

Influence of Rainfall Characteristics, Land Use and Land Cover (LULC) On The Morphology of River Kontien in Benue State, Nigeria

Tersoo Stephen Yiye, Maxwell Idoko Ocheri, Anule Peter Terngu, Patricia Ali
Department of Geography, Rev. Fr. Moses Orshio Adashio University, Makurdi

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Abstract: *This study evaluated the influence of rainfall characteristics, land use and land cover (LULC) on the morphology of River Kontien in Benue State, Nigeria. A descriptive survey and experimental research design were adopted to examine how basin processes shape channel form and behaviour. The study population comprised the entire River Kontien drainage basin, including its upper, middle and lower reaches, tributaries, slopes, soil units and hydrometric stations. Primary data were obtained through field measurements of channel dimensions, discharge, slope, soil and sediment properties using standard survey equipment, while secondary data were sourced from satellite imagery and meteorological records. Soil and sediment samples were analysed in the laboratory for physical and chemical properties, while geospatial techniques using ArcGIS 10.5 and Surfer software were applied to delineate the basin and derive morphometric parameters such as drainage density, stream order, bifurcation ratio, basin slope and relief ratio. Data were analysed using descriptive statistics, Pearson correlation, multiple regression and ANOVA with SPSS Version 31. The findings revealed that rainfall characteristics significantly influence channel morphology, particularly through variations in rainfall amount, intensity and erosivity. It was also found that land use and land cover changes, especially the expansion of agricultural land and reduction in vegetation cover, strongly affect channel width, depth and cross-sectional area. A strong relationship exists between rainfall variables, land use parameters and river morphological features, while rainfall erosivity and vegetation cover were identified as key predictors of cross-sectional area. Basin slope was found to exert an inverse influence on channel development, with steeper slopes associated with narrower channels and gentler slopes with wider, more sinuous channels. The study concluded that River Kontien morphology is shaped by the combined effects of rainfall variability, land use dynamics and basin physical characteristics. It was recommended that sustainable land use planning, afforestation programmes and integrated river basin management strategies be implemented to reduce erosion, stabilise channel morphology and ensure environmental sustainability.*

Keywords: river morphology, rainfall erosivity, land use and land cover, basin processes, channel morphology, river kontien, GIS analysis, Benue state; fluvial geomorphology; watershed management.

INTRODUCTION

River morphology represents the visible expression of the dynamic interaction among hydrological processes, climatic controls, basin structure and anthropogenic disturbances operating within a drainage basin. The form, dimensions and behaviour of river channels are shaped through continuous adjustments to water discharge, sediment supply, channel slope, vegetation cover and land-use conditions within the contributing basin. These controls determine channel width, depth, sinuosity, bank stability, erosion patterns, sediment deposition and floodplain development, thereby influencing the geomorphic evolution of river systems over time (Chen et al., 2023). Consequently, understanding the influence of rainfall, land use and land cover on river morphology has become central in fluvial geomorphology because these variables directly regulate runoff generation, infiltration, sediment yield and hydraulic response, which in turn govern channel form and adjustment.

Globally, rainfall is recognized as one of the most critical climatic controls influencing river morphology because it regulates the volume, intensity, duration and seasonal variability of runoff entering drainage channels. Variations in rainfall characteristics influence discharge magnitude, flood frequency, stream power and sediment transport processes, all of which affect channel erosion, widening, aggradation and meander development. High-intensity rainfall events often generate increased overland flow and peak discharge capable of accelerating bank undercutting, channel incision and lateral migration, while prolonged moderate rainfall may sustain base flow and sediment redistribution that promotes channel stabilization (Gazon et al., 2023). In many tropical and subtropical environments, seasonal rainfall variability has been linked with repeated morphological adjustments, especially in rivers characterized by unstable banks and erodible alluvial materials.

Recent advances in fluvial research have increasingly demonstrated that rainfall-induced hydrological responses do not operate in isolation, but interact closely with land use and land cover conditions within the basin. Land use determines how rainfall is partitioned into infiltration, evapotranspiration and runoff, while land cover influences soil protection, hydraulic roughness and sediment detachment. Natural vegetation, especially forest and riparian cover, tends to intercept rainfall, enhance infiltration, reduce runoff velocity and stabilize river banks, thereby moderating channel adjustment processes. In contrast, deforestation, cultivation, grazing, urbanization and infrastructural development often increase imperviousness or reduce vegetation protection, resulting in accelerated runoff generation, sediment production and channel instability (Andualem et al., 2024). Such land-use driven hydrological disturbances frequently alter river geometry and trigger morphological responses including channel widening, bed degradation and floodplain sedimentation.

Within the broader discourse of watershed processes, land use and land cover change have emerged as major drivers of geomorphic transformation in many river systems worldwide. Gurnell

et al. (2022) observed that anthropogenic modification of Basin surfaces often disrupts the equilibrium between water discharge and sediment load, causing channels to adjust through erosion or deposition in order to attain a new dynamic balance. This adjustment may manifest as channel enlargement where runoff increases beyond channel capacity, or as sediment aggradation where excessive sediment supply exceeds transport competence. Such processes are particularly significant in agricultural landscapes where cultivation on slopes, bush burning and vegetation removal intensify soil erosion and sediment delivery to streams.

