Received: 25.05.2026| Accepted: 29.06.2026 |Published: 02.07.2026

Citations: Abraham, M.C. et al (2026) Differences in morphometric parameters across the various segments of the Cross River Basin GAIJASSVol.2.1.2026 pp 17-28. https://globreshub.org/index.php/gaijass/article/view/63 **DOI:** https://doi.org/10.5281/zenodo.21577682

DIFFERENCES IN MORPHOMETRIC PARAMETERS ACROSS THE VARIOUS SEGMENTS OF THE CROSS RIVER BASIN

[1]Comfort Monday ABRAHAM, [2]Ekong Sunday EBUKANSON, [3]Akan Abel TOM

[1]Department of Geography and Natural Resources Management, University of Uyo, Uyo, Nigeria, ***[2] University of Uyo Teaching Hospital, Uyo, Nigeria,*** *[3]Department of Geography and Regional Planning, Igbinedion University Okada, Edo State, Nigeria*

[1]comfortabraham@uniuyo.edu.ng,[2]ekongebukanson5@gmail.com[3]akan.tom@iuokada.edu.ng

Abstract

Although a drainage basin is often described by a single set of whole-basin parameters, its component segments, or sub-basins, can differ substantially in morphometric character, with direct consequences for how hydrologic hazard is distributed across the catchment. This study examines the differences in morphometric parameters across the seventeen third-order sub-basins, or segments, of the Cross River Basin (CRB), a transboundary catchment of approximately 51,892 km² in southeastern Nigeria and western Cameroon. Descriptive variability statistics (mean, standard deviation and coefficient of variation) and paired t-tests were applied to linear and areal parameters extracted from a 2020 ASTER Digital Elevation Model. Results show that the seventeen segments differ most sharply in size-related parameters, with basin area exhibiting a coefficient of variation (CV) of 53.6%, total stream length 49.2%, and number of streams 48.5%, the largest segment (4,769.49 km²) exceeding the smallest (826.94 km²) by a factor of nearly six. Shape-related parameters occupy an intermediate position (CV between 19% and 36%), while drainage density (CV = 11.4%) and length of overland flow (CV = 10.7%) are comparatively uniform across segments. A paired t-test comparing first-order and second-order mean stream length across the seventeen segments returned statistically significant difference ($t = 3.66$, $p = 0.002$), while a paired t-test comparing first-to-second-order and second-to-third-order bifurcation ratios did not reach significance ($t = 1.69$, $p = 0.111$). On the strength of this evidence, the null hypothesis of no significant difference in the morphometric parameters of the Cross River Basin's segments is rejected. The findings demonstrate that the CRB is morphometrically heterogeneous at the sub-basin scale, most markedly in size and network complexity and least markedly in drainage density, a pattern with direct implications for how the basin's hydrologic response and flood risk should be assessed and managed on a segment-by-segment rather than whole-basin basis.

Keywords

Keywords: sub-basin differences; coefficient of variation; paired t-test; morphometric variability; Cross River Basin; segment analysis

*Corresponding author(s) agree that this article remain permanently open access under the terms of the Creative Commons Attribution License 4.0 International License

1. INTRODUCTION

It is a well-established principle in fluvial geomorphology that different segments of the same river system frequently exhibit markedly different morphometric and hydrologic characteristics, a hierarchical organisation of particular interest to physical geographers concerned with basin-scale hazard management (Hagget & Chorley, 1972). A basin described only by its whole-basin parameters, however precisely measured, can conceal substantial internal heterogeneity: two segments of identical area may differ several-fold in drainage density, bifurcation ratio or shape, with correspondingly different implications for how each segment concentrates or attenuates storm runoff (Udosen, Ubom, Etuk & Okoroji, 2021). Detecting and quantifying this internal, segment-level heterogeneity is therefore a necessary complement to whole-basin morphometric description, and is the specific concern of this study. The literature on watershed prioritisation, which ranks sub-basins for targeted soil-conservation or flood-management investment, is built entirely on the premise that meaningful morphometric differences exist among a basin's component segments; if no such differences existed, prioritisation would be meaningless (Shaikh, Yadav & Manekar, 2022). Kandekar, Gavit, Atre, Bansod and Ninbalkar (2021) demonstrated this directly for a set of Indian watersheds, in which sub-watershed prioritisation for natural resource management depended on statistically significant differences in bifurcation ratio, drainage density and drainage texture among the component units of an otherwise contiguous catchment. Similarly, the compound-factor flood-vulnerability classification of the upper Cross River basin by Ogarekpe, Obio, Tenebe, Emenike and Nnaji (2020) implicitly assumed, and its results confirmed, that the UCRB's sub-basins differed sufficiently in their morphometric parameters to justify classification into high, moderate and low flood-vulnerability zones.

Despite this, no published study to the best of my knowledge, has formally tested the statistical significance of morphometric differences among the full complement of third-order segments of the Cross River Basin. Existing work has either described individual sub-basins in isolation (Eze & Efiong, 2010) or classified upper-basin sub-basins by flood vulnerability without separately establishing, through formal variability or difference statistics, how much the underlying morphometric parameters themselves differ from one segment to the next (Ogarekpe *et al*., 2020). This study aims to addresses this gap directly by examining the differences in morphometric parameters across the various segments of the Cross River Basin, quantification to ascertain the extent to which the seventeen third-order sub-basins of the CRB differ from one another in their linear and areal morphometric parameters. Quantifying the degree and pattern of morphometric difference among CRB segments provides the statistical justification required before any sub-basin-level prioritisation, whether for flood management, soil conservation, or infrastructure planning, can be undertaken with confidence. Where differences are shown to be statistically significant, segment-specific management is justified; where a parameter shows little variation, uniform, basin-wide management approaches may be more appropriate for that particular characteristic.

