

RESEARCH ARTICLE

CONCEPT OF CHANNEL PLANFORMS CHANGES ON POTENTIAL RIVER FLOODING

Okonofua E.S^a, Emeribe C.N^b, Dewingong C.L^c, Butu A.W^d^a Department of Geomatics, Faculty of Environmental Sciences, University of Benin, PMB 1154 Benin City, Nigeria^b National Centre for Energy and Environment, Energy Commission of Nigeria, University of Benin, PMB 1154 Benin City, Nigeria^c Department of Geography, faculty of Arts and Social Sciences, Nigeria Defense Academy, Kaduna^d Department of Geography, Nigerian Army University, Biu, Borno State*Corresponding Author's Email: ehizonomhen.okonofua@uniben.edu

This is an open access journal distributed under the Creative Commons Attribution License CC BY 4.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited

ARTICLE DETAILS

Article History:

Received 25 September 2022

Revised 05 October 2022

Accepted 15 November 2022

Available Online 19 December 2022

ABSTRACT

This study investigated the effect of channel planforms changes on potential river flooding in Kaduna state (River Kaduna as case study); with the aim to ascertain the effects of river channel planform on its potential flooding and put measures in place to avert the environmental menace. Topographic maps covering the entire course of the river and the characteristics of the river to be studied were obtained from the federal ministry of survey. The reliability of satellite images was verified by ground measurements using a 30m Surveyor's tape on four bridges that cross River Kaduna. The measurements obtained were compared with correspondent measurements on the satellite image and found that the ground measurements and the measurements on both SPOT and Sentinel images were close. Three reaches (Meander 1, 2, 3; Straight reach 1, 2, 3 and Braided reach 1, 2, 3) were selected for this study. Variations measured along the river were changes in channel width, changes in sinuosity index, changes in braiding index channel lateral migration and changes in channel length from 1962 to 2017. The results showed a reduction in the channels width in all the reaches from average of 190m in 1962 to 74m in 2017; the sinuosity index was low in the duration considered (average of 1,15) while the braiding index value had a mean of 0.55. Channel migration also reduced from an average of 82m in 1962 to 53m in 2017 while the river reduced by 12% within this same period. The propensity of river flooding in the study area is high hence there is the need to carry out channel improvement, early warning system and desiltation of the river in order to eliminate the potential danger.

KEYWORDS

Channel, Planforms, Flooding, Sinuosity, Migration

1. INTRODUCTION

Rivers have been a focus of man's activities since his sojourn on earth. So important to humanity are the benefits derived from rivers, and so necessary is the protection against floods and other river disasters, that pursuit for knowledge of riverine systems has advanced in leaps and bounds. Their irrigational use has provided the basis for powerful bureaucratic territorial governments typified by those that flourish in the Wang Ho in China, the Tigris and Euphrates in Mesopotamia (the area of land covering today's Iraq mostly, but also part of modern-day Iran, Syria, Turkey and Kuwait), the Nile in Egypt, and the Ganges-Brahmaputra in India (Xiufang et al., 2013; Conniff et al., 2012). Rivers have formed political boundaries between and within nations, and their vicissitudes have frequently led to disputes, for example, the Nile water problems between Egypt and Sudan, and the Mekong Basin Disputes in Vietnam and Cambodia (Russell, 2010).

A group researcher observes that the behavior of rivers, their channel network and interflaves and the character of their associated sedimentary deposits are of interest to a variety of engineers, geologists and geographers as well as individuals losing their property, cornfield or pasture to an aggressive river (Lords et al., 2009). Economically, rivers provide routes of commerce; they are important in terms of the petroleum, uranium, gold and placer minerals obtained from their sedimentary deposits. Channel planform is the two-dimensional appearance of a river in map view or the channel pattern as seen from an

airplane (Jagers, 2003). Some researchers suggest that channel patterns (planform) include straight, meandering and braided forms (Lords et al., 2009). Straight river segments, as described by Jagers are those that are seldom longer than 10 times their channel width (Jagers, 2003). The meanders are winding curves or bends in a river, resulting from both lateral erosion and depositional processes and while the braided segment as a system of channels, splitting and rejoining around islands (Jagers, 2003).

The impacts of river planform changes on cultural features; bridges, culverts, and socio-economic holdings; agriculture and other investments and how they relate to flooding have attracted the attention of many scholars who have made immense contributions on the impact it has on flooding and socioeconomic activities within a catchment (Yearwood, 2010; Kondolf et al., 2002; Larsen and Greco, 2002). Adjustments in river planform are also known to have adversely affected the ecosystem (Lord et al., 2009; Petts and Amoros, 1996). Several studies have revealed that invertebrates, fish, riparian vegetation, and wildlife adjust to the channel form, hydrologic and sediment transport regimes following adjustment in river planform (Naiman et al., 1993; Hughes, 1997; Ward, 1999; Holburn, 1984; Tiegs and Pohl, 2005). Hence, this attest to the fact that having a firm understanding of the planform dynamics of river channels has important implications for maintaining biodiversity and minimizing flood damage.

