REVIEW PAPER

Updating morphometric features and their accuracy: a case study of the Sanaga watershed in Cameroon

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Abstract

The watershed delineation and morphometric analyses are the openings of hydrological studies. Hence, their accuracy and precisions can be a limiting factor. This article proposes an update of the morphometric parameters of the Sanaga watershed using modern methods on the one hand and on the other hand to compare it with the morphometric parameters obtained by old methods. To this end, the Sanaga watershed was updated using modern techniques combined with GIS (Geographic Information System) and SRTM (Shuttle Radar Topography Mission) images. The parameters updated in this study include area, perimeter, gravel compactness index (KG), equivalent rectangle length (L), rock slope index (SI), overall slope index (GI), and maximum, mean, and minimum elevations. The two methods (old and modern) were compared with each other and it was found that the nine updated parameters had deviations at various percentages (- 65 to 33%; - 47 to 41%; - 9 to 53%; - 34 to 119%; - 71 to 27%; - 37 to 62%; - 45 to 24%; - 12 to 10%; - 117 to 13%, respectively).

Keywords Watershed · Sanaga · Morphometric features

Introduction

Physiographic characteristics allow the determination and analysis of hydrological behaviour (Kabuya et al. 2020) and therefore strongly influence the hydrological response of a catchment (Biswas et al. 1999; Benzougagh et al. 2019; Sridhar and Ganapuram 2021). Veltri et al. (1996) indicate that morphometric indices are important subjects of investigation in understanding the dynamics of a river, just as hydrology is for the analysis of a catchment. The morphological characteristics and morphometric indices of

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a catchment are essential to characterize its physical environment and its influences on surface flow (Ahmed et al. 2016). Therefore, the exact knowledge of the morphometric parameters of a watershed is an important and determining value for all hydrological studies related to it. However, the watershed is a part of nature, and nature being dynamic, the determination of these characteristics should therefore be a permanent operation. However, the physiographic characteristics, i.e. the area and perimeter of a catchment, do not change rapidly and enormously over human time. Traditionally, the identification of the boundaries of a catchment area and the determination of its characteristics was based on multiple manoeuvres on topographic maps by planimetry, length measurement with a curvimeter, stereographic observation of aerial photographs. However, the measurement and accuracy of these depend on the maps used and therefore on the accuracy of the planimeter and the curvimeter (Dubreuil 1974). For example, the use of the curvimeter to determine the perimeter of a catchment area indicates that the perimeter does not need to follow sinuosities that do not bypass a runoff drainage thalweg; otherwise, it would lead to an exaggerated value for the compactness index. Stylization is therefore necessary to obtain perimeters with homogeneous compactness (Dubreuil 1966, 1974). To

do this, the length of the equivalent rectangle (Leq) must be greater than the length of the longest watercourse, from its origin to the outlet (Triboulet et al. 1996). This manual matching procedure is time-consuming and therefore depends on the experience of the user. The results obtained from classical techniques used in the study of the physical complex of a watershed related mainly to manual methods are generally incorrect (Ahmed et al. 2016). So, given that other attributes are derived from the watershed delineation, it is generally desired to minimize the possibility of error at this stage. Furthermore, materials and methods for their determinations undergo advances in innovation where their accuracy is continuously improved. These characteristics are therefore logically subject to change and, to neglect them, would be to risk exposure to serious setbacks in hydrological analysis. Hence, their accuracy, precision, and duration of determination are elements that, as they improve, show their evolution. With the advent of DEMs, the study of extraction algorithms related to DEMs for drainage networks has experienced strong growth (Prodanović et al. 2009; Tufa and Sime 2021). The DEM, which represents the continuous variation of relative elevation values in each pixel, can be used to identify the direction of a river or the flow path on the ground surface. Many algorithms, including the drainage network algorithm (Fairfield and Leymarie 1991; Yang et al. 2007) and the watershed delineation algorithm (Li et al. 2019; Hussain et al. 2022), are established to automatically extract hydrological features. These algorithms require the filling of the DEM to avoid slope depressions and generate a reasonable stream network in the preliminary phase. The process of creating a stream network usually starts with the assignment of flow directions for each cell of the DEM, then analyzes the flow accumulation, and finally selects the cells with a total flow accumulation threshold above a defined value (Lyu et al. 2021). Many factors, including the spatial resolution of the DEM, the calculated algorithm, and the physical characteristics of the basin, can directly affect the accuracy of drainage networks derived from DEM data (Ariza-Villaverde et al. 2015; Xiong et al. 2021). The use of the DEM with an algorithm has clear advantages, as the processing of the catchment takes less time and is not influenced by human subjectivity.

Cameroon has five watersheds, among which the Sanaga watershed is entirely national and the most important, as it serves many national needs such as domestic needs (wells, boreholes and springs in rural areas, river intakes, and retention dams in urban areas), agropastoral needs (ponds, collinear retention, and wells), irrigation needs (river intakes mainly used for large areas), hydroelectric production (retention dams), and industrial and mining activities. Despite this strong potential, which today convinces Cameroon to establish its economy there, only the singular study carried out by Dubreuil et al. (1975) from small scale topographic maps (1/500 000 and 1/200 000) and classical techniques essentially based on manual methods, methods which would influence the accuracy of the results obtained, is known for its morphometric characterization. With the advent of new tools such as GIS and remote sensing, it has become easy to determine the shape and relief parameters of a watershed. The present study is a first attempt to update the morphometric characteristics, i.e. area, perimeter, Gravelius coefficient, length of the equivalent rectangle, rock slope index, overall slope index, and characteristic altitudes related to the flows of the Sanaga watershed, using the numerical model (SRTM1 of the resolution, 30 m).

Study area

The Sanaga basin is the longest tributary of Cameroon's Atlantic coast (920 km), with a surface area of about 133,000 km^2 ($> 25\%$ of the country). With its oven-like shape oriented WSW-ENE to SSW-NNE, it is connected to the Gulf of Guinea by a peduncle (Olivry 1986). Located in the central region in the forest-savanna contact zone, it extends to seven other regions, from parallel 3° 32′ to 7° 22′ north, and from meridian 9° 45′ to 14° 57′ east (Fig. 1). Cretaceous volcanic rocks cover the predominant Precambrian basement.

On the whole, the two-season tropical climate above the Bertoua-Bafia line and the four-season equatorial climate below are the main climates in the Sanaga catchment area. There are five soil classes, mainly sesquioxides (class VI11) a subclass of ferritic soils according to the soil classification. Phytogeographical landscapes vary from forest to shrubby savannah. The vegetation is mainly forest, grassy savannah, and shrubby savannah. The average density of the population, about 27 in hab/km^{-2}, is lower than that of the population of Cameroon, about 41.6 in hab/km^{-2}.

Globally, the two main branches (Fig. 2) of the Sanaga meet 175 km upstream from Edéa, some 242 km away from the Atlantic Ocean. Djerem-Sanaga is the main branch; Mbam is the other tributary on the left bank of the Sanaga. There are 25 sub-basins, 15 in the Djerem-Sanaga and 9 in the Mbam. The Sanaga drains the 25th sub-basin, common to both branches, downstream and communicates directly with the Atlantic Ocean via the Edéa station.

