PRINT ISSN 1119-8362
Electronic ISSN 2659-1502

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 28 (1) 179-186 January 2024

# Assessment of Changes in Channel Width and Braiding: The Implications on Flooding Upstream of Shiroro Reservoir in river Kaduna, Kaduna State, Nigeria

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**ABSTRACT:** The objective of this paper was to presents potential implications of flooding on changes in channel width and braiding patterns within the nine study reaches upstream of the Shiroro Reservoir of River Kaduna, Kaduna Nigeria using standard methods for data acquisition and analysis. Preliminary findings reveal substantial alterations in channel morphology, characterized by an increase in channel width and a shift towards braided patterns in some of the study segments of River Kaduna. These changes are attributed to factors such as deforestation, urbanization, and land use changes within the river's catchment area resulting sediment released into the river. The hydrological consequences of these alterations, including increased flood risk in the upstream regions, sediment transport dynamics, and their implications for the functionality of the Shiroro Reservoir as a flood control mechanism has been pointed out. The outcomes of this study not only contribute to a better understanding of the evolving hydro-geomorphological dynamics of the Kaduna River but also provide valuable insights for sustainable river management practices and flood risk mitigation in the region. As Nigeria grapples with increasing challenges related to climate change and population growth, the findings presented in this paper hold significant relevance for policymakers, water resource managers, and communities living in flood-prone areas along River Kaduna.

**DOI:** https://dx.doi.org/10.4314/jasem.v28i1.20



**Cite this paper as**: SALAWU, O.G; LEKE, D. (2024). Assessment of Changes in Channel Width and Braiding: The Implications on Flooding Upstream of Shiroro Reservoir in river Kaduna, Kaduna State, Nigeria. *J. Appl. Sci. Environ. Manage.* 28 (1) 179-186

**Dates:** Received: 10 December 2023; Revised: 11 January 2024; Accepted: 21 January 2024 Published: 30 January 2024

**Keywords**: Channel narrowing; Channel Braiding; Braiding Index; Channel platform; Flooding

The River Kaduna, flows through Kaduna State in Nigeria and is a vital water resource that plays an essential role in the region's socio-economic development. One of the important features of this river is the Shiroro Reservoir, constructed primarily for hydroelectric power generation and irrigation. Floods of varying magnitude have been a recurrent phenomenon in river Kaduna. The recent flood events for example the floods of 2003, 2006 and 2012 have attracted the attention of researchers because of the extent of damages to lives and properties associated with the floods (Butu, et. al., 2020; Aggarwal and Jeb, 2008). In recent years, concerns have arisen regarding channel narrowing and braiding upstream of the reservoir, leading to increased flooding events in the area. This paper explores the implications of channel narrowing and braiding on flooding upstream of the Shiroro Reservoir and the potential consequences for the local communities. Despite human reliance on rivers, natural and anthropogenic factors have resulted in global degradation of river conditions which are easily noticed as changes in river planforms. These factors have led to fluvial processes such as floods, channel migration, and riverbank erosion, posing a significant threat to humanity (Olesco *et al*., 2023). Changes in shape and size of the river channel can affect its capacity to carry water and transport sediment load. Narrow but deep channels carry less water than wider channels. If the river channel is too narrow relative to the volume of water flowing into it,

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flooding can occur. Natural meandering rivers have a certain capacity to handle floodwaters by spreading them out over the floodplain. But certain changes like when rivers are artificially straightened or constrained, may lead to rivers losing their natural ability, leading to increased flood risk. Changes in braiding can lead to flooding, especially during periods of high discharge. This is because the complex network of channels and bars leads to water spreading out over a wide area during floods, affecting adjacent floodplains and most times making it difficult to predict the exact flow paths (Butu, *et al*., 2020). Channel narrowing and braiding are natural geomorphic processes that occur in rivers over time. Channel narrowing refers to the reduction in the width of the river channel, while braiding refers to the formation of multiple smaller channels within the riverbed. These processes are often the result of sediment deposition, changes in flow patterns, and fluctuations in water levels (Osterkamp *et al.,* 2006; Lovric and Tosic, 2016; Block 2014). In the case of the River Kaduna, channel narrowing and braiding have been observed upstream of the Shiroro Reservoir. These changes in the river's morphology can have several consequences, especially when combined with increased rainfall and climate variability. The river channel planform is a fundamental aspect of river morphology that describes a river's course as viewed aerially in two dimensional. It encompasses various characteristics and features that describe the river's configuration, such as the shape of the channel, the width, meander patterns and multiple channels interconnected to form a braided pattern with their channel islands. Point bars, meander Cut-offs (ox-bow lakes), straight channels and confluences (the points at which two or more rivers or streams join together) also constitute river channel planform (Jagers, 2003; Butu, et. al., 2020). Knowledge of river channel planform is crucial for studying and managing rivers, as it provides insights into the behavior of water flow, sediment transport, and the interactions between the rivers and their surrounding environment.

