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Research Article

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The Impact of Urban Land Use Changes on the Morphology of the New Calabar River Catchment, Port Harcourt Metropolis, Nigeria

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Abstract: The New Calabar River catchment has experienced significant alterations in land use and land cover patterns due to the fast population growth in Port Harcourt. This research investigated the influence of urban land use change on the morphological structure of the New Calabar River basin, which is experiencing rapid urbanization in Rivers State. The research utilized a combination of primary and secondary data sources, specifically satellite imagery and field measurements of the hydro-geomorphic channel's breadth and depth. The findings indicated a significant rise in urbanization, resulting in the encroachment upon various land uses, including water bodies, farmlands, dense forests, and wetlands. Moreover, correlation and regression analysis revealed a significant positive link between channel morphology, discharge, and urbanization index. Therefore, it can be argued that the urbanization index and discharge are crucial in determining the river channel's current channel form and size features. The study also demonstrated a positive correlation between discharge and channel dimensions, including width and depth. The stream channel has experienced an expansion in reaction to the modification of the natural soil caused by urbanization, leading to changes in the stream flow regime. Additionally, it has been observed that the segment of the New Calabar River that encompasses urbanized regions tends to have a comparatively more significant cross-sectional channel. Incorporating urbanization analysis and its impact on morphology has facilitated the implementation of diverse geospatial analyses and sustainable watershed management in the basin.

Keywords: Catchment; Channel Dimensions; Discharge; Urbanization; Sustainable Watershed.

1. Introduction

River networks play a vital role in the survival and reproduction of animals and plants, providing essential support for various functions of human society and ultimately upholding ecological stability [1], [2]. These natural watercourses serve as essential conduits, facilitating water flow, nutrients, and biodiversity while also providing vital resources for human societies [3], [4]. Over time, rivers have enabled the development of settlements, facilitated trade and transportation routes, and supported diverse ecosystems.

However, as human populations have grown and societies have evolved, rivers have become increasingly impacted by human activities. Urbanization has emerged as a prominent force, leading to significant modifications in river systems globally [5], [6]. Studies suggest that urbanization has caused substantial alterations in approximately 60% of the world's river systems and drainage channels [7], [8]. Consequently, rivers face many challenges due to anthropogenic activities, including urbanization, industrialization, and population growth. Rivers are experiencing significant changes due to human influence, particularly urbanization [9]. Understanding these impacts is crucial for effective management and conservation efforts to preserve the integrity and functionality of river ecosystems.

Urbanization is intricately linked to the proliferation of impermeable surfaces, which impede the process of infiltration and result in heightened surface runoff. Consequently, this alteration in water flow pathways directly impacts the hydrological dynamics of urban streams [3], [4]. The presence of diverse impermeable surfaces, ranging from compacted soils to roads, driveways,

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walkways, and rooftops, significantly influences the magnitude of surface runoff and subsequently shapes channel morphology [10]. The prevalence of impermeable surfaces on the Earth's surface is steadily increasing due to the construction of various urban structures such as roofs, driveways, sidewalks, pavements, and parking lots. As the ratio of impervious surfaces escalates, so does the overland flow volume, primarily originating from urbanized regions. These processes culminate in a notable outcome, exacerbating the frequency and magnitude of flood peaks during intense precipitation events. This phenomenon is particularly pronounced in small watersheds, predominantly within urban areas [11], [12]. Moreover, it diminishes groundwater reservoirs' recharge, consequently reducing the base flow's contribution to channels within the same vicinity. Hence, the degree of urbanization directly influences the entire spectrum of stream discharges, ranging from minimal levels during dry periods to peak levels during flooding [13]–[16].

The deployment of storm sewers, facilitating the direct conveyance of stormwater runoff from impermeable paved surfaces to stream channels for subsequent discharge, represents a prevalent engineering solution [17]–[19]. This expedited transport of runoff to the channel is characterized by a brief duration, coinciding with a notable escalation in runoff volume attributable to the proliferation of impervious surfaces. The swift pace of urban and suburban expansion has brought to light a concerning trend: specific low-lying residential areas, hitherto immune to flooding, are now confronting inundation issues stemming from the overflow of adjacent streams [20]. This phenomenon underscores the complex interplay between urban development, hydrological dynamics, and flood risk management strategies in contemporary urban environments.