The influence of land use and land cover on river morphology is particularly pronounced in developing regions where demographic growth and pressure on land resources have accelerated landscape transformation. In many sub-Saharan African basins, conversion of natural vegetation to cultivated and built-up surfaces has altered drainage behaviour, increased runoff coefficients and enhanced sediment mobility, leading to widespread channel instability (Kabir et al., 2024). Nkwocha and Eboh (2023) documented that land-use modifications in West African basins have contributed to increased floodplain sedimentation, channel migration and morphological adjustments through changes in hydrological and sediment delivery regimes. These findings reinforce the growing recognition that basin-scale land surface changes exert strong controls on river form and geomorphic evolution.

In tropical environments such as Nigeria, the interaction between rainfall regimes and land-cover dynamics assumes even greater significance because many river systems respond rapidly to seasonal hydrological extremes. Nigeria's tropical climate, characterized by marked wet and dry seasons, often produces intense rainfall capable of generating substantial runoff and sediment transport, particularly where land-use activities have reduced vegetation cover and soil stability. Ijafiya et al. (2023) observed that in many Nigerian basins, altered rainfall-runoff relationships coupled with land degradation have contributed to bank erosion, channel migration and siltation. Their study on the lower course of River Mayo Inne showed that changes in discharge regimes, sediment dynamics and anthropogenic disturbances significantly altered channel morphology over time.

Similarly, studies on land use impacts within Nigerian river systems provide growing evidence that landscape transformation contributes directly to morphological change. Abali and Nkii (2024) found in the New Calabar River Basin that urbanization significantly increased channel width and depth through modified runoff characteristics and greater hydraulic stress on channel boundaries. Their findings suggest that land-use change influences not only hydrological response but also channel geometry and sediment redistribution. In related vein, Ocheri et al. (2024), in their assessment of the River Mu sub-basin of the Lower Benue Basin, demonstrated that drainage characteristics, form factor, elongation ratio and land surface conditions collectively influence basin hydrological efficiency and may shape downstream channel morphology.

Beyond land use, land cover dynamics involving vegetation depletion or recovery also influence river morphological processes through their effects on erosion resistance and bank cohesion. Riparian vegetation plays a particularly important role in reinforcing channel banks, trapping sediment, reducing flow energy near channel margins and moderating lateral migration. Where vegetation cover is degraded, channels often become more susceptible to widening, meander cut-offs and bank collapse, especially under intense rainfall conditions (Abubakar & Ibrahim, 2021). Thus, evaluating land cover changes in relation to rainfall behaviour offers critical insight into the processes driving morphological evolution in tropical river systems.

Benue State presents a particularly suitable context for investigating these interactions because of its location within a transitional ecological zone marked by considerable rainfall seasonality, fragile soils and intensive agricultural activity. The Basin environments of the state experience increasing land-use conversion through cultivation, settlement expansion and vegetation removal, while seasonal rainfall often generates substantial runoff capable of modifying river channels. These conditions create strong interactions among rainfall, land use, land cover and channel processes, making river systems in the region especially sensitive to geomorphic adjustment. Yet empirical understanding of how these factors influence river morphology in medium-sized basins such as River Kontien remains limited.

River Kontien, as a tributary within the Lower Benue drainage system, exhibits observable signs of morphological adjustment including bank erosion, sediment deposition, channel widening and seasonal shifts in channel alignment. Field observations suggest that these adjustments may be linked to variability in rainfall intensity, land-cover conversion and agricultural expansion across the basin. However, despite these observable changes, there is limited integrated empirical evidence quantifying the extent to which rainfall, land use and land cover influence the morphology of the river. Existing studies in the region have focused more broadly on morphometric analysis or generalized watershed conditions, with relatively little attention to the combined hydro-climatic and land-surface controls of channel morphology.

This knowledge gap underscores the significance of evaluating rainfall, land use and land cover as interacting determinants of River Kontien morphology. Such evaluation is important because channel responses to climatic and land-surface disturbances often determine flood vulnerability, sediment hazards, agricultural land stability and ecological resilience. Understanding these controls can therefore provide a scientific basis for predicting downstream geomorphic evolution, managing erosion risks and designing sustainable watershed interventions.

Against this background, the present paper examines the influence of rainfall, land use and land cover on the morphology of River Kontien in Benue State, Nigeria, with emphasis on how hydrological variability and land surface transformation shape channel dimensions, adjustment processes and downstream geomorphic evolution. Specifically, the paper addresses Objective III

of the broader study, which seeks to evaluate the extent to which rainfall, land use and land cover influence the morphology of the river and contribute to observed geomorphic responses.

Statement of the Research Problem

River systems in many parts of Nigeria are experiencing increasing morphological instability arising from the combined effects of rainfall variability, land-use transformation and land-cover alteration, yet the extent to which these factors influence channel adjustment remains inadequately understood. Although rivers naturally adjust their form in response to hydrological and geomorphic controls, growing anthropogenic pressures have accelerated rates of bank erosion, channel widening, sediment deposition and floodplain modification beyond natural thresholds in many basins (Ijafiya et al., 2023). Across Nigeria, deforestation, cultivation on fragile slopes, sand mining, urban expansion and riparian vegetation loss have altered runoff pathways and sediment delivery processes, thereby intensifying pressure on channel systems. These disturbances, when combined with intense rainfall events and highly erodible soils, often trigger morphological responses such as incision, lateral migration and channel instability. Despite increasing recognition that rainfall dynamics and land-surface changes are central drivers of river morphology, empirical studies integrating these variables within a basin-scale geomorphic framework remain limited, particularly in north-central Nigeria (Abali & Nkii, 2024).

