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Morphometric Analysis of Upper Yewa River Basin: Hydrological and Geomorphological Insights in Southwest Nigeria

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Abstract: The upper course of the Yewa River Basin in Southwest Nigeria plays a vital role in regional hydrology, contributing significantly to groundwater recharge, surface runoff, and sediment transport. However, this region faces growing hydrological instability due to increasing anthropogenic pressures such as deforestation, sand mining, urbanisation, and unsustainable agricultural practices. Despite its importance, the morphometric characteristics of this section remain underexplored, limiting efforts to develop effective watershed management strategies. This study employs high-resolution geospatial datasets and advanced GIS techniques to conduct a detailed morphometric analysis of the upper Yewa River Basin, focusing on parameters such as drainage density, stream frequency, bifurcation ratio, and basin shape indices. The findings reveal a predominantly dendritic drainage pattern, moderate to high relief ratios, and structural homogeneity, indicating significant runoff potential and erosion susceptibility. This research fills a critical knowledge gap by linking morphometric features with landscape vulnerability; thus providing actionable data for informed catchment planning, environmental conservation, and sustainable water resource management in the context of land-use change and climate variability.

Keywords: Morphometric analysis, drainage basin, yewa river, upper course, southwest nigeria

1. Introduction

A key method in hydrology and geomorphology is the morphometric analysis of river basins, providing crucial insights into sediment transport, surface runoff, and watershed management dynamics. Integrating Geographic Information System (GIS) technologies has transformed this discipline in recent years, allowing more thorough and accurate assessments of drainage basin characteristics. A region of major ecological and socioeconomic significance, the upper course of the Yewa River Basin in Southwest Nigeria is the subject of this study.

Hydrological research conducted worldwide between 2020 and 2024 highlights how important morphometric analysis is to comprehending basin dynamics. It is well acknowledged that morphometric factors, including drainage density, form factor, bifurcation ratio, and stream order, are crucial markers of resource potential, flood susceptibility, and hydrological behaviour (López-Lambraño et al., 2022). As an illustration of the usefulness of these characteristics in sustainable development, studies conducted in Colombia's Sinú River Basin showed how morphometric evaluation influenced flood risk management with possible rainwater harvesting zones (López-Lambraño et al., 2022).

The dendritic drainage pattern of the Yewa River Basin, which covers an area of about 4,832.4 km2, is a sign of uniform surface runoff behaviour and homogeneous geological formations. GIS-based morphometric analyses have been used in recent studies to evaluate the drainage density, bifurcation, and elongation ratios. These are crucial to comprehending the hydrological response of the basin and the possible hazards of flooding. Adeaga et al. (2019), for example, used GIS tools to investigate the morphometric characteristics of the Yewa Basin and found a mean bifurcation ratio of 2.03, which suggests that there is little structural control over the drainage development.

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Due to its significance in groundwater recharge and vulnerability to erosion processes, the upper channel of the Yewa River warrants special attention. The topography and morphometric features of the upper basin have a major impact on the river's discharge patterns and sediment load, affecting human settlements and ecosystems downstream. Comprehending these attributes is essential for formulating efficacious watershed management tactics, particularly given the region's growing land-use shifts and climate fluctuations.

Moreover, comparative morphometric analyses with adjacent river systems in Southwest Nigeria can provide a broader perspective on regional hydrological behaviours. Such comparisons can identify unique or common morphometric features, enhancing the understanding of geomorphological processes at a regional scale. For example, studies on the Benue River Basin have demonstrated the utility of morphometric analysis in surface water development and management, highlighting the relevance of such approaches in diverse hydrological settings.

Drainage basins are fundamental units of hydrological analysis, directly influencing water flow, sediment transport, and flood patterns. In recent years, the Yewa drainage basin in Southwestern Nigeria has faced significant environmental and socio-economic challenges due to increasing flood events, sediment deposition, and inefficient water resource management. These issues are worsened by climate variability and unregulated land-use changes, which heighten the risks of water scarcity, erosion, and disaster vulnerability in the region.

The Yewa drainage basin, characterised by a predominantly dendritic drainage pattern, is situated in a region with high annual rainfall variability, ranging from 1,200 mm to 2,000 mm. Despite its hydrological significance, studies on its morphometric characteristics remain scarce, limiting the region's capacity to implement proactive water management and flood control strategies. According to the World Bank (2022), flooding in Nigeria caused economic losses of over $1 billion, with Southwestern states, including Ogun (where the Yewa basin is located), frequently impacted. This underscores the urgency of integrating morphometric data into planning frameworks.

Advanced technologies like Geographic Information Systems (GIS) and remote sensing have revolutionised basin analysis, enabling precise and cost-effective evaluation of drainage parameters. Recent studies in Africa highlight the value of these tools in identifying erosion-prone areas and optimising water storage designs (Ahmad et al., 2022). However, the application of such innovations in the Yewa basin has been limited, creating a critical knowledge gap in addressing the hydrological challenges facing the region.

1.1 Study Area

The study area basin is a sub-basin of the Yewa drainage basin which lies approximately within latitudes 6.2oN and 7.75°N and longitudes 2.70oE and 3.00oE. It is a transboundary river basin between Nigeria and the Republic of Benin. It upper part begins around Igboho hill in Ayetoro (Salami 2024). It drains through five local government areas of Ogun State before emptying into Badagry Creek, which connects Lagos Lagoon, as shown in Figuere 1. The basin has a total catchment area of approximately 50002 km and falls within Nigeria's hydrological Area 6, which is under the jurisdiction of the Ogun-Osun River Basin Development Authority. Yewa drainage basin shares boundaries with the Republic of Benin in the East, on the Northern edge with Oyo State, while Ifo and Ewekoro Local Governments are on the West, and the Atlantic Ocean and lagoon in the South where it empties its resources. Yewa River Basin is a reference river basin to the Ogun-Osun River Basin Development Authority (OORBDA). It constitutes one of the five significant basins of the Ogun River Basin Development Authority (ORBDA).

Climatologically, the basin is located in the moderately hot, humid tropical climatic zone of southwestern Nigeria that is under the influence of the tropical continental (CT) air mass and the tropical maritime (MT) air mass. The narrow zone of convergence of the two air masses is called the Intertropical Convergence Zone (ITCZ), which usually shifts seasonally with the pressure belts and Isotherms. There are two distinct seasons; the wet season begins from March/April to October/November, and the dry season, which lasts for the rest of the year, starts from October/November till March/April.