The channel of a stream refers to a small passage that is formed by the hydraulic forces exerted by the flowing water, with the primary objective of efficiently transporting water and sediment inside the stream. The rate of stream gradient influences the dimensions of the channel. As a stream undergoes gravitational descent, the water experiences resistance in the form of friction with the walls of the channel [21]–[24]. Consequently, the water near the riverbed and banks exhibits reduced velocity, while the deepest and most centrally placed zone has heightened flow rates due to the amplified impact of turbulence. Hydraulic action possesses the capacity to excavate substantial volumes of unconsolidated materials swiftly. This process results in the undermining of structures, causing them to collapse into the river. The particles are promptly disintegrated and incorporated into the stream's sediment load. The hydraulic force induces both mechanical and chemical weathering processes in channel erosion, specifically through the mechanisms of abrasion and corrosion [25], [26].

The New Calabar River has witnessed a substantial surge in anthropogenic activities, including urbanization, agriculture, and sand mining. The river channel experiences channel enlargement primarily due to the following factors [27], [28]. Before engaging in these activities, the channel had maintained a state of equilibrium between deposition and erosion. Nevertheless, the escalating human-induced disturbances have significantly affected the river channel's morphology. This study is conducted against the backdrop of urbanization to examine the effects of urbanization on the New Calabar River system [29]. The downstream slope, breadth, and depth pertain to the characteristics of the channel and its downstream geometry in terms of water flow and sediment transport. These factors play a crucial role in shaping the channel, which serves as a conduit for the transportation of water and sediment. Consequently, the channel undergoes continuous modification due to these transport processes.

Understanding the correlation between channel geometry, which includes variables such as width, depth, slope, and bed roughness, and how these parameters vary in response to discharge and sediment flux [30]. Channels are inherently shaped and influenced by their surrounding environment. For example, a meandering river often features a wide floodplain, similar to Louisiana rivers. In contrast, a small alpine river is typically confined and displays limited lateral movement. These variations in channel morphology reflect the dynamic interplay between hydrological processes, sediment transport, and geomorphic controls, underscoring the complex nature of river systems and their diverse environmental contexts [31], [32].

The alterations in the dimensions and configuration of a channel are intricately linked to fluctuations in discharge and its temporal evolution at a given cross-section and downstream [33]. Channel bed morphology can undergo modification through two primary processes: bed degradation and bed aggradation. Bed degradation involves the lowering of the channel bed, leading to channel incision. Conversely, bed aggradation entails the continuous deposition of sediment, resulting in the accumulation of material on the channel bed. In sinuous fluvial systems like the New Calabar River, there is a notable increase in the transportation and deposition of fine silt, contributing to the development of natural levees along the sides of the river channel. Consequently, during flood events, the river stage surpasses the elevation of these levees, leading to inundation of adjacent areas. This natural process underscores the dynamic interplay between sediment transport, channel morphology, and floodplain development in fluvial environments [34], [35].

2. Material and Methods

2.1. Location Study

The designated study area encompasses a specific segment of the New Calabar River, which is visually represented in Figure 1. This segment has been chosen for detailed examination within the broader context of the river system. The New Calabar River is located at the geographical coordinates of longitude 006°53 53086'E and latitude 04°53' 19.020'N, serving as the focal point for this study due to its ecological significance and potential human impact.

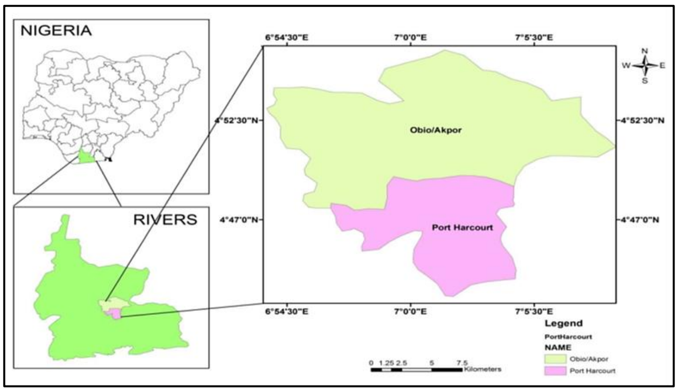

Figure 1. Nigeria and Rivers State Showing Study Area.

