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RESEARCH ARTICLE

Morphometric analysis of drainage basins using ArcGIS for understanding erosion patterns and hydrological characteristics

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ABSTRACT

The Anambra River Basin's hydrological and erosion dynamics are critical for regional water resource management. This study aims to analyze the morphometric characteristics of the five major basins within the Anambra River Basin to understand their impact on hydrology and erosion patterns. The study aims to provide a comprehensive morphometric analysis of the Anambra River Basin to inform effective water resource management and erosion control strategies. Morphometric parameters such as area and perimeter of the five major basins were analyzed. Stream order analysis was conducted to classify streams into secondary, primary, and tertiary orders, along with a category labeled "Others" for minor streams. The First Basin, the largest, covers an area of 1459.27 km² with a perimeter of 257.38 km. The smaller basins, Fourth and Fifth, have areas of 171.81 km² and 227.45 km², respectively. Tertiary streams, with an area of 0.78 km² and perimeter of 75.37 km, were identified as having the highest runoff volume. Larger basins like the First Basin are more susceptible to erosion due to their extensive surface areas exposed to rainfall and runoff. Smaller basins, influenced by localized factors, experience less intense erosion. Stream order analysis highlights the significant hydrological contributions of tertiary streams. Effective water resource management in the Anambra River Basin requires understanding the distinct morphometric characteristics of each basin. Larger basins necessitate extensive erosion control measures, while smaller basins require localized strategies. The study underscores the importance of tailored management practices to mitigate erosion and ensure sustainable water use. This study provides a detailed morphometric analysis of the Anambra River Basin, offering insights into the hydrological and erosion dynamics of different basin sizes and stream orders. It emphasizes the need for tailored management strategies to address specific hydrological and environmental challenges within the basin.

1. INTRODUCTION

Morphometric analysis is a critical tool in the study of river basins, involving the quantitative evaluation of the basin's shape, size, drainage pattern, and network (Kaliraj et al., 2014; Różycka & Migoń, 2021). Such an analysis offers valuable insights into the processes governing erosion and hydrological behavior, which are essential for effective water resource management, environmental planning, and mitigating the impacts of erosion and flooding (Owens, 2020). The Anambra River Basin exhibits a predominantly dendritic drainage pattern, characterized by a tree-like branching network of streams and rivers. This pattern suggests a relatively homogeneous lithology and uniform slope across the basin (Ayogu et al., 2019; Kaliraj et al., 2014). The dendritic pattern indicates that the underlying geological materials are equally resistant to erosion, facilitating a well-defined and interconnected drainage network. This uniform resistance to erosion helps in maintaining a consistent flow of water through the network, enhancing the basin's hydrological efficiency (Konsoer et al., 2016; Peifer et al., 2020).

Drainage density, defined as the total length of streams per unit area, provides insights into the density and complexity of the drainage network. In the Anambra River Basin, a high drainage density indicates a well-developed network of streams and rivers (Ayogu et al., 2019). This characteristic suggests a relatively low permeability of the underlying geological materials, which promotes higher surface runoff and enhances the basin's erosion potential. The dense drainage texture further underscores the efficient channeling of water within the basin, influencing sediment transport, flood patterns, and overall hydrological dynamics (Ferrer-Boix & Hassan, 2015). Erosion within the Anambra River Basin is influenced by a combination of natural processes and human activities. Natural factors such as rainfall intensity, soil type, and slope gradient play pivotal roles in shaping erosion patterns (Ocheli et al., 2021). The region experiences a tropical climate with distinct wet and dry seasons, where heavy rainfall during the wet season accelerates surface runoff and soil erosion. The basin's geological composition, predominantly sedimentary rocks of varying resistances, further influences erosion susceptibility.

Human activities significantly exacerbate erosion within the Anambra River Basin. Deforestation, primarily for agricultural purposes and urban expansion, exposes soils to erosion by removing protective vegetation cover. Agricultural practices such as improper land management and the use of heavy machinery contribute to soil compaction and increased sedimentation in water bodies. Urbanization alters natural drainage patterns and increases impervious surfaces, further amplifying surface runoff and erosion rates (Chukwuka, 2016; Igwe & Egbueri, 2018; Aigbadon et al., 2021).

Morphometric analysis of the Anambra River Basin provides valuable insights into its erosion history and current landscape formation. The basin's high bifurcation ratio indicates a mature drainage network characterized by well-developed tributaries (Ocheli et al., 2021; Igwe & Egbueri, 2018). This maturity suggests that the basin has undergone extensive erosion over geological timescales, resulting in a well-defined network capable of efficiently transporting sediment and runoff. Despite its maturity, ongoing erosion processes are evident in the Anambra River Basin, particularly in areas with steep slopes and loose, easily erodible soils (Ayogu et al., 2019). The basin's high drainage density and stream frequency suggest continuous sediment transport and channel adjustment. These factors highlight the dynamic nature of erosion within the basin, influenced by both natural erosion processes and anthropogenic activities.