The problem is further compounded by the fact that many existing studies have emphasized either morphometric analysis or general watershed conditions without adequately quantifying the specific influence of rainfall, land use and land cover on river channel morphology. Yet these variables represent critical process controls because rainfall determines runoff magnitude and erosive energy, while land use and land cover regulate infiltration, sediment yield, bank stability and drainage response. Their interaction shapes channel dimensions, flow behaviour and downstream geomorphic evolution. In north-central Nigeria, where rainfall variability is pronounced and agricultural pressure on basin landscapes is intensifying, the absence of integrated analysis of these controls has created a major gap in understanding channel behaviour and predicting morphological change (Adeniran et al., 2018). This gap has constrained the development of effective watershed management strategies and weakened scientific capacity to explain or manage river instability.

River Kontien clearly reflects this problem. Field observations indicate recurrent channel widening, bank erosion, sediment accumulation and seasonal shifts in channel alignment, particularly following intense rainy seasons. These observable changes suggest that rainfall variability and changing land-use and land-cover conditions may be exerting significant influence on the morphology of the river. However, there is little scientific evidence quantifying the extent of these influences or explaining how they contribute to downstream geomorphic adjustment. In the absence of such evidence, it remains unclear whether rainfall intensity, agricultural land expansion, vegetation loss, built-up growth or their combined interactions are the dominant factors driving morphological instability within the basin. While studies such as Ijafiya et al. (2023) and

Abali and Nkii (2024) have demonstrated the effects of land-use modification and hydrological change on channel form in other Nigerian basins, these findings cannot be assumed to apply directly to River Kontien because of differences in basin structure, climatic regime and geomorphic setting. The specific problem addressed by this study, therefore, is the inadequate empirical understanding of how rainfall, land use and land cover influence the morphology and downstream geomorphic evolution of River Kontien.

Objectives of the Study

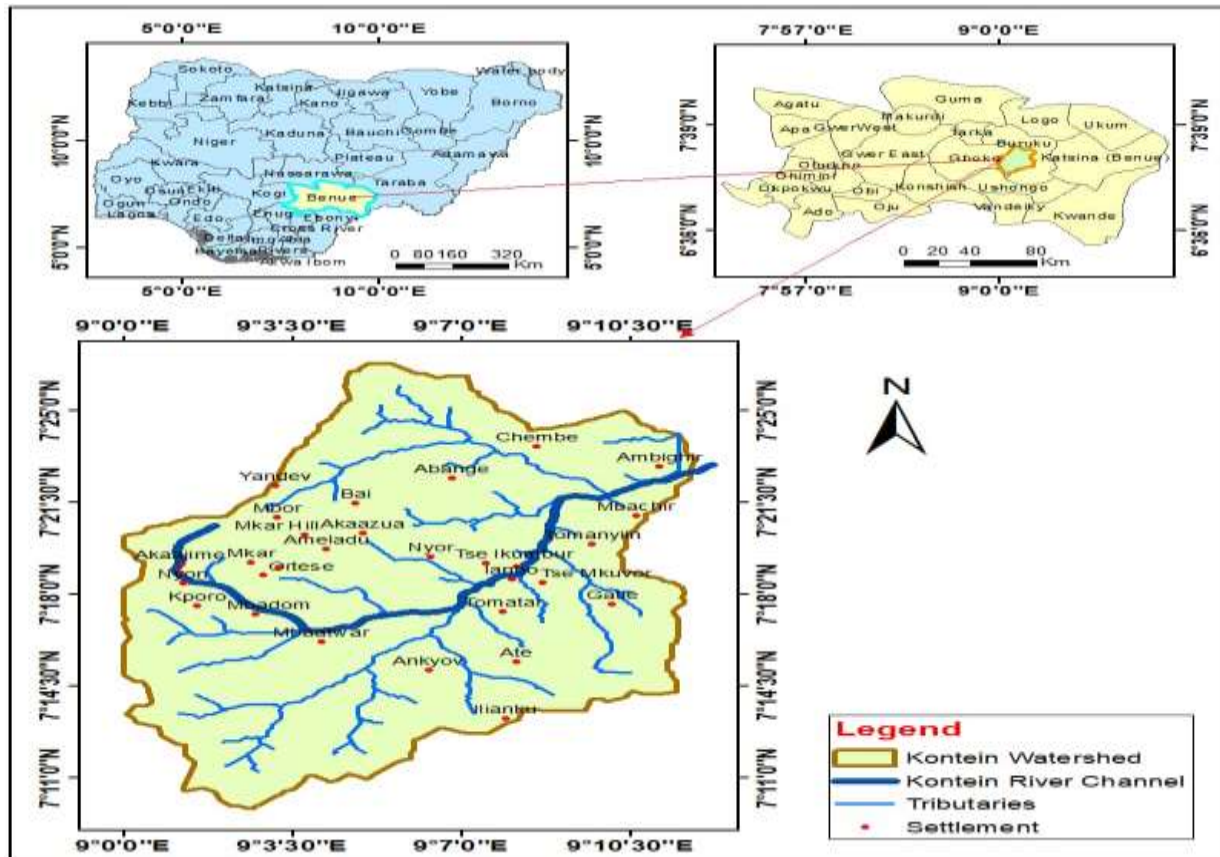
The focus of this study is to evaluate the influence of rainfall, land use and land cover on the morphology of River Kontien in Benue State, Nigeria. Specifically, of the study seeks to:

1. Examine the temporal variability of rainfall characteristics (amount, intensity and erosivity) and their influence on channel morphology in River Kontien.
2. Assess the influence of land use and land cover changes, particularly vegetation, agriculture and built-up areas, on channel width, depth, cross-sectional area and sinuosity.
3. Determine the statistical relationships between rainfall, land use/land cover variables and river morphological characteristics in the River Kontien basin.
4. Evaluate the predictive influence of rainfall erosivity, vegetation cover and built-up area on cross-sectional area as an indicator of morphological adjustment in River Kontien.

