



# Erosion susceptibility assessment through morphometric analysis and sub-watershed prioritization in the nyong watershed, Southern Cameroon

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## Abstract

The Nyong River sub-watershed in the southern Cameroon plateau has been prioritized for urgent conservation action due to its erodibility, using the morphometric and hydrological criteria. Six sub-watershed were delimited from the Shuttle Radar Topography Mission (SRTM) data in a geographic information system environment. The Sub-Watershed Prioritization Tool (SWPT) was used to analyze the weighted sum (WSA) parameters of these sub-watersheds. Field investigations, including river water sampling, were carried out from January to August 2024 to estimate the suspended solids (SS) rate in each sub-catchment. Key morphometric parameters, such as compactness index, drainage density and form factor, were calculated and weighed. Based on the results, particularly the CPV, the Ayos, Mbalmayo and Olama sub-watersheds with CPV ranging between  $-853$  to  $-3.6$  were classed as high priority and therefore most erodible. On the contrary, Abong-Mbang, Akonolinga, and Pont So'o sub-catchments with CPV of  $-275.27$ ,  $-311.36$  and  $-33.86$ , respectively, showed moderate vulnerability. The CPV results were generally coherent with suspended solid content from river water samples in the area. The suspended solids content (in mg/l) obtained from river water samples was as follows in the sub-catchments: Ayos (18.12); Mbalmayo (14.24); So'o (10.1); Olama (6.24); Abong-Mbang (6.17), and Akonolinga (2.81). Except for Pont Soo, the sub-basin prioritization CPV ranking ties closely with the SS values. This study provides decision-makers with strategic information for land and water resource management in tropical ecosystems.

**Keywords** Basin classification · Erodibility · Suspended solids · SWPT · Topo-hydrological analysis

## Introduction

Soil erosion is a global environmental problem that seriously endangers the sustainability of ecosystems, food security and water resources. Worldwide, particularly in sub-Saharan Africa, water-induced soil erosion is a key factor; It reduces soil fertility, intensifies biodiversity losses and endanger sustainable agriculture (Negese et al. 2021; Elnashar et al. 2021). The main forms of water erosion (splash, sheet, rill, gully and bank erosion) are aggravated by unsustainable land use practices. In developing countries, farmers lack the means to compensate for soil and nutrient losses, which intensifies the impact of soil erosion, endangers livelihood and exacerbates food security problems (MINEE-GWP 2009).

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In sub-Saharan Africa, and particularly in Cameroon, anthropogenic activities such as deforestation, intensive agricultural practices and over-exploitation of natural resources are intensifying the degradation of watershed ecosystems. The Nyong River, which flows in the southern Cameroon plateau, well illustrates these problems. The area is faced with rapid soil erosion, reduction of water resources and the deterioration of river ecosystems. The basin, which is a major contributor to river hydrology, has experienced soil degradation due to water erosion for decades (Ndam Ngoupayou et al. 2002; Sigha-Nkamdjou et al. 2005).

Previous studies have focused on various aspects of this basin, including (1) modeling of pedological, hydrological and geochemical dynamics for effective resource management (Braun et al. 1998; Ndam Ngoupayou et al. 2002); (2) assessment of suspended solids and annual sedimentary loads to estimate their importance and calculate the erosion rate (Lienou et al. 2005); Other studies include (3) analysis of the carbon cycle in terrestrial and aquatic reservoirs to determine the influence of soil erosion on the carbon cycle within these ecosystems (Nkoue-ndondo 2008); and (4) the impact of physicochemical water parameters on the health of riparian populations (Essa'a et al. 2017). The findings from these studies revealed that the catchment has been greatly impacted by anthropogenic pressures resulting in soil degradation, eutrophication of water bodies and the proliferation of invasive macrophytes such as the water hyacinth. This situation has led to a reduction in the depth of the water course and an increase in sedimentation. However, no study has focused on prioritizing the Nyong River sub-basins based on their vulnerability to erosion. This shortcoming limits management effort in this basin. It is therefore vital to develop tools and methods that are adapted to the local environment and can also help to understand the local hydrogeologic characteristics of the area. Such methods can also help manage natural hazards (erosion, siltation, flooding, and landslides).

Morphometric analysis has been widely accepted by several authors as a realistic approach for watershed management and the development of natural resources (Horton 1945; Javed et al. 2011). It provides a quantitative description of the drainage system, which is an important aspect of watershed characterization (Strahler 1964). Morphometric analysis is of great contribution in watershed prioritization according to the order in which they should be considered for soil conservation measures, for appropriate planning and management of natural resources, and pledge of their sustainable development (Sreedevi et al. 2009; Kanth and Hassan 2012; Rahaman et al. 2015; Yonnana et al. 2020).

Therefore, several studies using this approach have been conducted in Africa for the improvement of watershed management. Ahmad (2018) identified erosion-prone areas in the Gumara watershed in Ethiopia using DEM and GIS. He realized that about 21.71% of the total watershed area was prone to severe erosion. Dzwaïro et al. (2025) used DEM and GIS-based morphometric and morphotectonic analysis to identify erosion-prone zones in the Rietspruit sub-basin of South Africa that are critically threatened by mine and general domestic pollutants, thus rendering some of the water resources unusable for normal processes. Also, Naoui et al. (2025), through the morphometric and hypsometric analysis, evaluated the erosion risks within the sub-watersheds, which pose a direct threat to the El Wahda dam's efficiency in Morocco. They combined spatial analysis with statistical methods to refine the prioritization in order to help decision-makers gain a clear visualization of high-risk areas.

More specifically, morphometric and topo-hydrological analyses, when combined with the remote sensing data and the Sub-Watershed Prioritization Tool (SWPT) in a Geographic Information System (GIS) environment are reforming the traditional methods such as field observations and topographic map interpretation (Krishnamurthy et al. 1996; Attoubounou et al. 2025). Sub-Watershed Prioritization Tool (SWPT), a user-friendly tool using Python programming language, is designed to automatically identify watersheds with critical and priority status through geospatial and statistical analysis (Khan et al. 2001; Brahim et al. 2016). It has been successfully used by several authors to identify and prioritize sub-watersheds requiring adequate soil and water management measures (Aher et al. 2014; Abdulkareem et al. 2018; Rahmati et al. 2019; Ahmad et al. 2019; Terefe et al. 2024).

The primary objective of this study is to classify the sub-catchments of the Nyong according to their risk of erosion, using a weighted sum analysis (WSA) based on the Sub-watershed Prioritisation Tool (SWPT). Specifically, the study seeks to (1) determine and present the morphometric and topographical-hydrological characteristics of the six sub-catchments using remote sensing data and GIS; (2) establish the hierarchy of intervention in these sub-catchments to prioritize areas requiring urgent conservation action for the management of possible erosion risks. Field investigations to estimate the suspended solids (SS) rate are considered a novelty for this methodology. The results will provide valuable tools for the sustainable management of land and water resources, while strengthening efforts to restore and protect aquatic ecosystems in the Nyong basin. Furthermore, the study will identify the main development threats and propose a timely intervention approach.

## Data and methodology

### Study area description and geologic setting

The Nyong watershed extends between latitudes 2°48'N and 4°40'N, and longitudes 9°54'E and 13°30'E (Fig. 1), covering three Regions of Cameroon: the East, the Centre, and the South, with an area of approximately 18,510 km<sup>2</sup> at Olama (Nkoue-ndondo 2008). It is bordered to the north by the Sanaga Basin, to the west by the Atlantic Ocean (where it flows), to the south by the Lokoundjé and Ntem basins, and to the east by the Dja, Boumba, and Kadey basins. The Nyong River originates in the East Region at an altitude of approximately 690 m, following a sinuous course with a general ENE-WSW orientation towards the Atlantic Ocean.

The Nyong watershed experiences a Guinean equatorial climate, characterized by four unevenly distributed seasons: two high-water seasons (March to June and September to November) and two low-water seasons (July-August and December-February). Long-term annual distribution of rainfall varies from 1147 to 2637 mm within the watershed

(Fig. 2). The lowest river flows occur in February and March (Lieunou 2007). Air temperatures show minimal variation, ranging from 23.0 °C (short dry season, July-August) to 25.4 °C (long dry season, February-March) (Ndam Ngoupayou et al. 2016).

The watershed forms part of the southern Cameroon plateau, characterized by undulating terrain with altitudes ranging from 600 to 900 m (see Fig. 1c). Whilst the average slope is shallow, a major slope break separates the Ntem unit from the Pan- African belt (Fig. 3).

Geological studies identify two petro-structural groups: The Central African Pan-African belt (Yaoundé group) and the Congo Craton (Ntem complex) (Nzenti et al. 1988). These groups consist of:

- Yaoundé Series: migmatites, gneisses, micaschists, amphibolites, and more.
- Ayos-Mbalmayo-Bengbis Series: micaschists and quartzites.
- Nyong Unit: sedimentary and plutonic rocks (TTG, charnockites, etc.).