Data and methods

Data

In this study, the various images used include (i) topographic images and (ii) a digital elevation model (DEM) extracted from Shuttle Radar Topography Mission (SRTM). This was georeferenced in the World Geodetic System (WGS 84) and
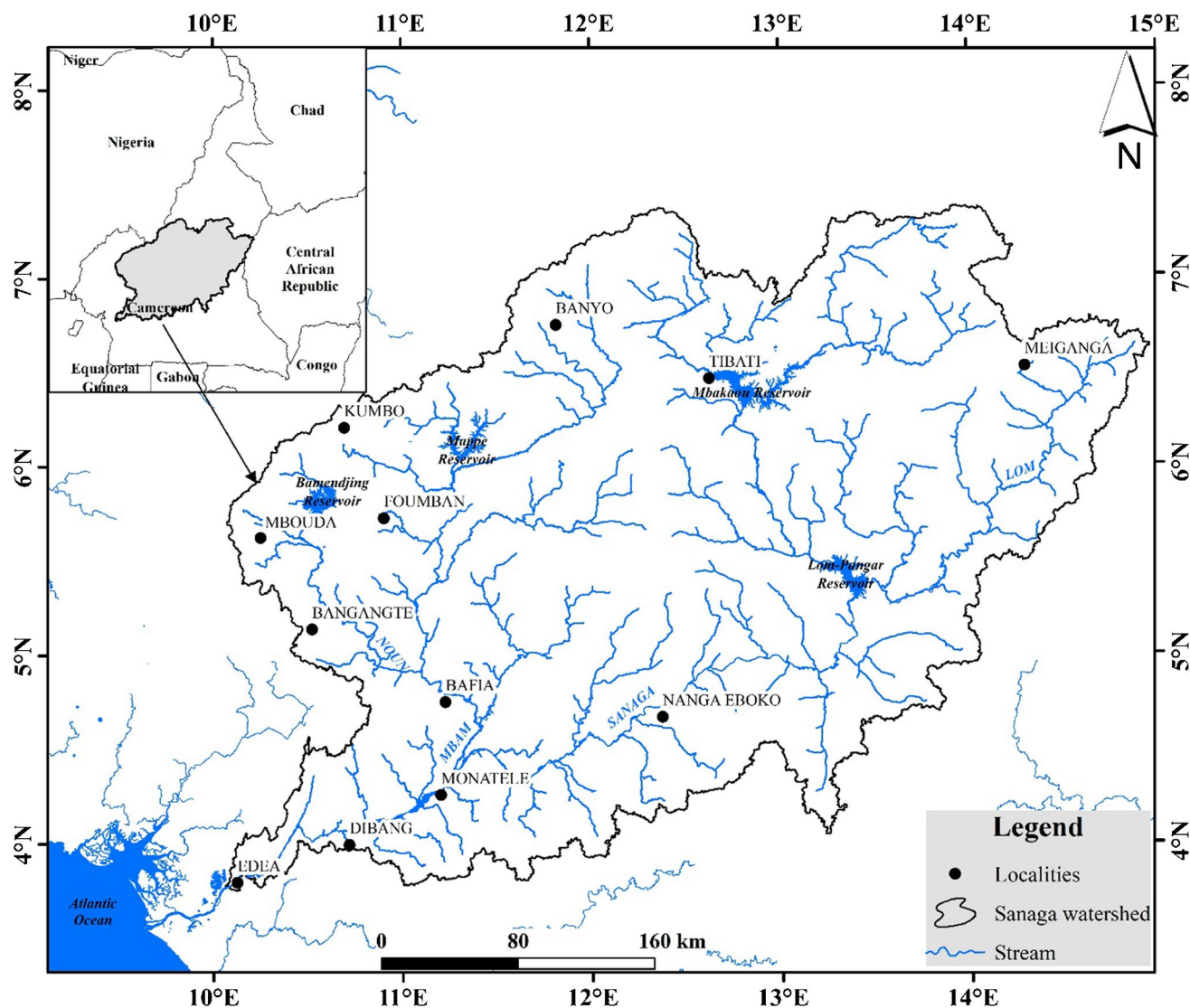
Fig. 1 Sanaga catchment area

projected in the Universal Transverse Mercator (UTM) zone 33 N. This SRTM can be freely downloaded from the US Geological Survey Earth Resources Observations and Science Center (EROS) via the http://earthexplorerer.usgs.gov website. The digital image processing, thematic mapping, extraction length, and watershed delineation were performed using the global map, Arcgis, and Microsoft Excel.

Methodology

Watershed and stream network delineation

Watershed and stream network delineation was done from a digital elevation model (DEM) using the Hydrology toolset from the Spatial Analyst toolbox in Arcgis 10.5. The following instructions provide a workflow to create a watershed and stream network using the Hydrology toolset from the Spatial Analyst toolbox and convert the model to watershed bounding polygons and stream network polylines. These stages comprised (i) Mosaic images using Mosaic toolbox, present in ArcMap; (ii) filling operation for all the DEMS used fill tools of Spatial Analysts Hydrology option; (iii) flow direction and flow accumulation tools of the same spatial Analyst Hydrology Option were used to create flow direction and flow accumulation maps; (iv) using a threshold value (750 cells) for all the Dems using Con tools of spatial Analyst tool Conditional option; (v) stream order and stream to feature were performed using stream order and stream to feature of spatial Analyst tool and end four points were delineated, and the correct location of the watershed exit point was selected; (vi) the watershed boundary was plotted, and its surface area calculated; and (vii) hypsometric maps were performed after SRTM using extract
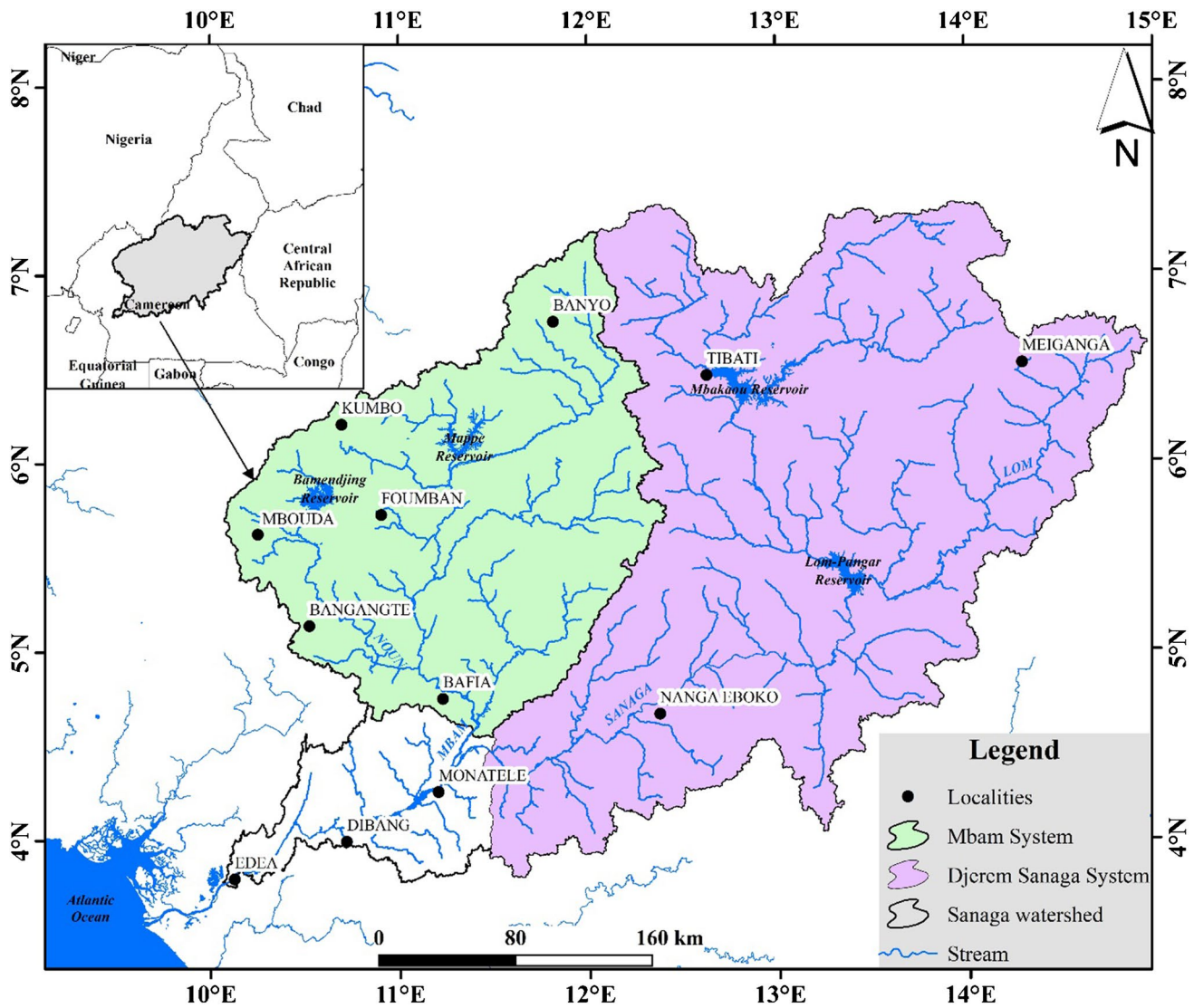
Fig. 2 The two main branches of the Sanaga

by mask, reclassify of spatial analyst surface tools. Microsoft Excel software was used to make the hypsometric curve.

Geometric (morphological) characteristics

The Gravelius compactness index (KG) of the catchment area is the ratio of its perimeter to the perimeter of the circle having the same area (Dubreuil 1966; Olivry 1986; Wade 2020; Abdo 2020). It can only be calculated, with sufficient accuracy, if the perimeter P is measured on a very simplified basin contour. Thus, it is necessary to remove all sinuosities that do not correspond to the head of an active thalweg. To check that the stylization of the perimeter is sufficient, one should ensure that the length of the equivalent rectangle Leq is not longer than the length of the longest watercourse from its origin to the outlet. It is calculated by the formula (1):

$$K_G = K_C = P/2\sqrt{\Pi A} = 0.28P/\sqrt{A} \tag{1}$$

with A as the surface area (km^2) and P as the perimeter of the catchment area (km).