METHODOLOGY

This study adopted a descriptive survey and experimental research design to investigate the influence of basin processes on the morphology of River Kontien. The descriptive survey design was used to observe, describe and measure existing geomorphic and environmental conditions in the basin, while the experimental aspect involved field measurements, laboratory analysis and geospatial techniques for generating empirical data. The integration of field survey, remote sensing and Geographic Information System (GIS) provided a robust framework for examining both natural and anthropogenic controls on river morphology.

The study was conducted in the River Kontien Basin from the source of the River at Mkar hills to where it empties its water in River Buruku, Buruku Local Government Area, Benue State. River Kontien Basin is found on the Northwestern part of Benue State and cuts across the parts of Gboko and Buruku Local Government Areas. This Basin is located between latitude 7°10'00"N and 7°28'15"N as well as longitude 9°1'00"E and 9°12'00"E and it occupies a total area of 445 km² according to the high-resolution topographic analysis of the area. The basin, being a sub-basin of the River Katsina-Ala, has its main stem measuring a total of sixty-two (62) kilometres long and drains into the River Katsina-Ala. Such location situates the Kontien basin in Benue State, which is a transitional area between Nigeria's humid south and the arid north, whose social and ecological conditions and processes are highly dynamic and changing with increased rates. The location of the study area is shown in Figure 1.



Source: Researcher's Field work, 2026

Figure 1. Drainage Map of River Kontien

The study population comprised the entire River Kontien drainage basin, including upper, middle and lower reaches, tributaries, slopes, land use units, soil sampling points and hydrometric stations. A stratified and systematic sampling technique was adopted to ensure spatial representation of basin processes and channel characteristics. The river was stratified into three geomorphic zones, from which 30 sampling points were systematically selected at 100-meter intervals, with ten points in each reach. In addition, thirty soil samples, thirty sediment samples and thirty hydrometric observations were collected to adequately capture spatial variability in the basin.

Data for the study were obtained from both primary and secondary sources. Primary data were generated through direct field measurements of channel width, depth, cross-sectional area, bank height, discharge, slope, soil properties and sediment characteristics using survey equipment such as measuring tapes, ranging poles, GPS, grab samplers and soil cores. Soil samples were subjected to laboratory analysis to determine particle size distribution, soil texture, organic matter, porosity,

bulk density and erodibility, while sediment samples were analyzed for grain size and suspended sediment properties.

Secondary data were obtained from Nigerian Meteorological Agency (NiMet) rainfall records, Shuttle Radar Topography Mission (SRTM) data, Landsat satellite imagery, topographic maps and hydrological records. Rainfall data for 2021–2025 were used to determine rainfall amount, intensity and erosivity using the Modified Fournier Index (MFI), while remote sensing and GIS techniques were used to derive land use/land cover and basin morphometric parameters.

Geospatial analysis was carried out using ArcGIS 10.5 and Surfer software to delineate the drainage basin and derive morphometric parameters such as stream order, drainage density, bifurcation ratio, basin slope, relief ratio, elongation ratio and form factor. Land use/land cover analysis was undertaken through supervised classification of satellite imagery into vegetation, agricultural land, built-up areas, water bodies and bare surfaces. Spatial overlay techniques were further used to examine the relationship between land use patterns and channel morphological conditions across the basin.

Data collected were analyzed using both descriptive and inferential statistical techniques. Descriptive statistics such as mean, percentages, range and standard deviation were used to summarize variations in hydrological, geomorphological and land use variables. Pearson Product Moment Correlation was used to determine relationships among rainfall, land use, soil and morphological variables, while Multiple Regression Analysis was employed to identify the predictive influence of basin processes on channel morphology. Analysis of Variance (ANOVA) was further used to test differences in morphological characteristics across upper, middle and lower reaches of the river. All statistical analyses were conducted using SPSS Version 31, while GIS-based spatial analyses supported interpretation of the interactions among basin processes and river morphology.

RESULTS**Influence of Rainfall Characteristics on Channel Morphology****Table 1: Monthly Rainfall Amount in the Study Area (2021-2025)**

Month	2021	2022	2023	2024	2025	Average Rainfall Amount(mm)
January	18	22	20	19	21	20
February	32	35	30	33	31	32.2
March	85	90	88	92	87	88.4
April	145	150	138	142	148	144.6
May	210	220	205	250	225	222
June	280	295	270	285	290	284
July	320	335	310	325	330	324
August	290	305	280	295	300	294
September	310	320	300	315	325	314
October	240	250	230	245	255	244
November	95	100	90	98	102	97
December	25	28	24	26	27	26
Total	2050	2150	1985	2125	2141	2090.2

Source: NIMET, Akperan Orshi Polytechnic, Yandev Gboko, 2025

Results in Table 1 show that rainfall distribution in the River Kontien basin follows a clear seasonal pattern with rainfall intensifying from April and peaking between July and September. The highest mean monthly rainfall was recorded in July (324 mm), followed by September (314 mm) and August (294 mm), while the lowest occurred in January (20 mm) and December (26 mm). Annual rainfall totals ranged from 1985 mm in 2023 to 2150 mm in 2022, with a five-year mean of 2090.2 mm. This indicates substantial water input into the basin capable of generating high runoff volumes and erosive energy. The concentration of over 44% of annual rainfall between July and September alone suggests that erosive processes are most active during these months, with likely impacts on bank erosion, sediment mobilization and channel reshaping. For instance, the increase from 145 mm in April to 320 mm in July represents over 120% rise in rainfall input, implying a corresponding increase in runoff power. This supports the interpretation that rainfall amount and seasonal concentration are major drivers of morphological adjustment in River Kontien, particularly widening and deepening of channels during peak rainy periods.