To appreciate changes in river planform it is pertinent to understand the dynamics of river landforms and patterns of water and sediment discharge as these influence short term and long term changes in channel pattern. The links between drivers of change (controlling factors), processes (actions resulting from the controls) and response of rivers (outcomes of the actions) needs to be properly expressed (Selander, 2015). The drivers of changes in river planform could be natural or anthropogenic. Climatic factors trigger processes of erosion, transportation and deposition in rivers (Ibisate, *et al.,* 2011; Chalov and Ermakova, 2011). These result in meanders; the sinuous bends in a river that migrate downstream over time due to erosion on the outer bank (cut bank) and sediment deposition on the inner bank (point bar). Also, the river may cut into its banks during high-flow events, deepening and widening the channel. Conversely, during low-flow periods, sediment can settle out, reducing channel width. As meander loops migrate and approach each other, the river may eventually cut across the neck of a bend, creating a shorter channel (cutoff). This process can lead to the abandonment of the old meander loop, forming an oxbow lake. Rivers with high sediment loads and dynamic flow conditions can form braided channels, where the river splits into multiple interconnected channels. This can be due to changes in sediment supply, channel slope or flow regime.vTectonic or geologic activities are also driving factors in changing the river planform. Geological factors, such as faulting, subsidence or uplift can alter the course of a river over long geological timescales (Ziyad, 2014; Li, *et al*., 2023). Human activities play a critical role in changing river planform (Gregory, 2006). River engineering projects can artificially create cutoffs to alter the river's course for navigation, flood control and other purposes. Activities like urbanization and dam construction can lead to channelization, where the river's course is straightened and constrained to control flooding or facilitate navigation. Urban development can change the hydrology of a region, altering runoff patterns and sediment delivery to rivers. Urban areas often have engineered channels that may not resemble the natural planform. Agriculture increase soil erosion and sediment runoff into rivers, affecting channel morphology. Dams significantly alter river flow, sediment transport, and downstream channel dynamics leading to changes in sediment deposition and erosion patterns. Removing vegetation from riverbanks destabilizes the soil and increase erosion, leading to changes in channel planform (Knighton, 1998, Gregory, 2006, Kiss and Blanka, 2012, Biswas, *et al.,* 2015).

River bank erosion, accretion and lateral channel migration have resulted in changes in channel narrowing and lateral channel migration (Lovric and Tosic, 2016 and Block 2014). Short-term changes in braided rivers occur in response to a specific flood event, but longer-term changes over a sequence of flood events suggest major alterations in discharge and/or sediment load and the pattern and degree of development of active bars (Osterkamp *et al.*, 2006). Hence, this paper examines the implications of changes in channel width and braiding patterns on flooding from the nine study reaches upstream of the Shiroro Reservoir of River Kaduna, Kaduna Nigeria.

## MATERIALS AND METHODS

*Study Area:* This study is limited to Kaduna River upstream of the Shiroro Reservoir. The study area is geographically located between latitudes 9°52′38″ N and 10°39′07″ N and between longitudes 6°52′33″ E and 8°28′50″ E as shown in Figure 1.

Nine reaches in River Kaduna upstream of the Shiroro Reservoir Figure 2, were analyzed for changes in channel width and braiding as geographically defined below.

Latitude 9°52′38″N-9°53′43″N and longitude 8°26′48″E-8°28′50″E Straight Reach 1
Latitude 10°05′25″N-10°09′45″N and longitude 8°11′27″E-8°14′15″E Meander Reach 1
Latitude 10°23′35″N-10°25′47″N and longitude 7°52′30″E-7°54′00″E Straight Reach 2
Latitude 10°35′16″N-10°39′07″N and longitude 7°30′08″E-7°40′26″E Braided Reach 1
Latitude 10°33′01″N-10°35′58″N and longitude 7°27′51″E-7°30′56″E Meander Reach 2
Latitude 10°28′46″N-10°32′55″N and longitude 7°23′02″E-7°28′56″E Braided Reach 2
Latitude 10°28′21″N-10°30′16″N and longitude 7°20′16″E-7°22′36″E Straight Reach 3
Latitude 10°23′36″N-10°29′21″N and longitude 7°15′02″E-7°17′59″E Meander Reach 3
Latitude 10°08′54″N-10°14′55″N and longitude 6°52′33″E-6°59′53″E Braided Reach 3