This index is close to 1 for an almost circular (well-drained) catchment area with a higher infiltration potential than that with an elongated shape. It is 1.12 for a square catchment area and above 1.12 for an elongated catchment area (Musy 2005; Rudraiah et al. 2008).

The length of the equivalent rectangle was introduced to compare the influence of geometric characteristics of watersheds on flow. The rectangular watershed results from the geometric transformation of the real watershed with the same surface area, the same perimeter (or the coefficient of compactness), and the same hypsometric distribution (Roche 1963; Dubreuil 1966, 1974; Layati et al.

2021). *L* and *l* are the length and width of the rectangle, and *P* and *A* are the perimeter and area of the catchment area; we have (Eq. 2 & 3):

$$\begin{cases} A = L \times l \\ P = 2 \times (L + l) \end{cases} \tag{2}$$

$$L = K_G \sqrt{A}/1.128 \left[1 + \sqrt{1 - (1.128/K_G)^2} \right] \tag{3}$$

The Roche slope index (Ip) that characterizes the average slope of the catchment area is calculated from the equivalent rectangle. It is the sum of the square roots of average slopes of each partial element between two contour lines, weighted by its associated partial area:

$$I_P = 1/\sqrt{L} \sum \sqrt{a_i . d_i} \tag{4}$$

with a_i = fraction (in %) of area A between two neighbouring contour lines C_i and C_{i-1} spaced apart of d_i, $d_i = C_i - C_{i-1}$.

The global slope index (Ig) is used to determine the specific gradient of the basin characterize and classify the relief of the catchment area. In a homogeneous geomorphology region, the slope decreases from upstream to downstream, like the Ig for the same basin while the surface area increases. However, since the length of the equivalent rectangle is almost close to that of the longest river, Ig remains close to the longitudinal slope (Triboulet et al. 1996). On the hypsometric curve, two points were taken such that the upper and lower surface is 5% of the total area A of the catchment area. This gives the altitudes H5% and H95% between which 90% of A and the overall difference in height D = H5%-H95% are inscribed, is defined by:

$$I_G = D/Linm/Km \tag{5}$$

with D = h5%-h95%, D is the difference in height between the points corresponding to 5% and 95% of the hypsometric curve.

The average altitude of the catchment area does not very much represent reality. However, it is sometimes used in assessing certain hydrometeorological parameters or the implementation of hydrological models. It can be deducted directly from the hypsometric curve or the reading of a topographic map. It is:

$$\text{Average} = 1/A \sum_{i=1}^{n} \left[S_i (h_i + h_{i+1})/2 \right] \text{in(m)} \tag{6}$$

with *A* as the total area of the catchment area, S_i as the area between two contour lines in (km²), and h_i and h_{i+1} as the high and low altitude which delimits the S_i surface.

Figure 3 shows a step by steps flowchart methodology applied in this study.

Results

Different image processing methods made it possible to produce the map of the Sanaga watershed and its sub-basins. From this map were derived the desired morphometric parameters and their intervals of values in raw non-stylized then subsequently in stylized. They are as folloes:

- Surface area [166 and 132971] km²; perimeter [70 and 3400] km; Gravelius compactness index [1.3 and 2.8]; length of the equivalent rectangle [29.34 and 1618] km; global slope index [0.44 and 11.08]; Roche slope index [0.0272 and 0.143]; maximum altitude [784 and 3005] (m); average altitude [630 and 1695] (m); minimum altitude [-1 and 1385] m (Table 1).

- Surface area [166 and 132971] km²; perimeter [61 and 2228] km; Gravelius compactness index [1.15 and 2.08]; length of the equivalent rectangle [23.41 and 978.04]; global slope index [0.69 and 13.9]; Roche slope index [0.034 and 0.1601]; maximum altitude [784 and 3005] (m); average altitude [630 and 1695] (m); minimum altitude [-1 and 1385] m (Table 2).

A quick examination of the results in stylized form shows that out of twenty-five basins, for fourteen (Maouor at the bridge, Meng at Tibati, Djerem at Mbakaou E₂, Sanaga at Goyoum, Sanaga at Nanga Eboko, Téré at Ndoumba, Nianiang in Megenme, Sanaga in Nachtigal, Mapé in Magba, Mbam in Mantoum, Mifi in Bamoungoum, Choumi in Banock, Mifi in Bafounda, Sanaga in Edéa), KG is ≥ 1.40 (Table 2); for thirteen (Maouor at the bridge, Meng at Tibati, Djerem at Mbakaou E₂, Sanaga at Goyoum, Sanaga at Nanga Eboko, Téré at Ndoumba, Nianiang at Megengme, Sanaga at Nachtigall, Mapé at Magba, Mbam at Mantoum, Choumi at banock, Mifi at Bafounda, Sanaga at Edéa), KG is ≥ 1.50 (Table 2). The longest basins are Nianiang at Megengme (KG = 2.08) and Sanaga at Nachtigal (KG = 1.91. The best compactness indices are in Lom to Oya KG = 1.15 and Noun to Bamendjing KG = 1.15.

Discussions

Updating morphometric parameters of the Sanaga catchment area is an innovative remark, the increasing use of DTMs and the remote sensing tool to improve the quality of maps. Only Dubreuil et al. (1975) studied it from topographic maps of Central Africa at the scale of 1/200 000. To determine its physical factors, they used, for basins whose surface area is above 15,000 km², the coverage at 1/500,000 and for those with a smaller surface area, the coverage at 1/200,000. The
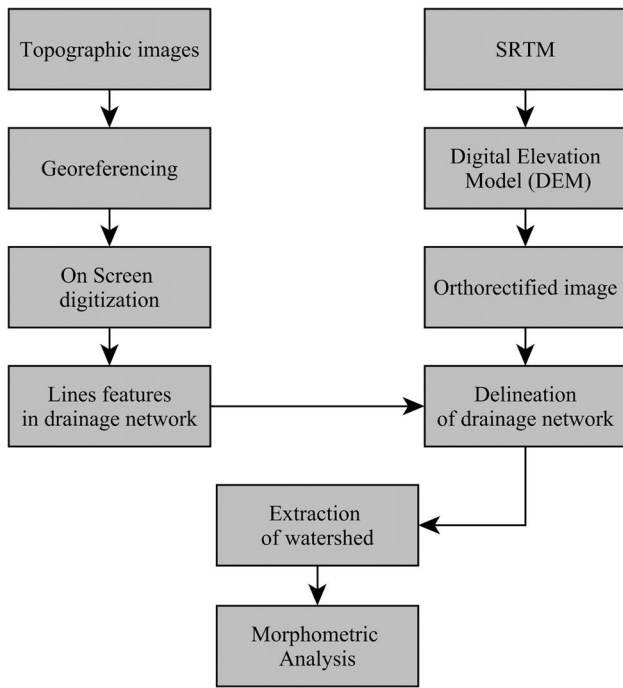
Fig. 3 Flowchart methodology

surface areas of sub-basins were obtained by planimetry on these maps with perimeters determined with a curvimeter. It was sometimes necessary to "stylize" natural perimeters, i.e. linearize certain contours to render them more easily measurable.