Table 2: Modified Fournier index variability in River Kontien

Year	MFI
2021	233.5
2022	244.5
2023	226.9
2024	238.7
2025	244.0

Source: Author's Fieldwork, 2026

Table 2 further reveals that rainfall erosivity in the basin is consistently high. The Modified Fournier Index (MFI) ranged from 226.9 in 2023 to 244.5 in 2022, with 2025 also recording a similarly high value of 244.0. Since all values exceed 160, they fall within the “very high erosivity” class, indicating strong rainfall-induced erosion potential throughout the period. The fluctuation between 226.9 and 244.5 reflects inter-annual variability in rainfall concentration, with 2022 and 2025 likely exerting stronger geomorphic effects due to greater erosive energy. For example, the difference of 17.6 units between 2022 and 2023 suggests significant variation in rainfall aggressiveness capable of influencing sediment yield and channel response. The implication is that years of higher MFI are associated with intensified runoff, bank instability and possible increases in channel dimensions.

Influence of Rainfall, Land Use/Land Cover and Morphology

Table 3: Rainfall, Land use and Land Cover and Morphology of River Kontien

Site	RAIN	MFI	Q	VEG	AGRIC	BUILT	WIDTH	DEPTH	CSA	SINU
Mkar	1320	78.2	2.5	72	22	6	14.2	1.8	25.6	1.21
Ameladu	1315	77.5	2.8	70	24	6	15.1	1.9	28.7	1.24
Mbadom	1330	79.0	3.1	75	20	5	13.5	1.7	23.0	1.18
Mbaamandev	1345	81.2	3.4	78	18	4	12.8	1.6	20.5	1.15
Tomanyiin11	1335	80.0	3.8	74	21	5	13.9	1.7	23.6	1.19
Anikyov	1340	80.5	4.2	76	20	4	13.0	1.6	20.8	1.17
MkarHills	1360	83.4	4.5	82	15	3	11.5	1.5	17.3	1.12
Ilianku	1355	82.8	4.9	80	17	3	12.0	1.6	19.2	1.14
Bai	1338	79.8	5.3	73	22	5	13.3	1.7	22.6	1.18
Akaajime	1370	84.5	5.7	85	12	3	11.2	1.4	15.7	1.10
TomatarM	1385	86.0	6.1	60	30	10	16.8	2.0	33.6	1.30
Agasha	1390	86.8	6.5	58	32	10	17.5	2.1	36.7	1.32
Mkovur	1382	85.7	7.0	62	29	9	16.9	2.0	33.8	1.29
Tomataan	1395	87.5	7.4	55	35	10	18.2	2.2	40.0	1.35
Kporo	1388	86.4	7.9	61	30	9	16.4	2.0	32.8	1.28
Gyura	1386	86.2	8.3	59	31	10	17.0	2.1	35.7	1.31
TseKumbur	1380	85.9	8.8	63	28	9	16.2	2.0	32.4	1.27
Ambighir	1398	88.1	9.2	54	36	10	18.5	2.3	42.6	1.36
Chembe	1392	87.0	9.7	56	34	10	17.8	2.2	39.2	1.34
Ambigbere	1384	85.8	10.1	60	30	10	16.7	2.1	35.1	1.30
Nyor	1410	90.2	10.6	45	40	15	20.5	2.6	53.3	1.45
Akaazua	1415	91.0	11.0	42	42	16	21.0	2.7	56.7	1.47

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Ate	1420	92.3	11.5	40	44	16	21.8	2.8	61.0	1.49
Fayum	1425	93.1	12.0	38	45	17	22.5	2.9	65.3	1.50
Ortese	1418	91.5	12.6	41	43	16	21.2	2.7	57.2	1.46
Nyikwagh	1422	92.7	13.2	39	44	17	22.0	2.8	61.6	1.48
Nyongoso	1424	93.0	13.8	37	46	17	22.3	2.9	64.7	1.49
Mbor	1416	91.4	14.5	41	43	16	21.6	2.8	60.5	1.47
Abanger	1430	94.2	15.2	35	48	17	23.0	3.0	69.0	1.52
Iambo	1435	95.0	16.0	34	49	17	23.5	3.1	72.9	1.54

Source: Author's Field Work, 2026

Table 3 reveals a strong downstream pattern in hydrological and morphological variables. Rainfall increases from 1320 mm at Mkar in the upper reach to 1435 mm at Iambo in the lower reach, while MFI rises correspondingly from 78.2 to 95.0. This increase in hydrological inputs coincides with a reduction in vegetation cover from 72–85% in upper reaches to as low as 34–41% in lower reaches, while agricultural land expands from 12–22% upstream to 40–49% downstream.