2.2. Sample Stations

Figure 2 overview the diverse human activities observed at various sampled stations along the New Calabar River. These activities encompass a wide range of interactions between human communities and the river ecosystem, including but not limited to fishing, transportation, agriculture, industrial operations, and recreational activities. The depiction in Figure 2 allows researchers to assess the extent and nature of human influence on the riverine environment within the study area.

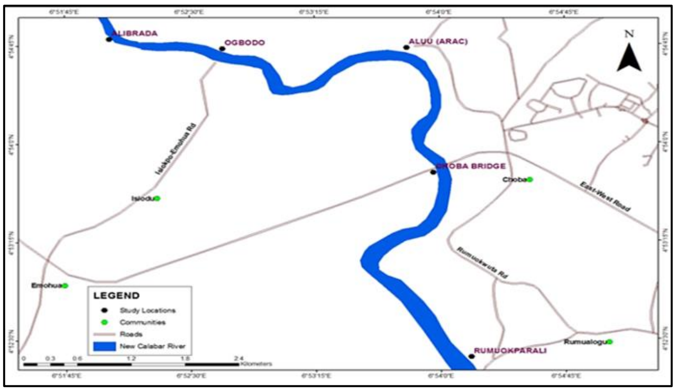

Figure 2. Study Area Showing Sample Stations.

2.3. Parameter Samples

Table 1 complements the visual information in Figure 2 by presenting additional details about the sampled stations. It includes data on the distances between stations, the sampling framework employed, and a breakdown of the specific activities observed at each station. This tabulated information offers a structured overview of the spatial distribution of human activities along the New Calabar River, facilitating further analysis and interpretation within the study.

Table 1. Distance, Sample Frame, and Activities within the Sampled Stations [36].

Sta.	Latitude	Latitude	Longitude	Sample Frame/ Distance (m)	Sample Size (m)	Activities within Location
1	Rumuokparali-Choba Bridge	4°52.37N	6°54.17E	551.09	11.02	The river harbor pipes are used for dredging, and domestic effluents are emptied into the river. A market is close to the river, which houses an abattoir where all waste goes into the river.
2	Choba Bridge-Aluu	4°53.78N	6°53.95E	224.25	4.49	Activities here include building and repairing oil pipelines, dredging, and fishing.
3	Aluu (ARAC)-Ogbodo in Iskiokpa	4°54.73N	6°53.79N	213.53	4.27	Dredging activities as well as domestic and recreational activities. It is also a narrow creek linking the discharge point of the farming activities within the African Regional Aquaculture Centre in the river.
4	Ogbodo (Isiokpa)-Elibrada (Emohua)	4°54.80N	4°52.01E	71.80	1.44	Dredging activities, domestic purposes like fishing by the inhabitants, and recreational activities are sometimes carried out.

Sta.	Latitude	Latitude	Longitude	Sample Frame/ Distance (m)	Sample Size (m)	Activities within Location
5	Elibrada (Emuoha)-Rumuokparali	4°54.80N	6°52.01E	510.97	10.22	Dredging activities in this river and villagers around carry out fishing activities. It is also used for recreational activities by neighboring villages.
	Total			1,571.64	31.44	

This study provides crucial insights into human activities along the New Calabar River segment and their environmental implications. It reveals significant practices such as domestic and industrial waste disposal, fishing, and commercial activities like market trading and pipeline maintenance. These findings bear substantial implications across various domains. The gathered information supports sustainable natural resource management efforts. Given the potential ecological disruptions caused by human activities, a nuanced understanding of their types and locations is essential for formulating effective management policies and strategies. The study is relevant to public health considerations. Activities such as riverine waste disposal can compromise water quality, thereby increasing health risks for local communities. Consequently, these findings can inform disease prevention measures and enhance community well-being.

