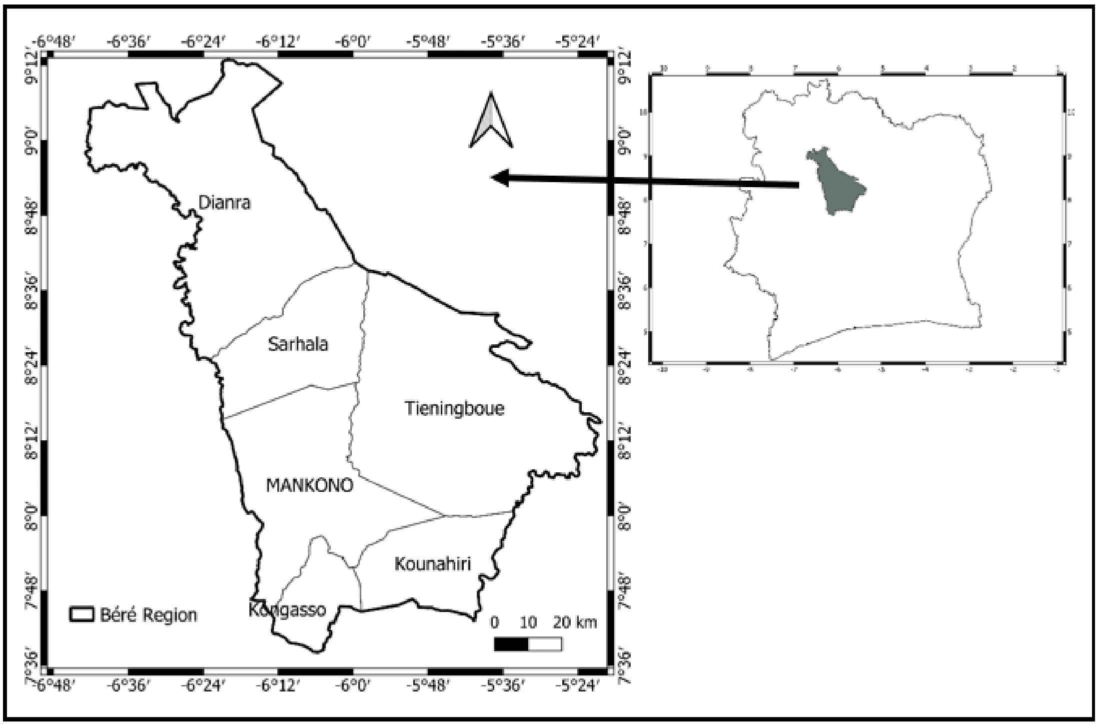

Figure 1 Location map of the study area

The exposed rocks are mainly granites. Several bands of Birimian schistose formations join the granites near the boundaries; they represent depressed gutters for rivers such as Bandama, Bou and Béré on some specific points of their streams [20]. The region lies at the core of the Leo rise and the geological formations of the Béré region belongs to the Birimian or Paleoproterozoic.

3. Materials and methods

The study utilized Quantum GIS Geographic Information System (QGIS) software to extract the drainage network and other relevant parameters. The Shuttle Radar Topography Mission satellite images served as the basis for the study.

3.1. Extracting The Hydrographic Network and Sub-Watersheds

We used the D8 algorithm to extract the drainage network. The D8 algorithm was introduced by [21].

Algorithm: Min [(Z (x, y) -z (xi, yi)]

Où x_i= (x-1, x, x+1); y_i= (y-1, y, y+1);

Z (x, y): central pixel elevation;

z (xi, yi): altitudes of the 8 neighbors.

The extraction of watershed boundaries was conducted automatedly following the elevated ridgeline on the flow direction raster and was based on the previously extracted hydrographic network. The algorithm of [22] was applied. All parameters were extracted from the satellite image of the Shuttle Radar Topographic Mission (SRTM).

3.2. Morphometric Analysis of Drainage Network and Prioritization Of Sub-Basins

We calculated the morphometric parameters of the sub-watersheds in the Béré region using the formula provided in Table I. And the morphometric parameters calculated include area, perimeter, stream order, stream length, number of streams, bifurcation ratio, drainage density, flow frequency, drainage texture, basin length, form factor, circulatory ratio, elongation ratio, length of surface flow, basin form factor, and compactness coefficient.