These shifts in land use correspond with marked changes in channel morphology. Channel width increases from 11.2 m at Akaajime to 23.5 m at Iambo, while channel depth rises from 1.4 m to 3.1 m. Cross-sectional area increases substantially from 15.7 m² to 72.9 m², representing over a 360% increase downstream. Similarly, sinuosity rises from 1.10 to 1.54, showing intensified meandering.

Figure 1 below shows rainfall intensity in the area on a scattergram and plate 3 shows LULC in the area

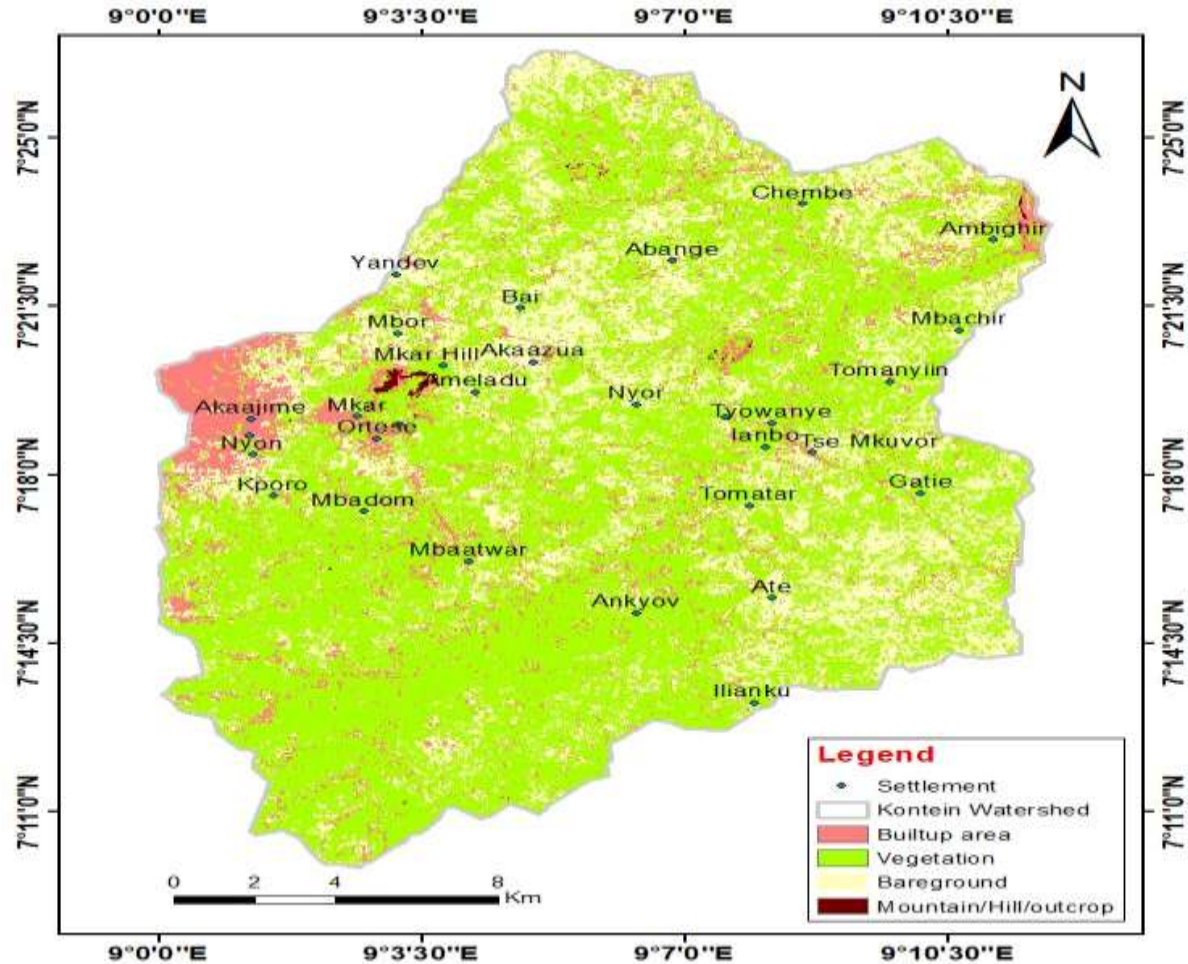


Figure 1: Land Use/Land Cover map of River Kontien Drainage Basin

Source: Authors GIS work, 2026

Figure thus, reveals a clear downstream trend in hydrological and morphological characteristics of River Kontien. Vegetation cover declines due to expanding agriculture and urban settlements. Correspondingly, river channels widen, deepen, and become more sinuous in lower reaches, reflecting the interactive influence of climatic inputs, land use, and Basin morphology. The integration of land use, and channel characteristics provides critical insight into the dynamics of river response to environmental and anthropogenic pressures, highlighting the need for sustainable land and water management to maintain river health and ecological balance.