Furthermore, the research has the potential to bolster local economic development initiatives. By elucidating economic activities surrounding the river, such as local fisheries and trade, sustainable economic development efforts can be planned to improve the welfare of local populations. By identifying potentially environmentally damaging human activities, appropriate actions can be taken to mitigate their negative impacts. Measures such as improved waste management and the designation of protection zones can help safeguard river ecosystems and the species inhabiting them.

3. Result and Discussion

Table 2 provides a comprehensive overview of the land utilization trends within the Port Harcourt Metropolis from 1986 to 2020. This analysis delves into the evolving landscape dynamics, shedding light on the shifting proportions of various land cover types over the years.

In 1986, the data indicated that water bodies covered a combined area of 53.71 square kilometers, constituting 7.19% of the total land area. These bodies of water play a crucial role in the region's ecological balance and hydrological cycle. Riparian and swamp forests, spanning 95.91 square kilometers, accounted for 12.84% of the total area, serving as vital habitats for diverse flora and fauna. Dense vegetation across 336.65 square kilometers, representing 45.06% of the landscape, highlights the significant green cover within the metropolis. Farmlands, covering 170.5 square kilometers, occupied 22.82% of the area, reflecting the agricultural activities prevalent in the region. Lastly, the built-up area, encompassing 90.31 square kilometers, accounted for 12.09% of the land, indicating the extent of urbanization and infrastructure development in 1986.

Moving to 1990, the spatial distribution of land cover types continued to transform. While the area of water bodies remained relatively stable at 53.83 square km, other land cover categories exhibited notable changes. Riparian and swamp forests experienced a slight reduction to 83.56 square kilometers (11.18%), reflecting potential habitat alterations or land use conversions. Dense vegetation maintained a significant coverage of 364.87 square kilometers (48.84%), indicating the persistence of green spaces within the urban fabric. Farmlands decreased to 142.75 square kilometers (19.11%), possibly due to urban expansion or changes in agricultural practices. Meanwhile, the built-up area expanded to 102.07 square kilometers (13.66%), indicative of urban sprawl and infrastructure development.

By the turn of the millennium in 2000, the landscape dynamics within the Port Harcourt Metropolis continued to evolve. While the area of water bodies remained relatively consistent at 53.88 square kilometers, other land cover types experienced notable shifts. Riparian and swamp forests decreased slightly to 94.86 square kilometers (12.7%), possibly due to anthropogenic pressures or natural disturbances. Dense vegetation persisted across 304.74 square kilometers (40.79%), highlighting the resilience of green spaces amidst urbanization. Farmlands covered 143.62 square kilometers (19.22%), indicating ongoing agricultural activities within the urban fringe. The built-up area expanded significantly to 149.98 square kilometers (20.08%), underscoring the intensification of urban development and infrastructure expansion during this period. The detailed analysis in Table 2 underscores the dynamic nature of land utilization patterns within the Port Harcourt Metropolis over the past few decades, highlighting the interplay between urbanization, environmental changes, and socio-economic factors.

Table 2. Land Use Pattern of Port Harcourt Metropolis (1986, 1990, 2010, and 2020) [27].

Land Use Change Category	1986		1990		2010		2020	
	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)
Water bodies	53.71	7.19	53.83	7.21	53.88	7.21	57.30	7.67
Urban Area	90.31	12.09	102.07	13.66	149.98	20.08	177.39	23.74
Farmland	170.5	22.82	142.75	19.11	143.62	19.22	105.31	14.10
Thick Forest	336.65	45.06	364.87	48.84	304.74	40.79	313.15	41.92
Riparian/Swampy Forest	95.91	12.84	83.56	11.18	94.86	12.70	93.93	12.57
Total	747.08	100.00	747.08	100.00	747.08	100.00	747.08	100.00

The investigation revealed significant changes in land use patterns within the study area between 2010 and 2020. The analysis, facilitated by satellite imagery, provided a comprehensive understanding of the evolving landscape dynamics and their implications.

In 2010, aquatic bodies covered an area of 57.3 square km, constituting 7.67% of the total land area. Riparian and swamp forests occupied 93.93 square km, representing 12.57% of the land, while thick vegetation spanned a substantial area of 3313.15 square km, accounting for 41.92% of the total area. Farmlands encompassed 105.31 square km, equivalent to 14.10% of the land, and built-up areas had an extent of 177.39 square km, constituting 23.74% of the total area.