Table 1 Calculation of morphometric parameters for all watersheds

Parameters	**Equation**	**Eq. N°**	**References**
Basin area	QGIS		[18]
Perimeter (P)	QGIS		[16]
Stream order (U)	Hierarchical rank		[18]
Number of stream (N_u)	Individual order stream number		[14]
Stream length (L_u)	L_u= L_{u1}+L_{u2}+…L_{un}	Equation 1	[14]
Basin length (L_b)	$L_b = 1.321 \times A^{0.568}$ where, A=Basin area (km^2)	Equation 2	[23]
Stream length ratio (R_l)	$R_l = \frac{L_u}{L_{U-1}}$ where R_l= Stream length ratio, Lu= Total number of order « u » streams, Lu-1= Total number of flows for the next lower order.	Equation 3	[14]
Bifurcation ratio (R_b)	$R_b = \frac{Nu}{N_{u+1}}$ where N_u = total number of stream segments of order u. N_{u+1} = number of stream segments of next higher order.	Equation 4	[16]
Mean Bifurcation ratio (R_{bm})	R_{bm} = moyenne des rapports de bifurcation de tous les ordres	Equation 5	[17]

Drainage density (D_d)	$D_d = \frac{L_u}{A}$ where L_u= total stream length of all orders, A=Basin area	Equation 6	[14]
Stream frequency (F_s)	$F_s = \frac{N_u}{A}$ where N_u= total number of streams of all orders, A= Basin area	Equation 7	[14]
Texture ratio (R_t)	$R_t = \frac{N_u}{P}$ where N_u= total number of streams of all orders, P= Basin perimeter	Equation 8	[14]
Elongation ratio (R_e)	$R_e = \left(\frac{2}{L_b}\right) \times \left(\frac{A}{\pi}\right)^{0.5}$ Où L_b= Basin length, A=Basin area, et π = "Pi" 3.14	Equation 9	[16]
Circulatory ratio (R_c)	$R_c = \frac{(4 \times \pi \times A)}{P^2}$ where R_c= circulatory ratio, π = "Pi" 3.14, A=Basin area (km^2), P= Basin perimeter (km)	Equation 10	[15]
Form factor (F_f)	$F_{fo=} \frac{A}{{L_b}^2}$ where A=Basin area (km^2), L_b= Basin length	Equation 11	[24]
Basin Shape (B_s)	$B_s = \frac{{L_b}^2}{A}$ where L_b= Basin length, A=Basin length (km^2).	Equation 12	[24]
Compactness constant (C_c)	$C_c = \frac{(0.2821 \times P)}{A^{0.5}}$ where A=Basin area (km^2), P= Basin perimeter (km)	Equation 13	[14]
Length of over land flow (L_o)	$L_o = \frac{1}{(2 \times D)}$ Où D= Drainage density	Equation 14	[14]

3.3. Number Of Flows (Nu), And the Length Of the Flow (Lu)

The number and length of streams of each order as well as the perimeter, length and width of the basin, were calculated from the SRTM DEM using a GIS.

3.4. Flow Length Ratio (Rl)

The flow length ratio is defined as the ratio between the average length of the segments of a given order (lu) and the average length of segments of the next lower order (lu-1) [14].

3.5. Linear Parameters

3.5.1. Stream Frequency (F_s)

The stream frequency refers to the total number of stream segments of all orders per unit area, as defined by [24]. Higher F_s values indicate higher drainage density values in a watershed, which in turn indicates higher runoff and a steep soil surface [24], [25], [13].

3.5.2. Drainage Density (D_d)

Drainage density refers to the length of the drainage network per unit area of the watershed [14], [26]. Low drainage density is associated with regions with very permeable soils and subsoils, dense vegetation cover, and low landform. Regions with impermeable subsoil materials, sparse vegetation, and mountainous landform have high drainage density values [12]. Drainage density is typically classified into four categories: low <2, moderate 2-4, high 4-6, very high> 6) [27].

3.5.3. Texture Ratio (R_t)

Drainage texture is defined as the ratio of the total number of stream segments of all orders to the perimeter of the area ([14]; [28]) classified the texture of a basin as very coarse (<2 per km), coarse (2-4 per km), moderate (4-6 per km), fine (6-8 per km) and very fine (>8 per km).

3.5.4. Bifurcation Ratio (R_b)

The bifurcation ratio (Rb) is a parameter that expresses the degree of branching of the drainage network [10]. It is defined as the ratio of the number of stream segments of a given order to the number of segments of the next higher order [16]. If the bifurcation ratio is low, it indicates a flat land with a soft, permeable rock bed where more water infiltrates, creating an area with groundwater potential [29]. When the Rb value ranges from 3.0 to 5.0 for a watershed, the impact of geological structures on the drainage network is insignificant. ([30]; [18]).