The hydrology of the Anambra River Basin exhibits distinct seasonal variations in river discharge, driven by its tropical climate. During the wet season, characterized by heavy and intense rainfall, the basin experiences increased surface runoff and higher river discharge rates. The combination of the basin's high drainage density and low permeability of underlying materials results in rapid runoff and short lag times between rainfall events and peak discharge (Ayogu et al., 2019; Egbueri & Igwe, 2020). This hydrological response contributes to the basin's susceptibility to flooding during periods of prolonged or intense rainfall. The elongation ratio of the Anambra River Basin, indicative of its relatively elongated shape, influences flow concentration and flood potential. An elongated basin typically exhibits a more prolonged flow concentration time, which can mitigate peak discharge rates during storm events by spreading out the flow over a larger area. However, the presence of numerous tributaries and a dense drainage network can complicate this pattern, leading to localized flooding in specific areas with constrained drainage capacities.

Understanding the morphometric characteristics of the Anambra River Basin is crucial for effective water resource management. The high drainage density and stream frequency indicate a need for erosion control measures, such as afforestation, terracing, and the construction of check dams, to reduce surface runoff and sediment transport. These measures can help stabilize the soil and reduce the impact of erosion (Dragičević et al., 2019). The seasonal variability in river discharge necessitates the development of storage facilities, such as reservoirs and dams, to capture excess water during the wet season for use during the dry season. These structures can also help mitigate the impacts of flooding by regulating the flow of water. These structures can store excess water during the wet season, which can be used during dry periods. They can also help in controlling the flow of water, reducing the risk of flooding (Aduojo et al., 2018). Implementing flood management strategies, such as creating floodplains and constructing levees, can help in managing the excess water flow during heavy rainfall and reduce the impact of floods.

The morphometric analysis of the Anambra River Basin reveals critical insights into its erosion patterns and hydrological behavior. The dendritic drainage pattern, high drainage density, and bifurcation ratio highlight the basin's well-developed and interconnected network, shaped by both natural processes and human activities (Egbueri & Igwe, 2020). Understanding these morphometric characteristics is essential for developing effective water resource management strategies, erosion control measures, and flood mitigation plans. The study focuses on the Anambra River Basin, aiming to integrate natural and anthropogenic factors influencing erosion and hydrology through a comprehensive morphometric analysis using ArcGIS. Key research questions include: How do erosion patterns impact water resources? What are the hydrological characteristics? The study's importance lies in informing sustainable management practices for environmental protection and resource conservation. Addressing these questions will highlight the necessity of this research and elevate its relevance beyond local interest by providing insights applicable to broader geographical contexts and informing policy development.