2. LITERATURE REVIEW

Sub-Basin Heterogeneity as a Basis for Watershed Prioritisation

The entire watershed-prioritisation literature rests on the empirical observation that sub-basins of a common parent catchment differ measurably in their morphometric character. Kandekar *et al.* (2021) applied morphometric prioritisation to Indian watersheds precisely because bifurcation ratio, drainage density and drainage texture varied enough among sub-watersheds to support a meaningful ranking for natural-resource management; without such variability, compound-factor and similar prioritisation methods would return uniform, uninformative rankings. Shaikh, Yadav and Manekar (2022) formalised this logic in their application of the compound-factor method to the Rel basin of Gujarat, ranking five sub-watersheds on runoff potential using twenty-one parameters whose sub-watershed-to-sub-watershed variability was the entire basis of the resulting prioritisation.

Measuring Morphometric Variability: Coefficient of Variation

The coefficient of variation (CV), the ratio of the standard deviation to the mean expressed as a percentage, is the standard descriptive measure of relative variability across a set of comparable spatial units, since it allows variability to be compared across parameters measured on very different scales (for example, basin area in km² against a dimensionless ratio such as circularity). A comprehensive review of watershed morphometric methods notes that CV is now routinely reported alongside mean parameter values in sub-watershed comparison studies specifically because it identifies which parameters are the primary sources of inter-basin heterogeneity, information that is otherwise lost when only basin-wide means are reported (Morphometric analysis of watersheds review, 2023).

Differences in Size, Shape and Network Parameters across Basin Segments

Size-related parameters are consistently reported as the most variable across sub-basins of a common parent catchment, since sub-basin delineation by definition partitions a basin into unequal-sized units, whereas process-related parameters such as drainage density, which are governed more by regional climate and lithology than by the accident of where a sub-basin boundary happens to fall, tend to vary considerably less. The comprehensive geospatial assessment of five contrasting Mexican basins found exactly this pattern, with basin area and stream number varying far more across the basins studied than drainage density, which remained comparatively stable within each climatic-lithological zone (Comprehensive geospatial assessment, Mexican basins, 2025). A similar pattern was reported by Andriopoulou-Mounteanou, Skilodimou and Bathrellos (2025) in their comparison of an active and an abandoned channel segment of the same river system, where drainage density differed by a factor of nearly two between the two segments despite both belonging to the same parent basin, illustrating that even process-related parameters can differ sharply where segments have experienced genuinely different hydrogeomorphic histories.

Statistical Testing of Paired Differences

Where morphometric parameters are measured as paired observations on the same set of spatial units, for example, comparing first-order against second-order stream length for each of several sub-basins, the paired t-test is the appropriate statistical technique for testing whether the two related measurements differ significantly, since it accounts for the correlation between paired observations that an independent-samples test would ignore (Joshi, Pankaj & Purabi, 2021). This approach has been applied in morphometric contexts to test whether stream-length ratios or bifurcation ratios differ systematically between successive stream orders within the same set of basins, providing a formal statistical basis for claims about network development that are often made only descriptively elsewhere in the literature.

Segment Heterogeneity in Comparable Tropical and Sub-Tropical Basins

Beyond the Nigerian context, segment-level heterogeneity has been documented as a near-universal feature of large tropical and sub-tropical basins once they are examined below the whole-basin scale. In an assessment of the upper Jhelum basin, sub-basin-level flood-hazard classification depended on morphometric parameters that varied enough among sub-basins to separate them into distinct hazard classes, with drainage density and relief-related parameters identified as the principal sources of that variation (Bhat, Alam, Ahmad, Farooq & Ahmad, 2019). This finding, that some parameter families vary far more than others across sub-basins of the same parent catchment, mirrors the pattern anticipated for the Cross River Basin in this study and tested formally in the results that follow, and it underlines that segment-level heterogeneity is not a peculiarity of any one climatic zone but a structural feature of large basins generally, arising from the simple fact that no basin's geology, relief and drainage development are perfectly uniform across its full areal extent.

3. STUDY AREA

Location

The Cross River Basin (CRB) is located in southeastern Nigeria and western Cameroon. The Cross River originates from Wabane in the upper Banyang sub-division of the South-West Region of Cameroon, flows through Nigeria, and drains into the Atlantic Ocean, making it a transnational basin. The CRB covers an area of approximately 53,590 km² (Folorunsho & Awosika, 2014), lying between longitudes 07° 00′ 55″ E and 010° 15′ 00″ E, and between latitudes 04° 20′ 00″ N and 07° 15′ 00″ N. The basin cuts across Cross River, Akwa Ibom, Abia, Ebonyi, Enugu, Benue and Taraba States in Nigeria, and the South-West Region of the Republic of Cameroon. As a hydrological rather than an administrative unit, the CRB does not conform to the boundaries of the Cross River Basin Development Authority, since hydrological processes obey drainage divides rather than political boundaries, and conditions in upstream segments of the basin directly affect downstream reaches.