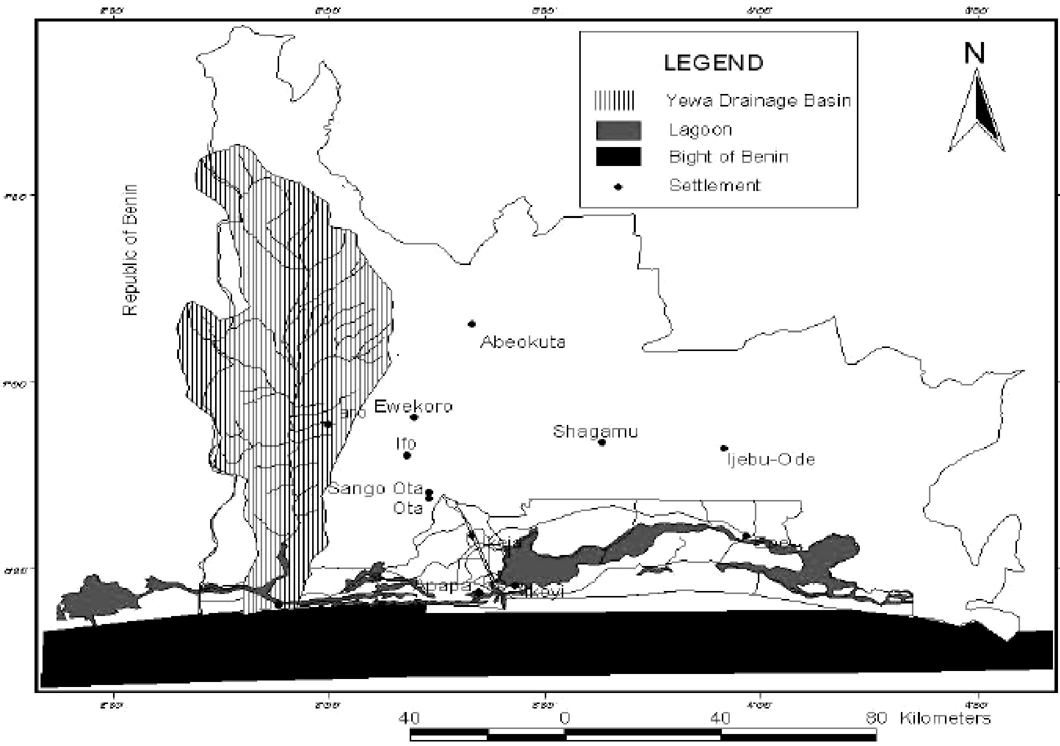

Fig. 1: Study Area Map (Upper Stream of Yewa Drainage Basin)

The temperature is relatively high during the dry season, the mean annual temperature in the basin being about 26oC in the south and 28°C in the north, with a yearly range of + 4oC. The harmattan, which brought the northeasterly wind from December to February, has a positive impact on the dry season. The wet season is characterised by low temperatures, particularly in July and August when temperatures can drop as low as 24°C. But in the Yewa drainage basin, rainfall typically drops from the south to the north, ranging from roughly 1500 mm in the south to roughly 800 mm in the north (Adeaga 2007). It has an annual runoff of 35.4 x 10'm' or a depth of runoff of 354mm per year (Federal Dept. of Water Resources, 1986).

The basin population is estimated at 1,543,400 people, with a projected annual population growth rate of 2.77%, distributed across the five local governments (NPC 2006). Out of this, Yewa North 255, 700, Yewa South 234,400, Imeko-Afon 111,400, Ipokia 209,200 and Ado-Odo Ota 733,400, The study area has a population density of about 214 persons per square kilometre, with Imeko-Afon having the lowest population density of 69.73 km per persons per square and Ado-Odo Ota with the highest number of 835.3 km2 persons per square kilometres.

About 80% of the basin population engages in Agriculture, while during the dry season, the primary means of livelihood in the basin is recession or floodplain farming. (Oyebande and Adeaga 2007). The basin will most likely become more rapidly urbanised in the next decade due to the recently established Dangote Cement Factory at Ibese via Ilaro, in addition to the Ota and Agbara industrial zone, coupled with population influx from Lagos metropolis into the Yewa catchment (Salami 2024). It may, therefore, in effect, be a basin in transition from a rural one to an urbanised one.

There is an increasing urban socio-economic influence from the Lagos metropolis. This growth has led to higher per capita water demand and greater pressure on available freshwater resources, resulting in uncoordinated withdrawals from both surface and groundwater resources (Adeaga 2007). As a result, the basin is experiencing water stress, with very poor access to water among different sectors, which significantly impacts the socioeconomic development of the study area. Climate change and variability, land use, land cover and increased population are some factors that contribute to the challenges of water scarcity in the study area (Salami 2024). Therefore, this is greatly responsible for the challenges being experienced in the basin, including the lack of proper allocation of resources and unsustainable water management policies.

1.2 Research Problem

The upper course of the Yewa River Basinplays a critical role in local hydrology, serving as a significant zone for groundwater recharge, surface runoff, and sediment transport. Despite its importance, limited research exists on the morphometric characteristics of this section, which are essential for understanding its hydrological and geomorphological behaviour. Current studies on the Yewa River Basin primarily focus on the entire drainage system, leaving gaps in knowledge about the specific dynamics of its upper course

Additionally, increasing anthropogenic activities such as deforestation, sand mining, urbanisation, and agriculture in the region have altered the natural landscape, exacerbating erosion, sediment deposition, and hydrological instability. The lack of detailed morphometric analysis has hindered the development of effective watershed management and conservation strategies tailored to the upper course of the basin.

Therefore, a comprehensive morphometric analysis of the upper Yewa River Basin is necessary to bridge this knowledge gap. Such an analysis would provide valuable insights into the region's drainage patterns, runoff potential, erosion susceptibility, and groundwater recharge capabilities, thereby contributing to sustainable water resource management and environmental resilience in the face of climate change and land-use pressures.

1.3 Objective of Study

Analyzing the morphometric characteristics of the upper course of the Yewa River Basin in Southwest Nigeria will help us understand its hydrological and geomorphological behavior and support sustainable watershed management.

Specific Objectives :

1.To determine the drainage pattern and morphometric parameters of the upper Yewa River Basin, including drainage density, stream frequency, bifurcation ratio, and basin shape indices.

2.To examine the hydrological implications of the morphometric characteristics, focusing on surface runoff potential, groundwater recharge, and erosion susceptibility.

3. To assess the impact of topography and geology on the morphometric attributes of the upper course of the Yewa River Basin.

4.To evaluate the influence of land-use changes on the morphometric dynamics and hydrological responses of the basin.