Relationship among Basin Parameters and Morphological Variables

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Table 4: Correlation Matrix of Rainfall, Land Use/Land Cover, River Morphology, and Hydrological Variables of River Kontien

		Mean Annual Rainfall (mm)	Rainfall Erosivity Index	Vegetation Cover (%)	Agricultural Land (%)	Built-up Area (%)	Channel Width	Channel Depth	Cross Section Area	Sinuosity	River Discharge (m ³ /s)	Basin Slope	Bank Height (m)
Mean Annual Rainfall (mm)	Pearson Correlation	1											
	Sig. (2-tailed)												
	N	30											
Rainfall Erosivity Index	Pearson Correlation	.994**	1										
	Sig. (2-tailed)	.000											
	N	30	30										
Vegetation Cover (%)	Pearson Correlation	-.897**	-.913**	1									
	Sig. (2-tailed)	.000	.000										
	N	30	30	30									
Agricultural Land (%)	Pearson Correlation	.890**	.905**	-.998**	1								
	Sig. (2-tailed)	.000	.000	.000									
	N	30	30	30	30								
Built-up Area (%)	Pearson Correlation	.903**	.919**	-.993**	.985**	1							
	Sig. (2-tailed)	.000	.000	.000	.000								
	N	30	30	30	30	30							
Channel Width	Pearson Correlation	.889**	.907**	-.998**	.997**	.990**	1						
	Sig. (2-tailed)	.000	.000	.000	.000	.000							
	N	30	30	30	30	30	30						
Channel Depth	Pearson Correlation	.881**	.909**	-.991**	.989**	.986**	.993**	1					
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000						
	N	30	30	30	30	30	30	30					
	Pearson Correlation	.888**	.918**	-.987**	.984**	.983**	.989**	.998**	1				

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Cross Section Area	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000				
	N	30	30	30	30	30	30	30	30				
Sinuosity	Pearson Correlation	.890**	.908**	-.998**	.996**	.991**	.998**	.994**	.990**	1			
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000				
	N	30	30	30	30	30	30	30	30	30			
River Discharge (m ³ /s)	Pearson Correlation	.905**	.933**	-.987**	.983**	.986**	.988**	.996**	.998**	.989**	1		
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000			
	N	30	30	30	30	30	30	30	30	30	30		
Basin Slope	Pearson Correlation	-.866**	-.871**	.985**	-.984**	-.978**	-.985**	-.962**	-.952**	-.983**	-.953**	1	-.962**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000		.000
	N	30	30	30	30	30	30	30	30	30	30	30	30
Bank Height (m)	Pearson Correlation	.904**	.929**	-.992**	.988**	.988**	.992**	.997**	.997**	.992**	.999**	-.962**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	
	N	30	30	30	30	30	30	30	30	30	30	30	30

** . Correlation is significant at the 0.01 level (2-tailed).

Source: Author's GIS work, 2026

Major Predictors of Morphological Characteristics

Table 5: Multi-Regression of Rainfall, Rainfall Erosivity, Vegetation Cover, and Built-up Area as Predictors of Cross-Section Area of River Kontien

Predictor Variable	R	R ²	df	F	B	T	Sig
Constant	.998	.977	25	1952.499		13.687	.000
Mean Annual Rainfall (mm)					-1.324	-12.910	.000
Rainfall Erosivity Index					1.495	13.343	.000
Vegetation Cover (%)					-.849	-8.977	.000
Built-up Area (%)					-.039	-.394	.697

Source: Author's Field Work, 2025

Results in Table 5 show that rainfall and land cover variables jointly explain 97.7% ($R^2 = 0.977$) of the variation in cross-sectional area, while the model's F-value of 1952.499 ($p < 0.001$) confirms very high predictive strength. Rainfall erosivity is the strongest positive predictor of cross-sectional area ($\beta = 1.495$, $t = 13.343$, $p = 0.000$), indicating that increases in erosive rainfall substantially enlarge the river channel. Vegetation cover has a significant negative effect ($\beta = -0.849$, $t = -8.977$, $p = 0.000$), showing that dense vegetation reduces channel expansion by stabilizing banks and reducing runoff.

Mean annual rainfall also has a significant effect ($\beta = -1.324$, $t = -12.910$, $p = 0.000$), indicating its contribution to morphological response, though influenced by interactions with slope and erosivity. Built-up area, however, has a weak and non-significant effect ($\beta = -0.039$, $p = 0.697$), suggesting limited direct influence on channel form within the study area.

DISCUSSION OF FINDINGS

The first finding revealed that rainfall characteristics, particularly rainfall amount, intensity and erosivity, exert significant influence on the morphology of River Kontien. Evidence from Table 1 showed that annual rainfall increased from 2050 mm in 2021 to 2150 mm in 2022, while the lowest value of 1985 mm was recorded in 2023. Similarly, the Modified Fournier Index (MFI) values ranged from 226.9 in 2023 to 244.5 in 2022, indicating high rainfall erosivity throughout the study period. The implication of this finding is that variations in rainfall characteristics enhanced runoff generation, sediment detachment and transport, thereby contributing to channel widening, deepening and morphological adjustments in the basin. This finding means that rainfall serves as a major climatic driver of geomorphic processes in River Kontien, particularly through its control over erosion intensity and fluvial energy. The finding agrees with the work of Udosen (2008), who found that rainfall amount and intensity significantly influence channel erosion and basin morphology in tropical drainage systems. It also agrees with Iorkua and Oche (2012), who reported that concentrated rainfall in Benue State increases erosive energy and accelerates channel modification. The finding is justified for the fact that rainfall provides the hydraulic force required

for detachment, transportation and deposition of sediments, which are fundamental processes in river morphological evolution.