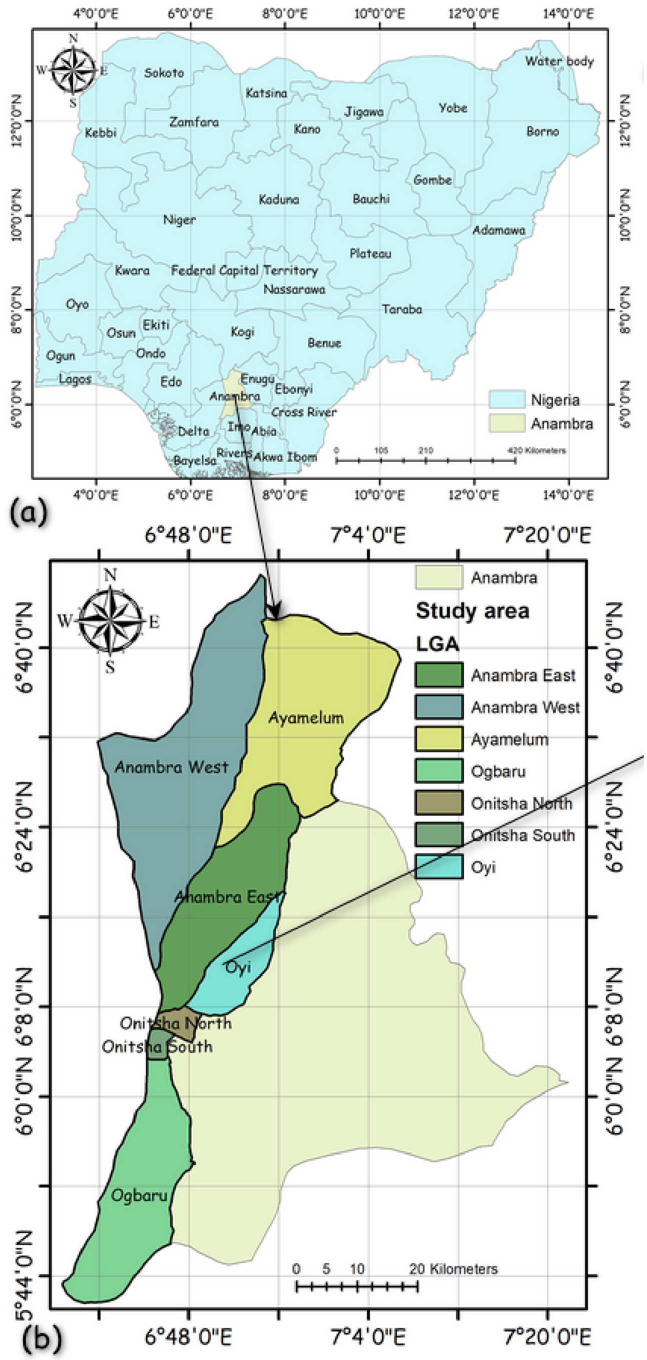
1.1. The study area

Anambra State, Nigeria, encompasses several Local Government Areas (LGAs) crucial for studying the Anambra River Basin's hydrology and geomorphology, the study location is shown in Figure 1. Anambra West LGA, located in the northwestern part of the state (approximately between coordinates 6.059°N latitude and 6.985°E longitude), features an extensive network of tributaries and floodplains that significantly influence the basin's hydrology. Major towns like Nzam, Umueze Anam, and Mmiata Anam characterize this low-lying area prone to seasonal flooding, especially during the rainy season (Egbueri & Igwe, 2020). Anambra East LGA, situated where the Anambra River converges with the River Niger (around coordinates 6.112°N latitude and 6.932°E longitude), includes prominent towns such as Aguleri, Umuleri, and Otuocha. This convergence area is critical for studying hydrological interactions and sediment transport dynamics within the basin. Ayamelum LGA, positioned in the northern part of Anambra State (approximately between coordinates 6.296°N latitude and 6.972°E longitude), provides insights into the upper reaches of the Anambra River (Egbueri & Igwe, 2020). Towns like Omor, Umumbo, and Ifite Ogwari are situated amidst gently undulating hills and valleys that direct the flow of the river and its tributaries.

Oyi LGA, centrally located in Anambra State (around coordinates 6.208°N latitude and 6.936°E longitude), is influenced by the Anambra River's drainage patterns. It features a mix of lowland areas and gentle hills, with towns such as Nteje and Ogbunike contributing to the overall water flow and sediment load of the basin. Onitsha North and South LGAs, near the confluence of the Anambra River and the River Niger (around coordinates 6.149°N latitude and 6.785°E longitude), encompass the urban center of Onitsha. This confluence zone is vital for studying hydrodynamic interactions between the rivers, particularly in terms of flood dynamics and sediment transport. Ogbaru LGA, situated along the western banks of the River Niger (approximately between coordinates 6.202°N latitude and 6.783°E longitude), features lowland floodplains and riverine environments influenced by both the Anambra River and the River Niger. These areas contribute significantly to the hydrology and geomorphology of the region, playing a crucial role in the broader dynamics of the Anambra River Basin.

1.2. Geology of the study area

Geologically, Anambra West LGA forms part of the Anambra Basin, a sedimentary basin that spans a significant portion of southeastern Nigeria as in shown in Figure 2. The area's geological formations predominantly comprise sandstones, shales, and siltstones, deposited during the Cretaceous to Tertiary periods. These relatively young rocks vary in erosion resistance, contributing to the dendritic drainage pattern observed across the basin (Igwe, 2014). Floodplains and wetlands in Anambra West LGA play vital roles in water management and agriculture, supporting extensive farming during dry seasons but posing challenges during floods. Anambra East LGA is characterized by alluvial deposits consisting of sands, silts, and clays, deposited by the Anambra River and the River Niger (Allen et al., 2016). These fertile soils facilitate agriculture but are prone to erosion and flooding, particularly during peak rainy seasons. The confluence of these rivers influences sediment deposition patterns and the formation of natural levees and floodplains. Ayamelum LGA lies within the Anambra Basin, sharing similar sedimentary rock formations with Anambra West LGA, including sandstones, shales, and mudstones. The upper reaches of the Anambra River in Ayamelum LGA exhibit higher flow velocities and lower sediment deposition compared to downstream areas, influencing sediment transport dynamics.