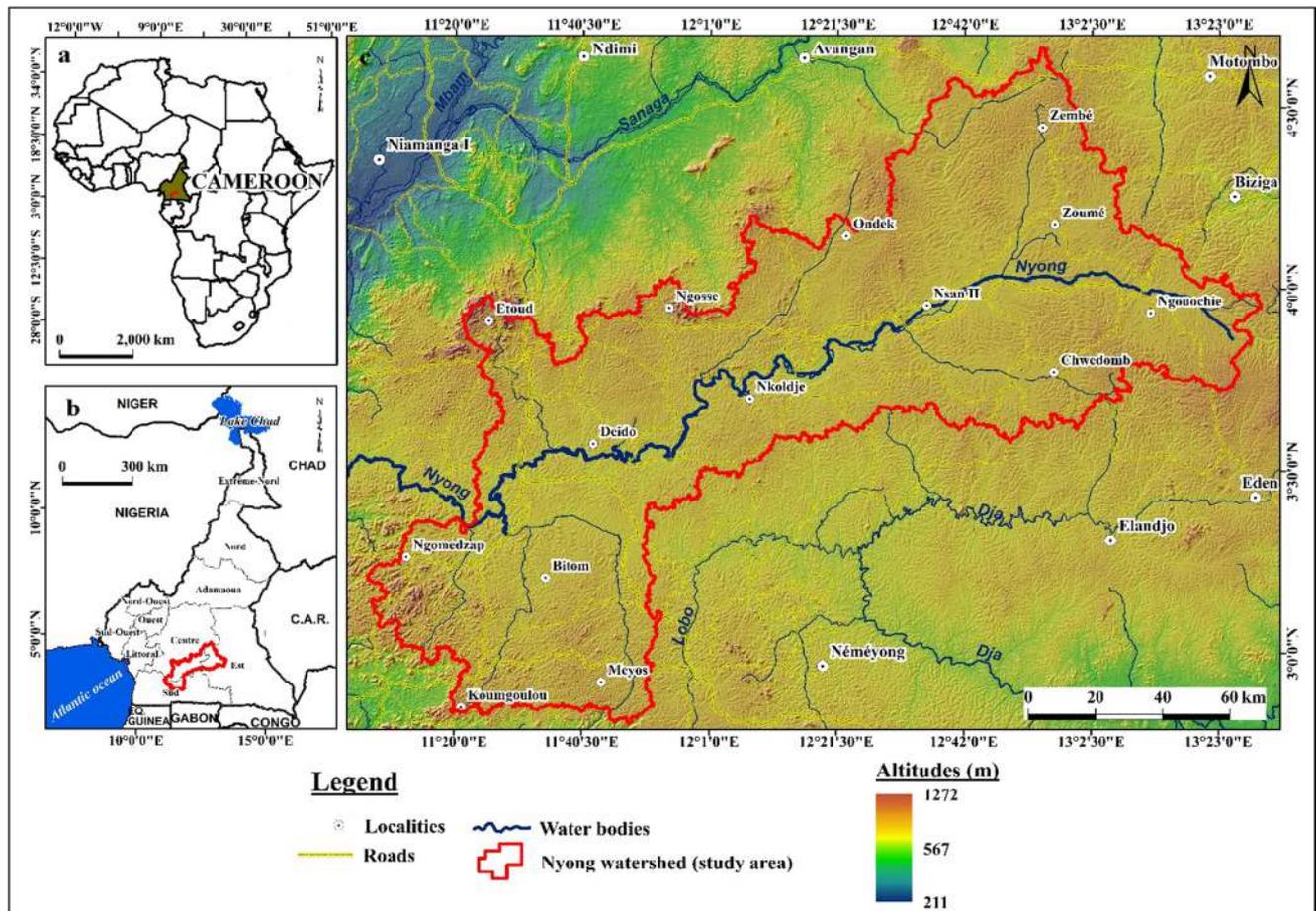
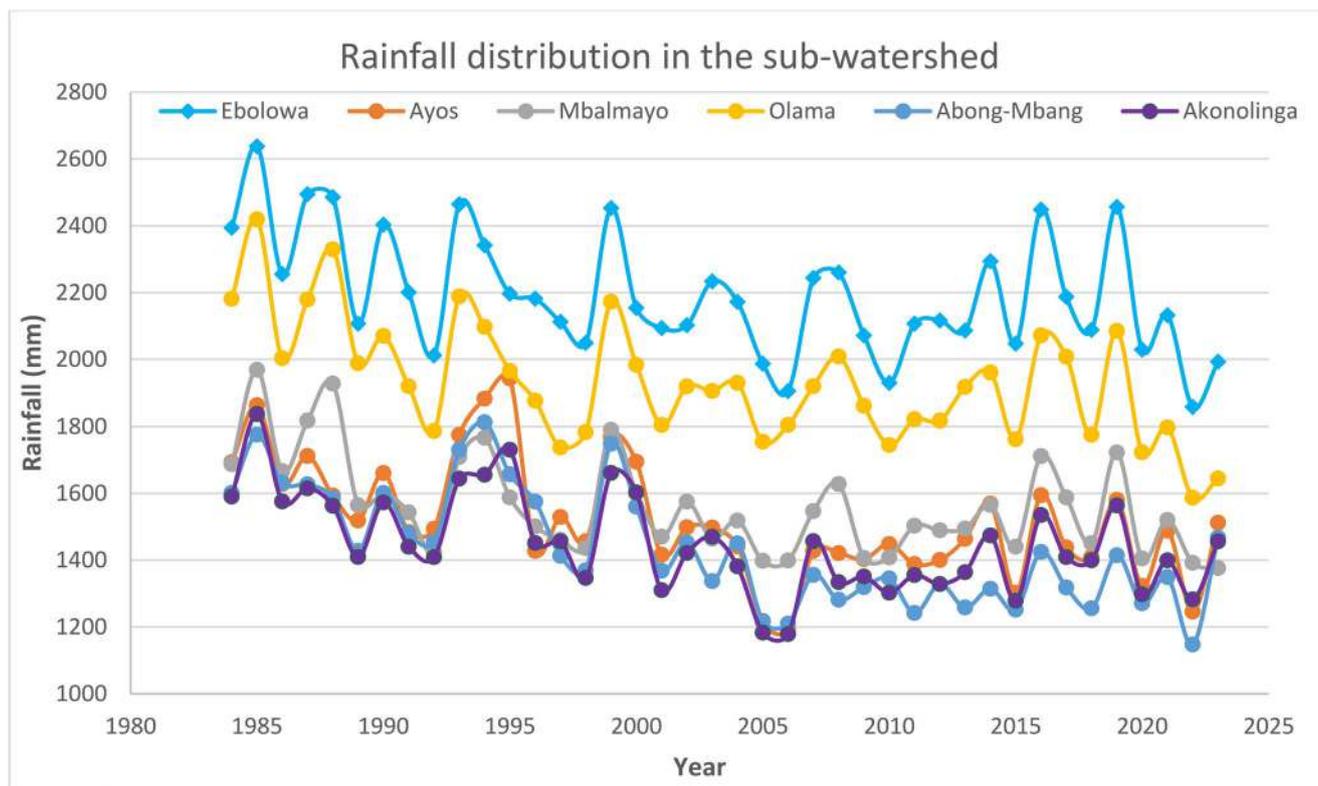


Fig. 1 Location of the study area



**Fig. 2** Long-term (1984–2023) annual distribution of rainfall within the sub-watershed

- Ntem Unit: charnockitic magmatic rocks, banded iron formations, and paragneisses (Maurizot et al. 1986; Pouclet et al. 2007).

The soils are predominantly ferralitic (80% of the surface), deep, acidic, and highly weathered, characteristic of humid tropical climates (Braun et al. 2005). Hydromorphic soils are primarily found in swampy areas, influenced by local hydrological fluctuations (Santoir and Bopda 1995). The black water of the Nyong River, marked by high organic matter content and acidity, is the result of the area's hydrologic dynamics. The vegetation is dominated by semi-deciduous Congolese-Guinean forests (Sterculiaceae, Ulmaceae) (Letouzey 1968). *Raphia* palms characterize swampy areas, while grassy savannas and dense evergreen Atlantic forests persist in some regions (Moustapha et al. 2022). However, these ecosystems face increasing pressure from deforestation, urbanization, and mining activities in the region.

### Data collection

The main data used in this study is the Shuttle Radar Topography Mission (SRTM) Digital Terrain Model (DTM) with a resolution of 90 m. This DTM was used to characterize the morphology of the sub-catchments. The Hydrology module of the ArcGIS software was used to calculate the physical

parameters of the sub-catchments. These parameters include the surface area and perimeter of the catchment areas, as well as the extraction and prioritization of the drainage network according to Strahler's classification. Morphometric analysis was then used to characterize the specific features of each sub-catchment. Furthermore, the Sub-Watershed Prioritization Tool (SWPT), an open-access tool on (<https://github.com/mahmoodsamadi/SWPT.git>), integrated into ArcGIS, was used. This tool enhanced the identification of priority sub-catchments in terms of erosion risk intervention through combining a geospatial analysis with advanced statistical operations.

### Research methods

The 90 m SRTMs were first converted into Cartesian coordinates, UTM Zone 33 N, with distances expressed in metres. Using six different outlet points, six sub-catchment were delimited from the SRTM of the study area. These are, from upstream to downstream, the Nyong sub-watersheds at Abong-Mbang, Ayos, Akonolinga, Mbalmayo, Pont-So'o and Olama (Fig. 4). The drainage network generated during the process was prioritized using Strahler's classification. Such a classification supports the effective management of a watershed by identifying the importance and role of the streams in the watershed.