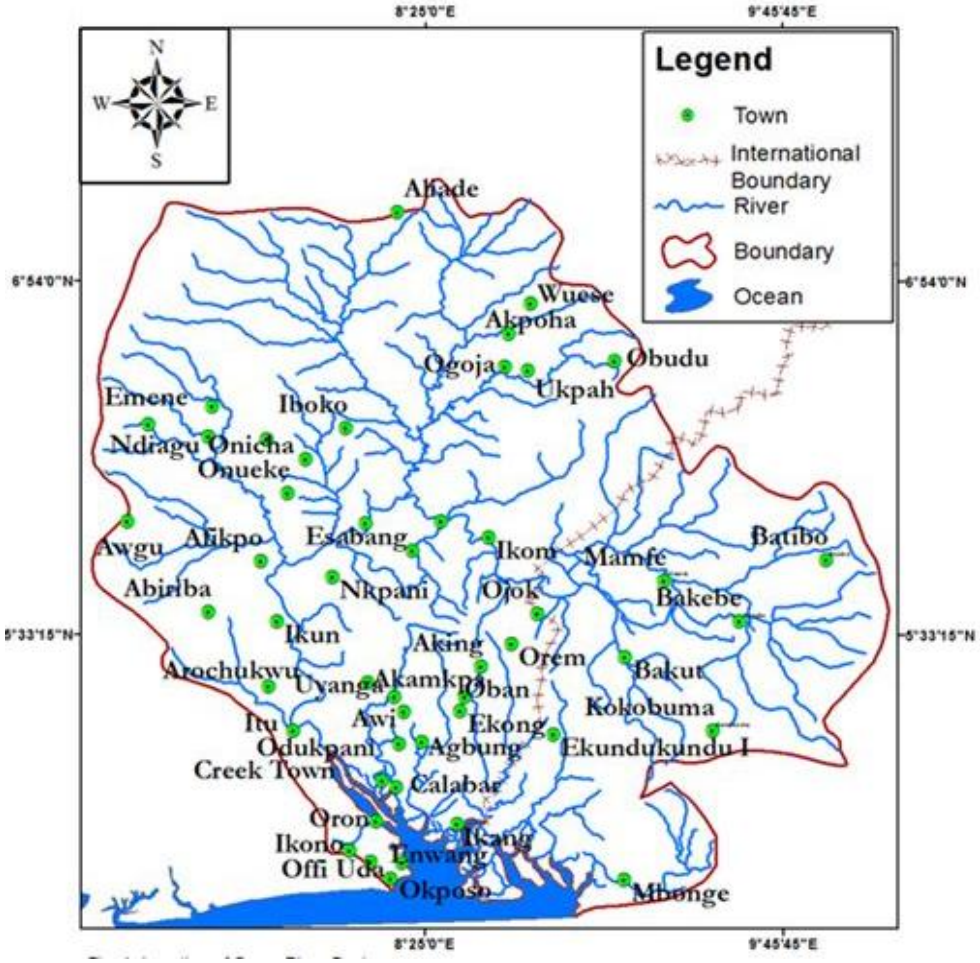

Figure 1: Location of the Cross River Basin
Source: GIS/Cartography Unit, Dept. of Geography, University of Uyo

Drainage, Geology and Climate

The Cross River, known locally as the Oyono, takes its course from Cameroon, where it is known as the Manyu River, before entering Nigeria. Over its last 80 km to the sea it traverses swampy rainforest, forming an inland delta near its confluence with the Calabar River before draining into a broad Atlantic estuary approximately 24 km wide. Geologically, the upper CRB comprises Precambrian basement complex and Phanerozoic sedimentary formations, with hard rock formations, including volcanic, basement complex and igneous units, dominating to the east toward Cameroon, and gently dipping Cretaceous-to-Tertiary sedimentary formations dominating to the west (Murat, 1972; Petters, Nyong, Akpan & Essien, 1995; Ekwueme, 1990, 1995). The lower CRB belongs to the Precambrian rocks of the Oban Massif, the Cretaceous sediments of the Calabar Flank, and the

Niger Delta sedimentary basin. The watershed experiences a tropical wet-and-dry climate, with a wet season from April to October receiving between 2,000 and 3,000 mm of rainfall annually and exhibiting two distinct peaks in June/July and September/October separated by the short 'August break', and a dry season from November to March (National Bureau of Statistics, 2011). This pronounced seasonality, combined with the mixed hard-rock and sedimentary geology described above, is a first-order control on the basin's runoff regime and is referred to repeatedly in the discussion of results that follows.

4. MATERIALS AND METHODS

Data Types and Sources

The study employed continuous and discrete quantitative secondary data. Morphometric parameters were extracted from a 10 m resolution 2020 ASTER Digital Elevation Model (DEM) of the catchment, obtained from the United States Geological Survey (USGS) website, supplemented by topographic map sheets of the study area obtained from the Office of the Surveyor-General of Cross River State and geospatial consortium web resources.

Sampling and Basin Delineation

A stratified random sampling approach was adopted, with the entire Cross River Basin demarcated into third-order sub-basins for comparative data collection and analysis, a spatial structuring adopted both for the convenience of handling the vastness of the study area and for enabling like-for-like comparison between segments. Seventeen third-order sub-basins were delineated across the CRB and formed the unit of comparison throughout this study.