This study was carried out on an SRTM1 type DEM with a resolution of 30 m, which was downloaded free of charge from the www.explorer.com site and then treated. The image gives a planimetric accuracy up to 30 m close to that of topographic maps on a scale of 1/50,000. SRTM1 (Shuttle Radar Topography Mission) is the serious alternative to AW3D30, the best 30 m resolution image adapted to Cameroon in terms of altimetric accuracy (Yap et al. 2019). The spatial resolution of this DEM helped to refine and update the results obtained by Dubreuil (1975). Based on the same 25 Sanaga watersheds, each with its outlet was characterized by its different automated functionalities with the Arc-Gis 10.5 software; imperfections are minimal and easily understood, easing to reproduce this type of study in a short time and at low cost on all the watersheds of a region. The results obtained (Tables 1 and 2) are compared with those of Dubreuil et al. (1975). Nine abovementioned morphometric

Table 1 Morphometric parameters in raw, non-stylized values

N°	Basins	Area (Km²)	Perimeter (Km)	Form (K_G)	L(Km)	Ig	Ip	Altitudes in m			Hydro. Stations	
								Max	Aver	Min	Lat. N	Long. E
1	Vina in Lahore	1667,1	265	1,83	11,84	3,45	0,0803	1968	1281	1024	7°15'	13°34'
2	Djerem in BétaréGongo	10,890	717	1,94	325	1,46	0,0497	1968	1050	837	6° 35'	13°12'
3	Maouor at the bridge	2232	390	2,33	182,8	1,2	0,068	1344	1031	840	6°31'	12°43'
4	Meng in Tibati	1951	374	2,39	175,9	2,02	0,0617	1344	1052	845	6°36'	12°36'
5	Djerem in Mbakaou E $_2$	20,387	1249	2,2	589,9	0,92	0,0386	1972	969	835	6°20'	12°49'
6	Lom in Bétaré oya	7203	575	1,91	259,8	1,17	0,0496	1290	993	763	5°55'	14°08'
7	Sanaga in Goyoum	51,085	1857	2,32	869,8	0,64	0,0326	2382	934	620	5°12'	13°22'
8	Avea in S5	374	109	1,59	46,45	2,86	0,0965	857	659	584	4°50'13"	12°32'31"
9	Sanaga in NangaEboko	65,671	2375	2,61	1129	0,45	0,0293	2384	844	541	4°42'	12°23'
10	Téré in Ndoumba	1730	363	2,46	171,4	0,82	0,0508	849	691	576	4°38'	12°17'
11	Nianiang in Megenme	222	144	2,73	68,77	1,72	0,0781	784	671	572	4°36'	12°14'
12	Ndjeke in Gongon	3732	431	1,99	196,5	0,83	0,0501	1077	630	562	4°48'	12°00'
13	Sanaga in nachtigal	78,079	2779	2,8	1331	0,44	0,0273	2384	846	430	4°21'	11°38'
14	Mapé in Magba	3800	405	1,85	181,6	5,03	0,072	2273	922	688	5°59'	11°16'
15	Mbam in Mantoum	16,028	1028	2,29	480,7	2,05	0,048	3001	1021	655	5°37'	11°11'
16	Monkie in S $_2$	174	71	1,52	29,63	33,85	0,1908	2523	1601	1159	5°57'	10°25'
17	Noun in Bambalang	838	153	1,49	63,25	15,64	0,131	2976	1498	1145	5°54'23"	10°33'02"
18	Noun in bamendjing	2197	216	1,3	80,81	10,22	0,1086	2940	1380	1139	5°42'	10°30'
19	Mifi in Bamoungoum	366	119	1,75	52,53	9,6	0,12	1923	1508	1268	5°31'	10°21'
20	Choumi in banock	346	149	2,26	69,52	6,11	0,1095	2739	1572	1384	5°29'	10°17'
21	Metchie at falls	166	70	1,53	29,34	11,08	0,143	1923	1695	1449	5°22'	10°20'
22	Mifi in Bafounda	864	184	1,77	81,38	6,29	0,1048	2739	1529	1262	5°32'40"	10°20'17"
23	Noun in Bafoussam	4784	375	1,53	157	6,12	0,0842	2946	1378	991	5°28'	10°33'
24	Mbam in the Goura tray	42,969	1507	2,05	691,3	1,58	0,042	3005	932	393	4°34'	11°22'
25	Sanaga in Edéa	132,971	3400	2,63	1618	0,45	0,0272	3005	855	-1	3°46'	10°04'

Table 2 Stylized morphometric parameters

N°	Basins	Area (Km2)	Perimeter (Km)	Form (KG)	L(Km)	Ig	Ip	Altitudes in m			Hydro. Stations	
								Max	Aver	Min	Lat. N	Long. E
1	Vina in Lahore	1667,1	188	1,3	70,28	5,82	0,104	1968	1281	1024	7°15'	13°34'
2	Djerem in BétaréGongo	10,890	464	1,25	166,66	2,85	0,069	1968	1050	837	6° 35'	13°12'
3	Maouor at the bridge	2232	293	1,75	129,23	2,82	0,072	1344	1031	840	6°31'	12°43'
4	Meng in Tibati	1951	289	1,85	129,43	2,74	0,072	1344	1052	845	6°36'	12°36'
5	Djerem in Mbakaou E $_2$	20,387	885	1,75	390,26	1,4	0,047	1972	969	835	6°20'	12°49'
6	Lom in Bétaréoya	7203	345	1,15	84,85	3,57	0,087	1290	993	763	5°55'	14°08'
7	Sanaga in Goyoum	51,085	1225	1,53	512,9	1,09	0,042	2382	934	620	5°12'	13°22'
8	Avea in S5	374	91	1,33	34,73	3,83	0,112	857	659	584	4°50'13"	12°32'31"
9	Sanaga in NangaEboko	65,671	1603	1,76	708,86	0,72	0,037	2384	844	541	4°42'	12°23'
10	Téré in Ndoumba	1730	272	1,84	121,8	1,15	0,060	849	691	576	4°38'	12°17'
11	Nianiang in Megenme	222	110	2,08	50,61	2,34	0,091	784	671	572	4°36'	12°14'
12	Ndjeke in Gongon	3732	297	1,37	116,45	1,4	0,065	1077	630	562	4°48'	12°00'
13	Sanaga in nachtigal	78,079	1894	1,91	855,76	0,69	0,034	2384	846	430	4°21'	11°38'
14	Mapé in Magba	3800	332	1,52	138,58	6,6	0,083	2273	922	688	5°59'	11°16'
15	Mbam in Mantoum	16,028	764	1,7	334,01	2,95	0,055	3001	1021	655	5°37'	11°11'
16	Monkie in S $_2$	174	64	1,37	25,05	40	0,208	2523	1601	1159	5°57'	10°25'
17	Noun in Bambalang	838	129	1,26	28,91	34,2	0,194	2976	1498	1145	5°54'23"	10°33'02"
18	Noun in bamendjing	2197	191	1,15	46,65	17,7	0,143	2940	1380	1139	5°42'	10°30'
19	Mifi in Bamoungoum	366	101	1,49	41,73	12,1	0,135	1923	1508	1268	5°31'	10°21'
20	Choumi in banock	346	126	1,91	56,92	7,47	0,121	2739	1572	1384	5°29'	10°17'
21	Metchie at falls	166	61	1,34	23,41	13,9	0,1601	1923	1695	1449	5°22'	10°20'
22	Mifi in Bafounda	864	176	1,69	76,74	6,67	0,108	2739	1529	1262	5°32'40"	10°20'17"
23	Noun in Bafoussam	4784	338	1,38	133,04	7,22	0,0915	2946	1378	991	5°28'	10°33'
24	Mbam in the Goura tray	42,969	1019	1,39	402,83	2,71	0,055	3005	932	393	4°34'	11°22'
25	Sanaga in Edéa	132,971	2228	1,72	978,04	0,75	0,035	3005	855	-1	3°46'	10°04'

parameters compared with those of Dubreuil et al. (1975), in raw values (Table 3), and then stylized (Table 4), show differences or rounded deviations to the unit in percentages:

- Surface area, raw − 65 to 33% and then stylized − 65 to 33% (Fig. 4a)
- Perimeter, raw − 39 to 11% and then stylized − 47 to 41% (Fig. 4b)
- Gravelius compactness index (KG), raw 4 to 114% and then stylised − 9 to 53% (Fig. 4c)
- Equivalent rectangle length (L), raw − 38 to 222% and then stylized − 34 to 119% (Fig. 4d)
- Roche slope index (PI), raw − 88 to 2% and then stylized − 71 to 27% (Fig. 4e)
- Global slope index (GI), raw − 93 to 20% and then stylized − 37 to 62% (Fig. 4f)
- Maximum altitude, raw − 45 to 24% and then stylized − 45 to 24% (Fig. 4g)
- Medium altitude, raw − 12 to 10% and then stylized − 12 to 10% (Fig. 4h)
- Minimum altitude, raw − 117 to 13% and then stylized − 117 to 13% (Fig. 4i)

These results on nine revised parameters starting with the edge of the catchment area are probably more accurate due to the quality of information from both sources.

The first study based on topographic maps used a local reference system, based on the Clarke 1880 reference ellipsoid (Kande et al. 2016); today's modern DEMs are referenced on the World Geodesic Reference System 1984 (WGS84). Old maps drawn from aerial photographs are of poor quality than those produced with advanced satellites and better and consistent geodesy. Besides, GPS/levelling data are also available, collected during the construction of the Cameroon Geodetic Network (Hirt et al. 2010). Space missions for modelling the earth's topography, recent technological developments, and global DEMs now improve the knowledge of topography in developing countries with poor geospatial data infrastructures (Hirt et al. 2010).