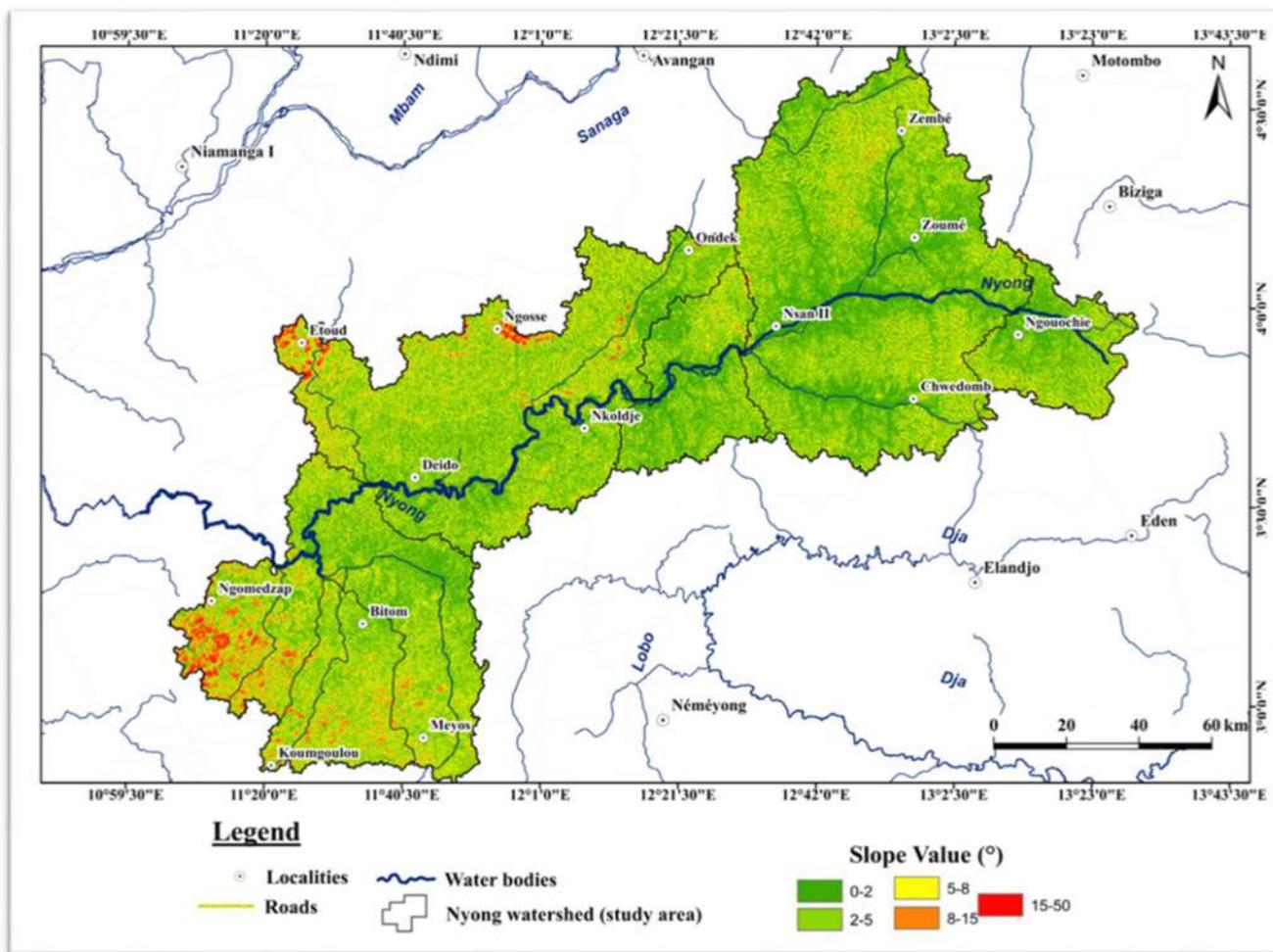


Fig. 3 Slope gradient map of the area

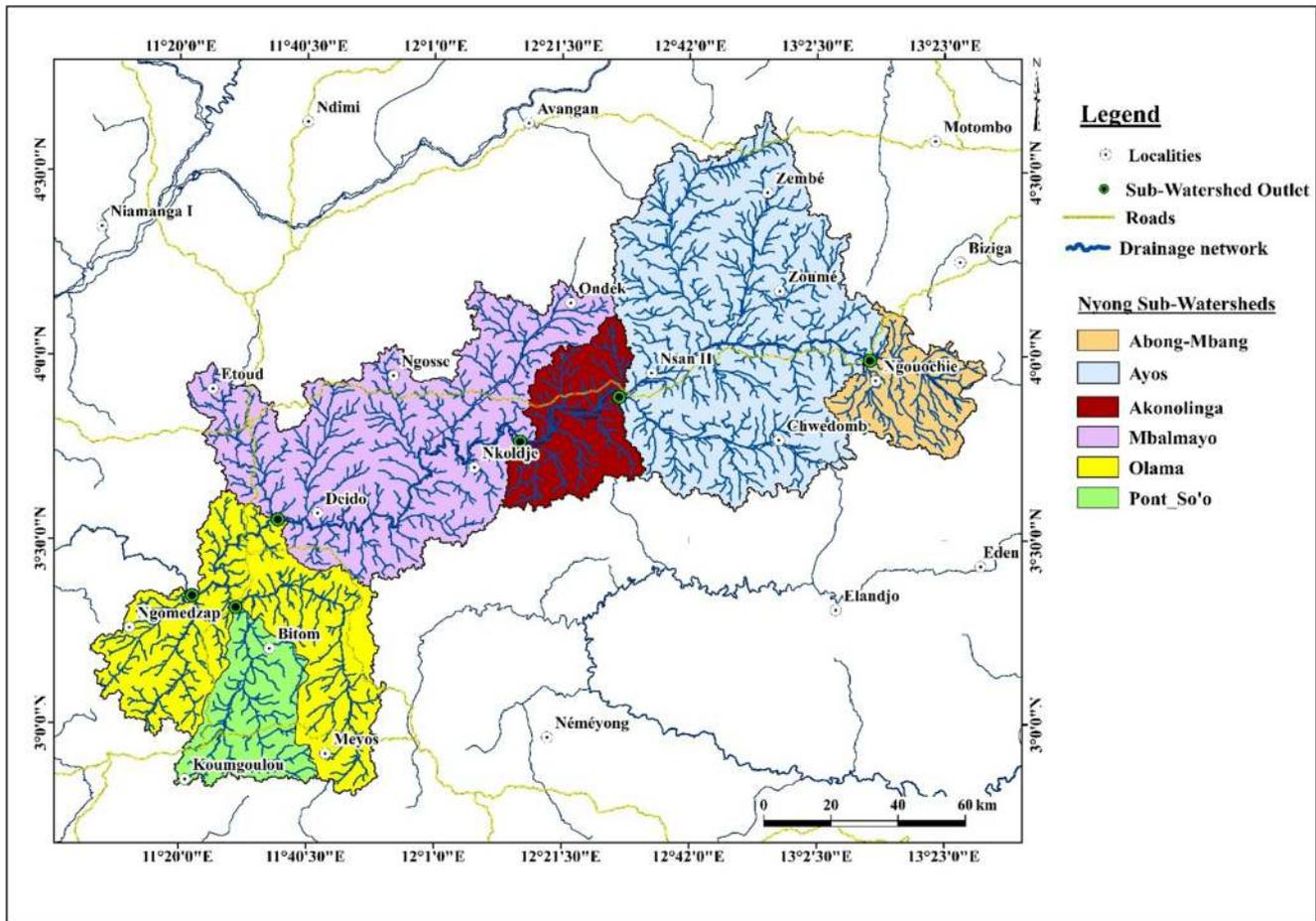
The morphometric and topographical-hydrological parameters of all sub-catchments were determined using the SWPT script from the SWPT analysis toolbox. The tool is based on the hydro-geomorphometric analysis concept. A representation of the SWPT conceptual architecture is shown in Fig. 5. Thus, the SWPT prioritization tool was integrated into ArcToolbox as an extension to ArcGIS 10.5 software (Marowka 2018).

### Sub-catchment prioritization stage

The prioritization of sub-catchments in the Nyong basin was based on morphometric and topohydrological parameters. Morphometric factors include drainage density (D), stream frequency (Fs), drainage texture (Rt), form factor (Rf), circularity ratio (Rc), constant of channel maintenance (C), elongation ratio (Re), compactness coefficient (Cc), as Surface Aspects and bifurcation ratio (Rb) as Linear Aspects. The topographic-hydrological parameters include the Topographic Moisture Index (TWI), the Stream Power Index

(SPI) and the Sediment Transport Index (STI). The TWI is derived from the DEM and quantifies the potential for accumulation and movement of water over a topographic surface (Beven and Kirby 1979). SPI quantifies the erosive power of flowing water. It represents sediment transport parameters (Montgomery and Dietrich 1994). The automatic analysis of these parameters adopted in this study is consistent with the methods and formulae proposed by several authors and presented in Table 1.

Where  $u$  = Stream order;  $Nu$  = Number of stream order;  $Lu$  = Length of stream orders;  $Rb$  = Bifurcation ratio;  $Nu + 1$  = no of segments of the next higher order;  $Rb$  = Mean bifurcation ratio;  $A$  = Total basin area;  $P$  = Total basin perimeter;  $Lb$  = Basin length;  $Rf$  = Form factor;  $Dt$  = Drainage texture;  $Cc$  = Compactness coefficient;  $Rc$  = Circularity ratio;  $Re$  = Elongation ratio;  $Dd$  = Drainage density;  $F$  = Stream frequency;  $As$  is the local upslope area draining through a certain point per unit contour length and  $\tan\beta$  is the local slope;  $\beta$  is the local slope



**Fig. 4** Map of the Nyong sub-catchments and hydrographical network

gradient in degrees,  $m$  is the contributing area exponent and  $n$  is the slope exponent.