5. To provide recommendations for sustainable watershed management based on the findings.

1.4 Conceptual framework

Stream Order according to McGraw (2013) is defined as "the designation by a dimensionless integer series (1, 2, 3 ...) of the relative position of stream segments in the network of a watershed. The stream order hierarchy was officially proposed in 1952 by Arthur Newell Strahler, a geoscience professor at Columbia University in New York City, in his article Hypsometric (Area Altitude) Analysis of Erosional Topology". The article, which appeared in the Geological Society of America Bulletin, outlined the order of streams as a way to define the size of perennial (a stream with water in its bed continuously throughout the year) and recurring (a stream with water in its bed only part of the year) streams (Briney, 2013).

2. Methodology

This study adopted geographic information systems and remote sensing models. Data used includes: Shuttle Radar Topography Mission (SRTM) with 90 m resolution, Advanced Space born Thermal Topography Mission and Global Elevation Model (ASTER-GDEM) data, with 30 m spatial resolution and grid cells of 1 by 1 arc-second spacing or elevation values at 30-meter intervals obtained from ASTER GDEM, Remote sensing data and Land sat Thematic Mapper OLI data were used as a raw input data. All these were downloaded from the (http://www.usgs.gov) website in addition to a topographical map (1.50,000), geological maps, field data, and reconnaissance. The elevation data in raster format (digital elevation models or DEMs) were obtained from a remote sensing instrument known as the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) attached to a satellite platform SRTM. Data on sediment samples were collected through fieldwork using composite sampling.

ASTER-DEM was used to evaluate the morphometry parameters. Delineation of watershed boundaries, drainage network, and digitisation of the drainage basin were carried out using ArcGIS 10.2 software. The remotely sensed data was geometrically rectified to topographical maps (1:50,000 scale) using satellite imagery, ASTER DEM (30 m resolution). ArcGIS 10.2 software was used to gain a deeper understanding of the drainage system in the study area. The sub-catchments were delineated as shown in Figure 4, based on the water divide line from the watershed raster layer derived from DEM in the hydrology toolbox of ArcGIS, and the morphology of terrain observed on the topographic maps. The Drainage pattern was characterised using a linearly stretched False Colour Composite (FCC) of IRS-1C LISS IV Satellite as detailed in the Arc-Info GIS Software. The digital layers of the hydrological network, land use patterns, and geological conditions of the river basin were obtained by digitising 1:50,000 topographic sheets.

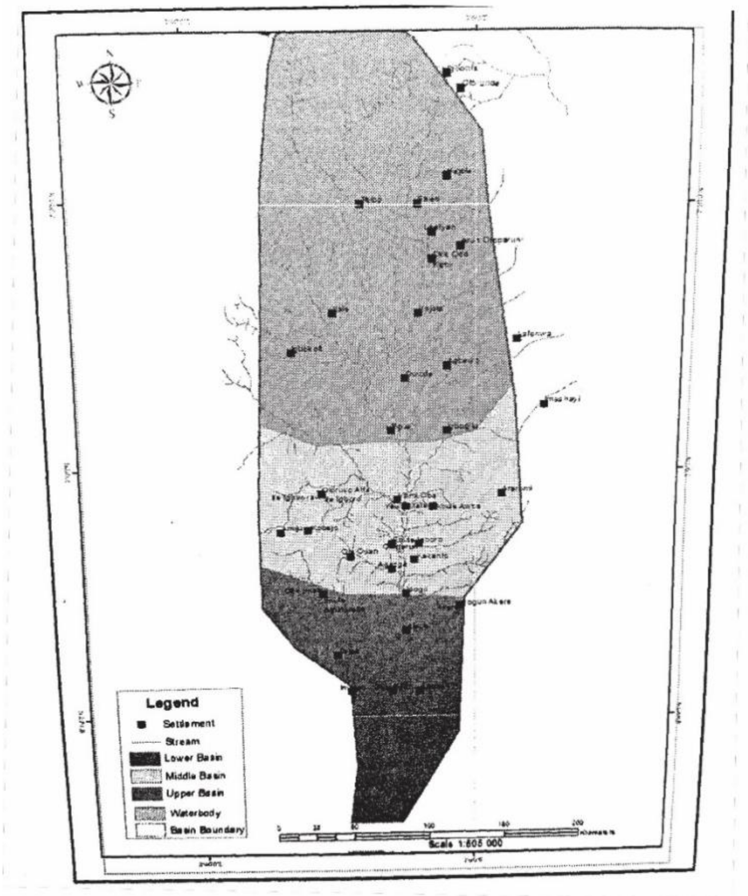

Fig. 2: Indicating the sub-basin of the Yewa drainage basin

The measurement of linear, areal and relief aspects of morphometry parameters, viz: Area (A), stream order (U), number of streams in each order (Nu), stream length (Lu), mean stream length (Lsm), stream length ratio (RL), bifurcation ratio (Rb) mean bifurcation ratio (Rbm), drainage density (Dd), stream frequency (Fs), form factor (R), circulatory ratio (Rc), elongation ratio (Re), drainage texture (T), drainage intensity (ld), length of overland flow (Lo), basin relief (H), relief ratio (Rh) and relative relief (Rhp) were computed using GIS Software analysis tools and different models developed and published through the scientific literature in Geomorphology (Horton 1945, Miller 1953, Schumm 1956 and Strahler 1964) as shown in Table 1.

Table 1: Models for Computation Morphometric Parameters

Morphometry Parameters	Methods	Reference
Linear Aspects		
Stream order (U)	Hierarchical rank	Strahler (1964)
Number of stream (Nu)	Nu= N1+N2… +N6	Horton (1945)
Stream length in Km (Lu)	Lu = L1 + L2 ….. +L6	Horton (1945)
Mean stream length (Lsm)	Lsm = Lu / Nu km Where, Lu = Mean stream length of a given order Nu= Number of stream segments	Strahler (1964)
Bifurcation Ratio (Rb)	Rb = Nu / Nu + 1 Where, Nu = Number of stream segments present in the given order Nu+1= Number of segments of the next highest order	Schumm (1956)
Mean Bifurcation Ration	Rbm = Average of bifurcation ratios of all order	Strahler (1964)