This study is based on a more refined technology (GIS, remote sensing…) with the use of the SRTM1 type DEM (Shuttle Radar Topography Mission), which, according to Yap et al. (2019), is the serious alternative to the AW3D30, and better in terms of altimetric accuracy for Cameroon among the last three freely available high-resolution (30 m)

Table 3 Comparison in percentage differences (in red) between raw, unstylized results (in bold black) from this study and those (in bold black) of Dubreuil and et al. (1975)

N°	BASINS	AREA (Km2)	Gap in %	PERIMETER (Km)	Gap in %	FORME (KG)	Gap in %	L(Km)	Gap in %	Ig	Gap in %	Ip	Gap in %	ALTITUDES in m MAX.	Gap in %	AVER.	Gap in %	MIN.	Gap in %	HYDRO. STATIONS Lat. N	Long. E
1	Vina in Lahore	1680		184		1,27		67		6,19		0,093		1923		1290		1050		7°15'	13°34'
		1667,1	-1	265	44	1,83	44	11,84	77	3,45	-44	0,0803	-14	1968	2	1281	-1	1024	-3		
2	Djerem in BétaréGongo	11000		419		1,12		105		4,76		0,078		1923		1050		840		6°35'	13°12'
		10890	-1	717	71	1,94	73	325	210	1,46	-69	0,0497	-36	1968	2	1050	0	837	0		
3	Maouor at the bridge	2250		218		1,3		81		4,05		0,073		1290		1170		840		6°31'	12°43'
		2232	-1	390	79	2,33	79	182,8	126	1,2	-70	0,068	-17	1344	4	1031	-12	840	0		
4	Meng in Tibati	4900		300		1,21		102		9,5		0,101		2460		1153		850		6°36'	12°36'
		1951	-60	374	25	2,39	98	175,9	72	2,02	-79	0,0617	-39	1344	-45	1052	-9	845	-1		
5	Djerem in Mbakaou E₂	20200		760		1,5		315		1,92		0,051		2460		1059		829		6°20'	12°49'
		20387	1	1249	64	2,2	47	589,9	87	0,92	-52	0,0386	-24	1972	-20	969	-9	835	1		
6	Lom in Bétaré oya	11100		430		1,15		128		9,48		0,061		1263		936		675		5°55'	14°08'
		7203	-35	575	34	1,91	66	259,8	103	1,17	-88	0,0496	-19	1290	2	993	6	763	13		
7	Sanaga in Goyoum	50500		1010		1,27		370		1,59		0,049		2460		925		630		5°12'	13°22'
		51085	1	1857	84	2,32	83	869,8	135	0,64	-60	0,0326	-33	2382	-3	934	1	620	-2		
8	Avea in S5	375		96		1,4		38,8		3,2		0,069		870		670		580		4°50'13"	12°32'31"
		374	0	109	14	1,59	14	46,45	20	2,86	-11	0,0965	40	857	-2	659	-2	584	1		
9	Sanaga in Nanga Eboko	65100		1207		1,34		465		1,27		0,044		2460		870		570		4°42'	12°23'
		65671	1	2375	97	2,61	95	1129	143	0,45	-65	0,0293	-93	2384	-3	844	-3	541	-5		
10	Téré in Ndoumba	1730		204		1,38		80,1		1,62		0,048		820		665		571		4°38'	12°17'
		1730	0	363	78	2,46	78	171,4	114	0,82	-49	0,0508	5,9	849	4	691	4	576	1		
11	Nianiang in Megenme	224		88		1,65		37,8		3,02		0,065		760		645		571		4°36'	12°14'
		222	-1	144	64	2,73	65	68,77	82	1,72	-43	0,0781	20	784	3	671	4	572	0		
12	Ndjeke in Gongon	3720		242		1,12		61		2,09		0,058		1027		630		560		4°48'	12°00'
		3732	0	431	78	1,99	78	196,5	222	0,83	-60	0,0501	-14	1077	5	630	0	562	0		
13	Sanaga in nachtigal	76000		1380		1,42		555		1,06		0,042		2460		835		426		4°21'	11°38'
		78079	3	2779	101	2,8	97	1331	140	0,44	-58	0,0273	-35	2384	-3	846	1	430	1		
14	Mapé in Magba amont and aval	4020		252		1,12		63,4						2177				690		5°59'	11°16'
		3800	-6	405	61	1,85	65	181,6	186	5,03	####	0,072	####	2273	4	922	####	688	0		
15	Mbam in Mantoum	14700		565		1,31		212						2417				660		5°37'	11°11'
		16028	9	1028	82	2,29	75	480,7	127	2,05	####	0,048	####	3001	24	1021	####	655	-1		
16	Monkie in S₂	181		58,4		1,22		20,1						2616				1158		5°57'	10°25'
		174	-4	71	22	1,52	25	29,63	47	33,85	####	0,1908	####	2523	-4	1601	####	1159	0		
17	Noun in Bambalang	632		107		1,2		35,8						3008				1143		5°54'23"	10°33'02"
		838	33	153	43	1,49	24	63,25	77	15,64	####	0,131	####	2976	-1	1498	####	1145	0		
18	Noun in bamendjing	2190		171		1,03		46,8						3008				1140		5°42'	10°30'
		2197	0	216	26	1,3	26	80,81	73	10,22	####	0,1086	####	2940	-2	1380	####	1139	0		
19	Mifi in Bamoungoum	306		76		1,22		26,1		19		0,147		1924		1537		1270		5°31'	10°21'
		366	20	119	57	1,75	43	52,53	101	9,6	-49	0,12	-18	1923	0	1508	-2	1268	0		
20	Choumi in banock	360		103		1,52		42,6		11		0,126		2740		1560		1385		5°29'	10°17'
		346	-4	149	45	2,26	49	69,52	63	6,11	-44	0,1095	-13	2739	0	1572	1	1384	0		
21	Metchie at falls	480		115		1,47		47		10,9		0,127		2740		1547		1297		5°22'	10°20'
		166	-65	70	-39	1,53	4	29,34	-38	11,08	2	0,143	13	1923	-30	1695	10	1449	12		
22	Mifi in Bafounda	854		142		1,37		55,6		8,98		0,117		2740		1530		1260		5°32'40"	10°20'17"
		864	1	184	30	1,77	29	81,38	46	6,29	-30	0,1048	-10	2739	0	1529	0	1262	0		
23	Noun in Bafoussam E1 and E2	4740		267		1,1		68,8						3008				988		5°28'	10°33'
		4784	1	375	40	1,53	39	157	128	6,12	####	0,0842	####	2946	-2	1378	####	991	0		
24	Mbam in the Goura tray	42300		840		1,15		250		4,37		0,081		3008		980		395		4°34'	11°22'
		42969	2	1507	79	2,05	78	691,3	177	1,58	-64	0,042	-48	3005	0	932	-5	393	-1		
25	Sanaga in Edéa	131500		1585		1,23		550		1,82		0,055		3008		860		6		3°46'	10°04'
		132971	1	3400	115	2,63	114	1618	194	0,45	-75	0,0272	-51	3005	0	855	-1	-1	-117		

DEMs in the world. This type of DTM equals that of the 1/50,000 scale maps.

The results of nine revised parameters starting from the watershed edges are still likely to be more accurate and precise, also due to processes. The first study carried out much by rudimentary means, cartography mainly manual, long, and in several stages by man was liable to errors (reading, appreciation, clumsiness, lightness, incorrectness, mistake, accident, confusion, forgetfulness, etc.) of positions of points, calculations, and curvimeter and planimeter

Table 4 Comparison in percentage differences (in red) between stylizsed results (in non-boldblack) of this study and those (in bold black) of Dubreuil and et al. (1975)