3.5.5. Length Of Over Land Flow (Lo)

The length of overland flow is approximately equal to half the inverse of the drainage density. [14]: Lo = 1/2Dd. The length of overland flow is the length of water flow over the ground before concentrating in the channels of defined streams [31]. Overland flow and runoff are two distinct terms. Runoff refers to the water that moves through a channel to reach the outlet. Lo is inversely proportional to the average slope of channel [19]. In small watersheds, the length of over land flow is more dominant than in larger ones [3]. The length of overland flow indicates the speed of the process. Shorter lengths indicate a faster process, and longer lengths indicate a slower process [29].

3.6. Shape Parameters of the Basin

3.6.1. Form Factor (F_f)

[24] defines the form factor as the ratio of the surface area of the basin to the square of its length. The smaller the value of the form factor, longer the watershed will be. The basins with low form factors have lower peak flows of longer duration. Watersheds with high form factors are circular in shape and have high peak flows of shorter duration [32].

3.6.2. Elongation Ratio (R_e)

[16] defines the elongation ratio as the ratio between the diameter of the circle with the same area as the drainage basin and the basin's maximum length. Elongation ratio (Re) values typically range from 0.6 to 1, and is influenced by various climatic and geological factors. Regions of very low relief typically have values close to 1, while high landform and steep land are generally associated with values in the range of 0.6 to 0.8 [18]. According to [33], a higher Re indicates a high percolation rate, low runoff, and limited soil erosion.

3.6.3. Circulatory Ratio (R_c)

The Circulation Ratio (R_c) is the ratio between the surface area of a basin and the area of a circle having the same perimeter as the perimeter of the basin [15]. Rc is influenced by various factors, including the length and frequency of streams, tectonics, lithology, climate, slope, and vegetation cover of the basin. The Rc value ranges from 0 (minimum circularity) to 1 (maximum circularity). A high Rc value indicates that the tributaries of the basin are mature. Low, medium, and high Rc values correspond to young, mature, and old stages of tributaries in the basins. [29].

3.6.4. Compactness Constant (Cc)

The Coefficient of Compactness is the ratio of the perimeter of a basin to that of a circle with the same area [14]. The compactness coefficient is directly related to the assessment of erosion risk. Lower values of this parameter indicate that the basin is more elongated and less eroded, while higher values indicate the opposite [34]. The shape of a watershed varies depending on the value of Cc. A watershed is circular when Cc equals one, while those with a Cc value of 1.28 have a square shape. Watersheds with a Cc value greater than 3.0 have a variable shape ([32]; [35]).

3.6.5. Basin Shape (B_S)

This is the ratio between the squared length of the basin and the area of the basin [24]. This parameter is comparable to the circularity ratio, and form factor, as it provides an indication of the circularity of the watershed. The rapid response of a basin after a storm increases with the circularity of the basin [36].

3.7. Sub-Watershed Hierarchy Through Morphometric Analysis

Linear parameters have a direct and proportional relationship with erodibility, higher values indicate greater erodibility. In contrast, there is an inverse relationship between the shape parameters and erodibility. As these parameters increase, erodibility decreases. Their values are ranked in ascending order [23].

The sub-watersheds were ranked based on above criteria, prioritizing the highest value for linear parameters and the lowest value for shape parameters. The composite factor, which is calculated from these parameters, helps prioritize each sub-watershed.

The calculation involves adding up the ranks of all parameters and then dividing the total by the number of parameters. The sub-basin with the lowest composite factor is then assigned the highest rank, and so on. The sub-watersheds with the lowest parameter values are given the highest priority, while the sub-watershed with the highest compound factor value is given the lowest priority.

4. Results

4.1. Watershed Areas and Drainage Network

The drainage network was extracted from sixteen sub-watersheds, as shown in figure 2. In the study area, the order of the stream varies from first to fifth according to Strahler's classification. There are eleven sub-watersheds that are third-order, four that are fourth order, and one that is fifth-order.