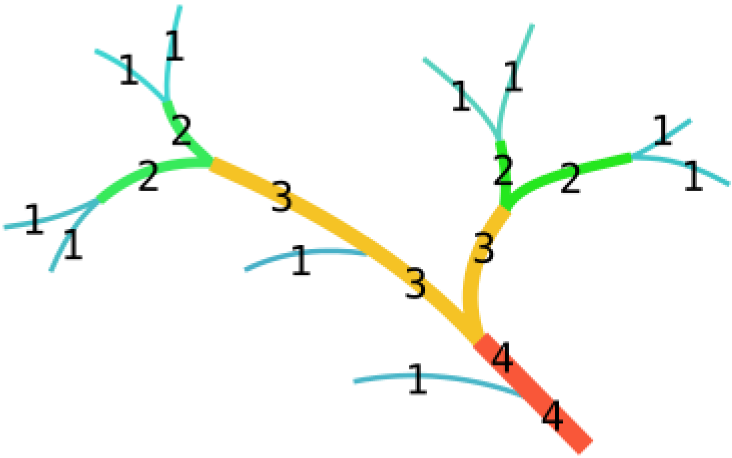

Fig. 3: Conceptual Framework adapted from Strahler's Stream Ordering System (Source: Kreger, 2004)

In the classification of streams by stream order, sizes range from a first-order stream to the largest, a twelfth-order stream (Briney, 2013). A first-order stream is the smallest type of streams and consists of small tributaries (Ogunkoya, 2013). These streams flow into larger streams but typically do not have any water flowing into them from other sources. Moreover, first and second-order streams usually form on steep slopes and flow quickly until they slow down and merge with the next order of waterway. Small drainage basins or watersheds often combine to form larger networks of drainage basins. These integrated drainage basins are referred to as a watershed, while the area between two drainage basins is known as a drainage divide. Classifying stream order is crucial because it allows scientists to study the amount of sediment in an area and to utilize waterways more effectively as natural resources. Stream order also assists geomorphologists, biogeographers, ecologists, and biologists in determining the morphometry of the waterways and the types of life that may inhabit them. This concept is central to the River Continuum Concept (Kreger, 2004). Therefore, this study adopts the conceptual overview of a watershed and stream order pattern as outlined by Strahler in 1964, as shown in Figure 2. The certainty of GIS and Remote Sensing applications in watershed management is well documented, as exemplified by this study.

Additionally, assessing water and sediment quality is a crucial component of environmental monitoring. Any deficiencies in water quality can adversely affects not only aquatic life but also the surrounding ecosystem (Salami 2021). According to Fondriest (2021), the parameters influencing water quality can be categorized as physical, chemical, or biological (. Physical properties include temperature and turbidity. Chemical assessments involve parameters such as pH, nitrogen, phosphorus, and salinity. dissolve oxygen and conductivity. Biological assessments of water quality focus on the presence of algae and phytoplankton. These parameters are vital not only for surface water studies in oceans, lakes and rivers but also for understanding groundwater and industrial processes (Fondriest, 2021).

3. Result

3.1 Linear Parameters of Yewa River Catchment

The linear characteristics of the drainage basin include various computed parameters such as stream order, stream length, mean stream length, stream length ratio and bifurcation ratio. The results of this analysis are shown in Table 3, discussed as follows.

3.2 Analysis of Stream Order

Strahler's stream ordering system classifies streams hierarchically. First-order streams have no tributari, while higher-order streams are formed by the confluence of lower-order streams. The morphometric parameters obtained from the stream order of the upper Yewa River Basin offer essential insights into its hydrological and geomorphological characteristics.

3.3 Stream Order Distribution and Bifurcation Ratio

The stream order analysis shows that first-order streams are the most common, with 44 out of 86 streams classified as first-order. As the stream order increases, the number of streams decreases significantly. This pattern aligns with the classical law of stream hierarchy, which states the number of streams declines exponentially as the order increases.

Table 2: Stream Order of Yewa Drainage Basin

Order	Number	Total
1	44	308.04
2	27	140.62
3	9	29.44
4	6	79.07
Total	86	557.17

3.4 G.I.S. Stream Order Data

The bifurcation ratio (Rb), calculated as the ratio of the number of streams in a given order (Nu) to the number of streams in the next higher order (Nu+1), serves as a key indicator of geological control and surface runoff potential:

$$Rb = \frac{Nu}{Nu + 1}$$

Order 1 to 2: Rb = $\frac{44}{27}$ = 1.63

Order 2 to 3: Rb = $\frac{27}{9}$ = 3.00

Order 3 to 4: Rb = $\frac{9}{6}$ = 1.50

The average bifurcation ratio is 2.04, suggesting that the basin has a moderate structural influence, where the drainage is primarily controlled by surface runoff rather than significant tectonic disturbances.

3.5 Stream Length Analysis and Hydrological Implications

The total stream length within each order adheres to Horton's law, with the highest cumulative length found in first-order streams, measuring 308.04 km. This is followed by a gradual decline in higher orders, with lengths of 140.62 km for second-order streams, 29.44 km for third-order streams, and 79.07 km for fourth-order streams.

The predominance of short, first-order streams indicates rapid surface runoff, which increases the susceptibility to erosion. Additionally, the shorter flow paths and steeper gradients limit groundwater recharge. The presence of dendritic drainage pattern further confirms a homogeneous geological structure in the area.

The total stream length at the fourth order is 79.07 km, indicating that some segments may have undergone more extensive channel development. This could be due to structural influences or resistance from the surrounding lithology. Overall, the total length of streams (Lt) in the Upper Yewa drainage basin is 557.17 km. Within this basin, the lengths of the streams by order are as follows: first-order streams measure 308.04 km, second-order streams measure 140.62 km, the third-order streams measure 29.44 km, and the fourth-order streams measure 79.07 km.

This change may indicate the streams are flowing from high altitudes, alongside variations in lithology and moderately steep slopes (Singh 1997). Observing stream order confirms Horton's law of stream number, which states that the number of stream segments of each order forms an inverse geometric sequence with the other number.

3.6 Hydrological Behaviour and Management Implications

3.6.1 Runoff Potential: The dominance of numerous first-order streams, a moderate bifurcation ratio, and a high relief ratio indicate that the catchment has significant surface runoff. This makes the basin prone to flash floods during heavy rainfall.

3.6.2 Groundwater Recharge: The relatively short total stream length and the quick transitions between stream orders suggest that the area gas lower infiltration rates. This highlights the importance of managing water resources sustainably.

3.6.3 Erosion Control: The morphological characteristics of the area emphasize the need for effective catchment management strategies. These should include afforestation and soil conservation measures to reduce the risk of erosion.