Procedure for Data Extraction

Basin area, perimeter, stream length and related parameters were extracted from the DEM in ArcGIS 10.7 using the Hydrology toolset of the Spatial Analyst extension. The DEM was first depression-filled using the Fill tool, after which flow direction and flow accumulation were computed, with a threshold value of 50 applied via the Raster Calculator to define the stream network. Stream ordering followed the Strahler (1964) method, and the resulting raster stream network was converted to vector format using the Stream to Feature function. The topographic base map was digitized, projected to the Universal Transverse Mercator (UTM) system on the Minna Datum, UTM Zone 32N, WGS 1984 spheroid, at a pixel resolution of 30 m.

Table 1: Morphometric parameters, formulae and sources

Feature	Parameter	Formula / Basis	Reference
Areal	Basin Area (A)	GIS boundary delineation (km²)	Strahler (1964)
Areal	Basin Perimeter (P)	GIS boundary length (km)	Schumm (1956)
Areal	Basin Length (Lb)	Straight-line distance, mouth to farthest point	Schumm (1956)
Areal	Form Factor (Ff)	$Ff = A / Lb^2$	Horton (1945)
Areal	Elongation Ratio (Re)	$Re = \sqrt{(A/\pi)} / Lb$	Schumm (1956)
Areal	Circularity Ratio (Rc)	$Rc = 4\pi A / P^2$	Miller (1953)
Areal	Drainage Density (Dd)	$Dd = L\mu / A$ (km/km²)	Horton (1945)
Areal	Stream Frequency (Fs)	$Fs = N\mu / A$ (km^{-2})	Horton (1945)
Areal	Lemniscate Ratio (K)	$K = Lb^2 / 4A$	Schumm (1956)
Areal	Constant of Channel Maint. (C)	C = 1/Dd	Horton (1945)
Areal	Drainage Texture (Rt)	$Rt = N\mu / P$	Horton (1945); Smith (1950)
Areal	Infiltration Number (If)	If = Dd × Fs	Faniran (1968)
Linear	Bifurcation Ratio (Rb)	$Rb = N\mu / N\mu_{+1}$	Schumm (1956)

Feature	Parameter	Formula / Basis	Reference
Linear	Mean Stream Length (Lsm)	Lsm = Lμ / Nμ	Strahler (1964)
Linear	Length of Overland Flow (Lg)	Lg = 1 / 2Dd	Horton (1945)
Relief	Basin Relief (H)	H = Z (max elevation) − z (min elevation)	Hadley & Schumm (1961)
Relief	Relief Ratio (Rr)	Rr = H / Lb	Schumm (1963)
Relief	Ruggedness Number (Rn)	Rn = H × Dd	Schumm (1963)

Source: Compiled from Strahler (1964), Schumm (1956, 1963), Horton (1945), Miller (1953), Hadley & Schumm (1961), Smith (1950) and Faniran (1968).

Techniques of Data Analysis

Two complementary statistical approaches were used to examine if there is significant difference in the morphometric parameters of the Cross River Basin's sub-basins. First, descriptive variability statistics, the mean, standard deviation and coefficient of variation (CV = standard deviation / mean × 100), were computed for thirteen linear and areal parameters across the seventeen third-order sub-basins, providing a continuous measure of how much each parameter varies from one segment to the next. Second, the paired t-test was applied to two sets of related within-sub-basin measurements: mean stream length of first-order against second-order streams, and bifurcation ratio between the first-and-second orders against bifurcation ratio between the second-and-third orders, in each case treating the seventeen sub-basins as matched pairs. The paired t-test statistics are computed as: $t = \bar{d} / (sd / \sqrt{n})$. where $\bar{d}$ is the mean of the seventeen paired differences, sd is the standard deviation of those differences, and n is the number of paired sub-basins (17), with the resulting t-statistic compared against the critical value at 16 degrees of freedom ($\alpha = 0.05$, two-tailed) to determine statistical significance. This technique was selected, following the approach adopted in the original CRB field investigation, because the hypothesis under test concerns the difference between two related measurements taken on the same set of sub-basins, rather than a comparison between two independent, unrelated samples.

5. RESULTS AND DISCUSSION

5.1 Overall Variability Across the Seventeen Segments

Table 2 presents the descriptive variability statistics for thirteen linear and areal parameters across the seventeen third-order segments of the Cross River Basin. Coefficients of variation range from a high of 53.6% for basin area to a low of 10.7% for length of overland flow, a nearly five-fold difference in relative variability that itself demonstrates the segments differ far more in some respects than in others.

Table 2: Descriptive statistics and coefficient of variation of morphometric parameters across the 17 segments

Parameter	Mean	Std. Dev.	Min	Max	CV (%)	Variability Class
Basin area (km²)	1,864.03	998.46	826.94	4,769.49	53.6	High
Total stream length (km)	221.87	109.22	85.09	508.01	49.2	High
Number of streams	15.06	7.31	9	34	48.5	High
Elongation ratio	0.47	0.17	0.28	0.94	35.8	Moderate
Mean bifurcation ratio	2.02	0.62	1.50	3.60	30.5	Moderate
Form factor	0.43	0.13	0.26	0.75	29.8	Moderate
Basin length (km)	66.03	18.14	37.76	99.67	27.5	Moderate
Basin perimeter (km)	242.41	65.41	153	380	27.0	Moderate
Lemniscate ratio	0.63	0.17	0.33	0.95	26.9	Moderate
Drainage texture	0.06	0.01	0.05	0.09	20.9	Low-moderate
Circularity ratio	0.39	0.08	0.22	0.49	19.2	Low-moderate

Parameter	Mean	Std. Dev.	Min	Max	CV (%)	Variability Class
Drainage density (km⁻¹)	0.12	0.01	0.10	0.15	11.4	Low
Length of overland flow	8.39	0.90	6.67	10.00	10.7	Low

Source: Author's computation from extracted sub-basin morphometric data, 2026. Variability classed as High (CV > 40%), Moderate (20-40%), Low (< 20%) following conventional CV thresholds used in watershed comparison studies.