By 2020, notable changes were observed in land use patterns. Water bodies decreased slightly to 55.65 square km, representing 7.45% of the total land area. Riparian and swamp forests also experienced a reduction to 83.42 square km, accounting for 11.17% of the land. However, the most significant change was observed in thick vegetation, which decreased to 225.36 square km, constituting 30.17% of the land. Farmlands expanded to 136.47 square km, representing 18.27% of the land, while the built-up area expanded significantly to 246.18 square km, now constituting 32.95% of the total land area.

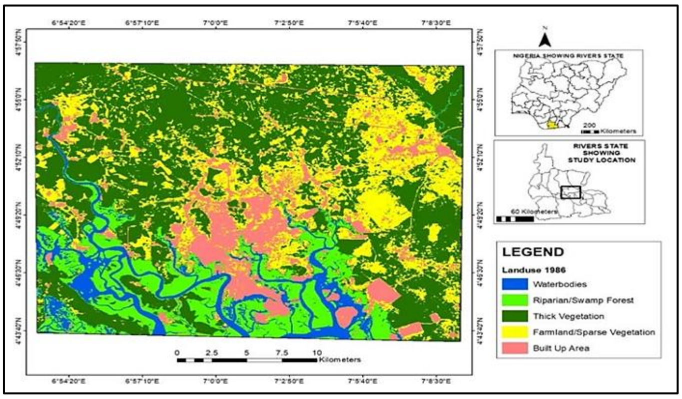

Figure 3. Land use of Port Harcourt City in 1986

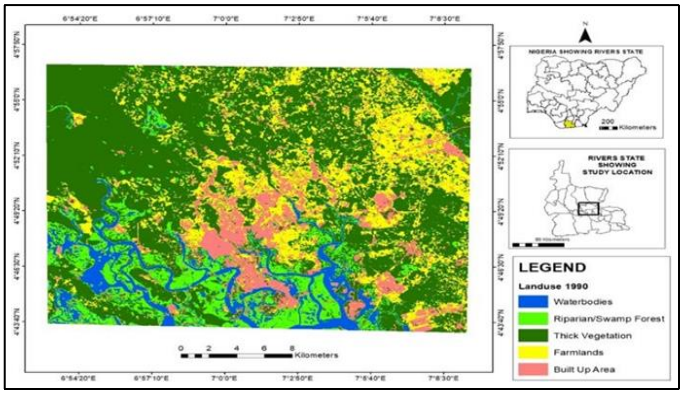

Figure 4. Land use of Port Harcourt City in 1990

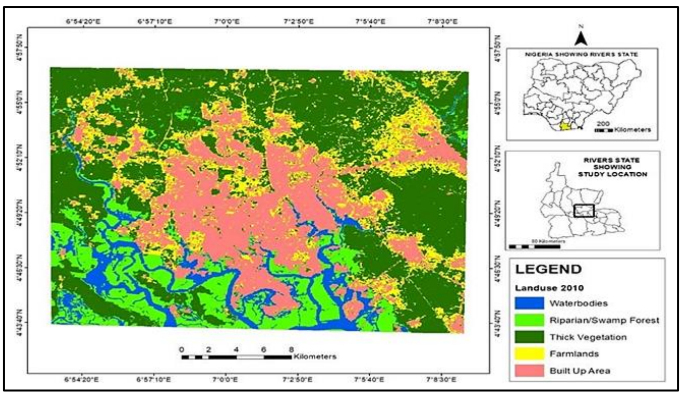

Figure 5. Land use of Port Harcourt City in 2010

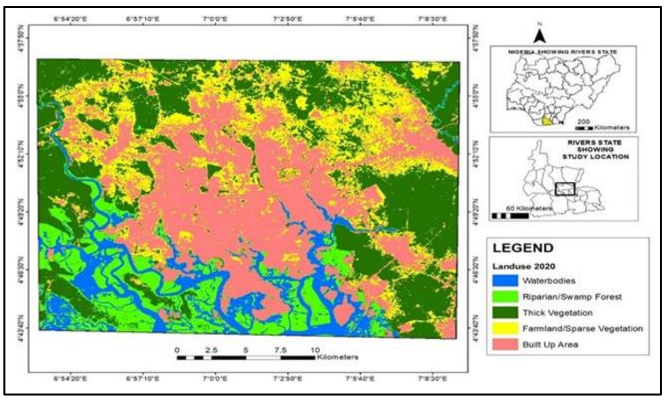

Figure 6. Land use of Port Harcourt City in 2020

These findings highlight a shift in land use dynamics over the decade, characterized by a decline in natural vegetation cover and an expansion of built-up areas and agricultural lands. Such changes can profoundly affect the study area's ecosystem health, biodiversity, and socio-economic activities. Using satellite imagery proved instrumental in visualizing and quantifying these landscape changes, providing valuable insights for land use planning, environmental management, and sustainable development initiatives.