4. Stream orders map of the study area

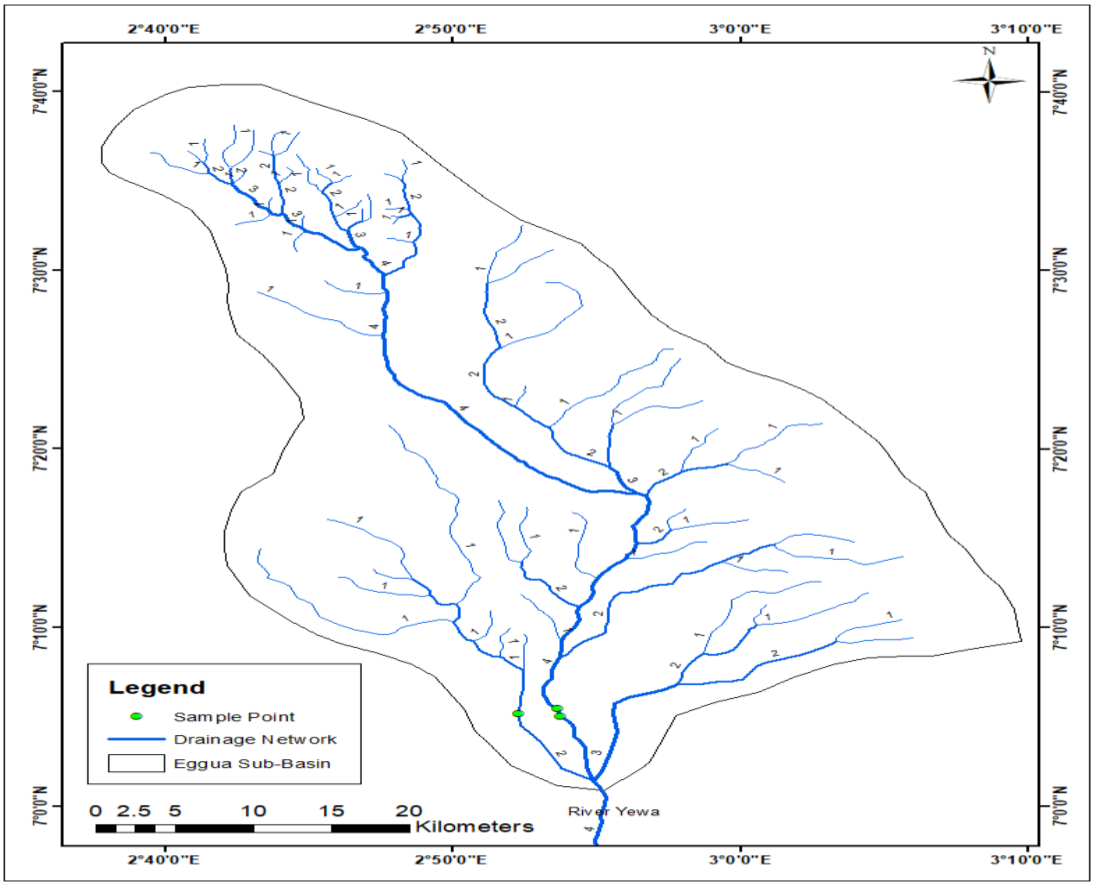

Fig. 3: Topographic Map Sheet Generated from G.L.S

Table 3: Stream Length Ratio of Yewa Drainage Basin

S/N	Length Ratio	LR
1.	L1	2.19
2.	L2	4.78
3.	L3	0.37
	Length Mean	2.45

RL Analysis From G.I.S

4.1 Stream Number (Nu) Analysis

The total number of stream segments present in each order is referred to as the the stream number (Nu), which represents the number of streams of order ‘u’. According to Horton's principle, the number of streams is inversely correlated with the order, meaning that as the stream number increases, the number of streams decreases. In this present study, the number of streams (Nu) forn each order is presented in Table 4.1. A total of 118 streams were identified in the entire Upper Yewa drainage basin. Of these, 51.7% (61l) are 1st order streams, 29.7% (35) are 2nd order, 7.6% (9) are 3rd order, 11.01% (13) are 4th order stream. The calculations show a gradual decrease in the number of streams with increasing stream order, with the exception of the 4th-order stream.

4.2 Stream Length (Lu) Analysis

The stream network of the Upper Yewa drainage basin was previously classified into several orders, which were analysed using the ‘Measure’ tool of ArcGIS software, utilising topographical sheets of the study area as the primary data. Stream lengths were calculated according to the law proposed by Horton, which is significant because it reveals the characteristics of surface runoff within the basin. Typically, the total length of stream segments is Maximum in first-order streams and decreases as stream order increases except for the fourth-order streams, which have a greater length than the third-order streams. In the Upper Yewa drainage basin, the total length of streams (Lt) is 557.17 km. specifically, the lengths of the streams are as follows: first-order streams ismeasure 308.04 km, the second-order streams are 140.62 km, the third-order streams are is 29.44 km, and the fourth-order streams are 79.07 km.

This variation in lengths may indicate that streams flowing from higher altitudes, experiencing lithological changes, and traversing moderately steep slopes (Singh 1997). The observed stream order supports Horton's law of stream numbers, which states that the number of stream segments of each order follows an inverse geometric sequence compared to the order number.

4.3 Mean Stream Length (L_{SM}) Analysis.

The mean stream length is a characteristic of the drainage network and its associated surfaces (Strahler, 1964). The mean stream length (Lsm) is calculated by dividing the total length of streams of a certain order by the number of streams of that order. For this study, the mean stream lengths are as follows: 0.63 km for the first-order streams, 1.14 km for second-order streams, 1.88 km for third-order streams, and 2.43 km for fourth-order streams. This indicates that the mean stream length in the study area increases with the increase with the stream order.

4.4 Stream Length Ratio (RL) Analysis

The stream length ratio is defined as the ratio of the mean stream length of a given order to the mean stream length of the next lower order. This ratio has an important relationship with surface flow and discharge (Horton, 1945). As shown in Table 4, the stream length ratio varies between 2.19 and 0.37, with an average of 2.45. The RL values across different streams orders in the basin indicate variations in slope and topography.

Table 4: Bifurcation Ratio of Yewa Drainage Basin

S/N	Length Ratio	BR
1.	B1	1.74
2.	B2	3.89
3.	B3	0.69
	Bifurcation Mean	2.11

Rb Analysis from G.I.S

4.4 Bifurcation Ratio (Rb) Analysis

The bifurcation ratio (Rb) can be defined as the ratio of the number of stream segments of a given order to the number of segments of the next higher order (Schumn 1956). Horton (1945) considered the bifurcation ratio as an indicator of landscape relief and dissections. Strahler (1957) demonstrated that the bifurcation ratio exhibits a relatively small range of variation across different regions or environmental conditions, except in cases where geology plays a dominant role. It is important to note that Rb can vary from one order to the next order. In the study area, the mean Rb ranges from 1.74 to 0.69, an overall mean Rb of 2.11 for the entire basin (Table 5). These values are typically observed in areas where geological structures do not significantly influence the drainage pattern.