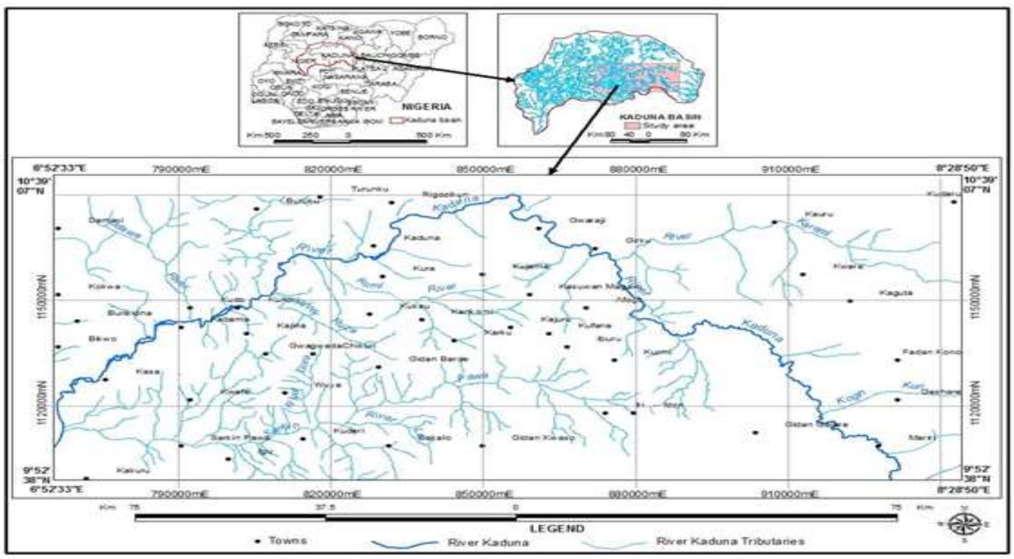


**Fig 1:** The Study area

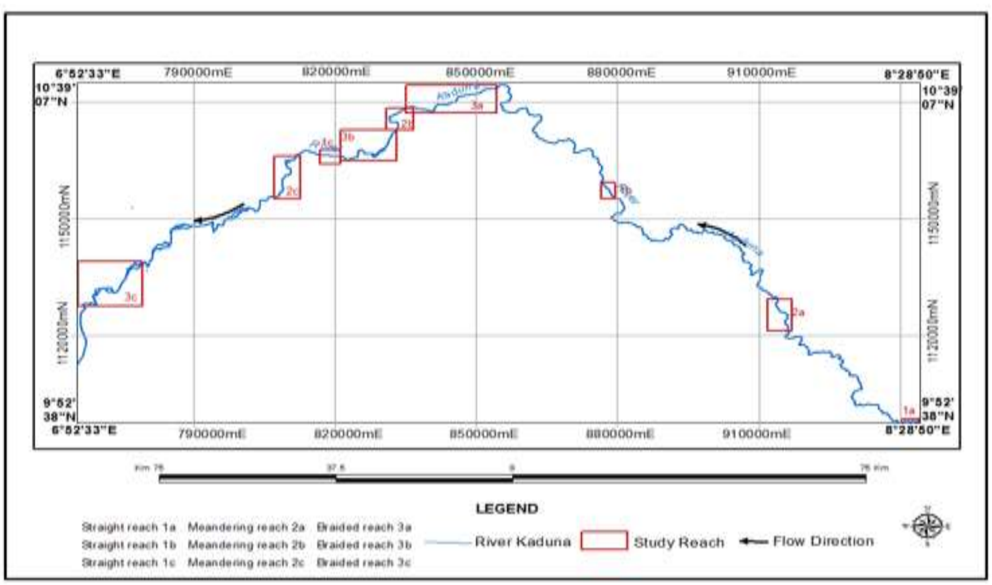


**Fig 2:** The Study reaches

*Data Collection:* Spatial data analyzed in this study included Topographical maps and Satellite images. The Topographic maps provided information for 1962 as shown in Table 1. Spot 5 image and Sentinel-2 images provided information for 2005 and 2017 and 2022 respectively, as shown in Table 2.

**Table 1:** Details of the Topographic maps

| Year | Scale | Type | Source | Season of Photography |
|---|---|---|---|---|
| 1962 | 1:50,000 | Topographic map | Federal Surveys | Dry |

**Table 2:** Details of the Satellite Images

| Year | Resolution | Type | Source/Sensor | Season of Imaging |
|---|---|---|---|---|
| 2005 | 5m | Satellite image | National Population Commission/SPOT-5 | Dry |
| 2017 | 10m | Satellite image | Glovis-USGS Free Downlaod Site/ Sentinel-2 | Dry |
| 2022 | 10m | Satellite image | Glovis-USGS Free Downlaod Site/ Sentinel-2 | Dry |

*Data Analysis:* The channel width was measured following the algorithms used by Pavelsky and Smith, (2008) and Fisher, *et al*., (2013).