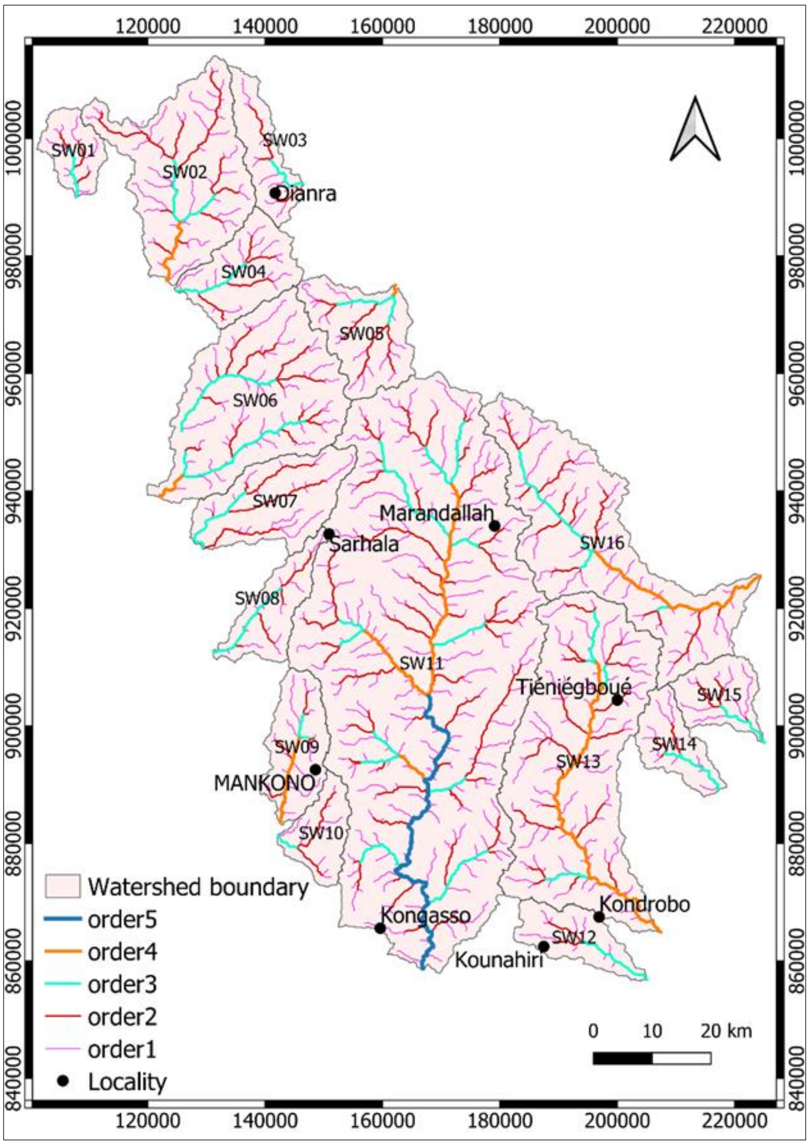

Figure 2 Map of the sub-watershed areas and drainage network of the Béré region

4.2. Morphometric Analysis of the Drainage Network

4.2.1. Analysis of the Streams in the Sixteen Sub-Watersheds

A total of 1366 streams were found, with 694 being first-order, 339 second-order, 187 third-order, 105 fourth-order, and 41 fifth-order. Table 2 displays the number, order, and length of each watershed. The data shows that SW11 has the highest number of streams (512) while SW15 has the lowest (17). Additionally, first order streams are the most abundant in all sub-watersheds, while the highest order (5) has the fewest streams.

Therefore, higher order streams are associated with greater discharge and higher flow velocity, indicating that 41 rivers (5th order) are highly susceptible to flooding during the monsoon season. The abundance of first-order rivers suggests that downstream rivers may experience flash flooding following heavy rainfall [37].

The length of the stream decreases as the order of the stream increases, except for SW 09, SW 13, and SW 14. This could be due to an abrupt change in gradient or an obstacle that needs to be bypassed. The length of the stream is a crucial variable in a drainage basin.

Table 2 shows the values for the number of flows, length of flow, and length ratio for different orders and sub-watersheds.