Drainage basin is primarily a sediment production area where climate,

Quick Response Code



Access this article online

Website:

www.earthsciencesmalaysia.com

DOI:

[10.26480/esmy.01.2023.20.28](https://doi.org/10.26480/esmy.01.2023.20.28)

diastrophism, and land use act as upstream controls. Sediments eroded from the drainage basin flow through the tributaries and the mainstream, the hydraulic geometry of the stream channels and their longitudinal profile are altered to cope with the additional load. Rivers dictate landscape evolution, exert controls on erosional processes, set boundary conditions for hillslope processes, and govern the height limits of mountain ranges. The materials eroded through hill slope processes and bedrock channel incision are eventually transported by alluvial channels and that while these activities take place the channel morphology is also governed by a number of drivers including tectonic processes, climate, and local lithology that influence the river system over a range of time scales (Garde, 2006; Selander, 2004; 2015).

Floods are natural occurrences that have been considered as a tragedy in some parts of the world for instance in Nigeria, but they have presented great opportunities in others for instance in Egypt. Floods move large amounts of sand, silt and debris downstream onto adjacent land, and eventually deposit water and suspended sediment over vast areas. These sediments have helped replenish topsoil components particularly valuable to agricultural lands and in some places, it has gradually elevated the landmass above sea level (Abowei and Sikoki, 2005). The causes of riverine flooding in most developing countries (including Nigeria) have been attributed to factors such as prolonged rainfall and urbanization with an attendant increase in runoff, but little attention has been paid to river channel changes as they influence floods. Therefore, this study attempts to assess Changes in Channel Planform and flooding in River Kaduna, Kaduna State, Nigeria.

1.2 Related Work

Lateral abrasion, accretion and lateral channel migration are the most important geomorphological processes, which affect river stability. Understanding the dynamics of lateral abrasion, accretion and lateral channel migration of rivers is significant to practical issues such as predicting channel migration rates for engineering and planning purposes as well as soil and water management. Lovric and Tosic assessed the rate of lateral abrasion and accretion, as well as the rate of lateral channel migration of the Bosna River in Bosnia and Herzegovina using remote sensing and GIS (Lovric and Tosic, 2016). Their investigations revealed that the river's shape and position have changed significantly during the period of study, with less erosion on the left bank and more erosion on the right bank. Accretion was more on the left bank and less on the right bank. They were able to estimate the average lateral channel migration per year.

Fashae and Faniran is a work on the alluvial section Lower Ogun River in Nigeria. They examine the morphologic variables collected through field measurements which included cross-section, depth and width, velocity and other field data (Fashae and Faniran, 2015). Analysis of Variance and Pearson Product Moment Correlation respectively revealed that downstream morphological characteristics of the river vary distinctively at each cross-section with bed slope as the most significantly varied among all other morphologic parameters. Fashae and Faniran found out that bank-full width had a strong positive correlation with wetted perimeter and cross-sectional area, bank-full depth (maximum) also enjoyed a positive correlation with hydraulic radius, wetted perimeter and cross-sectional area and yet another strong positive correlation existed between gradient and discharge (Fashae and Faniran, 2015). The study ascertains the extent of variability in the morphologic characteristic of River Ogun which provides a sound basis for river maintenance and management.

A group researcher compare the morphology of braided and meandering threads of streams from the Bayanbulak Grassland, Tianshan, China; a basin where meandering and braided gravel-bed streams coexist under the same climatic and geological settings (Métivier et al., 2015). They carried out measurements of the rivers discharge, width, depth, slope and grain size at two different periods and for the same month of the year, during high flow season to enable comparison. A group researcher measure the cross-section and the water discharge of large streams, using a 2Mhz acoustic Doppler current profiler (ADCP, Teledyne-RDI StreamPro) and in shallower streams, they used wading rods, rulers and floats to measure the surface velocity and estimate the vertically-averaged velocity from it (Métivier et al., 2015). Topcon theodolite with a laser rangefinder was used to measure the long profile of the streams and estimate their slope. They also measured the grain-size distribution from surface counts and extracted the median grain size and the size of the 90th percentile from these distributions.

Some researchers carried out a study on how the large wood in rivers influenced flood hazards (Ruiz-Villanueva et al., 2014). They observed

that in terms of flood hazard, the presence of large wood (logs, trees, branches and roots) in rivers may aggravate the consequence of flood events as these materials may affect infrastructure such as bridges, weirs and culverts, especially those intersecting forested mountainous rivers. They suggest that the presence of these woody materials in rivers must be managed and included in flood hazard and risk analysis rather than the practice of systematically removing wood debris from river channels as preventive measure, since studies have shown that this practice may be useless as the materials are transported and deposited after each flood and may not even be of benefit to the long-term natural balance of the river ecosystem.