The centre line in each straight and meandering reach was determined and line widths of the river from bank to bank orthogonal to the channel centre line were established at 50m interval along the full length of the centre line Figure 3 to Figure 8. The total sum of transects legs was divided by the number of transects to obtain the average width of the river at the given reach.

In calculating braiding index, the method used by Lalit, *et al*., (2018) was adopted. It utilizes the fraction of area covered by Sand bars, number of mid-channel bars and maximum width of the reach and is expressed in equation 1:

$$BI = X * N * \frac{W}{L} \qquad (1)$$

Where BI is braiding index, $X$ is the fraction of area covered by bars, $N$* the number of mid-channel bars, $W$ is the maximum width of the reach and $L$ the length of reach in Figure 9 to Figure 11.

This method of calculating braiding index considers the following:

(i) River or reach with more fraction of area by bars has more braiding value.

(ii) (ii) In case of same fraction of area by bars, the number of mid-channel bars will influence braiding value.

(iii) (iii) Braiding of rivers or reaches with same fraction of area by bars and same number of mid-channel bars will differ by maximum width.

(iv) (iv) Length is used in denominator to get a dimensionless value of braiding index.

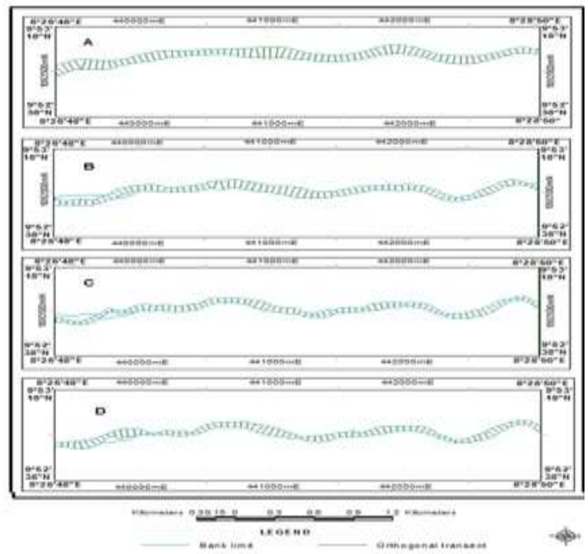

**Fig 3:** Calculation of river width at straight reach 1; A-1962 B-2005 C-2017 and D-2022

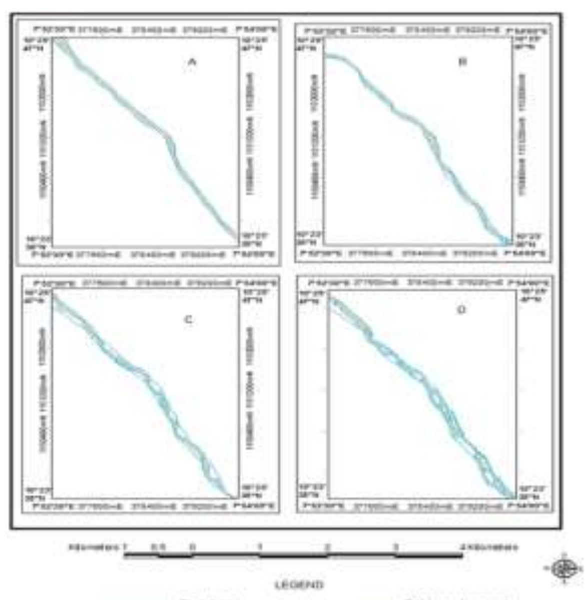