Table 2 Analysis of flows in the sixteen sub-watersheds

Sub-watershed	Number of streams					Stream length					Length ratio			
	1	2	3	4	5	1	2	3	4	5	2/1	3/2	4/3	5/4
SW01	14	6	7	-	-	28.42	13.74	10.83	-	-	0.48	0.78	-	-
SW02	50	32	10	7	-	133.62	76.50	20.45	12.56	-	0.57	0.26	0.61	-
SW03	13	7	5	-	-	21.17	18.61	9.44	-	-	0.88	0.5	-	-
SW04	19	9	9	-	-	53.53	27.42	14.63	-	-	0.51	0.5	-	-
SW05	22	14	6	-	-	54.33	37.55	17.20	-	-	0.69	0.45	-	-
SW06	64	26	35	2	-	151.73	72.81	59.66	6.60	-	0.48	0.81	0.11	-
SW07	23	17	4	-	-	56.38	54.07	16.47	-	-	0.95	0.3	-	-
SW08	19	9	9	-	-	30.23	20.94	18.48	-	-	0.69	0.86	-	-
SW09	22	7	4	10	-	51.35	16.33	6.56	16.91	-	0.31	0.4	-	-
SW10	10	7	2	-	-	25.57	21.61	4.59	-	-	0.84	0.22	-	-
SW11	258	121	53	39	41	690.84	315.49	125.73	66.32	67.20	0.45	0.39	0.52	1.01
SW12	11	5	5	-	-	26.57	12.65	14.72	-	-	0.47	1.16	-	-
SW13	81	38	12	30	-	240.88	103.33	26.12	69.10	-	0.42	0.25	2.64	-
SW14	11	4	6	-	-	34.39	11.97	14.56	-	-	0.34	1.21	-	-
SW15	9	5	3	-	-	39.41	14.03	12.35	-	-	0.35	0.88	-	-
SW16	68	32	17	17	-	181.45	76.06	31.99	38.08	-	0.41	0.42	1.19	-

4.2.2. Estimation Of Linear Parameters of Sub-Watersheds

The watersheds in the Béré region are characterized by a permeable bedrock, allowing for good water infiltration and moderate runoff. The reason for this is the relatively low values of linear morphometric parameters and the generally flat landform in our area. Table 3 shows the linear morphometric parameters for our area.

- **The average length of overland flow (Lo)** is 1.23 km2/km. For SW15, it is 1 km2/km, and for SBV03, it is 1.61 km2/km. For comparing the sub-basins based on the nature of the flow, the Lo is classified into three categories in the study area: (1) low (<1.20 km2/km), (2) medium (1.20-1.30 km2/km), and (3) high (>1.30 km2/km). The elevated Lo values observed in SW03 and SW12 suggest the existence of extended flow paths, which in turn indicate gentle soil slopes. These areas are characterized by reduced runoff and increased infiltration. The Lo values in SW1, SW11, SW14 and SW 5 are low. This indicates short flow paths with steep soil slopes. On the other hand, SW02, SW04, SW05, SW06, SW07, SW08, SW09, SW10, SW13, and SW16 have average Lo values, suggesting moderate soil slopes, flow paths, runoff, and infiltration (Table 3).
- **Bifurcation ratio (Rb):** The bifurcation ratio of the SW06 sub-watershed is the highest, above 3.0, indicating strong structural control over the drainage network. The bifurcation ratio of the other sub-watersheds, excluding SW06, is low, below 3.0, indicating flat terrain and a soft, permeable bedrock. This allows for more water infiltration, creating an area with moderate groundwater potential (Table 3).
- **Texture ratio (Rt)**: According to Table 3, this parameter has an average of 0.46/Km, which suggests a coarse drainage texture. The value indicates low rainfall, high infiltration, and low relief.
- **Stream frequency (Fs)**: The data in table 3 shows that the value of the sub-basins is low, less than 1/km2 in all sub-basins. As a result, the soil slopes are gentle, and the rock permeability is high in these sub-basins. This leads to low runoff and moderate to high infiltration (Table 3).

Table 3 Linear parameters of sub-watersheds

Sub-watershed	Perimeter (Km)	Area (Km^2)	Drainage density (Km/Km^2)	Stream Frequency (Km^{-2})	Bifurcation ratio	Texture ratio (Km^{-1})	Length of overland flow (Km)
SW01	62.61	112.16	0.47	0.24	1.59	0.43	1.06
SW02	175.03	582.30	0.41	0.17	2.06	0.56	1.21
SW03	96.303	155.52	0.31	0.16	1.62	0.25	1.61
SW04	94.838	230.70	0.41	0.16	1.55	0.39	1.21
SW05	107.288	263.57	0.41	0.15	1.95	0.39	1.21
SW06	172.1	709.40	0.40	0.17	6.9	0.73	1.25
SW07	113.696	315.65	0.40	0.13	2.8	0.38	1.25
SW08	100.331	167.71	0.41	0.22	1.55	0.36	1.21
SW09	93.373	212.63	0.42	0.20	1.76	0.46	1.19
SW10	73.234	134.71	0.38	0.14	2.46	0.25	1.31
SW11	394.733	2976.21	0.42	0.17	1.67	1.29	1.19
SW12	87.698	155.52	0.34	0.13	1.6	0.23	1.47
SBV13	238.011	1054.94	0.41	0.15	1.89	0.67	1.21
SW14	79.459	142.63	0.42	0.14	1.27	0.26	1.19
SW15	75.065	148.49	0.5	0.12	1.73	0.22	1
SW16	258.7	788.38	0.41	0.16	1.66	0.51	1.21

- **Drainage density (D_d):** The drainage density (D_d) is similar across the various sub-watersheds in the study area. The average value of 0.40 km/km2, which is less than 2 km/km2 and indicates a high permeability of the area; which is characteristic of a coarse drainage density ([28]; [17]) (figure 3). The watersheds in the region have a high infiltration capacity, making them ideal for groundwater recharge [38].