The Bifurcation Ratio is fundamental in drainage basin analysis, as it serves as the primary parameter linking the hydrological regime of a watershed to its topological and climatic conditions (Raj et. al., 1999). This ratio provides insight the shape of the basin and helps to understand runoff behaviour. Although, the bifurcation ratio will not remain constant from one order to the next due to changes in the watershed geometry and lithology, it tends to be relatively consistent throughout the sequence.

4.5 Determine Aerial Parameters of Yewa Drainage Basin.

The aerial characteristics of a drainage basin provide insights into various regional features, including lithology, geology, climatic conditions and the basin's denudation history. The areal aspects typically encompass parameters such as basin area and length, drainage density, drainage texture, stream frequency, form factor, circularity ratio, among others. In this study, the total area of the basin is measured at 2085.37 km^2 and the basin length is 77.12 km (Table 6).

Table 5: Results of Parameters of Areal Aspects

S/N	Perimeter	Measurement
1.	Basin Area	2085.37 km^2
2.	Basin Length	77.12 km^2
3.	Drainage Density	0.27 km^2
4.	Drainage Texture Ratio	0.57 km^2
5.	Form factor	0.35 km^2
6.	Circulatory ratio	1.82 km^2
7.	Elongated Ratio	0.67Km^2
8.	Constant Channel Maintenance	3.74km^2
9.	Length of overland flow	0.13Km^2

Areal Parameter Analysis from GIS

4.6 Drainage Density Analysis

Drainage density is defined as the total length of streams per unit area within a drainage basin. It is calculated by taking the ratio of the total stream lengths of all stream segments in a given drainage basin to the total area of that basin (Horton 1945), Several factors, including climate, soil type, relief, rock type, vegetation cover, infiltration capacity and runoff intensity, influence drainage density. Generally, low drainage density is associated with coarse texture, while high drainage density corresponds to fine texture (Strahler 1964). High drainage density typically results from weak and impermeable subsurface materials, sparse vegetation and mountainous relief. In this study, the drainage density of the Upper Yewa drainage basin was calculated in a GIS environment to be 0.27 (see Table 6). This means there are 0.27 km of channel for every 1 km of land surface. Thus, the value of 0.27 indicates that the region has permeable subsoil, dense vegetation cover, and moderate relief.

4.7 Drainage Texture Ratio (Rt) Analysis

Drainage Texture ratio (Rt) is an essential areal parameter of the basin, representing the relative spacing of drainage lines. Drainage texture refers to the total number of stream segments of all orders per perimeter of the area (Horton, 1945). Drainage lines are typically more numerous over impermeable areas compared to permeable ones. According to Horton (1945), the infiltration capacity is the most important factor which influencing drainage texture, which encompasses both drainage density and stream frequency. Smith (1950) classified drainage texture into five different categories: very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8), and very fine (>8). In the present study, the drainage texture value of the Upper Yewa drainage basin stands at 0.57 (see Table 6), indicating that the drainage texture pattern of the Upper Yewa drainage basin is very coarse.

5. Form Factor (Rf)

The form factor is a numerical index (Horton, 1932) commonly used to represent different shapes of drainage basins. The value of the form factor ranges from 0.1 to 0.8. The smaller form factor value indicates a more elongated the basin. The basins with a higher form factor of 0.8 tend to have high peak flows that last for a shorter duration, while elongated drainage basins with lower form factors exhibit lower peak flows that persist for a longer duration. For the Upper Yewa drainage basin, the form factor value is 0.35, which suggests an elongated shape (Table 6).

• Circulatory Ratio (Rc)

The circulatory ratio, defined by Miller (1953) compares the area of the basin to the area of the circle that has the same circumference as the basin perimeter. This ratio is significant as it indicates the degree of dissection in the study area. The value of the circulatory ratio ranges from 0 (indicating a linear shape) to 1 (indicating a circular shape). According to Miller (1953), Rc values close to 1 suggest that the basin is more circular, which allows for uniform infiltration and results in a longer time for excess water to reach the basin outlet. The Rc value for the Upper Yewa drainage basin is 1.82 (Table 6), indicating that the basin has an elongated shape.

- **Elongation Ratio (Re)**

The elongation ratio is defined as the ratio between the diameter of the circle that has the same area as the drainage basin and the maximum length of the basin (Schumm, 1956). Strahler (1964) noted that values close to 1.0 are found in regions with very low relief, while values between 0.6 and 0.8 are typically associated with high relief and steep ground slopes. These values can be categorized into three types: circular (>0.9), oval (0.9-0.8), and less elongated (<0.7). The elongated ratio (Re) for the study area is 0.67 (Table 6), indicating a less elongated shape with high relief and steep slopes.

- **Constant of Channel Maintenance (C)**

The constant channel maintenance (C) is the inverse of drainage density and has dimensions of length (Schumm, 1956). This constant indicates the number of kilometres of basin surface needed to develop and sustain a channel that is 1km long. The constant of channel maintenance reflects the relative size of landform units in a drainage basin and has a specific genetic connotation (Strahler, 1957). For this study area, the average constant of channel maintenance is 3.74 (Table 6).

- **Length of Overland Flow (Lg)**

The length of overland flow is closely related to the soil infiltration capacity. When this capacity is exceeded due to heavy precipitation, the excess water flows toward the channel and along the steep slopes. This parameter is crucial for analysing runoff and flood processes. According to Horton (1945), the length of overland flow is often about half the average distance between stream channels, which also roughly corresponds to half the reciprocal of drainage density. A shorter the length of overland flow results in quicker surface runoff from the streams. This length is inversely related to the average slope of the basin. In this study, the length of overland flow in the study area is 0.13 (as shown in Table 6), indicating low surface runoff in the basin. This further confirms the basin's lower susceptibility to both soil erosion and flooding.

- **Determination of the Relief Aspects of the Upper Yewa Drainage Basin**

The relief parameter refers to the vertical dimension of a drainage basin. Understanding the relief aspects is essential for studying three-dimensional features of the basin. It plays a significant role in understanding geomorphic processes and landform characteristics, as illustrated Figures 8 and 9, which display the elevation and aspect maps. According to Hadley and Schumm (1961), basin relief affects the stream gradient and influences flood patterns and the volume of sediment that can be transported. The relief aspects, which include Relative relief (R), Relief Ratio (R), and Ruggedness (k), have been calculated and are discussed below, with results presented in Table 7.