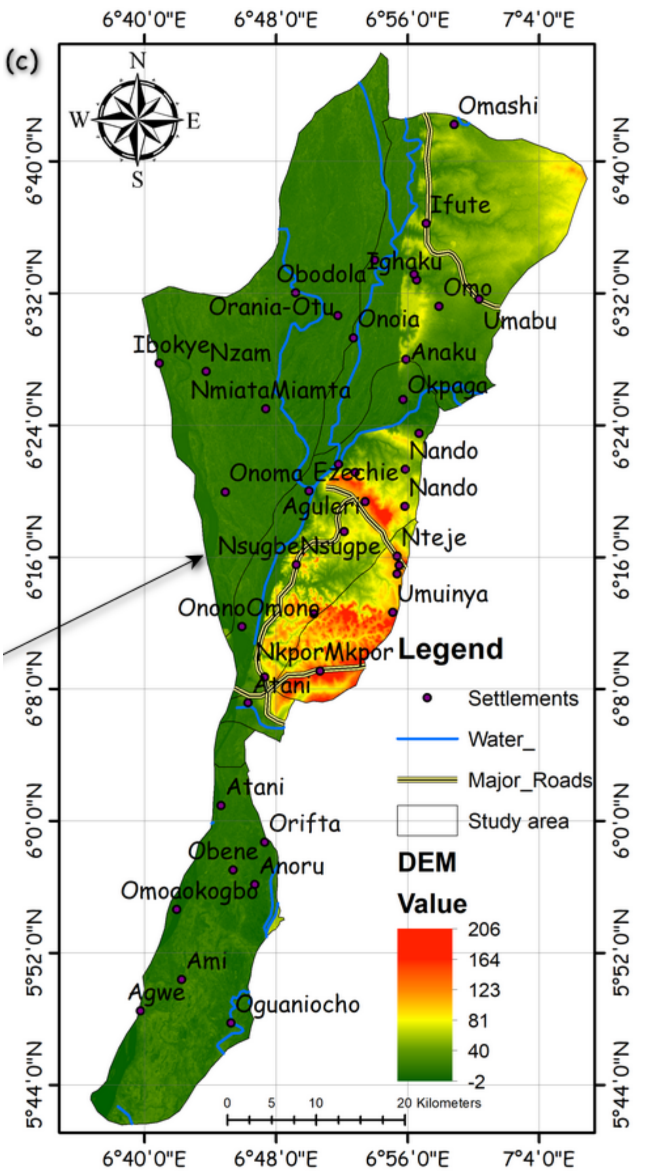


Figure 1: Showing (a) Nigeria (b) Anambra state and (c) DEM map of the study area

Oyi LGA's geology features sedimentary formations typical of the Anambra Basin, influencing dendritic drainage patterns and sediment transport within the mid-section of the Anambra River Basin. Onitsha, located near the confluence of the Anambra River and the River Niger, is characterized by alluvial deposits and recent sediments. Urbanization has altered natural drainage patterns, increasing erosion and flood risks, necessitating integrated water resource management strategies. Ogbaru LGA's geology is dominated by alluvial deposits from the River Niger and the Anambra River, supporting agriculture but susceptible to flooding, highlighting the need for effective flood management and erosion control measures. Figure 2 illustrates the geological framework essential for understanding the hydrological dynamics and sediment transport within the Anambra River Basin.

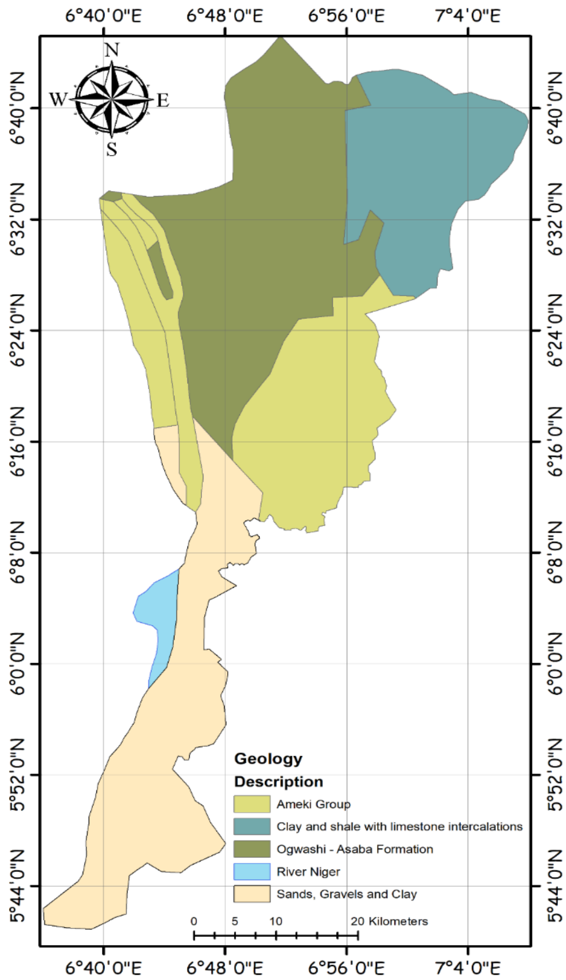


Figure 2: Geological map of the study area

2. MATERIALS AND METHODS

The morphometric analysis of the Anambra River Basin hinges on precise digital elevation model (DEM) data sourced from the United States Geological Survey (USGS). Specifically, the Shuttle Radar Topography Mission (SRTM) data was chosen for its exceptional accuracy and high resolution, qualities essential for conducting detailed morphometric studies. This dataset enables comprehensive analysis of terrain characteristics such as elevation, slope, and aspect, which are crucial for understanding watershed dynamics and geomorphological processes within the basin.