**Fig 4:** Calculation of river width at straight reach 2; A-1962 B-2005 C-2017 and D-2022

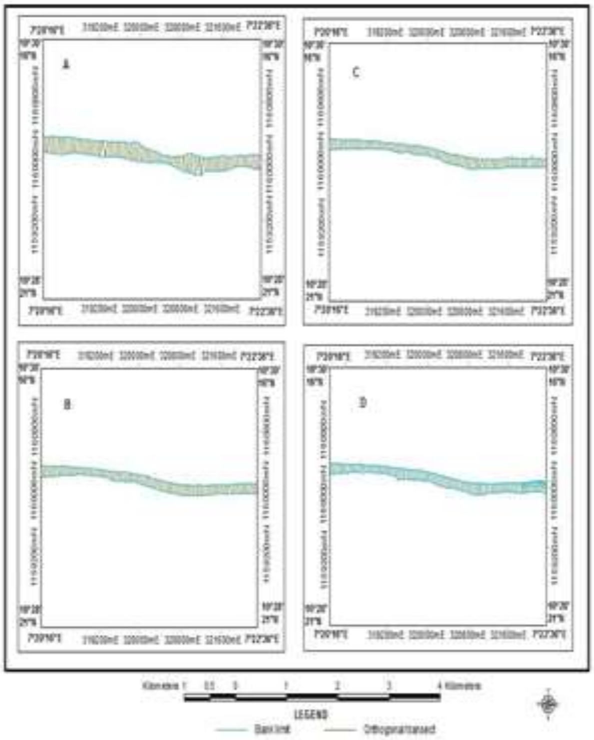

**Fig 5:** Calculation of river width at straight reach 3; A-1962 B-2005 C-2017 and D-2022

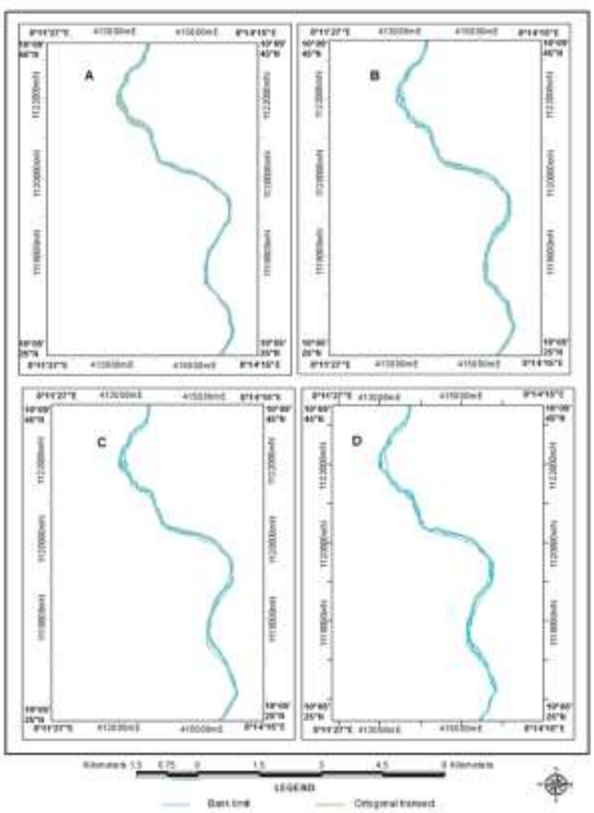

**Fig 6**: Calculation of river width at meander reach 1; A-1962 B-2005 C-2017 and D-2022

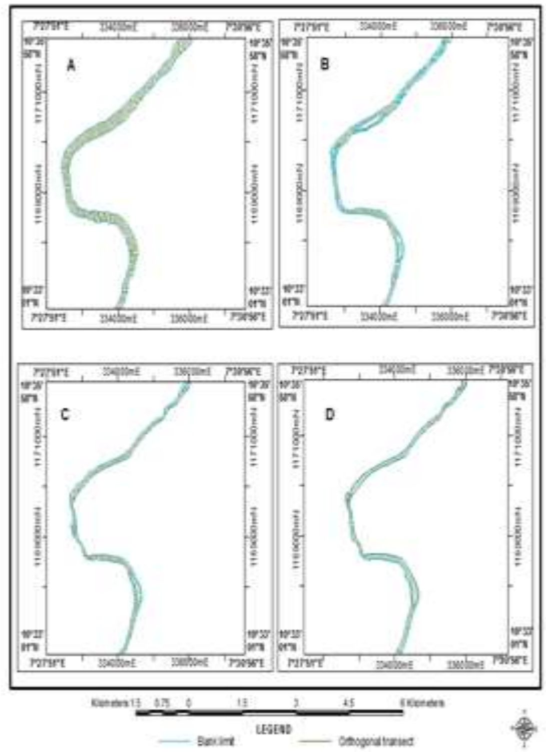

**Fig 7:** Calculation of river width at meander reach 2; A-1962 B-2005 C-2017 and D-2022

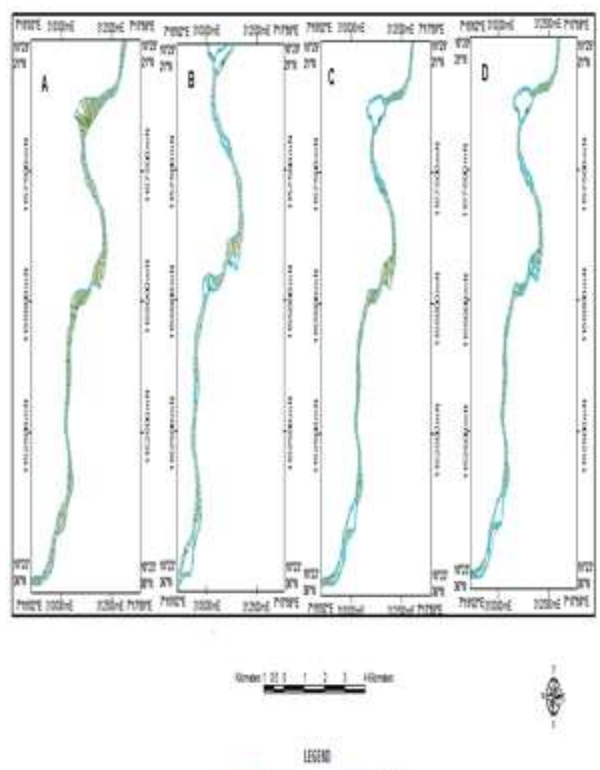

**Fig 8:** Calculation of river width at meander reach 3; A-1962 B-2005 C-2017 and D-2022

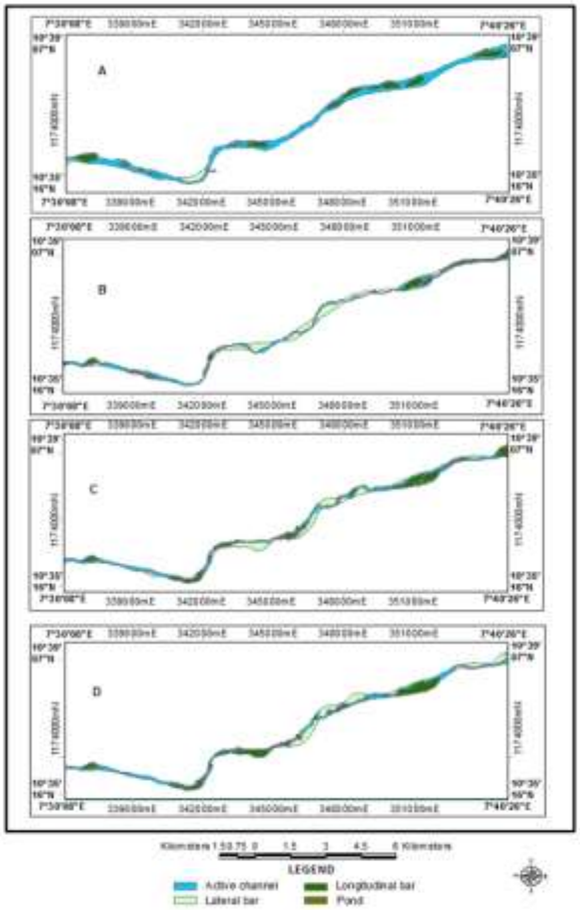


**Fig 9:** Calculation of river width at braided reach 1; A-1962 B-2005 C-2017 and D-2022

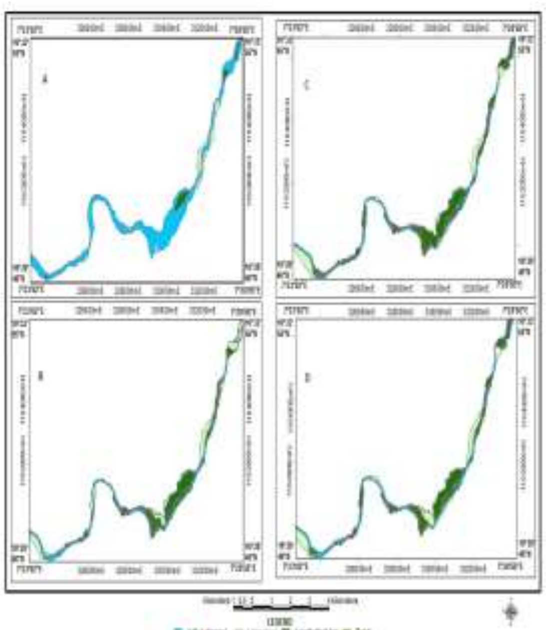

**Fig 10:** Calculation of river width at braided reach 2; A-1962 B-2005 C-2017 and D-2022

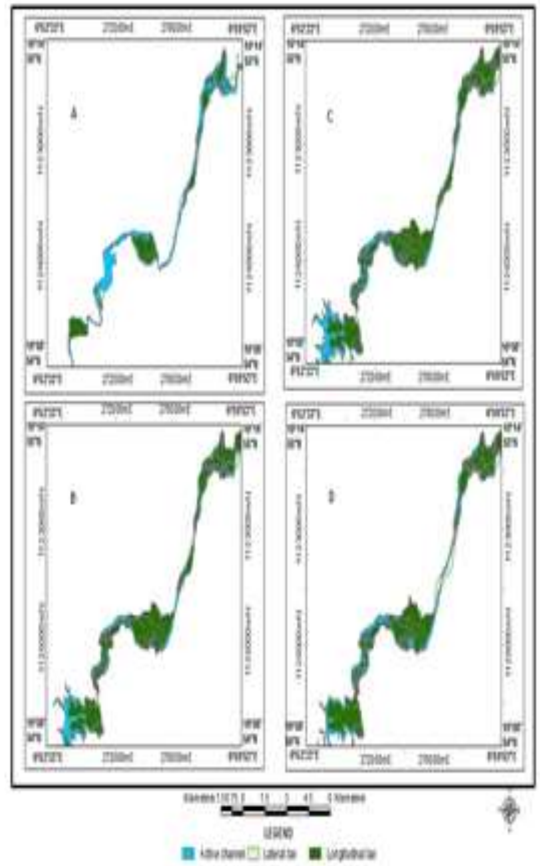

**Fig 11:** Calculation of river width at braided reach 3; A-1962 B-2005 C-2017 and D-2022

## RESULTS AND DISCUSSION

The results of measurements of average width of meandering and straight reaches are presented in Table 3 and Table 4 respectively. There was continuous decrease in width from 1962 to 2022 in meandering reach 1, indicating that steady depositional activities along the river banks were dominant in this reach. The situation is not the same for meandering reach 2 and 3 as significant decreases were experienced between 1962 and 2022. The slight increase in width