Table 3 presents morphological data along the New Calabar River Basin, detailing width and depth measurements at various locations. The measurements reveal significant variability in both width and depth across the surveyed locations. Rumuokpali exhibits the widest span with a measurement of 191.05 meters, while Allu (CARAC) boasts the highest width at 210.10 meters. In terms of depth, the river ranges from 5.28 meters to 7.54 meters at different locations. The average width and depth of the New Calabar River Basin are calculated at 108.53 meters and 7.54 meters, respectively. This data provides valuable insights into the morphological characteristics of the river and can be instrumental in further hydrological analysis and sustainable river management planning.

Table 3. Morphological Variables Along New Calabar River Basin.

	Rumuokpali	Choba Bridge	Allu (CARAC)	Ogbodo	Elibridi	Mean Width and Depth
Width	191.05	164.43	210.10	131.75	205.32	108.53
Depth	6.98	6.70	5.28	6.01	6.48	7.54

The morphological characteristics of rivers, as depicted in Table 3 along the New Calabar River Basin, have profound implications across various domains, including hydrology, ecology, infrastructure development, and socio-economic well-being. Variations in river width and depth directly impact hydrological dynamics. Wider sections like Allu (CARAC) may experience reduced flow velocities and increased sedimentation, affecting floodplain inundation and sediment transport. Conversely, narrower areas like Ogbodo may face accelerated flow velocities, posing erosion risks and channel stability concerns. Understanding river morphology is crucial for effective flood management and sustainable water resource utilization.

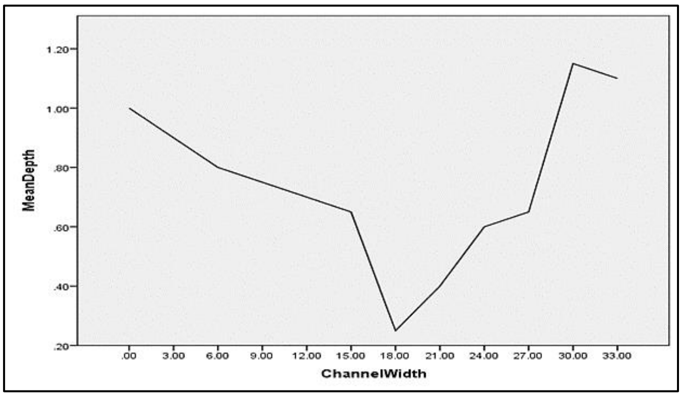

Figure 7. Cross-sectional Area Rumuokpali and Choba Bridge.

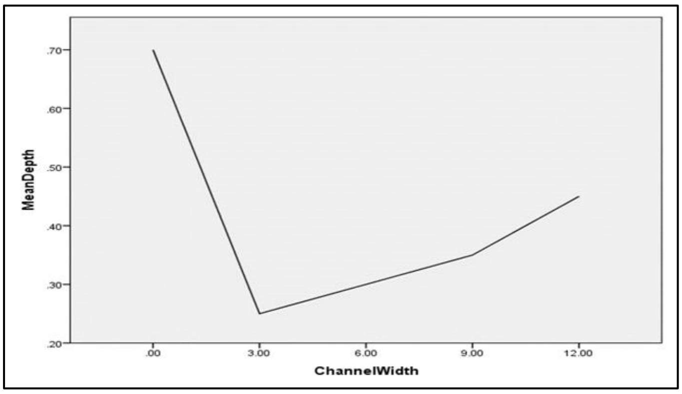

Figure 8. Cross-sectional Area Choba and Allu (CARAC).