Table 1 details the essential information regarding the GIS data utilized in the study. It categorizes the data type as GIS Data, specifying that it comprises SRTM Elevation Data. The USGS is identified as the provider of this critical dataset. Such information is vital for transparency and reproducibility in research, ensuring that the data sources are clearly documented for future studies and comparisons.

Table 1: Data Source and Type

Data Type	Source	Provider
GIS Data	SRTM Elevation Data	United States Geological Survey (USGS)

2.1. Data acquisition and preprocessing

The DEM data sourced from the USGS was integral to the morphometric analysis of the Anambra River Basin. Initially, the DEM data were downloaded and meticulously preprocessed using ArcGIS software to ensure accuracy and compatibility with the study's requirements (Okoli et al., 2024). The preprocessing workflow encompassed several crucial steps. The SRTM data was imported into ArcGIS, where it underwent reprocessing to conform to the WGS 84/UTM Zone 32N coordinate system, which is appropriate for the study area. This reprojection step is essential for aligning the data with other geospatial datasets and ensuring spatial accuracy in subsequent analyses.

Another significant preprocessing step involved filling sinks in the DEM. Sinks are depressions in the terrain that can disrupt the flow of water and affect the accuracy of hydrological modeling. By filling these sinks, the DEM was optimized to establish continuous flow paths, which are vital for accurately simulating surface water flow within the basin (Okoli et al., 2024). The DEM was clipped to match the precise boundary of the study area. This clipping process focused the analysis exclusively on the relevant geographic area, enhancing the accuracy and relevance of the morphometric studies conducted within this specific watershed.

The preprocessing of the DEM data involved meticulous attention to detail to ensure that the data were not only accurate but also effectively tailored to the study's geographic and analytical requirements (Akaolisa et al, 2024; Okoli et al., 2024). These steps are fundamental in geospatial analysis, providing a reliable foundation for studying terrain characteristics, watershed dynamics, and geomorphological processes within the Anambra River Basin.

2.2. Watershed delineation

Watershed delineation is a fundamental step in hydrological and geomorphological studies, crucial for accurately defining the boundaries of the Anambra River Basin and its sub-basins (Aziz et al., 2023). The process begins with calculating flow direction using the preprocessed DEM. This step determines the direction in which water would flow across the terrain, essential for understanding runoff patterns and identifying drainage pathways within the basin (Nwosu, 2018). Flow direction calculation, the next step involves generating a flow accumulation grid. This grid accumulates the number of cells that flow into each specific cell, effectively mapping out the stream networks within the basin (Zhang et al., 2017). This information is pivotal for delineating the primary channels and identifying potential areas prone to flooding or erosion.

Once the flow accumulation grid is established, the stream network is defined by applying a threshold value. This threshold distinguishes between intermittent and perennial streams based on the accumulation of water flow, aiding in the identification of the main channels and tributaries that form the basin's hydrological network (Paul et al., 2017). Watershed boundaries are delineated based on the established stream network. This process identifies the areas where all surface water drains to a specific point, typically a river outlet or a confluence of streams (Lai et al., 2015). By delineating these boundaries, researchers can precisely define the extent of the Anambra River Basin and its sub-basins, facilitating comprehensive analyses of water flow dynamics, sediment transport, and ecological processes within each delineated area.

Watershed delineation integrates advanced geospatial techniques with hydrological principles to provide a detailed understanding of basin morphology and dynamics (Aziz et al., 2023). These delineation processes are foundational for various environmental studies, supporting informed decision-making in water resource management and conservation efforts in the Anambra River Basin and similar watersheds worldwide.

2.3. Calculation of morphometric parameters

Several morphometric parameters were meticulously calculated to comprehensively analyze the shape, size, drainage pattern, and network characteristics of the Anambra River Basin. These parameters provide essential insights into the hydrological and geomorphological dynamics of the basin (Ayogu et al., 2019). Here are the key parameters and their respective calculations:

The basin area (A) was computed by summing the areas of all cells within the basin using the DEM. The perimeter (P) was determined by summing the lengths of all boundary segments of the basin.

$$A = \sum(Cell\ area) \quad (1)$$

$$P = \sum(boundary\ length) \quad (2)$$

The basin length (L_b) represents the longest distance from the outlet of the watershed to the farthest point on the basin boundary. This parameter helps characterize the spatial extent of the basin.

Stream order was established using the Strahler method, which assigns order 1 to the smallest streams and increases order where streams of the same order intersect (Olla et al., 2020). For each stream order, the total stream length (L_u) was computed by summing the lengths of all streams within that order.