### Prioritization of sub-watersheds

An automatic correlation analysis was carried out between the morphometric and topographical-hydrological parameters of the sub-catchments to prioritize the sub-catchments of the Nyong basin in order to identify the most influential factors contributing to erosion susceptibility. Only factors with a correlation coefficient greater than 0.6 were retained for further analysis (Aher et al. 2014). To assess the vulnerability of sub-catchments to erosion and runoff, the weighted sum analysis (WSA) method was applied. This is a statistical approach commonly used in geomatics. This method assigns weight to the different factors (morphometric, topo-hydrological) to depict their relative importance in erosion processes based on Eq. (1) as reported by Aher et al. (2014).

$$\text{Priorisation} = \sum_{i=1}^n W_i \times X_i \quad (1)$$

Where  $W_i$  is the weight of each morphometric parameter calculated by the WSA approach;  $X_i$  is the value of the morphometric parameter.

This approach allows the accurate assessment of the influence of each factor on erosion by calculating a vulnerability index (WSA) for each sub-basin. The results obtained enable the basins to be ranked from the most exposed to the least exposed. This ranking enables erosion control measures to be prioritized, focusing on the most critical erosion-prone areas.

### Water sampling and suspended solids analysis

In addition, flowing water samples were collected at a biweekly from January to August 2024 at six monitoring stations located at the outlet of each sub-catchment from upstream (see Fig. 4), from upstream (Abong-Mbang) to downstream (Olama). Samples were collected in 1.5-litre PVC bottles at the same vertical in the middle of the stream, between 10 and 50 cm deep, and preferably, where water velocities were sufficiently high to allow good homogenization of solid particles of different sizes. Ninety (90) samples

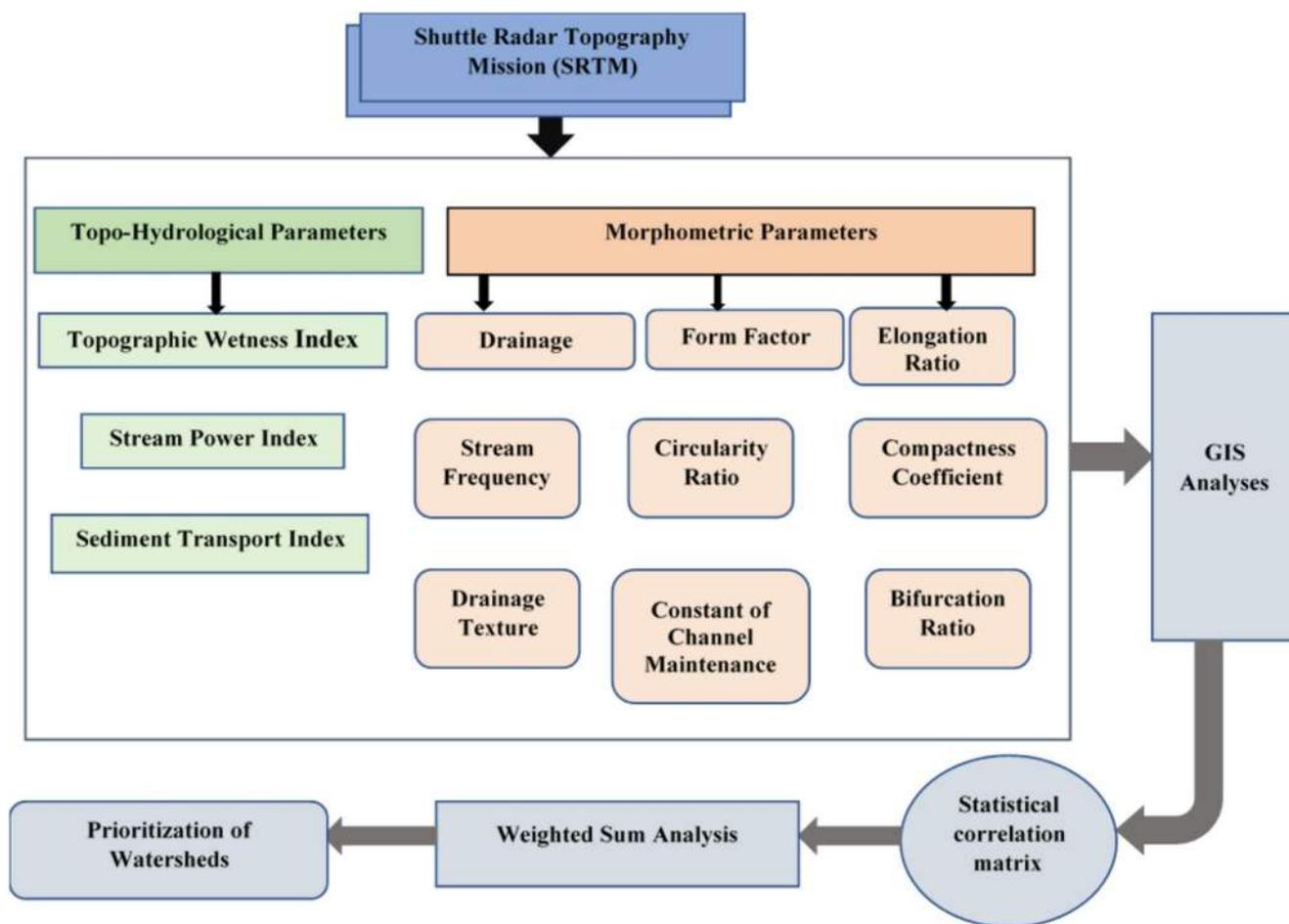


Fig. 5 Conceptual architecture for prioritizing sub-catchments (adapted from Sharma et al. 2023)

were collected and transported to the Laboratory of Water Analysis (LWA) of the Institute of Mining and Geologic Research (IRGM) in Yaounde for analysis (Fig. 6). The main objective of these analyses was to measure suspended solids (SS) and evaluate their spatial and temporal variation in the Nyong catchment. For the analysis, a well-mixed sample was filtered through a weighed standard glass-fibre filter, and the residue retained on the filter was dried to a constant weight at 103 to 105 °C. The increase in weight of the filter represented the total suspended solids.

## Results and discussion

### Geomorphometric characteristics

The results of the geomorphometric analysis are summarized in Table 2. The flow frequency, which reflects the density of the hydrographic network, presented the greatest spatial variability. The values obtained, ranging from 8.04E-08 (Akonolinga sub-catchment) to 1.32E-08 (Ayos sub-catchment),

were classified into five categories (very high, high, moderate, slightly high, low) according to the classification established by Venkatesan et al. (2013); Vulević and Dragović (2017). The Akonolinga sub-catchment, classified as very high, exemplifies a dense hydrographic network. This indicates a rapid hydrological response after a rainfall event, increasing the risk of erosion, sediment transport and flooding. These findings are consistent with the observations of Strahler (1957), who linked high runoff frequencies with steep relief and low infiltration capacity. Conversely, the Ayos sub-basin recorded the lowest flow frequency value (1.32E-08), classified in the low category. This low value reflects a sparse hydrography, characteristic of a more stable hydrologic regulation in the Ayos sub-basin, where the risks of erosion and flash floods are considerably reduced. Similar patterns have been observed in areas of dense vegetation or flat topography, as noted by Khan et al. (2001) and Oguchi (1997).

The bifurcation ratio (Rb) is calculated as the ratio of the number of streams of a given order to the number of streams in the next higher order. It serves as an indicator of

**Table 1** Method for calculating morphological and topo-hydrological parameters (adapted from Rahmati et al. 2019)

N <sup>o</sup>	Morphometric and hydrological parameters	Formula	Authors
1	Stream frequency ( <i>F</i> ) (number/km <sup>2</sup> )	<i>F</i>	Horton (1932)
2	Compactness coefficient ( <i>C<sub>c</sub></i> )	$C_c = 0.282 * P / \sqrt{A}$	Horton (1932)
3	Constant of channel maintenance ( <i>C</i> )	$C = 1/Dd$	Schumm (1956)
4	Bifurcation ratio ( <i>R<sub>b</sub></i> )	$R_b = Nu/Nu + 1$	Schumm (1956); Strahler (1952)
5	Drainage density ( <i>D<sub>d</sub></i> ) (km/km <sup>2</sup> )		Horton (1945); Strahler (1957)
6	Elongation ratio ( <i>Re</i> )	$Re = 1.129 * \sqrt{A/Lb}$	Schumm (1956)
7	Circularity ratio ( <i>R<sub>c</sub></i> )	$R_c = 4\pi A/P^2$	Miller (1953)
8	Form factor ( <i>R<sub>f</sub></i> )	$R_f = A/Lb^2$	Horton (1932)
9	Drainage texture ( <i>D<sub>t</sub></i> )	$D_t = Nu/P$	Horton (1945)
10	Topographic wetness index (TWI)	$TWI = \ln(As = \tan\beta)$	Beven and Kirkby (1984)
11	Stream power index (SPI)	$As \times \tan\beta$	Whipple and Tucker (1999)
12	Stream transport index (STI)	$STI = (m + 1) \times As / 22.13^m \times \sin\beta = 0.0896n$	Moore and Burch (1986)

the terrain's relief and degree of dissection (Horton 1945). A bifurcation ratio of 2 is typically associated with flat or gently rolling terrains, whereas values of 3, 4, or higher are indicative of mountainous or heavily dissected landscapes (Farhan et al. 2016). Higher Bifurcation Ratios (*R<sub>b</sub>*) suggest the likelihood of peak hydrograph events, which may result in flash floods (Altaf et al. 2013). These high ratios are also linked to episodic surface erosion processes such as sheet wash, the formation of rills, and gullies. In this study, the highest value is obtained in the Olama sub-catchment (2.7), while the Abong-Mbang sub-catchment showed the lowest value (1.3). Generally, the lower the *R<sub>b</sub>*, the less disturbed the watershed (Verstappen 2011). Consequently, if the *R<sub>b</sub>* is very high, then damages due to natural disasters such as flooding will be recurrent. This could lead to high surface runoff and increased soil erosion.