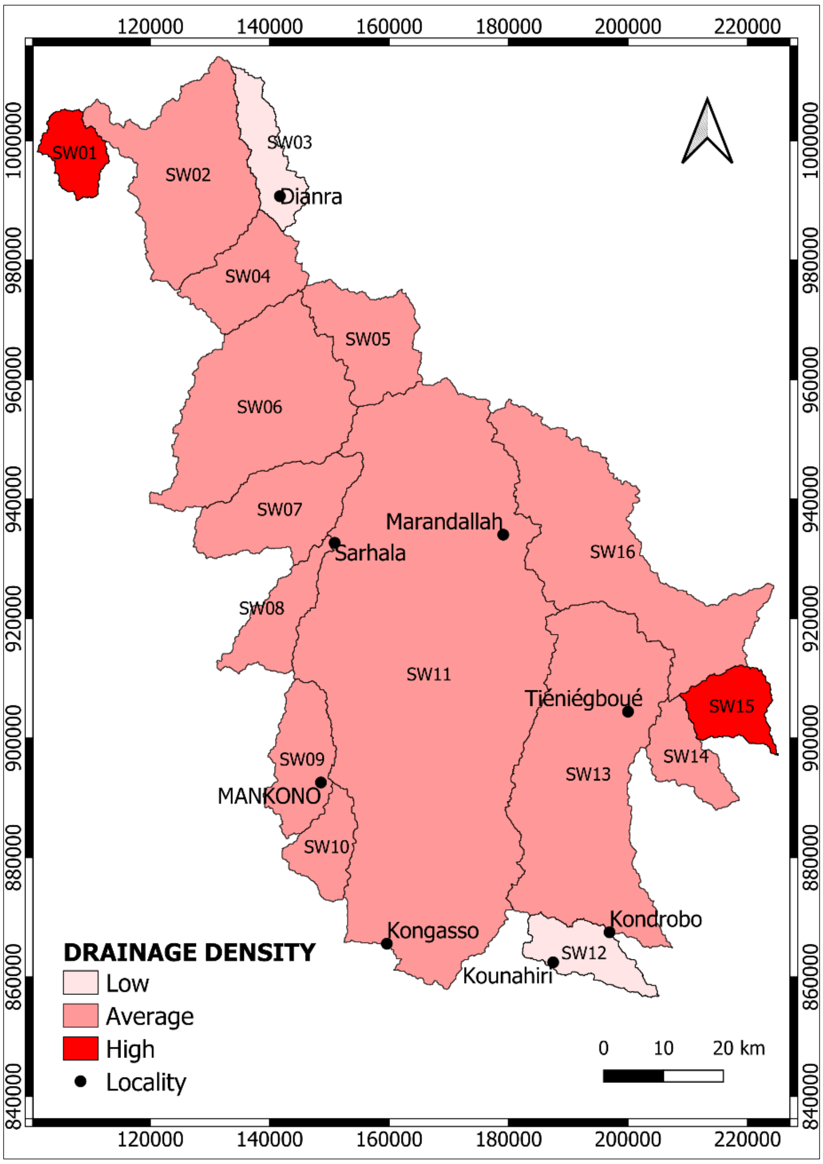

Figure 3 Map of the variation in drainage density in the sub-watersheds

4.2.3. Analysis of Sub-Watershed Shape Parameters

- **Form factor (F_f):** F_f analysis reveals that SW08 and SW12 are elongated. The sub-watersheds SW01, SW01, SW02, SW03, SW04, SW05, SW06, SW07, SW09, SW10, SW11, SW13, SW14, SW15, SW16 have a slightly circular shape, as indicated by the shape factor. In the study area, SW08 is the most elongated watershed with 0.21 and SW05 is the least elongated watershed with 0.72. The average form factor in the study area is 0.41, as shown in Table 4.
- **Circulatory ratio (R_c)**: Varies from 0.15 for SW16 to 0.35 for SW01, indicating that the sub-watersheds are not circular in shape (Table 4).
- **Elongation ratio (R_e):** R_e in sub-watersheds SW03, SW08, SW09, SW11, SW12, SW13, and SW16 are less than 0.7. This indicates that these sub-watersheds have an elongated shape, high relief, and steep slopes. Watersheds SW01, SW02, SW04, SW05, SW06, SW10, SW14, and SW15 have oval shapes, gentle slopes, low relief, low runoff and limited erosion (Table 4).
- **Basin shape (B_s):** The Beré region river basin has an average shape factor of 2 with a range of values between 1.37 and 4.73.
- **Compactness constant (Cc):** The value of this parameter ranges from 1.66 for SW01, the lowest, to 2.60 for SW16, the highest (Table 4). The Cc value ranges within the study area don't show a significant difference among sub-watersheds.

Table 4 Shape parameters of sub-watersheds

Sub-watershed	Form factor	Circulatory ratio	Elongation ratio	Basin shape	Compactness constant	Basin length (Km)
SW01	0.48	0.35	0.78	2.05	1.66	15.183
SW02	0.53	0.23	0.82	1.86	2.03	32.928
SW03	0.32	0.21	0.64	3.03	2.17	21.714
SW04	0.55	0.32	0.83	1.81	1.76	20.480
SW05	0.72	0.30	0.96	1.37	1.86	19.016
SW06	0.5	0.30	0.80	2	1.82	37.632
SW07	0.39	0.30	0.71	2.52	1.80	28.216