Drainage density (D_d) quantifies the total length of streams (L_u) per unit area (A) of the basin. It provides insights into the density of the stream network within the basin.

$$D_d = \frac{L_u}{A} \quad (3)$$

These morphometric parameters collectively offer a detailed characterization of the Anambra River Basin's hydrological and geomorphological features. They are crucial for understanding water flow dynamics, sediment transport, flood risk assessment, and ecosystem management within the basin (Omietimi et al., 2021). By quantitatively analyzing these parameters, researchers gain valuable insights into the basin's morphology and its implications for environmental and water resource management strategies.

2.4. Analysis of erosion patterns and hydrological characteristics

The morphometric parameters calculated for the Anambra River Basin offer crucial insights into its erosion patterns and hydrological behavior. Parameters such as drainage density and stream frequency provide indications of potential erosion, driven by rapid surface runoff in areas with high values of these parameters (Egbueri & Igwe, 2020). Areas characterized by low elongation ratios and high relief ratios are more prone to flooding, as they typically exhibit less elongated shapes and steeper slopes that facilitate faster runoff and higher accumulation of water during rainfall events. These insights are essential for assessing the basin's vulnerability to erosion, sediment transport, and flood hazards, guiding effective watershed management and conservation strategies to mitigate risks and sustainably utilize its resources (Olabode et al., 2020).

2.5. Data interpretation and validation

The morphometric parameters derived from the analysis were interpreted to comprehensively evaluate various aspects of the Anambra River Basin, including its shape, drainage efficiency, and susceptibility to erosion. These parameters serve as critical indicators in understanding the basin's geomorphological characteristics and hydrological dynamics (Ayogu et al., 2019). Parameters such as basin shape indices, drainage density, and stream frequency provide insights into the basin's overall shape, the density of its stream network, and potential erosion risks.

To ensure the accuracy and reliability of these interpretations, the results were rigorously validated through comparison with existing literature and field observations. This validation process helps to corroborate findings and ensure that the morphometric analyses accurately reflect the actual conditions and processes occurring within the Anambra River Basin. By integrating theoretical insights with practical observations, this approach enhances the robustness of the study's conclusions and supports informed decision-making in watershed management and environmental planning initiatives.

3. RESULT AND DISCUSSION

The morphometric analysis of the Anambra River Basin, as shown in Table 2 and Figure 3, revealed significant variations in the area and perimeter of the five major basins identified. The largest basin, referred to as the First Basin, encompasses an area of 1459.27 km² with a perimeter of 257.38 km. This considerable size suggests that it is a major catchment area, playing a crucial role in the hydrology of the entire region.

Table 2: Map of the major basins identified in the study area

Basin	Area	Perimeter
First	1459.27	257.38
Second	180.07	188.66
Third	222.43	178.22
Fourth	171.81	99.63
Fifth	227.45	81.25

In contrast, the smaller basins, such as the Fourth and Fifth Basins, cover areas of 171.81 km² and 227.45 km², respectively, with perimeters of 99.63 km and 81.25 km. These smaller basins likely contribute less to the overall hydrology but remain significant for local water management and erosion control strategies.

The erosion patterns within the Anambra River Basin were inferred from the morphometric parameters. Basins with larger areas and perimeters, such as the First Basin, are more susceptible to erosion due to the extensive surface area exposed to rainfall and runoff. This increases the likelihood of soil erosion and sediment transport, which can impact the river's flow and water quality.

Conversely, the smaller basins exhibit different erosion dynamics. The Fourth and Fifth Basins, with their relatively smaller areas and perimeters, are likely to experience less intense erosion. However, localized factors such as land use, vegetation cover, and soil type can significantly influence erosion rates in these areas.

The hydrological characteristics of the Anambra River Basin were assessed by examining the relationship between the basin area and perimeter. A larger area generally indicates a greater capacity for water storage and a more significant contribution to the river's flow. The First Basin, with the largest area, is expected to have the highest runoff volume, which could lead to higher peak flows during rainfall events.