N°	BASINS	AREA (Km²)	Gap in %	PERIME TER (Km)	Gap in %	FOR M (KG)	Gap in %	L(Km)	Gap in %	Ig	Gap in %	Ip	Gap in %	ALTITUDES en m MAX.	Gap in %	AVER.	Gap in %	MIN.	Gap in %	HYDRO. STATIONS Lat. N	Long. E
1	Vina in Lahore	**1680**		**184**		**1,27**		**67**		**6,19**		**0,093**		**1923**		**1290**		**1050**		7°15'	13°34'
		1667,1	-1	188	2	1,3	2	70,28	5	5,82	-6	0,104	12	1968	2	1281	-1	1024	-3		
2	Djerem in Bétaré Gongo	**11000**		**419**		**1,12**		**105**		**4,76**		**0,078**		**1923**		**1050**		**840**		6°35'	13°12'
		10890	-1	464	11	1,25	12	166,66	59	2,85	-40	0,069	-11	1968	2	1050	0	837	0		
3	Maouor at the bridge	**2250**		**218**		**1,3**		**81**		**4,05**		**0,073**		**1290**		**1170**		**840**		6°31'	12°43'
		2232	-1	293	34	1,75	35	129,23	60	2,82	-30	0,072	-1	1344	4	1031	-12	840	0		
4	Meng in Tibati	**4900**		**300**		**1,21**		**102**		**9,5**		**0,101**		**2460**		**1153**		**850**		6°36'	12°36'
		1951	-60	289	-4	1,85	53	129,43	27	2,74	-71	0,072	-29	1344	-45	1052	-9	845	-1		
5	Djerem in Mbakaou E₂	**20200**		**760**		**1,5**		**315**		**1,92**		**0,051**		**2460**		**1059**		**829**		6°20'	12°49'
		20387	1	885	17	1,75	17	390,26	24	1,4	-27	0,047	-7	1972	-20	969	-9	835	1		
6	Lom in Bétaré oya	**11100**		**430**		**1,15**		**128**		**9,48**		**0,061**		**1263**		**936**		**675**		5°55'	14°08'
		7203	-35	345	-20	1,15	0	84,85	-34	3,57	-62	0,087	42	1290	2	993	6	763	13		
7	Sanaga in Goyoum	**50500**		**1010**		**1,27**		**370**		**1,59**		**0,049**		**2460**		**925**		**630**		5°12'	13°22'
		51085	1	1225	21	1,53	21	512,9	39	1,09	-32	0,042	-13	2382	-3	934	1	620	-2		
8	Avea in S5	**375**		**96**		**1,4**		**38,8**		**3,2**		**0,069**		**870**		**670**		**580**		4°50'13"	12°32'31"
		374	0	91	-5	1,33	-5	34,73	-11	3,83	20	0,112	62	857	-2	659	-2	584	1		
9	Sanaga in Nanga Eboko	**65100**		**1207**		**1,34**		**465**		**1,27**		**0,044**		**2460**		**870**		**570**		4°42'	12°23'
		65671	1	1603	33	1,76	31	708,86	52	0,72	-44	0,037	-16	2384	-3	844	-3	541	-5		
10	Téré in Ndoumba	**1730**		**204**		**1,38**		**80,1**		**1,62**		**0,048**		**820**		**665**		**571**		4°38'	12°17'
		1730	0	272	33	1,84	33	121,8	52	1,15	-29	0,060	26	849	4	691	4	576	1		
11	Nianiang in Megenme	**224**		**88**		**1,65**		**37,8**		**3,02**		**0,065**		**760**		**645**		**571**		4°36'	12°14'
		222	-1	110	25	2,08	26	50,61	34	2,34	-23	0,091	40	784	3	671	4	572	0		
12	Ndjeke in Gongon	**3720**		**242**		**1,12**		**61**		**2,09**		**0,058**		**1027**		**630**		**560**		4°48'	12°00'
		3732	0	297	23	1,37	22	116,45	91	1,4	-33	0,065	12	1077	5	630	0	562	0		
13	Sanaga in nachtigal	**76000**		**1380**		**1,42**		**555**		**1,06**		**0,042**		**2460**		**835**		**426**		4°21'	11°38'
		78079	3	1894	37	1,91	35	855,76	54	0,69	-35	0,034	-19	2384	-3	846	1	430	1		
14	Mapé in Magba amont and aval	**4020**		**252**		**1,12**		**63,4**						**2177**				**690**		5°59'	11°16'
		3800	-6	332	32	1,52	36	138,58	119	6,6	####	0,083	####	2273	4	922	####	688	0		
15	Mbam in Mantoum	**14700**		**565**		**1,31**		**212**						**2417**				**660**		5°37'	11°11'
		16028	9	764	35	1,7	30	334,01	58	2,95	####	0,055	####	3001	24	1021	####	655	-1		
16	Monkie in S₂	**181**		**58,4**		**1,22**		**20,1**						**2616**				**1158**		5°57'	10°25'
		174	-4	64	10	1,37	12	25,05	25	40	####	0,208	####	2523	-4	1601	####	1159	0		
17	Noun in Bambalang	**632**		**107**		**1,2**		**35,8**						**3008**				**1143**		5°54'23"	10°33'02"
		838	33	129	21	1,26	5	28,91	-19	34,2	####	0,194	####	2976	-1	1498	####	1145	0		
18	Noun in bamendjing	**2190**		**171**		**1,03**		**46,8**						**3008**				**1140**		5°42'	10°30'
		2197	0	191	12	1,15	12	46,65	0	17,7	####	0,143	####	2940	-2	1380	####	1139	0		
19	Mifi in Bamoungoum	**306**		**76**		**1,22**		**26,1**		**19**		**0,147**		**1924**		**1537**		**1270**		5°31'	10°21'
		366	20	101	33	1,49	22	41,73	60	12,1	-36	0,135	-8	1923	0	1508	-2	1268	0		
20	Choumi in banock	**360**		**103**		**1,52**		**42,6**		**11**		**0,126**		**2740**		**1560**		**1385**		5°29'	10°17'
		346	-4	126	22	1,91	26	56,92	34	7,47	-32	0,121	-4	2739	0	1572	1	1384	0		
21	Metchie at falls	**480**		**115**		**1,47**		**47**		**10,9**		**0,127**		**2740**		**1547**		**1297**		5°22'	10°20'
		166	-65	61	-47	1,34	-9	23,41	50	13,9	27	0,1601	26	1923	-30	1695	10	1449	12		
22	Mifi in Bafounda	**854**		**142**		**1,37**		**55,6**		**8,98**		**0,117**		**2740**		**1530**		**1260**		5°32'40"	10°20'17"
		864	1	176	24	1,69	23	76,74	38	6,67	-26	0,108	-8	2739	0	1529	0	1262	0		
23	Noun in Bafoussam E1 and E2	**4740**		**267**		**1,1**		**68,8**						**3008**				**988**		5°28'	10°33'
		4784	1	338	26,592	1,38	26	133,04	93	7,22	####	0,0915	####	2946	-2	1378	####	991	0		
24	Mbam in the Goura tray	**42300**		**840**		**1,15**		**250**		**4,37**		**0,081**		**3008**		**980**		**395**		4°34'	11°22'
		42969	2	1019	21	1,39	21	402,83	61	2,71	-38	0,055	-32	3005	0	932	-5	393	-1		
25	Sanaga in Edéa	**131500**		**1585**		**1,23**		**550**		**1,82**		**0,055**		**3008**		**860**		**6**		3°46'	10°04'
		132971	1	2228	41	1,72	40	978,04	78	0,75	-59	0,035	-37	3005	0	855	-1	-1	-117		

graduations, drawing of the real and stylized limits of the catchment areas.

The current study is short and fast, instrumentally modern with automatic matching, sophisticated optical image technology, where machines sometimes check, correct, or signal imperfections to its user. For example, the coordinates of the hydrometric Lom station at Bétaré Oya by the old method in all the hydrological and monographic directories are latitude: 5° 55′ and longitude 14° 08′; altitude: about 662 m. The recent study with modern technology gives latitude: 5°

: Percentage difference between raw values found and values of Dubreuil and al. (1975)

: Percentage difference between stylized values found and values of Dubreuil and al. (1975)

◀**Fig. 4** Histograms of the percentage difference between unstylized and stylized values of new and old morphometric parameters. **a**. Area; **b**. perimeter; **c**. Gravelius compactness index; **d**. equivalent rectangle length; **e**. global slope index; **f**. Roche slope index; **g**. maximum altitude; **h**. Medium altitude; **i**. minimum altitude

36′ 08.6″ and longitude 14° 00′ 24.2″; altitude: 699 m, and its direct territorial view (Fig. 5).

Observation of the Avéa basin images (Fig. 6a) by Dubreuil (1974) gives a KG = 1.4; and (Fig. 6b); in this study, it is 1.33 and corresponds better to its elongation.