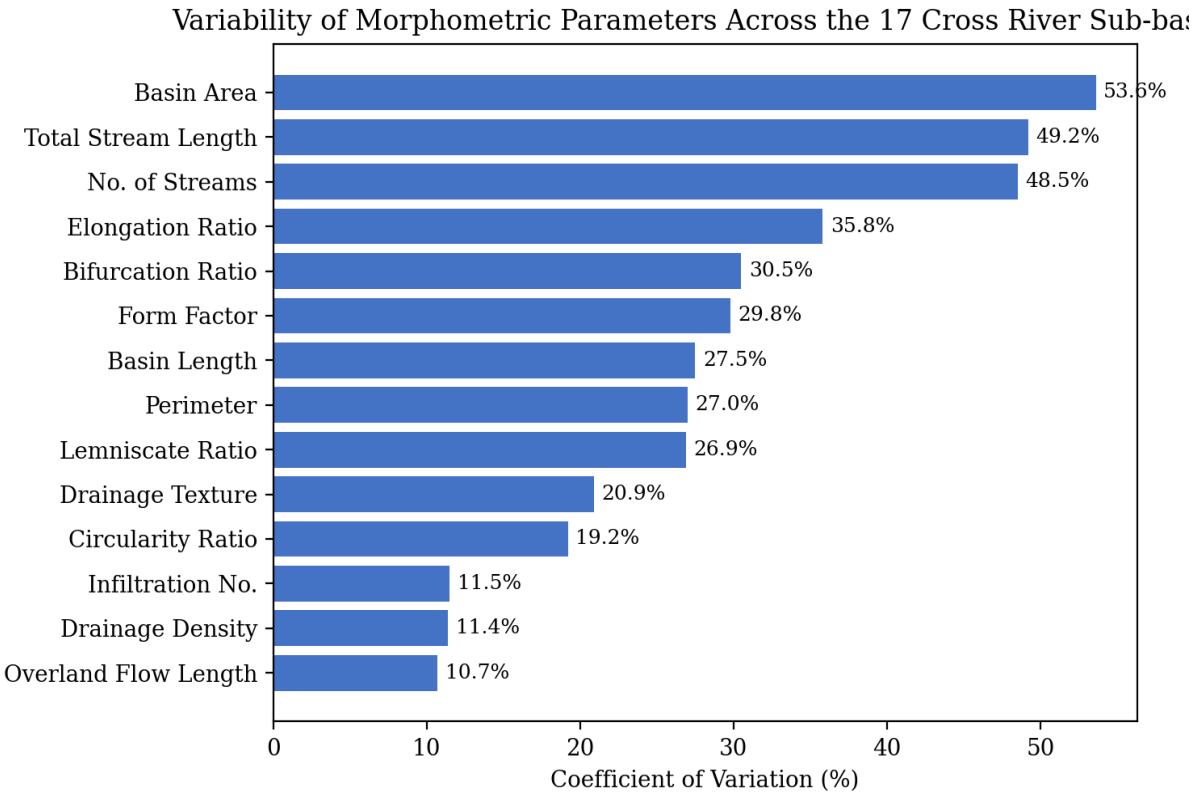

Figure 2: Coefficient of Variation of Morphometric Parameters Across the 17 Cross River Segments Source: Author's computation, 2026

5.2 Size-Related Parameters: The Greatest Source of Difference

Basin area, total stream length and number of streams form a distinct high-variability group (CV 48.5–53.6%), confirming for the CRB the general pattern reported for the five Mexican basins, in which size-related parameters varied far more sharply across sub-basins than process-related ones (Comprehensive geospatial assessment, Mexican basins, 2025). The largest segment in the CRB dataset, segment 3, covers 4,769.49 km², while the smallest, segment 14, covers only 826.94 km², a difference of 3,942.55 km², or a factor of 5.77. This scale of difference is not an artefact of arbitrary sub-basin delineation: because all seventeen segments were delineated at the same, third-order level using an identical stream-ordering threshold, the near six-fold range in area reflects genuine differences in how far upstream, and across how much terrain, the third-order threshold is reached in different parts of the CRB's drainage network, itself a function of underlying relief and lithological differences between the sedimentary lower basin and the harder headwater terrain in Cameroon.

5.3 Shape and Network-Structure Parameters: Moderate Difference

Elongation ratio (CV = 35.8%), mean bifurcation ratio (CV = 30.5%) and form factor (CV = 29.8%) occupy an intermediate position, differing appreciably among segments but far less than the size-related group. The elongation ratio ranges from 0.28 (segment 9, strongly elongated) to 0.94 (segment 14, near-circular), meaning that the CRB's segments span

almost the entire range of Strahler's (1964) shape classification from 'more elongated' through to 'oval', despite the whole-basin elongation ratio of 0.26 suggesting a uniformly elongated basin when examined only at the aggregate scale. These finding echoes that of Andriopoulou-Mounteanou *et al*. (2025), who found that a single river system's active and abandoned channel segments could differ sharply in shape-related indices despite sharing a common parent basin, and it directly cautions against inferring uniform hydrologic behaviour across a large basin from whole-basin shape parameters alone.