SW08	0.21	0.20	0.52	4.73	2.18	28.178
SW09	0.31	0.30	0.63	3.20	1.80	26.069
SW10	0.67	0.31	0.92	1.48	1.77	14.131
SW11	0.30	0.24	0.62	3.31	2.04	99.302
SW12	0.25	0.25	0.57	3.92	1.97	24.705
SW13	0.30	0.23	0.62	3.32	2.06	59.175
SW14	0.41	0.28	0.72	2.40	1.87	18.528
SW15	0.46	0.33	0.77	2.15	1.73	17.894
SW16	0.26	0.15	0.60	3.71	2.60	54.130

4.3. Prioritization of Sub-Watersheds Based on Morphometric Analysis

In terms of erosion and soil conservation measures, SW09 is the highest priority, while SW15 is the lowest priority of all sub-watersheds. The analysis of morphometric parameters also indicates that SW15 has the potential for groundwater, in contrary to SW09 (Table 5).

Table 5 Ranking of sub-watersheds

SW	Morphometric parameters											
	Linear parameters					Shape parameters					Compound parameter (C_P)	Priority Rank (R_p)
	D_d	F_f	L_b	R_b	R_t	F_{fo}	R_c	R_a	F_b	C_c		
SW01	2	1	15	13	7	11	16	11	6	1	8.3	9
SW02	6	4	6	4	6	13	4	13	4	11	7.1	5
SW03	16	7	1	11	13	7	3	7	10	14	8.9	11
SW04	6	7	6	14	8	14	14	14	3	3	8.9	11
SW05	6	10	6	5	8	16	9	16	1	8	8.5	10
SW06	12	4	4	1	2	12	9	12	5	7	6.8	3
SW07	12	14	4	2	10	8	9	8	9	5	8.1	8
SW08	6	2	6	14	11	1	2	1	16	15	7.4	7
SW09	3	3	12	7	3	6	9	6	11	5	6.5	1
SW10	14	12	3	3	13	15	13	15	2	4	9.4	13

SW11	3	4	12	9	1	4	6	4	12	12	6.7	2
SW12	15	14	2	12	15	2	7	2	15	10	9.4	13
SW13	6	10	6	6	3	4	4	4	13	13	6.9	4
SW14	3	12	12	16	12	9	8	9	8	9	9.8	15
SW15	1	16	16	8	16	10	15	10	7	2	10.1	16
SW16	6	7	6	10	5	3	1	3	14	16	7.1	5

N.B.: The watershed priority indicates the area with the highest groundwater deficit, while the lowest priority watershed indicates the area with the greatest groundwater surplus.

Figure 4 presents the final priority map of the study area, which shows the different sub-watersheds of the region. The map indicates the ranking of sub-watersheds for the implementation of soil conservation practices and the location of areas with high groundwater potential.