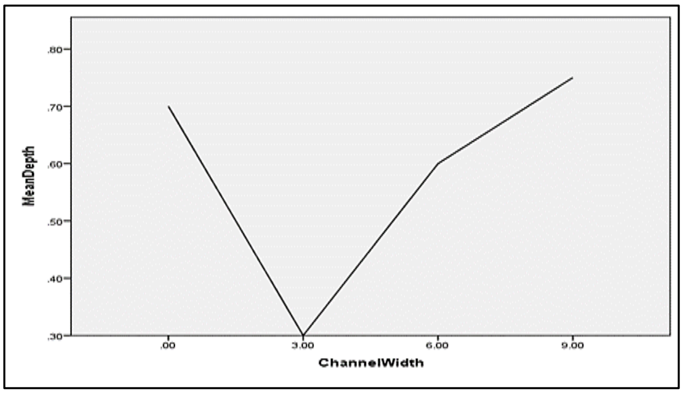

Figure 9. Cross-sectional Area Aluu (CARAC) and Ogbodo.

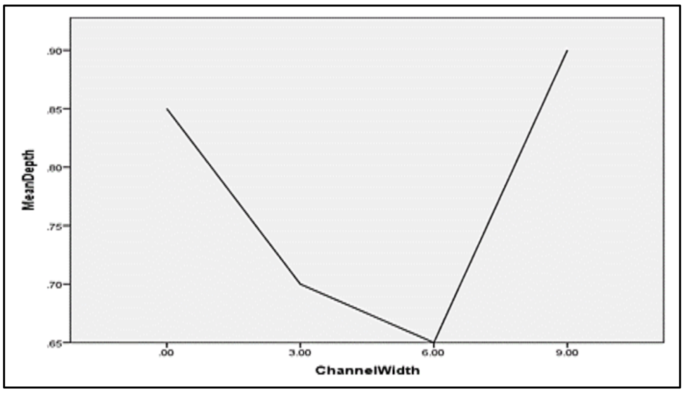

Figure 10. Cross-sectional Area Ogbodo and Elibridi

River morphology significantly influences ecosystem health and biodiversity. Deeper river sections provide critical habitats for aquatic organisms, while shallower areas support diverse vegetation. Maintaining habitat heterogeneity is vital for healthy ecosystems and biodiversity preservation. River morphology shapes infrastructure development and socio-economic activities along riverine areas. It informs decisions on bridge construction, dredging, and floodplain management. Changes in morphology affect navigation routes, fishing activities, and water access, impacting community livelihoods. From an environmental management standpoint, river morphology data aid in monitoring environmental changes and assessing conservation measures' effectiveness. Tracking width and depth variations helps identify areas needing intervention and promotes sustainable resource management.

Table 4. Hydraulic Variables for Stations A-H.

Stations	Width (m)	Mean Depth (m)	Velocity (m/s)	Discharge (cumecs)	Urbanizing Index (%)	Channel Morphology
Rumuokpali and Choba Bridge	33.00	0.84	0.3551	9.840	4.50	27.52
Choba and Allu (CARAC)	12.00	0.36	0.3639	1.570	9.30	4.32
Aluu (CARAC) and Ogbodo	9.00	0.60	0.3654	1.970	15.84	5.40
Ogbodo and Elibridi	9.00	0.80	0.3666	2.640	21.12	7.20

Based on the data gathered thus far, substantial fluctuations have been discerned within and among hydraulic variables across various cross-sectional sampling points. An in-depth analysis of Table 4 reveals pronounced relationships, underscoring discernible patterns within the dataset. These findings indicate a complex interplay of hydraulic factors, suggesting intricate dynamics within the studied river system. Further investigation into these relationships is warranted to elucidate the underlying mechanisms driving the observed fluctuations and their implications for the overall hydraulic regime of the New Calabar River.