5.4 Density and Overland-Flow Parameters: Least Difference

Drainage density (CV = 11.4%) and length of overland flow (CV = 10.7%) are the least variable parameters among the thirteen examined, ranging only from 0.10 to 0.15 km^{-1} and from 6.67 to 10.00 respectively across the seventeen segments. This comparative uniformity suggests that the underlying climatic and broad lithological controls on drainage density, principally rainfall intensity, soil infiltration capacity and vegetation cover, operate relatively consistently across the CRB despite the considerable differences in segment size and shape documented above, a pattern consistent with the low within-basin variability that the comprehensive Mexican basin study associated with process-governed, rather than boundary-governed, morphometric parameters (Comprehensive geospatial assessment, Mexican basins, 2025).

5.5 Paired Difference Testing

Table 3 presents the results of the two paired t-tests conducted to formally test for significant differences between related morphometric measurements across the seventeen segments.

Table 3: Paired t-test results for related morphometric measurements across the 17 segments(df = 16)

Paired Comparison	Mean 1	Mean 2	t-statistic	p-value	Result
1st-order vs 2nd-order mean stream length (km)	114.23	65.59	3.66	0.002	Significant (p < 0.01)
Bifurcation ratio (1st→2nd) vs (2nd→3rd)	2.27	1.79	1.69	0.111	Not significant (p > 0.05)

Source: Author's computation from extracted sub-basin morphometric data, 2024.

The paired t-test comparing mean first-order and second-order stream length across the seventeen segments returned a statistically significant difference (t = 3.66, p = 0.002), confirming that, within each segment individually and not merely at the whole-basin level, first-order streams are consistently and significantly longer on average (114.23 km, aggregated) than second-order streams (65.59 km), a pattern consistent with the general Hortonian expectation that mean stream length increases with order at the whole-network level, but which, at the individual-segment level examined here, reflects the greater cumulative length contributed by the far more numerous first-order channels within each segment rather than any single first-order stream being individually longer than a second-order one. By contrast, the paired t-test comparing bifurcation ratio between the first-to-second and second-to-third order transitions did not reach statistical significance (t = 1.69, p = 0.111), indicating that, unlike the strongly significant stream-length difference, the tendency noted in the companion description study for bifurcation ratio to rise between these two order transitions at the whole-basin scale is not consistently replicated as a statistically robust pattern when tested across the seventeen segments individually, and should therefore be treated as a basin-wide tendency rather than a segment-level rule.

5.6 Profiles of the Most Distinctive Segments

Beyond the aggregate variability statistics, it is instructive to identify the individual segments that anchor each extreme of the CRB's morphometric range, since these are the segments most likely to behave hydrologically differently from the basin average. Segment 3 is simultaneously the largest by area (4,769.49 km^2) and has the highest mean

bifurcation ratio (3.60), suggesting a well-organised, extensively developed network. Segment 14 is both the smallest by area (826.94 km²) and the most nearly circular in shape (elongation ratio 0.94) yet also has the lowest drainage density in the dataset (0.10 km^{-1}). Segment 4 records the highest drainage density (0.15 km^{-1}, tied with segment 12), while segment 9 is the most strongly elongated segment in the basin (elongation ratio 0.28). Segment 17 has the highest circularity ratio (0.49), and segment 10 the lowest (0.22). None of these extremes coincide consistently in the same segment, underscoring that a segment which is extreme on one morphometric axis is not necessarily extreme on another, a finding that is examined statistically in the companion study of parameter interrelationships and applied directly to flood-risk prioritisation in the companion study of flood-risk modelling.

5.7 Segment Ranking Across Key Differentiating Parameters

Table 4 ranks all seventeen segments simultaneously on the four parameters identified above as spanning the full range from highest to lowest variability, basin area (highest CV), mean bifurcation ratio and elongation ratio (moderate CV), and drainage density (lowest CV). Presenting these rankings together makes visible a pattern only implied by the aggregate statistics in Table 2: a segment's rank on one parameter carries little information about its rank on another. Segment 3, ranked first by area and first by bifurcation ratio, is ranked only fourteenth of seventeen by drainage density and fifteenth by elongation ratio; segment 14, ranked last (seventeenth) by area, is ranked first by elongation ratio but last by drainage density.

Table 4: Ranking of the 17 segments across four differentiating morphometric parameters (rank 1 = highest value)

Segment	Area (km²)	Area Rank	Elongation Ratio	Elong. Rank	Bifurcation Ratio	Bif. Rank	Drainage Density	Dd Rank
1	1,937.38	4	0.38	11	2.38	3	0.113	11
2	1,586.32	11	0.46	7	1.67	11	0.130	4
3	4,769.49	1	0.32	15	3.60	1	0.110	14
4	1,743.94	9	0.38	11	2.00	7	0.150	1
5	1,601.62	10	0.38	11	1.67	11	0.120	8
6	967.65	14	0.62	3	2.00	7	0.130	4
7	1,752.29	8	0.58	4	2.00	7	0.110	14
8	1,937.29	5	0.44	8	2.17	5	0.110	14
9	1,470.36	13	0.28	17	1.50	15	0.130	4
10	1,496.93	12	0.54	6	1.92	9	0.120	8
11	3,327.18	2	0.29	16	3.35	2	0.120	8
12	844.04	16	0.58	4	1.50	15	0.150	1
13	1,832.46	7	0.40	9	1.90	10	0.110	14
14	826.94	17	0.94	1	1.50	15	0.100	17
15	847.61	15	0.66	2	1.50	15	0.110	14
16	1,913.93	6	0.38	11	1.50	15	0.120	8
17	2,833.04	3	0.35	14	2.20	4	0.120	8

Source: Author's computation from extracted sub-basin morphometric data, 2026.