Table 6: Relief Aspect of Yewa Drainage Basin

Basin Relief	204m
Relief Ratio	2.64
Ruggedness Number	55.08

GIS Relief Parameter Analysis

- **Basin Relief (R) Analysis**

According to Schumm (1956), Basin relief is the vertical distance between the lowest and highest points of a watershed. In this study, the Basin relief of the Upper Yewa drainage basin is measured at 204 meter (Table 7), indicating a relatively low relief elevation.

- **Relief Ratio (Rh) Analysis**

According to Schumm (1956), the Relief ratio (Rh) is a dimensionless height/length ratio between the basin relief (H) and basin length (Lb). It represents the relationship between total relief and the length of the principal drainage line (Lindsay and Seibert, 2013). This ratio indicates the overall steepness of the drainage basin and is related degradation processes. Gottschalk (1964) proposed that the Rh typically increases as the drainage area and size of sub-watersheds decrease within a given drainage basin. In this study, the Rh value is calculated to be 2.64 (see Table 7 and Figure 8).

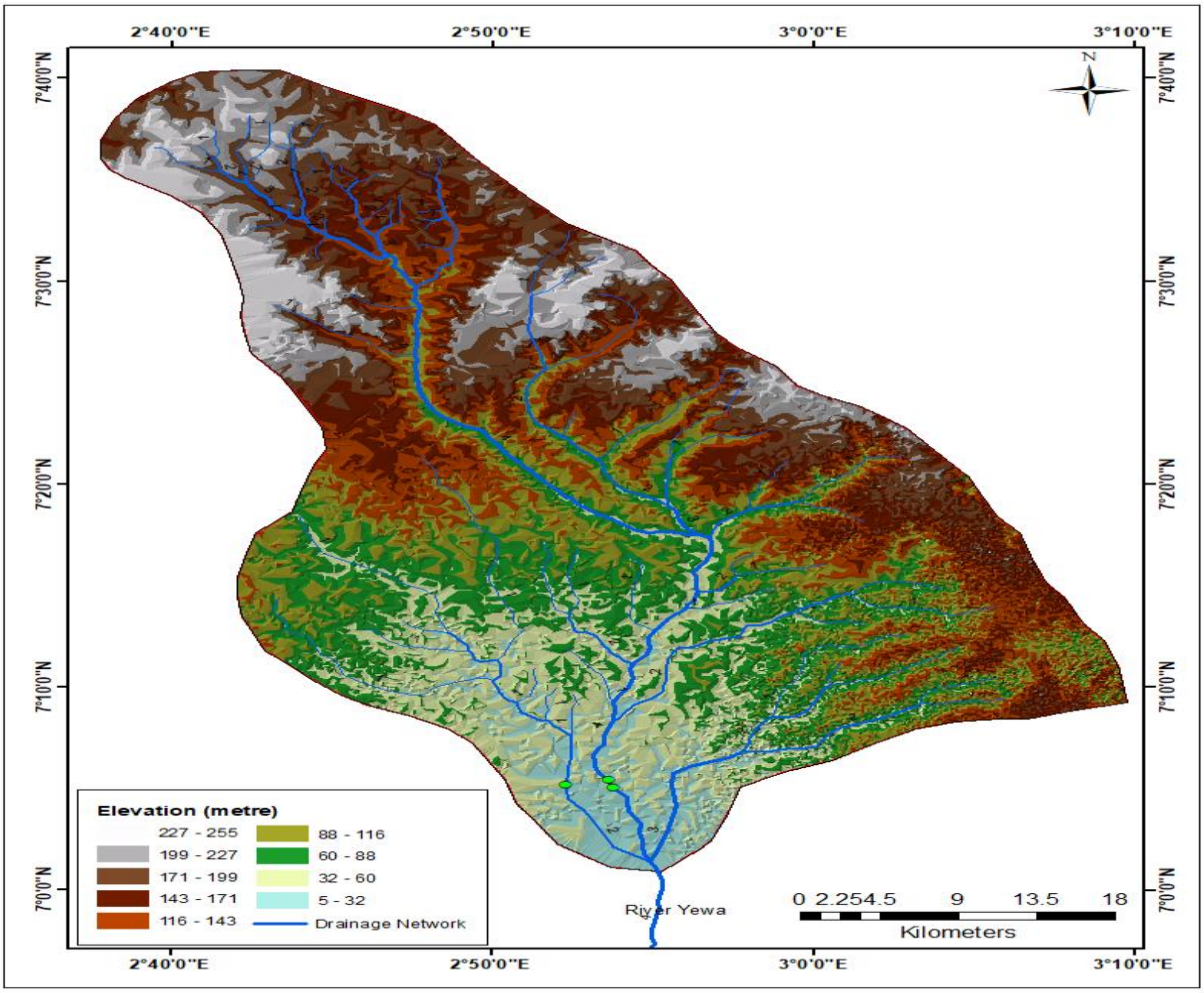

Fig. 4: Elevation map of the study area.

- ## Raggedness No (Rn) Analysis

The level of ruggedness does not necessarily reflect the structural complexity of the terrain. A very high ruggedness value does not occur when both variables, namely D and H, are large, and when the slope is both steep and long (Strahler, 956). In this study, the value of Rn is 55.08 (see Table 6).