Figure 11. Cross-sectional View of New Calabar (Plate 1)

Figure 12. Discharge flow along New Calabar (Plate 2)

The fluctuations in channel width of the New Calabar River demonstrate a consistent reaction of the downstream channel to an increase in discharge resulting from activities connected with urbanization. The data collected from several measuring stations indicates that downstream alterations have occurred due to the stream channel adapting to the urbanization conditions.

Furthermore, the correlation between breadth and depth again underscores the significant relationship between stream channel responsiveness and urbanization activities. The adjustment of channel depth is made in response to flow conditions that necessitate a greater channel depth to handle the increased runoff and flood volume resulting from urban surfaces.

The observed downstream increase in channel dimensions, including width, depth, and velocity, compared to the upstream section, underscores the dynamic nature of river channels and their response to changes in discharge. It is widely recognized that variations in discharge play a pivotal role in shaping channel morphology, with higher discharge levels typically associated with larger channel dimensions and increased flow velocities.

This phenomenon is further elucidated through statistical analysis, which allows for a more rigorous examination of the relationship between discharge and channel dimensions. By analyzing data collected from cross-sectional sampling at multiple sites along the river channel, researchers can quantitatively assess the extent of downstream changes in discharge and their corresponding effects on channel morphology areas.

Empirical findings consistently demonstrate a general trend of increasing discharge downstream, as evidenced by the cross-sectional sampling conducted at various sites. The observed discharge escalation is attributed primarily to outfall channels, sewers, and gutters that efficiently convey runoff and stormflow from urbanized areas to the river channel (Plates 1-2). This influx of urban runoff significantly contributes to the augmentation of downstream discharge levels, thereby influencing channel dimensions and flow characteristics.

Moreover, these findings align with previous research conducted by Galster et al. (2007), which similarly observed downstream increases in discharge in urbanized river systems [37]. Salerno et al. (2018) emphasized the intricate relationship between urbanization and river discharge, highlighting the role of impervious surfaces in amplifying runoff and altering hydrological processes [38]. Similarly, Nelson et al. (2009) underscored the impacts of urbanization on stream discharge, emphasizing the need for effective management strategies to mitigate the adverse effects of urban runoff on river ecosystems [39].

The observed downstream increase in channel dimensions and discharge underscores the profound influence of urbanization on river systems [40]–[43]. By elucidating the complex interplay between discharge, channel morphology, and urban development, this research contributes to understanding the dynamic processes shaping river ecosystems in urbanized environments.

4. Conclusion

As the transition of the New Calabar River from a rural to an urban environment takes place, there is a significant rise in the proportion of paved surfaces within this particular drainage basin. The present scenario has a detrimental effect on the process of infiltration. Therefore, the rapid delivery of precipitation to streams is due to overland flow. Enhanced watershed management strategies are designed to mitigate the impact of precipitation on terrestrial surfaces and enhance river dynamics by minimizing flood peaks and sediment transportation. Hence, it is imperative to implement sustainable watershed management practices inside the basin, specifically through exerting control over urban expansion. The afforestation program refers to a specific initiative to increase the number of trees and vegetation in a specific area.

The urbanization process continues to be a significant anthropogenic disruption to the hydrological cycle's theoretical functioning, with the primary impact stemming from the presence of paved surfaces. Hence, relevant authorities must undertake measures aimed at zoning various sections of the drainage basin to facilitate future development.

The afforestation program refers to a strategic initiative to increase the number of trees and vegetation in a particular area. An afforestation program should be implemented within the urban river catchment area due to the potential benefits of increased soil organic matter resulting from the accumulation of dense litter produced by trees in the afforested basin. This accumulation of organic matter can enhance the activities of soil organisms, leading to larger soil pores and a higher infiltration rate. As a result, the runoff discharge can be reduced, thereby contributing to mitigating basin degradation processes.

The implementation of a comprehensive degradation assessment plan is essential in engineering construction. This entails the adoption of many strategies and approaches, including the installation of spillways in terrace banks and the establishment of gully check runoff interception canals. It is recommended that the government implement shelter belts in metropolitan areas to promote infiltration and mitigate excessive runoff into the current river channel.

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