The aspect ratio (*R<sub>f</sub>*), as defined by Horton (1945), is the ratio between the surface area of a watershed and the square of its total length. In the context of the study area, the Olama and Pont So'o sub-catchments have *R<sub>f</sub>* values of 0.79 and 0.43, respectively. The Olama basin, with a high *R<sub>f</sub>* close to 0.79, tends towards a circular shape, implying a probable peak of runoff rate occurring over a short time after a rainfall event. In contrast, the Pont So'o sub-basin, with an *R<sub>f</sub>* of 0.43, has a more elongated shape, leading to a flow that

could spread out more over time, characterized by a less marked peak flow. These observations are consistent with the findings of Waikar and Nilawar (2014), who pointed out that basins with high *R<sub>f</sub>* respond quickly to rainfall due to a spatial concentration of flows.

The aspect ratio (*Re*) is defined as the fraction between the diameter of a circle having the same area as the watershed and the maximum length of the watershed (Strahler 1968). In this study, the Olama sub-catchment has the highest *Re* value (1) (indicating a circular shape), followed by the Abong-Mbang (0.97), Akonolinga (0.94), Ayos (0.93), Mbalmayo (0.81) and Pont-So'o (0.73), which has the lowest value. These variations reflect differences in infiltration capacity and runoff dynamics. In the case of the Olama sub-basin, a high *Re* value suggests high infiltration capacity and low runoff, with the tendency to influence groundwater recharge. In contrast, the Pont-So'o sub-basin, with a lower value characterizing an elongated shape, is potentially more vulnerable to erosion and sediment accumulation. Bera and Barman (2022) reported that soil conservation strategies and sediment flow measures should be accorded to such elongated basins.

The circularity ratio (*R<sub>c</sub>*), defined as the ratio between the area of a catchment and the area of a circle with the same perimeter, is a key indicator of catchment morphometry (Miller 1953; Strahler 1964). The *R<sub>c</sub>* values in the study area range from 0.10 (Olama) to 0.24 (Pont So'o). These results show that the Olama sub-basin is at an early stage of development, which could indicate active erosion dynamics and high sediment transport. This indicates a greater need for soil conservation and sediment management strategies to limit erosion. In contrast, the Pont So'o sub-basin, with a higher *R<sub>c</sub>*, tends towards a more mature morphological stage. The low *R<sub>c</sub>* of the Olama sub-basin indicates a greater need for soil conservation and sediment management strategies to limit erosion. Conversely, the relatively high *R<sub>c</sub>* of the Pont So'o sub-basin suggests more stable hydrological dynamics, necessitates continuous monitoring to manage flood risks.

The Drainage density (*D*), expressed as the ratio of total stream length to catchment area, provides information on landscape segmentation and runoff potential (Ahmed et al. 2010). In the Nyong catchment, low *D* values (<6) are observed in all sub-catchments (see Table 2), ranging from 0.000128 km/km<sup>2</sup> (Ayos) to 0.0004 km/km<sup>2</sup> (Abong-Mbang), which can be attributed to factors such as low relief, permeable soils, and relatively dense vegetation cover (Tavassol and Gopalakrishna 2016). These conditions favour infiltration and reduce runoff. On the other hand, high values of *D* (>8) would indicate basins with increased risks of flooding, due to rapid runoff and limited water retention capacity (Ahmed and Bhattacharyya 2022). The

**Fig. 6** Water analysis process: **a**, **b**) water sampling, **c**, **d**) water filtration in the Laboratory



low drainage densities observed in the sub-catchments highlight a moderate to high hydrological potential, indicating favourable conditions for groundwater recharge, but requiring careful management to maintain the ecological balance. Catchments with higher densities would merit special attention to reduce flood risks.

The Drainage texture ( $R_t$ ) is defined as the ratio between the total number of stream segments and the basin perimeter. A high  $R_t$  value typically indicates steep or rugged terrain or surface conditions favouring rapid drainage, whereas a low  $R_t$  value is often associated with flat areas or basins with high infiltration capacity (Sreedevi et al. 2005). In this study, the Akonolinga sub-basin recorded the highest  $R_t$  value at 0.0037, while the Mbalmayo sub-basin exhibited a much lower  $R_t$  value of 0.00016 (see Table 2). The high  $R_t$  value observed in the Akonolinga sub-basin can be attributed to more pronounced relief features or hydrological conditions that encourage rapid drainage. Sparse vegetation or a lithology with low permeability could also explain the relatively high drainage texture in this area. These findings

suggest that the Akonolinga sub-basin may be more prone to concentrated surface runoff, which could increase the risk of soil erosion or flooding during heavy rainfall events. Conversely, the low  $R_t$  value in the Mbalmayo sub-basin indicates hydrological conditions that promote greater infiltration or the presence of dense vegetation that slows surface drainage. This could also reflect relatively flat terrain or a more permeable geology in the sub-basin. Such characteristics may contribute to more stable hydrological processes, reducing surface runoff and favouring groundwater recharge.

The coefficient of compactness ( $C_c$ ) is the ratio between the perimeter of a basin and its circumference (Horton 1945). A catchment with a compactness coefficient  $C_c$  equal to 1 has a perfectly circular shape (Horton 1932). The lower the  $C_c$ , the greater the runoff and erodibility observed. In this study, the highest  $C_c$  was observed in the Olama sub catchment (3.11), while the Pont So'o-subcatchment recorded the lowest (2.05) sub-catchments, respectively. The lower the  $C_c$ , the greater the runoff and erodibility observed in the

**Table 2** Morphometric and topo-hydrological parameters of sub-catchments

Sub-watershed	Parameters													
	Fs	Rb	Rf	Re	Rc	D	Rt	Cc	C	TWI	SPI	STI		
<i>Abong-Mbang</i>	7.97E-08	1.320833	0.753473	0.979480	0.168532	0.000400	0.000307	2.435	2498.752	13.471	7.110	36.531		
<i>Ayos</i>	1.32E-08	2.0375	0.691654	0.938439	0.185849	0.000128	0.000130	2.319	7803.455	13.552	7.0741	37.668		
<i>Akonolinga</i>	8.04E-08	2.410714	0.700599	0.944488	0.188862	0.000353	0.000373	2.301	2834.012	13.461	6.976	34.525		
<i>Mbalmayo</i>	2.49E-08	1.560714	0.522127	0.81536	0.105521	0.000186	0.000166	3.078	5384.871	13.223	7.240	37.044		
<i>Olama</i>	5.29E-08	2.690323	0.789122	1.002382	0.103338	0.000276	0.000285	3.110	3618.502	13.143	7.3186	35.976		
<i>Pont_So'o</i>	6.00E-08	2.4375	0.423339	0.734185	0.235677	0.000286	0.000298	2.0594	3497.532	13.024	7.337	35.116		

area. A catchment with a compactness coefficient (Cc) equal to 1 has a perfectly circular shape (Horton 1932).

The channel maintenance constant (C) reflects the size of the landform features (Strahler 1957). Low values of C generally higher runoff conditions and potentially reduced permeability. The Ayos sub-basin, with the highest value of C (7803.45), presents the most unfavourable conditions, while the Abong-Mbang sub-basin (2498.75) offers the most stable conditions.

The Topographic Wetness Index (TWI), a key indicator of soil moisture and runoff potential, the study reveals significant variability in TWI between the sub-catchments. The Ayos sub-basin recorded the highest value at 13.55, suggesting high humidity and runoff potential. The Ayos sub-basin is followed by the Abong-Mbang (13.47), Akonolinga (13.46), Mbalmayo (13.22), and Olama (13.14) sub-basins. Pont So'o has the lowest TWI value at 13.02, indicating a comparably dryer environment compared with the others. The high TWI values in the Ayos, Abong-Mbang, Akonolinga, and Mbalmayo sub-basins indicate areas of poor natural drainage, where water accumulation is favoured by converging topography or low-permeability soils. These conditions are often associated with dense vegetation development and increased vulnerability to flooding, as excess water rapidly saturates the soil. Conversely, the low TWI value at Pont So'o indicates a more draining topography, characterized by well-permeable soils or steep slopes that facilitate rapid water runoff. This may explain the drier soils and lower moisture accumulation in this area. Recent studies have confirmed that high TWI values are correlated with areas of increased hydrological saturation, favouring infiltration but also increasing the risk of flooding. Consequently, the Ayos, Abong-Mbang, and Akonolinga sub-basins may necessitate drainage strategies to mitigate these risks.