noticed in meandering reach 2 in 2022 and also in meandering reach 3 in 2017 notwithstanding there were major depositional activities along the river banks over the years in meandering reaches 2 and 3. In the straight reaches the width continuously decreased between 1962 and 2017 resulting from depositional activities along the river banks but began to expand in 2022 indicating that very significant erosional activities resumed along the river banks in these reaches. All the meandering and straight reaches generally decreased significantly reducing the capacity of the river to transport its water and sediment load, hence, flooding occurrences in the river.

**Table 3**: Statistics of Average Width of Meandering Reaches in Metres

| Year | Meander Reach 1 | Meander Reach 2 | Meander Reach 3 |
|---|---|---|---|
| 1962 | 69.81 | 192.65 | 218.01 |
| 2005 | 65.91 | 107.38 | 143.21 |
| 2017 | 55.09 | 88.42 | 154.99 |
| 2022 | 47.53 | 94.89 | 141.37 |

**Table 4**: Statistics of Average Width of Straight Reaches in Metres

| Year | Straight Reach 1 | Straight Reach 2 | Straight Reach 3 |
|---|---|---|---|
| 1962 | 97.41 | 74.86 | 193.17 |
| 2005 | 77.62 | 59.63 | 122.68 |
| 2017 | 62.82 | 58.69 | 118.07 |
| 2022 | 68.28 | 80.56 | 123.28 |

The results of calculations of braiding index of braided reaches in Table 5 indicated that there was steady increase in braiding index in braided reach 1 from 1962 to 2022 which are attributed to depositional activities in the reach. Also, braiding index increased steadily in