Accurate and precise geographical coordinates of an outfall station are very decisive to characterize its catchment area. The positions on the DTM of certain geographical coordinates, in the archives of several stations

in the Sanaga catchment areas, were all located far from the river and sometimes generated (moved back to the outlet presented by the software as the closest on the river's course to reflect the reality of the terrain) there. Except the Djerem at Bétaré Gongo, Sanaga at Goyoum, Avea at Menvounga, Monkie at S2, Mifi at Bafounda, and Noun in Bafoussam stations with coordinates near or right in their watercourses, it was not the same for the 19 others. The Lom station at Bétaré Oya does not fall on the river (red point in Fig. 5), on which it was generated (yellow point in Fig. 5) for its modelling and obtaining of the results of parameters. Furthermore, the study strongly emphasizes the layout of the catchment areas (contiguous or nested) and provides certain corrections, in particular:

Fig. 5 Positions of the Lom hydrometric station at Bétaré Oya as a function of the sources in the Sanaga catchment area
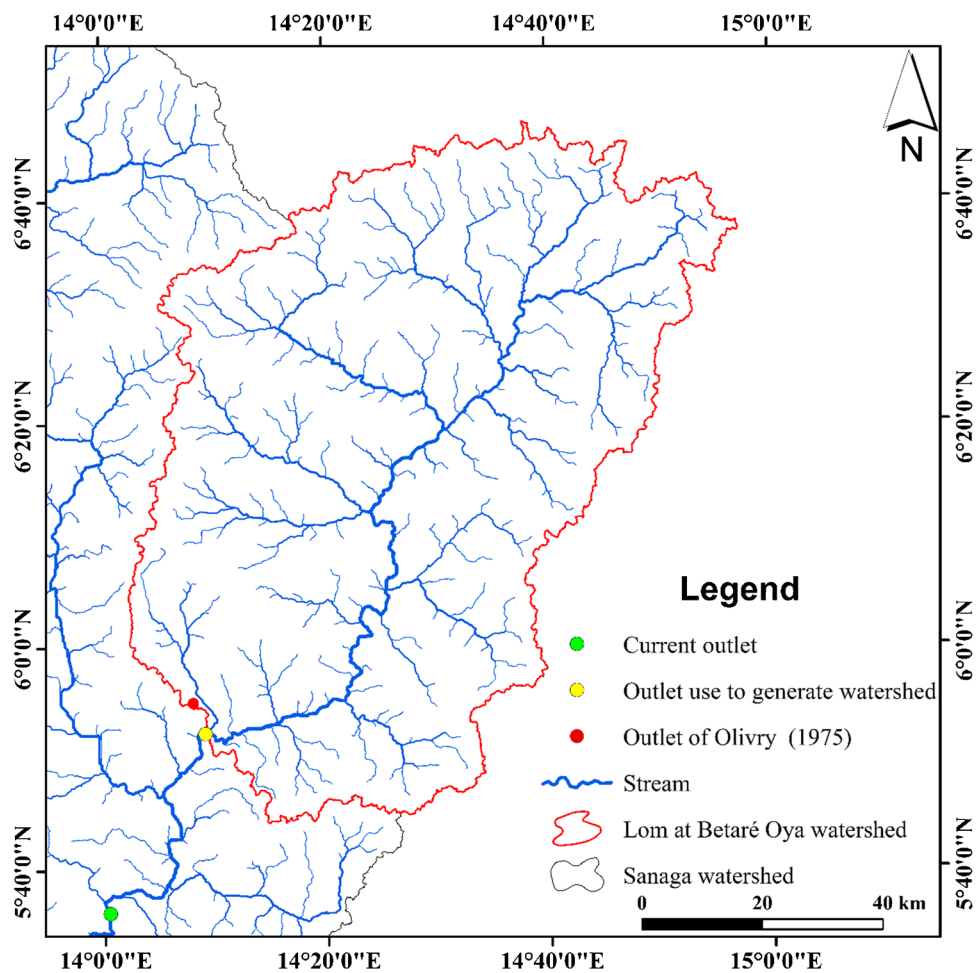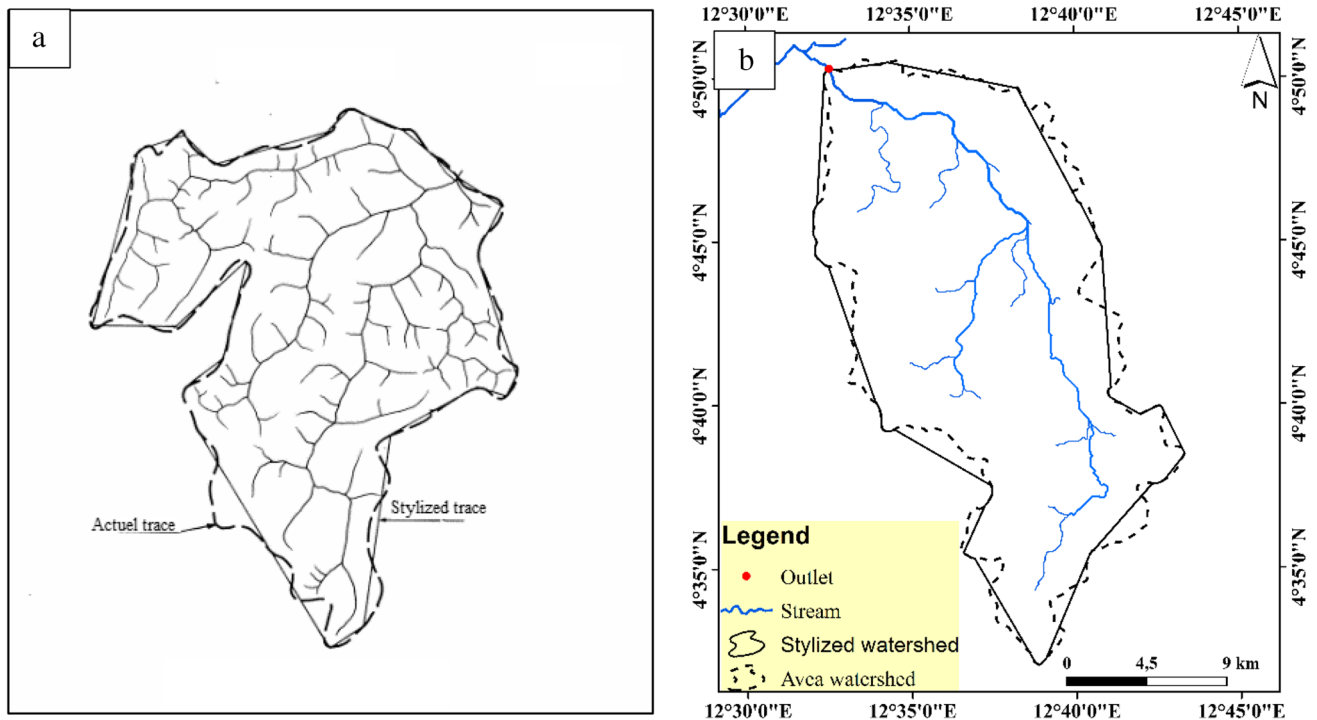
Fig. 6 Avéa catchment area at Menvounga (S5). **a** By Dubreuil et al. (1975); **b** this study

– The catchment area of Meng station at Tibati nests with that of Maouor at the bridge; thus, its surface area cannot be greater than that of Maouor (Fig. 7).

– The Metchié station at the falls nests with that of Mifi at Bamoungoum and its surface area (480 km^2) cannot be greater than that of the latter (306 km^2) (Fig. 8).

– The Djerem coordinates at Mbakaou E2 are different from those of Dubreuil et al. (1975) with coordinates: longitude 12° 49′ E and latitude 6° 20′ N on the river. The coordinates of the nearest outlet are longitude: 12° 49′ 16″ E and latitude: 6° 19′ 11.5″. The surface area (12,425.5 km^2) and perimeter (730.323 km) still far from the reality of the terrain led to a farther outlet (longitude: 12° 48′ and latitude: 6° 17′ 35.5″) close to the reality, with a surface area (20,387 km^2) and perimeter (885 km) in Fig. 7.

– The Gravelius coefficient is 1.12 for a square-shaped catchment area and above when elongated (Musy 2005), although criticized by Bendjoudi and Hubert (2002) and verified here. Mapé in Magba, Djerem in Bétaré Gongo, and Ndjéké in Ngongon are square-shaped basins (Dubreuil et al., 1975). But other values better justify their shapes.

– Moreover, it is necessary to sometimes stylize the contours of the catchment areas for efficient characterization, because of wide differences in graphs.

– Information on parameters not determined by Dubreuil et al. (1975) such as the global slope index, Roche slope index, and average altitude of six stations: Mapé at Magba, Mbam at Mantoum, Monkie at S2, Noun at Bambalang, Noun at Bamendjing, and Noun at Bafoussam (Tables 1 to 4).

In general, the results show features determined with a small or very high margin of error. The accuracy in the determination of the former is slightly dependent on the error made upstream, while the latter (area, length, shape, etc.) results from a poor appreciation of contours leading to very high margins errors.