5.8 Rank Correlation Among the Differentiating Parameters

To test formally whether a segment's position in the ranking on one differentiating parameter predicts its position on another, Spearman rank correlation

coefficients were computed among the four parameter rankings presented in Table 4. The results (Table 5) show that only the area-bifurcation ratio pair exhibits a strong, statistically significant rank association ($\rho = 0.79$, $p < 0.001$), confirming numerically the pattern already evident in Table 4, that larger segments tend also to have better-developed, higher-bifurcation-ratio networks. The area-elongation ratio pair shows a moderate, significant negative association ($\rho = -0.70$, $p = 0.002$), indicating that larger segments in the CRB dataset tend systematically toward more elongated shapes rather than toward circularity. All other parameter-ranking pairs, including elongation-bifurcation ($\rho = -0.43$, $p = 0.089$), area-drainage density ($\rho = -0.22$, $p = 0.400$), elongation-drainage density ($\rho = -0.23$, $p = 0.375$) and bifurcation-drainage density ($\rho = -0.15$, $p = 0.569$), are weak and not statistically significant.

Table 5: Spearman rank correlations among segment rankings on four differentiating morphometric parameters (n = 17)

Parameter pair	Spearman ρ	p-value	Interpretation
Area rank vs Bifurcation ratio rank	0.79	<0.001	Strong, significant
Area rank vs Elongation ratio rank	-0.70	0.002	Moderate, significant
Elongation ratio rank vs Bifurcation ratio rank	-0.43	0.089	Weak, not significant
Area rank vs Drainage density rank	-0.22	0.400	Weak, not significant
Elongation ratio rank vs Drainage density rank	-0.23	0.375	Weak, not significant
Bifurcation ratio rank vs Drainage density rank	-0.15	0.569	Weak, not significant

Source: Author's computation from extracted sub-basin morphometric data, 2024.

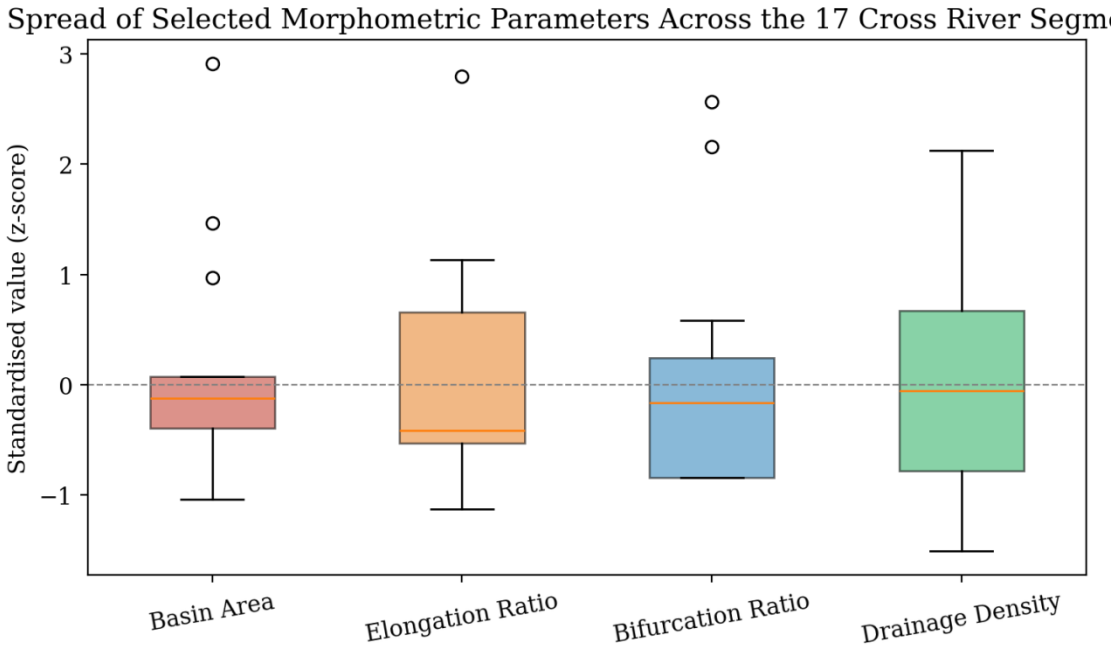

Figure 3: Standardised Spread of four key Morphometric Parameters across the 17 Cross River Segments
Source: Author's computation, 2026

The boxplot in Figure 3 visualises this same pattern on a common, standardised (z-score) scale: basin area and mean bifurcation ratio both show a pronounced positive skew, with a small number of segments (principally segment 3) extending well above the basin mean, while elongation ratio and drainage density are more symmetrically distributed around their means, consistent with the weaker, non-significant rank associations these two parameters show with the size-related parameters in Table 5.

Practically, this rank-correlation evidence means that, while a segment's absolute size is a reasonably reliable predictor of how well-developed its channel network will be, it is a poor predictor of that segment's shape or of its drainage density, reinforcing the conclusion reached descriptively in Sections 5.2 to 5.4 that no single morphometric parameter, including the most commonly cited one, basin area, can substitute for a full multi-parameter characterisation when the objective is to differentiate segments for management purposes.