Studies have confirmed that high TWI values are correlated with areas of increased hydrological saturation, enhancing infiltration in certain cases, but also increasing the risk of flooding favouring infiltration but also increasing the risk of flooding (Beven and Kirkby 1979; Tarboton 1997). In light of these findings, the Ayos, Abong-Mbang, and Akonolinga sub-basins may necessitate drainage strategies to mitigate these risks.

The SPI is an important metric or evaluating rainfall intensity and accompanying potential hydrological impact. The Pont So'o sub-basin had the highest SPI value at 7.33, falling in the highest risk category. Similarly elevated values were observed in the Olama (7.32), Mbalmayo (7.24), and Abong-Mbang (7.11) sub-basins, suggesting a high risk of erosion. Conversely, lower SPI values were observed in the Akonolinga (6.97) and especially Ayos (1.07) sub-basins, indicating a reduced risk of erosion in these areas (see Table 2). The elevated SPI values at Pont So'o, Olama,

and Mbalmayo indicate regions where heavy rainfall is likely to be exacerbated by extended periods of wet weather. When coupled with the slopes and local hydrology, this increases the risk of intense erosion processes, such as gully-lying, landslides, and soil degradation. This is consistent with the findings of Nyssen et al. (2008). In contrast, the Akonolinga and Ayos sub-basins, with their relatively low SPI, suggest moderate rainfall or longer dry periods, thereby reducing the risk of erosion. These findings underscore the importance of vegetation cover and soil management practices that limit sediment losses. This research demonstrates that irregular rainfall patterns, combined with inadequate vegetation cover, intensify erosion processes, particularly in tropical regions.

It is noteworthy that sub-basins with high TWI (wetlands) do not always have the highest SPI (erosion) values. For instance, Ayos exhibits a high TWI rating despite a low SPI, which can be attributed to the presence of dense vegetation that safeguards the soil or the efficacy of soil management practices, even within a hydrologically active environment. Conversely, Pont So'o, with a low TWI but a high SPI, indicates an area where soils are drier but more susceptible to erosion, likely due to concentrated rainfall and limited soil retention capacity.

The intense erosion observed in areas such as Pont So'o and Olama is consistent with the findings of Nyssen et al. (2008), which indicate that irregular rainfall patterns, combined with insufficient vegetation cover, amplify erosion processes, particularly in tropical regions. In high TWI areas such as Ayos, the implementation of controlled drainage systems and the promotion of wetland conservation practices are crucial measures to prevent flooding while maintaining the integrity of the local ecosystem. High SPI areas (Pont So'o, Olama, Mbalmayo) should benefit from reforestation and land management programs to reduce runoff and erosion.

### Correlation matrix for morphometric and topographic-hydrological parameters

The morphometric analysis using the SWPT tool describes the strongest and most significant relationships between the morphometric and topographic-hydrographic parameters of the Nyong sub-catchments. These relationships are presented in the correlation matrix is shown in Fig. 7 while the statistically significant correlation coefficients is found in Table 3.

The results indicate a highly significant positive relationship ( $r=0.96$ ) between stream frequency (Fs) and drainage density (D). This strong relationship suggests that areas with high drainage density also have a denser hydrographic network. This finding aligns with the hypothesis that high

density promotes efficient and rapid collection of rainwater, thereby increasing the number of active watercourses per unit area. This trend is particularly evident in sub-basins such as Abong-Mbang (0.0040) and Akonolinga (0.00037), where the hydrographic density translates into a high flow frequency. This suggests that these regions possess an enhanced capacity to drain rainwater, thereby contributing to a more rapid hydrological response. This aligns with the findings of Malavoi and Bravard (2011), who demonstrated that regions with high drainage density favour efficient water evacuation, thereby reducing the risk of stagnation and promoting local hydrographic dynamics.

Furthermore, the strong positive relationship between Fs and Rt ( $r=0.99$ ) highlights the pivotal role of drainage texture in stream density. Sub-basins with high Rt have a proportionally greater drainage network density and flow frequency. This phenomenon can be attributed to the finer particle sizes of the soils or the topographic features that enhance the segmentation of the hydrographic network. In contrast, Fs demonstrates a more moderate positive correlation with the drainage power index (SPI,  $r=0.36$ ). This suggests that, while flow accumulation and local relief influence Fs, this effect is less pronounced compared to that of Rt. This can be attributed to differences in the contribution mechanisms between the hydrological parameters. Additionally, Fs demonstrates a substantial negative correlation with the channel maintenance constant (C) ( $r = -0.73$ ). A high C indicates a lower maintenance requirement for rivers, which is typical of areas with low flow frequency. This illustrates an inverse dynamic between flow frequency and drainage efficiency.

The Topographic Wetness Index (TWI) and the Slope Transport Index (STI), with correlation coefficients of  $r = -0.42$  and  $r = -0.63$  respectively, are used to measure relationship between slope, moisture, and stream activity. These negative relationships imply that areas with a high flow frequency are often less wet and have lower slopes, which may be linked to well-drained soils or relatively flat landforms.

The bifurcation ratio (Rb), which reflects the hierarchical structure and branching of the drainage network, shows no significant correlation with most morphometric parameters, except for Fs. This suggests that Rb is more influenced by local tectonic and geological processes than by general hydrological or morphometric parameters. As a result, its effectiveness in prioritizing sub-basins appears limited in this region. The form factor (Rf), a measure of drainage compactness and efficiency, is another key parameter. Rf demonstrates noteworthy associations with several morphometric parameters: Positive correlations have been observed with aspect ratio (Re,  $r=0.99$ ) and compactness coefficient (Cc,  $r=0.56$ ). These relationships indicate that sub-basins with higher compactness and elongation tend to have higher

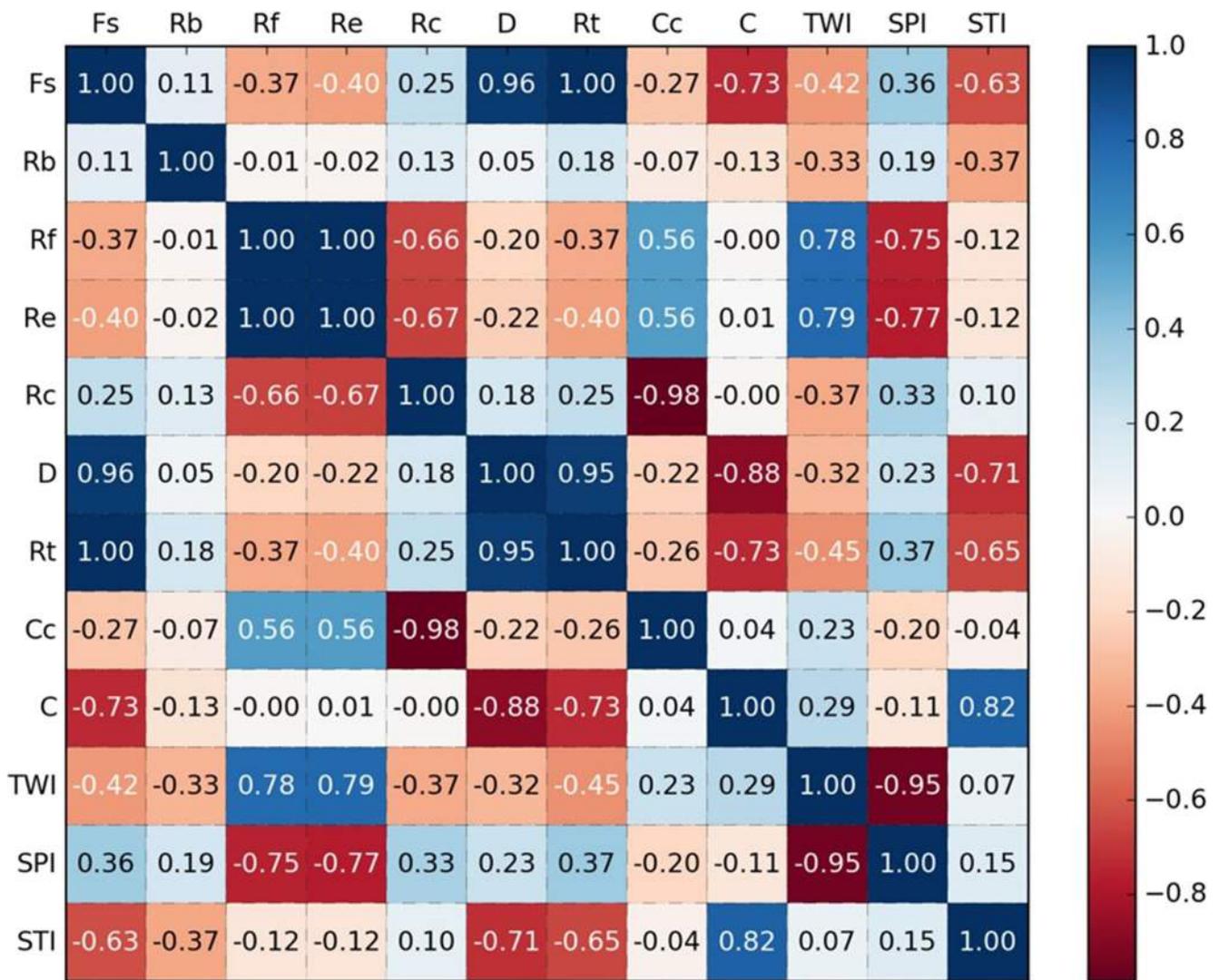


Fig. 7 Correlation matrix for morphometric and topo-hydrological parameters

Table 3 Prioritization and final ranking of sub-catchment areas

Sub-watershed	Compound parameters values	Priority ranking
Ayos	-852.99	1
Mbalmayo	-589.64	2
Olama	-396.85	3
Pont-So'o	-383.86	4
Akonolinga	-311.36	5
Abong-Mbang	-275.27	6

form factors, which suggests that they may experience faster stormwater drainage.