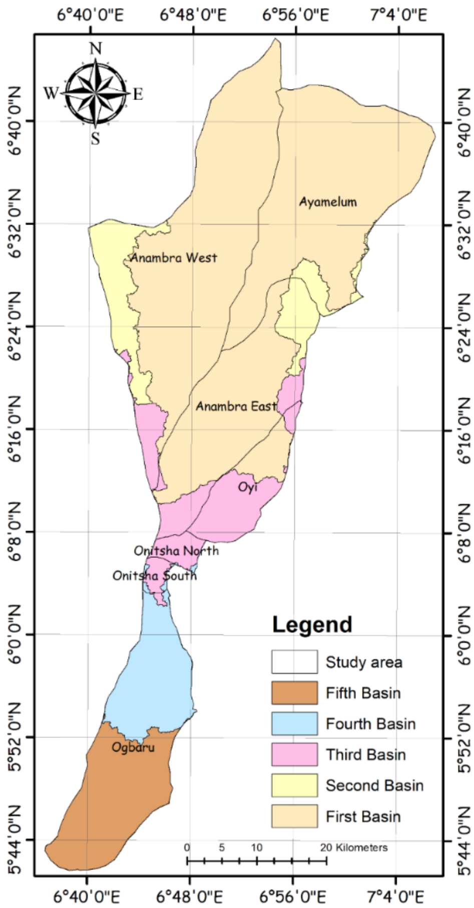


Figure 3: Map of various basin identified in the study area

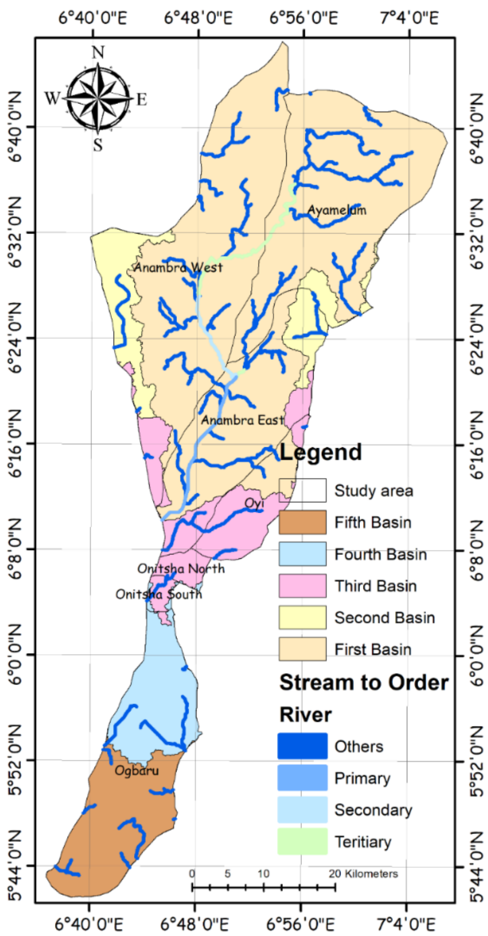


Figure 4: Map of rivers derived from stream to order for the study area

The perimeter of a basin is also an essential factor in understanding its hydrology. Basins with longer perimeters, like the Second and Third Basins, have more extensive riverbanks and are likely to experience more complex flow patterns. These basins may have multiple tributaries contributing to the main river, leading to a more intricate network of streams and channels.

Effective water resource management in the Anambra River Basin requires a thorough understanding of the morphometric characteristics of each basin. The significant differences in area and perimeter among the five major basins indicate that each one has unique hydrological and erosion dynamics. The First Basin's large area suggests a substantial water storage capacity, making it a critical area for managing water resources during dry periods (Okwara et al., 2020). In contrast, the smaller basins, like the Fourth and Fifth, may require more localized management strategies to address specific erosion and runoff issues.

Environmental protection efforts in the Anambra River Basin should focus on mitigating erosion and maintaining water quality. The larger basins, particularly the First Basin, are likely to be key areas for implementing erosion control measures, such as reforestation, soil conservation techniques, and sustainable land use practices. The smaller basins, although less prone to extensive erosion, still require attention to prevent localized degradation. Protecting these areas involves maintaining vegetation cover, controlling land use changes, and preventing activities that could exacerbate erosion and sediment transport (Pagliara et al., 2015; Sharda & Ojasvi, 2016; Sayah et al., 2019).

The stream order analysis categorizes streams into a hierarchy, starting from the smallest tributaries (first order) to the main river (higher order) as shown in Table 3 and Figure 4. This hierarchical classification helps in understanding the structure and function of the river network within the Anambra River Basin.

Table 3: Stream Order Classification with Corresponding Area and Perimeter in the Anambra River Basin

River	Area	Perimeter
Secondary	0.39	36.69
Primary	0.66	60.79
Tertiary	0.78	75.37
Others	10.62	987.71

In the study area, streams were classified into secondary, primary, and tertiary orders, along with a category labeled "Others" for smaller or less significant streams. The secondary streams cover an area of 0.39 km² with a perimeter of 36.69 km, indicating their limited extent and influence.

Primary streams, slightly larger, span 0.66 km² with a perimeter of 60.79 km. Tertiary streams, the largest among the classified orders, cover 0.78 km² with a perimeter of 75.37 km. The "Others" category includes a substantial number of minor streams, collectively covering an area of 10.62 km² with a perimeter of 987.71 km.