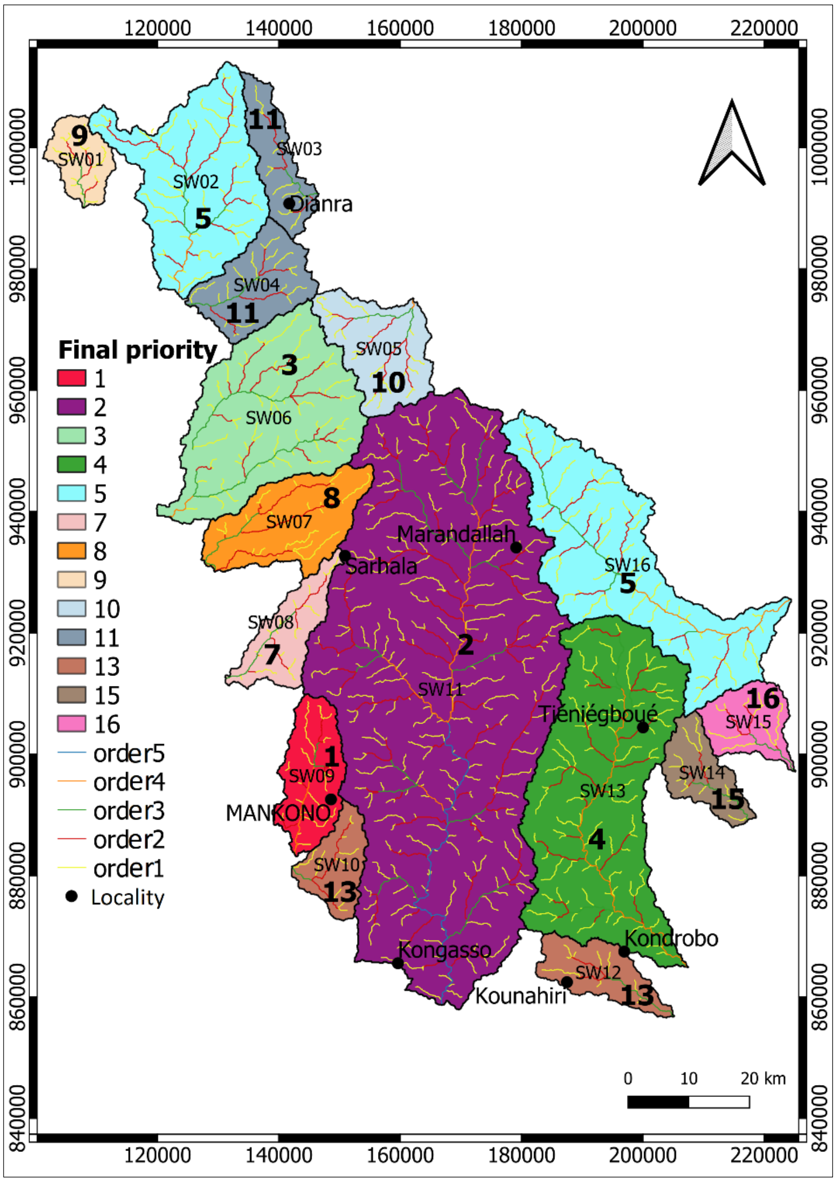

Figure 4 Map showing priority sub-watersheds and their ranks

5. Conclusion

The study utilized SRTM images and GIS to conduct a morphometric analysis of the sub-watersheds in the Béré region. The analysis allowed observations on the prioritization of areas that are susceptible to erosion and with high groundwater potential.

The results indicate that morphometric parameters are effective in assessing areas with higher and lower soil erosion, as well as groundwater deficit with leftover zones in the study area. The SW09 watershed is considered a high priority for water and soil conservation, while the SW15 watershed is considered a lower priority. The high-priority watershed is characterized by the greatest groundwater deficit, while the low-priority watershed has the greatest groundwater leftover.

The results of the ranking show that morphometric analysis clearly indicates a relationship between hydrogeology and the various morphometric parameters of the sub-watersheds. This helps to better understand the drainage network and groundwater prospecting. The results indicate that analyzing various morphometric parameters in the GIS environment can effectively establish priorities for watersheds, soil and water conservation, and natural resource management at the watershed level. The results we obtained can serve as a guide or decision-making tool for future field surveys in the Béré region.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no competing interests

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Houebagnon Saint-Jean Patrick COULIBALY, and Talnan Jean Honoré C. The first draft of the manuscript was written by, Koffi Claude Alain KOUADIO, and Issiaka SAVANE, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data availability statement

The data that supports the findings of this study are available on request to the corresponding author, Houebagnon Saint-Jean Patrick COULIBALY.

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