The second finding revealed that rainfall, land use and land cover collectively influence the morphological characteristics of River Kontien. Results in Table 2 showed that sites with lower vegetation cover and higher agricultural and built-up land had wider and deeper channels. For instance, at Mkar Hills, where vegetation cover was 82% and built-up area was only 3%, channel width was 11.5 m and cross-sectional area was 17.3 m², whereas at Iambo where vegetation cover declined to 34% and agricultural land increased to 49%, channel width increased to 23.5 m and cross-sectional area rose to 72.9 m². This finding means that anthropogenic modification of the basin surface through agriculture and settlement intensifies runoff and sediment yield, thereby altering channel geometry. The finding agrees with Okoye et al. (2019), who found that expansion of cultivated and built-up land contributed significantly to channel widening and instability in Nigerian river basins. It also corroborates Ifeanyi et al. (2020), who reported that combined climatic and land cover changes control river morphodynamics. The finding is justified for the fact that removal of vegetation weakens surface protection, reduces infiltration, increases overland flow and sediment delivery, which in turn modifies river channels.

The third finding revealed that there is a strong relationship between rainfall variables, land use parameters and channel morphology. The correlation matrix in Table 3 showed very strong positive relationships between rainfall and rainfall erosivity ($r = 0.994$), rainfall and channel width ($r = 0.889$), agricultural land and channel width ($r = 0.997$), as well as river discharge and cross-sectional area ($r = 0.998$). Conversely, vegetation cover had very strong negative relationships with channel width ($r = -0.998$), agricultural land ($r = -0.998$) and sinuosity ($r = -0.998$). This finding means that both natural and human-induced factors are strongly interconnected in determining river morphological responses. Increased rainfall and land use intensification promote channel enlargement, while vegetation serves as a stabilizing factor. The finding agrees with Morgan (2017), who found strong correlations between rainfall erosivity, runoff generation and fluvial adjustment. It also supports the findings of Olajuyigbe et al. (2018), who reported that basin slope and land use patterns significantly correlate with channel geometry and bank stability. The finding is justified for the fact that river systems function as integrated geomorphic systems where hydrological inputs, land cover conditions and channel processes interact continuously.

The fourth finding revealed that rainfall erosivity and vegetation cover are significant predictors of cross-sectional area in River Kontien. The multiple regression result in Table 4 showed that the model explained 97.7% ($R^2 = 0.977$) of the variation in cross-sectional area, with a highly significant F-value of 1952.499 ($p < 0.001$). Rainfall erosivity had a positive significant influence ($\beta = 1.495$, $t = 13.343$, $p < 0.001$), while vegetation cover had a negative significant influence ($\beta = -0.849$, $t = -8.977$, $p < 0.001$). Built-up area, however, was not statistically significant ($\beta = -0.039$, $p = 0.697$). This finding means that rainfall erosivity increases channel expansion whereas vegetation suppresses excessive channel enlargement through stabilization processes. The finding

agrees with Obafemi et al. (2019), who found that erosive rainfall significantly predicts channel expansion in humid tropical catchments. It also agrees with Adebayo et al. (2017), who found that vegetation cover reduces hydrological energy and limits geomorphic degradation. The finding is justified for the fact that erosive rainfall increases hydraulic stress on channel boundaries, while vegetation buffers this effect by improving cohesion and reducing runoff velocity.

The fifth finding revealed that basin slope exerts inverse control on river morphological development. From Table 5, basin slope had strong negative relationships with channel width ($r = -0.985$), cross-sectional area ($r = -0.952$), river discharge ($r = -0.953$) and bank height ($r = -0.962$). This indicates that as slope decreases downstream, discharge and channel size increase, leading to wider and deeper channels with greater sinuosity. This finding means that slope regulates energy distribution and controls whether erosion is predominantly vertical or lateral. The finding agrees with Schumm (1963), who found that basin slope is a major determinant of runoff response and channel adjustment. It also aligns with Gregory and Walling (1973), who observed that declining gradients downstream promote lateral channel expansion and meander development. The finding is justified for the fact that steep slopes favor rapid runoff and vertical incision, whereas gentle slopes encourage deposition, meandering and widening of channels.

CONCLUSION

Based on the findings of the study, it was concluded that the morphology of River Kontien is strongly influenced by the combined effects of rainfall characteristics, land use/land cover changes, basin slope, and other hydrological variables. Variations in rainfall amount, intensity, and erosivity significantly control runoff generation, erosion processes, and sediment transport, thereby driving channel adjustments such as widening, deepening, and increased sinuosity. In addition, changes in land use particularly the expansion of agricultural land and built-up areas alongside the reduction of vegetation cover intensify surface runoff and sediment delivery, which further alters channel form. Basin slope also plays a key regulatory role by influencing flow energy distribution, with steeper slopes promoting vertical incision and gentler slopes encouraging lateral channel expansion. Overall, the study concluded that River Kontien is a dynamic fluvial system whose morphology is continuously shaped by the interaction of climatic factors and human-induced land surface changes, highlighting the need for integrated watershed management to maintain channel stability and environmental sustainability.

Recommendations

Based on the findings of the study, the following recommendations are made to ensure sustainable management of River Kontien and its drainage basin:

- i. Government and environmental agencies should strengthen policies on sustainable land use planning to control uncontrolled agricultural expansion and settlement development along the river corridor.

- ii. Afforestation and reforestation programmes should be promoted within the basin to increase vegetation cover and reduce surface runoff, soil erosion, and channel instability.
- iii. Proper river basin management strategies should be implemented to monitor rainfall impact and reduce the effects of high rainfall erosivity on channel morphology.
- iv. Farmers should be encouraged to adopt soil conservation practices such as contour farming, mulching, and controlled grazing to minimize land degradation.
- v. Continuous monitoring of river morphology using GIS and remote sensing should be carried out to detect changes in channel form and guide early intervention measures.
- vi. Environmental awareness campaigns should be intensified to educate local communities on the impact of land use activities on river stability and ecosystem health.

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