From the results, errors accompany the delimitation of catchment areas with old methods which are more laborious and less precise. These arguments confirm the need to re-precise nowadays certain studies done with modest technical means in the past.
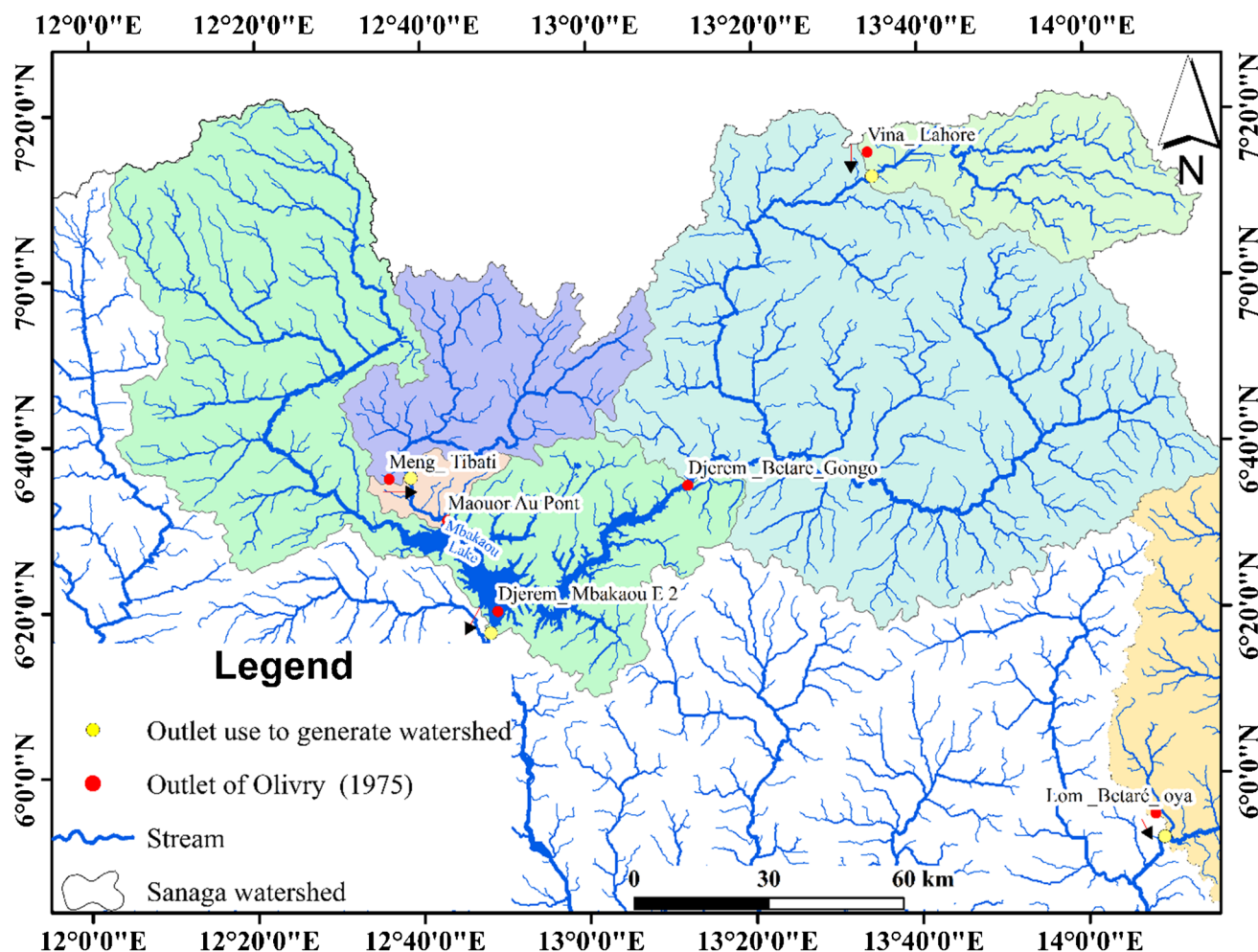
Fig. 7 Layout of the station's Vina at Lahoré, Meng at Tibati, Maouor at the bridge, Djerem at Mbakaou E2 as a function of two sources in the Sanaga catchment area

Conclusion

The use of modern techniques combined with GIS (Geographic Information System) and SRTM (Shuttle Radar Topography Mission) images has enabled us to update the morphometric characteristics and their precision: the case of the Sanaga watershed in Cameroon and some of its unit cells. It therefore emerges that almost all of the characteristics formerly determined by technical means at that time were so with a very large margin of error and require further precision given their downstream impact on the determination of flows and hydrological analyses. An enormous relative change in the values of the morphometric characteristics of the Sanaga watershed is confirmed at the end of the present study where, as an example of the coefficient of Gravelius, they vary between 4 and 114% in gross and between −9 and 53% in stylized. Given the importance of the differences obtained for most of these characteristics and in order to provide decision-makers with reliable and good quality data, it would be strongly recommended that practitioners take them into account in their work on modelling and sizing of structures hydraulic. In the looming horizon, updating from the same modern techniques will see a continuation for other types of physical characteristics of the said watershed.

Fig. 8 Layout of the Metchié stations at Les Chutes, Mifi at Bamoungoum according to two sources in the Sanaga catchment area
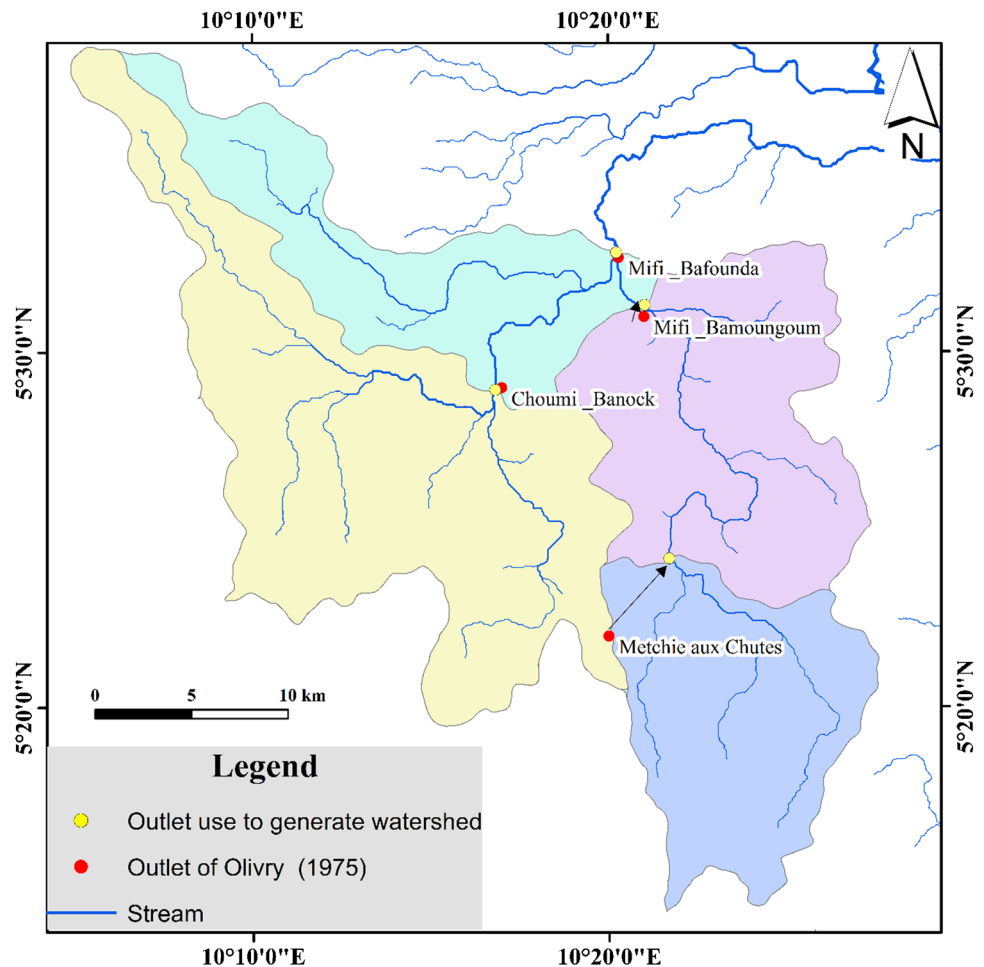
Data availability The data used to support the findings of this study are available from the corresponding author upon request.

Declarations

Competing interests The authors declare no competing interests.

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