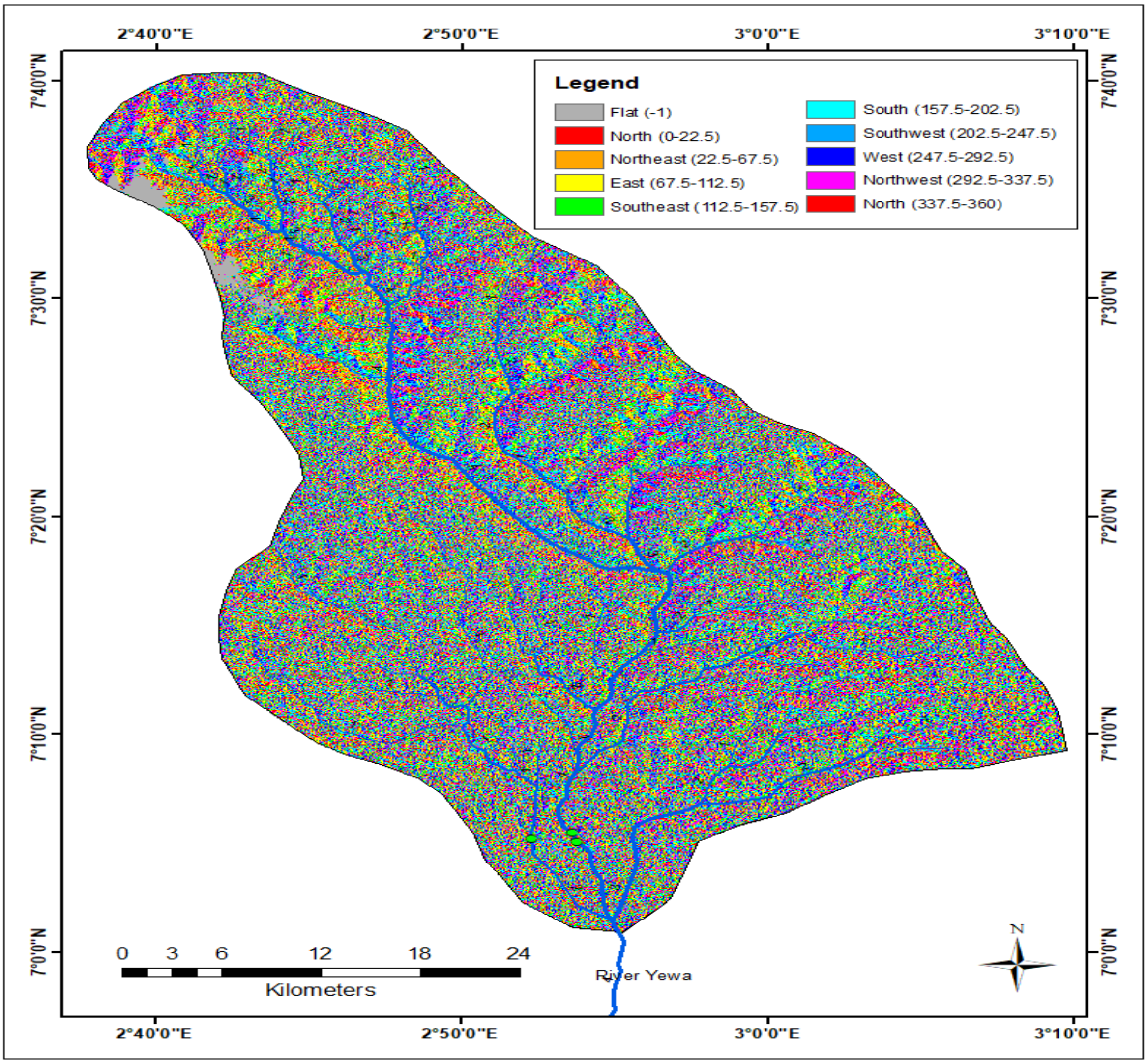

Fig. 5: Aspect Map of the study area.

Table7: Yewa Drainage Basin Coordinates

Aspect	Unit	Aspect	Unit
Flat	-1	South	157.5-202.5
North	0-22.5	Southwest	202.5-247.5
Northeast	22.5-67.5	West	247.5-292.5
East	67.5-112.5	Northwest	292.5-0337.5
Southeast	112.5-157.5	North	337.5-360

Aspect Coordinates from GIS

6. Conclusion

The stream order analysis of the Yewa River Basin follows Strahler's classification, indicating that it is a hydrologically active basin with high runoff potential and a moderate structural influence. These findings provide are essential for developing sustainable watershed management practices and effective flood mitigation strategies in Southwest Nigeria.

- Drainage Pattern and Morphometric Parameters: The Upper Yewa River Basin exhibits a dendritic to sub-dendritic drainage pattern, which indicates a homogenous geological structure with minimal structural control. The drainage density is moderate, suggesting a balanced interaction between runoff and infiltration. The bifurcation ratio is relatively low, signifying a less structurally disturbed basin with a stable drainage network.

- Hydrological Implications: The basin has a moderate to high potential for surface runoff, especially in areas with higher drainage density. Groundwater recharge potential varies across the basin, with greater infiltration expected in regions of lower drainage density. Erosion susceptibility is moderate, but some sections show increased vulnerability due to variations in stream frequency and slope.
- Impact of Topography and Geology: Elevation and slope variations significantly influence drainage characteristics. Steeper areas tend to have higher runoff and lower infiltration. The underlying geological formations play a crucial role in determining drainage density and stream patterns, which impact overall hydrological responses.
- Land Use and Hydrological Responses: Urbanisation and deforestation have altered runoff characteristics, leading to localised flooding risks in certain parts of the basin. Agricultural activities have affected sediment transport and degradation of water quality. Changes in land use have slightly modified morphometric attributes over time, influencing hydrological dynamics such as water retention and erosion rates. These findings provide valuable insights into the hydrological behaviour of the Upper Yewa River Basin and emphasize the need for sustainable water resource management and erosion control strategies.

7. Recommendations

Based on the morphometric analysis and hydrological insights derived from the upper Yewa River Basin, the following targeted recommendations are proposed:

- **Integrated Watershed and Land Use Management**
  Zoning and Development Control: Introduce strict land-use zoning, particularly in erosion-prone and high-relief zones, to manage deforestation, urban encroachment, and protect natural drainage channels.
  Eco-friendly Farming Practices: Encourage contour farming, agroforestry, and other soil-conservation techniques to reduce erosion and promote sustainable land use across the basin.

- **Hydrological Monitoring and Flood Risk Mitigation**
  Smart Monitoring Systems: Establish a real-time hydrological monitoring network using GIS and remote sensing to assess runoff, stream frequency, and erosion hotspots.
  Buffer Zones and Wetlands: Develop vegetative buffer strips and small wetland systems along critical tributaries to slow runoff and trap sediments.

- **Erosion and Sediment Management**
  Reforestation of Degraded Areas: Focus reforestation efforts in areas with high bifurcation ratios and drainage density to reduce surface runoff and soil loss.
  Gully Rehabilitation: Use check dams and terracing in high-relief segments to stabilise slopes and control sediment transport into the river system.

- **Sustainable Water Resource Management**
  Rainwater Harvesting and Recharge Zones: Implement decentralised rainwater harvesting systems in rural and peri-urban zones to improve groundwater recharge and reduce reliance on unregulated surface withdrawals.
  Equitable Water Access Framework: Develop a participatory water governance model that balances agricultural, domestic, and industrial needs amid increasing urban pressure from Lagos and industrial expansion in Agbara and Ibese.

- **Policy and Community Engagement**
  Community-Based Management Initiatives: Promote local stewardship through education and incentives for sustainable land and water management practices.
  Legislative Support: Enforce environmental regulations to manage sand mining and improper land conversion, ensuring hydrological stability and long-term sustainability.

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Conflict of Interest

The author declare there is no conflict of interest.

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