5.9 Comparison with the Upper Cross River Basin Compound Study

The magnitude of segment-to-segment difference documented in this study can be compared directly with the only other published quantitative segment-comparison of any part of the Cross River Basin, Ogarekpe *et al*.'s (2020) compound-factor classification of the upper Cross River basin (UCRB), which reported compound flood-vulnerability values ranging from 6.57 to 13.10 across its sub-basins, a range of 6.53, or roughly double the minimum value. The morphometric variability documented here for the full seventeen-segment CRB dataset, with, for example, drainage density ranging from 0.10 to 0.15 km^{-1} (a range representing 41.7% of the minimum value) and basin area ranging from 826.94 to 4,769.49 km^2 (a range representing 476.8% of the minimum value), is broadly consistent with the scale of heterogeneity the UCRB study found sufficient to justify a three-tier flood-vulnerability classification. This consistency lends support to the applicability of a comparable segment-based prioritisation approach across the whole Cross River Basin, an approach undertaken directly in the companion study on flood-risk modelling of the basin's segments, which draws on the difference statistics established here to justify treating the CRB's seventeen segments as hydrologically distinct management units rather than as a morphometrically uniform whole.

6. CONCLUSION AND RECOMMENDATIONS

This study has quantified the differences in morphometric parameters across the seventeen third-order segments of the Cross River Basin. Descriptive variability analysis found that size-related parameters (basin area, total stream length, number of streams) differ most sharply among segments (CV 48.5-53.6%), shape and network-structure parameters differ moderately (CV 19.2-35.8%), and drainage-density-related parameters differ least (CV 10.7-11.4%). A paired t-test confirmed a statistically significant difference between first-order and second-order stream length across the segments ($p = 0.002$), while a paired t-test on successive-order bifurcation ratios did not reach significance ($p = 0.111$). This indicated the there is significant difference in the morphometric parameters of the Cross River Basin's segments based on the strength of the coefficient-of-variation evidence and the significant paired t-test result. It is recommended that: (i) management interventions in the CRB that depend on basin size or network complexity, such as infrastructure sizing or channel-network mapping, be designed on a segment-specific rather than whole-basin basis, given the near six-fold range in segment area; (ii) interventions that depend on drainage density or infiltration behaviour may reasonably be designed with less segment-by-segment differentiation, given the comparatively low variability documented for these parameters; and (iii) future statistical work extend paired difference testing to additional parameter pairs, and to formal analysis of variance (ANOVA) across independent, rather than paired, segment groupings, to further strengthen the statistical characterisation of the CRB's internal morphometric heterogeneity.

REFERENCES

Andriopoulou-Mounteanou, S. A., Skilodimou, H. D., & Bathrellos, G. D. (2025). Comparative morphometric analysis of avulsed and active river systems using GIS and multivariate statistics.

Bhat, M. S., Alam, A., Ahmad, S., Farooq, H., & Ahmad, B. (2019). Flood hazard assessment of upper Jhelum basin using morphometric parameters. Environmental Earth Sciences, 78(2), 54. https://doi.org/10.1007/s12665-019-8046-1

Comprehensive geospatial assessment: morphometric parameters and hydrological

implications in five Mexican basins (2025). *Scientific Reports*, 15.

Eze, B. E., & Efiong, J. (2010). Morphometric parameters of the Calabar River basin: implication for hydrologic processes. *Journal of Geography and Geology*, 2(1), 18-26.

Hagget, P., & Chorley, R. J. (1972). Network Analysis in Geography. Edward Arnold, London.

Joshi, R., Pankaj, S., & Purabi, S. (2021). Interrelations of drainage basin morphometric parameters and their implication for hydrological disaster management.

Kandekar, V., Gavit, B., Atre, A., Bansod, R., & Ninbalkar, R. (2021). Morphometric analysis of watershed for the assessment of natural resource management using GIS techniques.

Morphometric analysis of watersheds: a comprehensive review of data sources, quality, and geospatial techniques (2023). Geosystems and Geoenvironment / ScienceDirect.

Ogarekpe, N. M., Obio, E. A., Tenebe, I. T., Emenike, P. C., & Nnaji, C. C. (2020). A dataset for the flood vulnerability assessment of the upper Cross River basin using morphometric analysis. *Data in Brief*, 29, 105344. https://doi.org/10.1016/j.dib.2020.105344

Ogarekpe, N. M., Obio, E. A., Tenebe, I. T., Emenike, P. C., & Nnaji, C. C. (2020). Flood vulnerability assessment of the upper Cross River basin using morphometric analysis. *Geomatics, Natural Hazards and Risk*, 11(1), 1378-1403. https://doi.org/10.1080/19475705.2020.1785954

Shaikh, M., Yadav, S., & Manekar, V. (2022). Application of the compound factor for runoff potential in sub-watersheds prioritisation based on quantitative morphometric analysis. *Journal of the Geological Society of India*, 98(5), 687-695. https://doi.org/10.1007/s12594-022-2045-7

Strahler, A. N. (1964). Quantitative geomorphology of drainage basins and channel networks. In V. T. Chow (Ed.), *Handbook of Applied Hydrology* (pp. 4.39-4.76). McGraw-Hill, New York.

Udosen, C., Ubom, R., Etuk, E., & Okoroji, C. (2021). Fluvial morphometry and hydrologic implication in the humid tropics.