Erosion patterns within the Anambra River Basin can be inferred from the stream order and corresponding river metrics. Streams of higher order, such as tertiary and primary, are generally more susceptible to erosion due to their larger surface area and greater flow volume. The tertiary streams, with the largest area and perimeter among the classified streams, are likely to experience significant soil erosion, contributing to sediment transport within the basin (Angileri et al., 2016). Conversely, secondary streams, with their smaller area and perimeter, are expected to have lower erosion rates. However, localized factors such as land use, vegetation cover, and soil type can significantly influence erosion rates even in these smaller streams. The "Others" category, despite its large cumulative area and perimeter, comprises numerous minor streams that individually may contribute less to erosion but collectively play a significant role in sediment dynamics.

The hydrological characteristics of the Anambra River Basin were assessed by examining the relationship between stream order, area, and perimeter. Streams of higher order, particularly tertiary and primary, typically have greater water storage capacity and contribute more significantly to the river's flow. The tertiary streams, with the largest area (0.78 km²) and perimeter (75.37 km), are expected to have the highest runoff volume, potentially leading to higher peak flows during rainfall events.

The primary streams, while smaller than the tertiary streams, still contribute significantly to the basin's hydrology. Their area of 0.66 km² and perimeter of 60.79 km suggest substantial water storage capacity and flow contribution. Secondary streams, with their smaller area and perimeter, play a less dominant but still crucial role in the basin's hydrology. The "Others" category, with its extensive cumulative area and perimeter, includes numerous minor streams that collectively influence the hydrological dynamics of the basin. These streams contribute to the flow and water storage, particularly during peak rainfall events, highlighting the importance of considering all stream orders in hydrological assessments.

Effective water resource management in the Anambra River Basin requires a thorough understanding of the stream order and corresponding river metrics. The significant differences in area and perimeter among the classified streams indicate that each stream order has unique hydrological and erosion dynamics. Tertiary streams, with their large area and perimeter, suggest substantial water storage capacity and a significant contribution to peak flows (Olusola et al., 2020). Managing these streams involves strategies to mitigate erosion, control runoff, and ensure sustainable water use. Primary streams, while slightly smaller, also require management strategies focused on erosion control and runoff management (Daramola et al., 2019).

Secondary streams, with their limited area and perimeter, may require localized management strategies to address specific erosion and runoff issues. The "Others" category, despite its extensive cumulative area and perimeter, comprises numerous minor streams that collectively play a significant role in the basin's water dynamics. Managing these streams involves maintaining vegetation cover, controlling land use changes, and preventing activities that could exacerbate erosion and sediment transport.

Environmental protection efforts in the Anambra River Basin should focus on mitigating erosion and maintaining water quality across all stream orders. Tertiary and primary streams, being more susceptible to erosion, are key areas for implementing erosion control measures such as reforestation, soil conservation techniques, and sustainable land use practices.

Secondary streams, although less prone to extensive erosion, still require attention to prevent localized degradation. Protecting these streams involves maintaining vegetation cover, controlling land use changes, and preventing activities that could exacerbate erosion and sediment transport (Kurowska et al., 2022; Bizi & Sidi, 2023). The "Others" category, with its numerous minor streams, requires a collective approach to environmental protection, ensuring that the cumulative impact of these streams is managed effectively.

4. CONCLUSION

The morphometric analysis of the Anambra River Basin reveals significant variations in the area and perimeter of its five major basins, each contributing uniquely to the region's hydrology and erosion dynamics. The First Basin, with an area of 1459.27 km² and a perimeter of 257.38 km, is identified as a major catchment area. Its large size suggests a high-water storage capacity and significant runoff volume, making it crucial for managing water resources during dry periods and implementing extensive erosion control measures. The smaller basins, Fourth and Fifth, with areas of 171.81 km² and 227.45 km², respectively, although contributing less to the overall hydrology, are essential for local water management and erosion control. They require localized management strategies to address specific erosion and runoff issues. Stream order analysis categorizes streams into secondary, primary, and tertiary orders, revealing the hydrological structure within the basin. Tertiary streams, with the largest area (0.78 km²) and perimeter (75.37 km), contribute significantly to peak flows and are more susceptible to erosion due to their larger surface area and greater flow volume. Effective management of these streams involves strategies to control erosion, manage runoff, and ensure sustainable water use. Environmental protection efforts in the Anambra River Basin should focus on mitigating erosion and maintaining water quality across all stream orders. Larger basins, particularly the First Basin, are key areas for implementing erosion control measures such as reforestation, soil conservation techniques, and sustainable land use practices. Smaller basins, although less prone to extensive erosion, still require attention to prevent localized degradation. The "Others" category, comprising numerous minor streams, collectively influences the basin's water dynamics and requires a collective approach to environmental protection. The morphometric analysis of the Anambra River Basin highlights the importance of understanding the unique characteristics of each basin and stream order. This understanding is essential for developing tailored management strategies to address specific hydrological and erosion challenges, ensuring sustainable water resource utilization and environmental protection within the basin.

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