The findings indicate negative correlations with the circularity ratio ( $R_c$ ,  $r = -0.66$ ) and drainage density ( $D$ ,  $r = -0.20$ ). These inverse correlations suggest that high-form-factor basins tend to have less dense and less circular drainage networks. This suggests that basins with concentrated and efficient flows may be more prevalent in these areas.

Therefore, the role of  $R_f$  is central to analyzing the compactness of basins and their hydrological behaviour. These results align with those of recent studies on catchment prioritization, such as Gajbhiye et al. (2014a, b), which indicate that high-form factors are often linked to rapid hydrological responses.

The correlation results obtained reveal an in-depth understanding of the relationships between morphometric and hydrological parameters in the Nyong sub-catchments. Key indicators, such as drainage density and stream frequency, have been identified as crucial factors in assessing the hydrological response of the sub-catchments. These results underscore the necessity for a systematic prioritization of sub-basins based on their effectiveness in managing rainwater, mitigating flood risk, and promoting sustainable water resource management.

The drainage texture (Rt) is well correlated to the drainage density (D), meaning that sub-basins with a high drainage density tend to have a finer dendritic drainage texture. This correlation can be explained by the tendency of drainage networks to branch more densely to optimise the flow of surface water (Misra and Kumar 2022a, b).

Recent studies have confirmed that the relationship between drainage texture (Rt) and drainage density (D) is influenced by several hydrological and topographical parameters (Misra and Kumar 2022a, b). Additionally, a high drainage density is positively associated with the specific power index (SPI), which is an indicator of energy fluxes and erosion potential. Conversely, it shows negative correlations with factors such as channel constant (C), topographic moisture index (TWI), and sediment transport index (STI), which are more closely related to geological characteristics and soil permeability (Ravindra and Anand 2021; Choudhari et al. 2023).

The SPI (specific power index) is strongly and negatively correlated with the TWI (topographic moisture index), with a coefficient  $r = -0.95$ . This relationship indicates that sub-catchments with a high TWI generally have more stable soils that are less susceptible to erosion by runoff. This phenomenon can be attributed to the prevalence of dense vegetation cover and cohesive soil in wetlands, which mitigate the impact of runoff forces (Ravindra and Anand 2021). Conversely, a low TWI often corresponds to soils with increased vulnerability to erosion. Additionally, while the TWI demonstrates a negative correlation with Fs, D, Rt, and SPI, it exhibits a notable positive correlation with morphometric indices such as aspect ratio (Rf) and aspect ratio (Re).

### Automated prioritization of sub-catchments

The prioritization of sub-catchments is based on the estimation of composite parameter values (CPV), which result from the weighting of different morphometric and topographic parameters obtained in Table 2 (Aher et al. 2014; Ghernaout et al. 2020). Sub-basins with low CPV are identified as the most exposed to erosion risks, while those with high CPV are considered less vulnerable. The composite parameter values (CPV) calculated for the sub-catchments (Sbv) enable for a classification of these sub-basins based on their vulnerability to erosion (Table 4). The results indicate substantial variation in CPV among the sub-catchments. The Ayos sub-catchment has the lowest CPV (-852.99), indicating its highest vulnerability; the Mbalmayo sub-catchment ranks second with a CPV of -589.64; and the Olama sub-catchment ranks third with a CPV of -396. The Pont So’o sub-catchment has a moderate CPV (-383.86) and ranks fourth, while the Akonolinga sub-catchment is ranked fifth with a CPV of -311.36. The Abong-Mbang sub-catchment has the highest CPV (-275.27), placing it as the least vulnerable among the sub-basins.

The CPV rankings provide a clear structure for identifying sub-catchments in need of immediate soil conservation measures. For instance, the Ayos sub-basin, which has the lowest CPV, should be the priority for implementing erosion mitigation strategies. Conversely, Abong-Mbang, with the highest CPV, appears to be the least at risk and may not require immediate intervention. However, it is important to acknowledge that CPV alone does not provide a comprehensive assessment of erosion risk. To strengthen these findings, the study also considered the concentration of

**Table 4** Results of suspended solids sampling analysis of sub-catchment areas

Date	SS (mg/l)					
	Olama	Mbalmayo	Pont So’o	Akonolinga	Ayos	Abong-Mbang
2024-01-05	6.7	6	4.1	8.4	22.07	4.53
2024-01-19	7.81	14.27	4.8	7.31	23.6	3.4
2024-02-08	11	20	10.83	6.32	22.23	2.8
2024-02-21	8	19.3	13.21	6.23	21.03	1.5
2024-03-14	7	14.3	7.6	5.3	18.46	1.4
2024-03-28	3	10	13.6	5.15	15.9	1.45
2024-04-04	0.6	11	5.8	7.01	15.55	3.57
2024-04-11	6.8	12	17.5	6.1	14.85	1.84
2024-05-02	8.5	9	8.11	6.52	15.43	3.93
2024-05-16	6.3	31.9	11.6	6.35	16.039	2.93
2024-06-05	5	10.6	18.4	6.2	21.6	0.2
2024-06-19	6	11.6	9.61	5.8	18.58	2.4
2024-07-03	7.4	14.53	8.8	5.55	18.11	2
2024-07-17	5.3	18	13.74	4.1	10.2	7.4
2024-08-09	4.8	16.3	10.4	-	-	-
2024-08-23	5.7	9	3.2	-	-	-
<b>Average</b>	<b>6.24</b>	<b>14.24</b>	<b>10.1</b>	<b>6.17</b>	<b>18.12</b>	<b>2.81</b>

**Table 5** Prioritization and final ranking of sub-catchment areas

Sub-watershed	Compound parameters values (-)	SS value (mg/l)	Priority ranking
Ayos	-852.99	18.12	1
Mbalmayo	-589.64	14.24	2
Olama	-396.85	6.24	3
Pont-So'o	-383.86	10.1	4
Akonolinga	-311.36	6.17	5
Abong-Mbang	-275.27	2.81	6

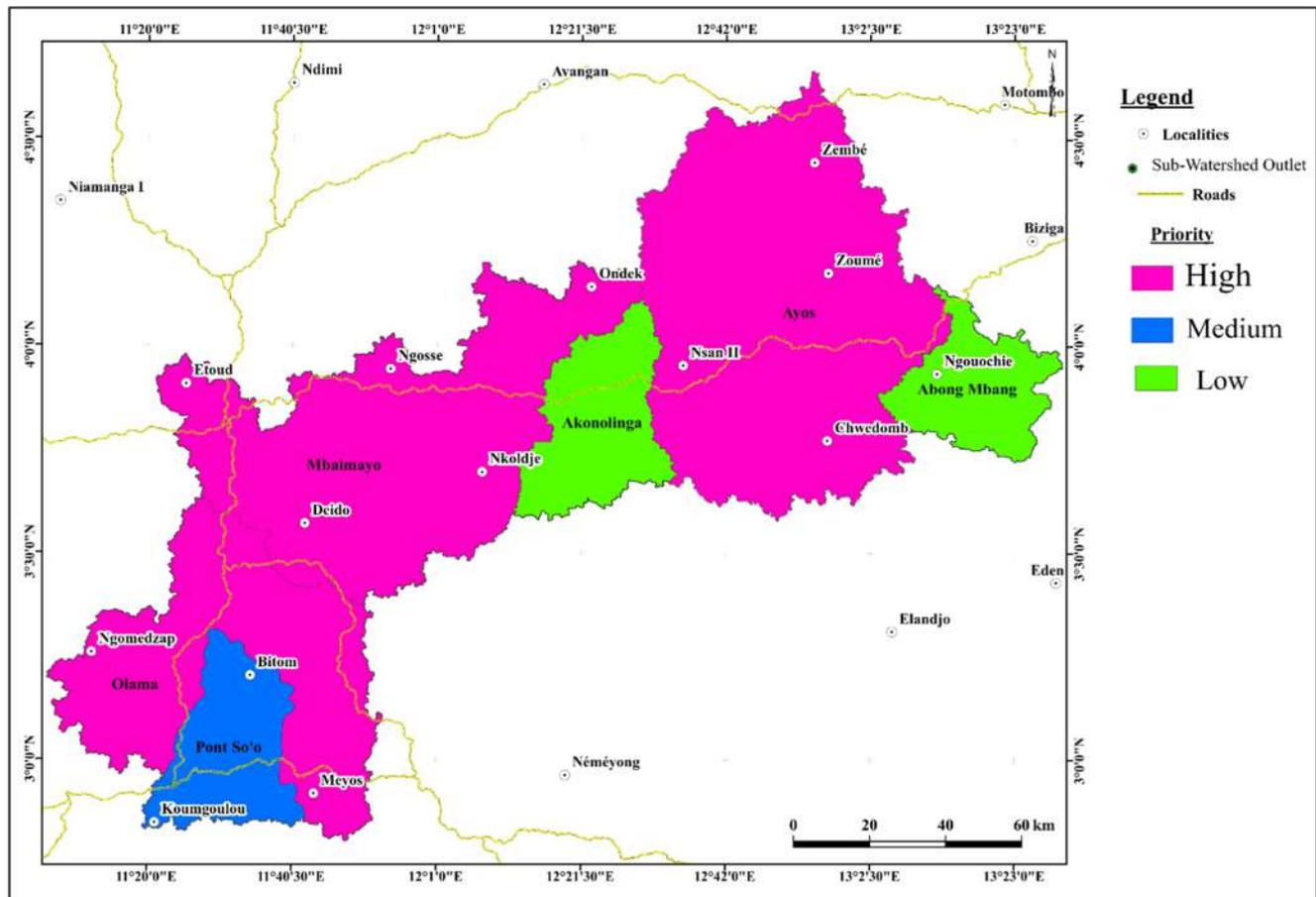
suspended solids (SS), which additionally corroborates the prioritization based on CPV.