braided reach 2 from 1962 to 2017 but slightly decreased in 2022. However, very significant increase in braiding index occurred in braiding reach 3 which can be attributed to the effect of the Shiroro dam. The back water effect of the Shiroro reservoir retards the steady flow of water and sediment load of the river at this reach. The consequence of this flooding as water is forced out of the channel.

**Table 5:** Statistics of Braiding Index

| **Braided reaches** | **Total area (Km$^2$)** | **Area covered by bars (Km$^2$)** | **proportion of area covered by bars (*X*)** | **No. of mid-channel bars (*N**)** | **Max. width of the reach in metres (*W*)** | **Length of the reach in metres (*L*)** | **BI** |
|---|---|---|---|---|---|---|---|
| 1962_1 | 6.23 | 1.72 | 0.28 | 16 | 579.37 | 21074.99 | 0.12 |
| 2005_1 | 4.36 | 2.34 | 0.54 | 25 | 558.75 | 21330.17 | 0.37 |
| 2017_1 | 5.15 | 2.76 | 0.54 | 35 | 526.28 | 21381.21 | 0.47 |
| 2022_1 | 5.14 | 2.75 | 0.54 | 33 | 534.39 | 21481.53 | 0.44 |
| 1962_2 | 5.07 | 0.91 | 0.18 | 4 | 558.75 | 18140.32 | 0.02 |
| 2005_2 | 4.38 | 2.57 | 0.59 | 46 | 777.11 | 18237.84 | 1.16 |
| 2017_2 | 4.68 | 2.94 | 0.63 | 89 | 806.31 | 18314.80 | 2.47 |
| 2022_2 | 4.69 | 2.89 | 0.62 | 61 | 853.78 | 18090.12 | 1.78 |
| 1962_3 | 7.57 | 3.24 | 0.43 | 36 | 534.01 | 21384.36 | 0.39 |
| 2005_3 | 12.61 | 8.07 | 0.64 | 108 | 806.31 | 19957.89 | 2.79 |
| 2017_3 | 13.29 | 8.11 | 0.61 | 123 | 2598.93 | 20014.49 | 9.74 |
| 2022_3 | 13.26 | 8.74 | 0.66 | 119 | 2199.83 | 19026.54 | 9.42 |