**Solid matter content**

The Suspended Solid (SS) concentrations measured in the sub-catchments over the eight months provide another key indicator of erosion risk (Table 5). The SS results are as follows: the Ayos sub-catchment recorded the highest average SS concentration (18.12 mg/L), suggesting significant sediment transport. The Mbalmayo sub-catchment ranks

second in terms of average SS concentration, with a value of 14.24 mg/L, and the Pont So'o sub-catchment, despite a moderate CPV, has the third-highest average SS concentration (10.1 mg/L). The Olama sub-catchment follows with an average SS concentration of 6.24 mg/L, followed by the Akonolinga sub-catchment, which exhibits a relatively low SS concentration (6.17 mg/L). Finally, the Abong-Mbang sub-catchment has the lowest average SS concentration (2.81 mg/L), indicating minimal sediment transport in this sub-basin (Fig. 8).

The SS concentration results generally correlate with the CPV rankings, with the Ayos sub-catchment exhibiting both the lowest CPV and the highest SS concentration. This validates its high susceptibility to erosion. Similarly, Abong-Mbang, which is classed as least vulnerable due to its high CPV, shows the lowest SS concentration, reflecting minimal erosion processes. However, there are notable exceptions, particularly in the Pont So'o sub-catchment, which has a moderate CPV but a relatively high SS concentration. This discrepancy suggests that additional environmental factors, such as localized land-use changes or climatic variations, may be influencing sediment transport in this sub-catchment.



**Fig. 8** Priority ranking of Nyong sub-catchments

## Combined analysis of CPV and SS concentrations

The prioritization and final ranking of sub-catchments are presented in Fig. 8. When combining the CPV and SS results, a general pattern emerges between low CPV and high SS concentrations, which is consistent with theoretical expectations for erosion-prone basins (Choudhari et al. 2023; Misra and Kumar 2022a, b). However, exceptions, such as the Pont So'o and Olama sub-catchments, indicate that the correlation is not absolute. The Ayos sub-catchment is particularly noteworthy, as it exhibits both the lowest CPV and the highest SS concentration, confirming its extreme vulnerability to erosion. The Pont So'o sub-catchment, despite a moderate CPV, exhibits a high SS concentration, potentially attributable to localised disturbances such as land-use changes or climatic variability. In contrast, the Olama sub-catchment demonstrates the opposite trend, with a moderate CPV but a relatively low SS concentration, suggesting that factors like enhanced vegetation cover or improved soil structure may be mitigating sediment transport in this sub-basin.

The integrated CPV and SS results provided a nuanced understanding of erosion risk across the Nyong sub-catchments. While there is a clear correlation between low CPV and high SS concentration in most cases, exceptions such as Pont So'o highlighted the need for further investigation into local environmental conditions. The prioritization process highlighted the importance of targeted conservation interventions in the Ayos, Mbalmayo, and Olama sub-catchments. For Ayos and Mbalmayo, soil conservation measures such as reforestation, erosion barriers, and control of human activities are essential. In contrast, a detailed study of the hydrological and climatic factors contributing to the high SS concentration in Pont So'o is required to identify appropriate mitigation strategies. The final prioritization result of the Nyong basin's sub-watersheds, based on morphometric and topohydrographic parameters, is illustrated in Fig. 8. The results demonstrated that while CPV provides a robust tool for prioritizing erosion risk, integrating SS concentrations offers additional insight into sediment transport dynamics. While a strong correlation exists between the indicators, it is crucial to consider site-specific factors when interpreting deviations. These findings underscore the necessity for integrated watershed management strategies tailored to the specific vulnerabilities of each sub-basin. While this study is the first to prioritize the watersheds in the Nyong basin, the methodology has been successfully applied in other regions, yielding similar results. Thus, the reliability of the results obtained from this methodology in the Nyong sub-watershed is attested by previous studies on watershed vulnerability to erosion. Indeed, Dzwayiro et al. (2025) previously emphasized the role of drainage density and form factor in characterizing erosion susceptibility in

South Africa's Rietspruit basin, supporting the relevance of these indicators in the Nyong context. Furthermore, the correlation observed between composite parameter values (CPV) and suspended solids (SS) in the Nyong basin echoes the findings of Attoubounou et al. (2025) in the Mékrou watershed and Terefe et al. (2024) in the Ayu watershed in Ethiopia, where spatial variability in erosion was quantified using RUSLE and remote sensing. The prioritization approach adopted in this study is consistent with that of Inyele (2024), who combined morphometric analysis and NDVI to rank sub-watersheds by erosion risk in Kenya and Ahmad (2018), who identified 21.71% of the Gumara watershed in Ethiopia as severely eroded using integrated GIS-based thematic layers. Collectively, these comparisons reinforce the methodological robustness of the Nyong basin analysis and its strategic value for guiding conservation interventions in tropical environments. The application of this tool in the Nyong forest watershed in Cameroon, a region with high vegetation cover and limited data, confirms its potential for adaptation to watersheds in Central Africa.

## Limitations and uncertainties

The methodology adopted throughout this study requires control of both the data quality and the modeling tools to ensure the reliability of the results. Indeed, despite the robustness of the morphometric approach and GIS-based prioritization, some limitations and uncertainties must be acknowledged. Regarding the DEM resolution and accuracy, the analysis relies on freely available Shuttle Radar Topography Mission (SRTM) DEM data at 90 m spatial resolution. While adequate for regional-scale assessments, this resolution may not capture fine-scale topographic variations such as micro-slopes, gullies, or anthropogenic features (e.g., terraces, drainage channels) that significantly influence localized erosion (Li et al. 2021; Kariminejad et al. 2024; Meadows et al. 2024). In addition, error in elevation due to canopy cover in this forested Nyong sub-watersheds could affect the accuracy of stream network extraction and relief parameters. Regarding the parameter weighting and prioritization method, various techniques such as assignment of weights using the weighted sum analysis (WSA), compound factor analysis or AHP, principal component analysis (PCA), or multi-criteria decision-making (MCDM), can be used (Ojha et al. 2023). However, these approaches introduce assumptions and degrees of subjectivity that may affect final rankings; thus, each method may yield slightly different prioritization of sub-watersheds. For sediment yield (SS) sampling, spatio-temporal variability could constrain the accuracy of obtained results (Duvert et al. 2011). Where SS records are used for comparison, the temporal variability of sampling (seasonal coverage),

the short monitoring periods or sampling can represent a source of uncertainty (Hirschberg et al. 2022) especially for sub-basins impacted by enthronezation. Therefore, future research should integrate high-resolution field data and longer-term monitoring of SS concentrations. Additionally, extending the application of the SWPT tool to other Central African watersheds would help validate its robustness in tropical environments and support regional-scale watershed management initiatives.

## Conclusion

The study aimed to prioritize the sub-catchments of the Nyong catchment for erosion risk management. To this end, analysis of morphometric and topo-hydrologic parameters was conducted using the SWPT tool after delimitation of the six sub-watersheds by the SRTM, accompanied with field measurement of Total Suspended Solids (SS). Key morphometric indicators such as the compactness index, drainage density, and form factor were calculated. The compactness index ranged from 2,498.7 in Abong-Mbang to 7,803.5 in Ayos, while drainage density values varied from 0.00018 to 0.00040. Based on these parameters, composite parameter values (CPVs) were computed to classify the sub-watersheds according to their erosion susceptibility. These sub-watersheds were classified on the basis of the values of the composite parameters. Sub-catchments with low CPVs— notably Ayos (−852.99), Mbalmayo (−589.60), and Olama (−396.86), indicated that the Ayos, Mbalmayo, and Olama sub-basins are the most vulnerable, as evidenced by their low CPV values. These findings were strengthened by suspended solid (SS) concentrations identified during field sampling, which showed correspondingly high values of 18.12 mg/L, 14.24 mg/L, and 6.24 mg/L, respectively. These sub-catchments are therefore identified as priority areas for erosion control. Given the ongoing hydroelectric dam projects in the Nyong catchment, the development and implementation of sustainable soil conservation strategies such as reforestation erosion control practices, strategic reforestation, creation of riparian buffer zones and community-based erosion control programs is essential to protect water resources and infrastructure from erosion-related impacts.

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**Data availability** No datasets were generated or analysed during the current study.

## Declarations

**Informed consent** The manuscript was written with the consent and inputs of all the authors.

**Conflict of interest** The authors declare that there is no competing interest while conducting this research.

**Competing interests** The authors declare no competing interests.

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