*Conclusion:* River width narrowing reduced the river's ability to effectively transport its water and sediment load, while braiding obstructed the flow pattern of the river resulting in flooding. The evaluation of channel narrowing and braiding in River Kaduna stresses the need for proactive measures to mitigate the associated flood risks. Tackling these issues is not only critical for the safety and well-being of the communities living in the region but also for preserving the ecological and economic values of this important water resource. Hence, a holistic approach including scientific research, engineering solutions and community involvement, is essential to manage the implications of channel narrowing and braiding efficiently and sustainably.

## REFERENCES

Aggarwal, SP; Jeb, DN (2008). Flood Inundation Modelling of the River Kaduna using Remote Sensing and Geographic Information Systems. *Nigerian J. of Appl. Sci. Research*, 4(12), pp. 1822-1833.

Biswas, SS; Pal, R; Pramanik, MK; Mondal, B (2015): Assessment of Anthropogenic Factors and Floods using Remote Sensing and GIS on Lower Regimes of Kangshabati-Rupnarayan River Basin, India. *Inter. J. of RS and GIS,* Vol. 4 (2): 77-86,

Block, D (2014): Historical Channel-Planforms Change of the Little Colorado River near Winslow, Arizona: U.S. Geological Survey Scientific Investigations Report 2014-5112, 24 p., 2 plates.

Chalov, S; Ermakova, G (2011): Fluvial response to climate change: a case study of northern Russian rivers, *Cold Region Hydrology in a Changing Climate* (Proceedings of symposium H02 held during IUGG2011 in Melbourne, Australia.

Butu, AW; Emeribe, CN; Leke, DC; Jibril, MS; Ananya, B J (2020): Effect of urbanization on channel platforms of River Kaduna from 1962-2017, Kaduna State, Nigeria, *J. of Geog. of Trop. Environ.* 4 (2), 13-35.

Fisher, GB; Bookhagen, B; Amos, CB (2013): Channel Planform Geometry and Slope from Freely Available High-Spatial Resolution

Imagery and DEM Fusion: Implications for Channel Width Scalings, Erosion Proxies, and Fluvial Signatures in Tectonically Active Landscapes. *Geomorphology,* 194, 46-56.

Gregory, KJ (2006): The human role in changing river channels. *Geomorphology* 79:172-191.

Ibisate, A; Ollero, A; Diaz, E (2011): Influence of catchment processes on fluvial morphology and river habitats: Fluvial morphology and river habitats, *Limnetica,* 30 (2): 169-182.

Jagers, HRA (2003): Modeling planform changes of braided rivers. Print Partners Ipskamp B.V:1-314.

Kiss, T; Blanka, V. (2012): River channel response to climate and human induced hydrological changes: Case study on the meandering Hernád River, Hungary. *Geomorphology,* 175-176, 115-125.

Knighton, D (1998): *Fluvial form and processes A New Perspective.* London: Arnold.

Lalit, S; Chandan, M; Suranjana, BB. (2018): A novel approach to calculate braiding of a large alluvial river, Research Communications, *Current Sci.* 115 (6): 1179-1185.

Li, M; Seybold, H; Wu, B; Chen, Y; Kirchner, JW (2023): Interaction between tectonics and climate encoded in the planform geometry of stream networks on the eastern Tibetan Plateau. *Geophysical Res. Let. 50,* e2023GL104121.

Lovric, N; Tosic, R (2016): Assessment of Bank Erosion, Accretion and Channel Migrationing Using Remote Sensing and GIS: Case Study – Lower Course of the Bosna River. *Questiones Geograhicae* 35(1): 81-92.

Olesco, LGD; Roleda, JHP; Daag, AS (2023): Spatio-Temporal Morphological Changes Of The Cagayan River Section In Tuguegarao City, Philippines, *J. Surv. Fisheries Sci.* 10(1S) 6349-6359.

Osterkamp, WR; Hooke, J; Ridgway J (2006): Stream channel morphology and position. International Union of Geological sciences, Geoindicators Initiative (GEOIN).

Pavelsky, TM; Smith, LC (2008): RivWidth: A Software Tool for the Calculation of River Widths from Remotely Sensed Imagery. *IEEE Geosci. RS Let.* **5:** 70-73.

Selander, JA (2015): Influences on River Morphology in a Sediment-dominated system. Department of Geology University of California, Davis, CA 95616.

Ziyad, ER (2014): Relationship between tectonic activity, fluvial system and river morphology in the Dohuk catchment, Iraqi Kurdistan, *geomorphologie.* 20 (1): 91-100