Hence, present a comprehensive methodological approach to studying the role of large wood in rivers with a focus on flood hazard, which involves firstly, understanding the dynamics of wood recruitment, the contributing areas delivering wood to the stream have to be delineated and the recruitment mechanism studied (Ruiz-Villanueva et al., 2014). This enables estimates to be obtained of the potential volume of deliverable wood. Then to analyze wood transport they present a numerical model, which allows simulation of the behavior of individual pieces of wood together with hydrodynamics. Finally, they analyze the impact of wood on the magnitude of flood events (in terms of water level, flow velocity or flooded areas) using a known flood event. They found out that the upstream water level rises by up 2 meters and reduces the flow velocity which favored debris and sediment deposition. Large wood in rivers can clog the channel and certainly influence flooding but as stated above, this is prominent in heavily forested areas not in areas where sediment transportation and deposition are the dominant processes.

River systems provide critical ecosystem sources to large populations and considerable pressure is exerted by population on these river systems through water abstraction for irrigation, pollution through industrial and urban expansion, as well as reduction in connectivity and alterations of hydrologic regimen by the construction of dams, barrages and related engineering structures. Aisuebeogun and Ezekwe attempt to explain the channel processes and dynamics of two river systems, the Sombreiro River and New Calabar River running through a rapidly urbanizing humid tropical deltaic environment in Nigeria, with visible threats from industrialization and consequent pollution (Aisuebeogun and Ezekwe, 2014).

Hydraulic processes and parameters are compared with established power function relations for hydraulic geometry, and it is discovered that the fundamental relations between channel-geometry dimensions, velocity, and flow can be expressed for the catchments. Ten gauging stations in each catchment are studied and results show that the studied catchments adjust their geometry to changing discharges. High values of coefficients of determination among variables indicate that much of the downstream variation in channel width to depth ratio can be accounted for by changes in discharge. Also in the study, the width/depth ratio is found to be related to the percentage of silt and clay in channel perimeter and that downstream hydraulic-geometry relations are in general agreement with previously published hydraulic and channel adjustment data.

2. STUDY AREA

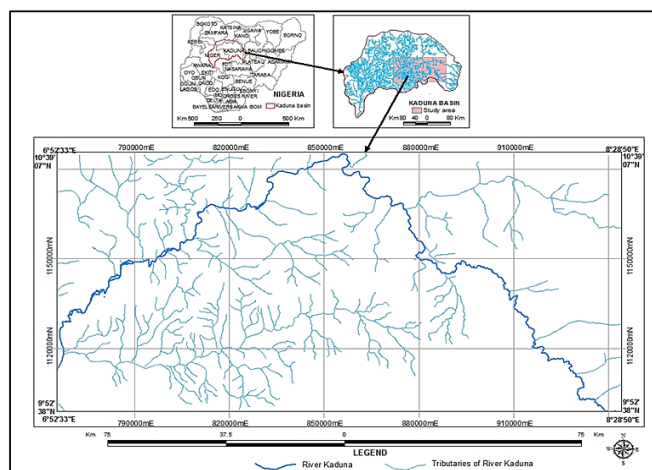


Figure 1: Map of the study Area.

The Kaduna River is a major tributary of the Niger that rises from the Jos Plateau, flows in a north-westerly direction, through Kaduna State and its

capital Kaduna and then southwards to join the Niger downstream at Wuya and Pategi. The river is the second trunk river within the Niger Central hydrological Area (HA II) rated after River Niger covering a total length of 612.6km as measure on satellite image as opposed to 550km reported in Wikipedia. This study is limited to that portion of the Kaduna River upstream of the Shiroro Reservoir, 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. The Kaduna River Basin lies between the 1000 mm and 1500 mm isohyets, which places the Basin within Nigeria's sub-humid zone.

3. METHODOLOGY

3.1 Type and Source of Data

Table 1: Details of the Topographic maps				
Year	Scale	Type	Source	Season of Photography
1965	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 Download Site/Sentinel-2	Dry

To study the changes in channel planform of River Kaduna, the main type of data needed were on the river planform characteristics, these data were obtained from topographic maps covering the entire course of the river, from which the study reaches were selected. The topographic maps provided information for earlier periods of the study for which satellite

images were not available. Multi-temporal satellite images covering the study were also used. To verify the reliability of the satellite images some direct ground measurements were taken on the field that was used to compare correspondent measurements on the images. Details of the topographic maps and satellite images used for the study are shown in Table 1 and Table 2 respectively.

3.2 Data Collection

Acquisition of Topographic Maps and Satellite Images: Topographic maps used were derived from aerial photographs of 1962 and published in 1965 by the Northern Nigerian Survey as indicated in the map reliability diagram. The maps were obtained from the Federal Survey Map Depot in Kaduna. Seven Map Sheets at scale 1:50,000 covering the study area were used namely, Kaduna Sheet 123 S. E., Kakuri Sheet 144 N. E., Kajuru Sheet 145 N. E., Kafanchan Sheet 167 N. E., Igabi Sheet 124 S. W., Geshare Sheet 146 S. W. and Alawa Sheet 143 S. E. Mosaic of SPOT 5 satellite images (5m resolution) of 2005 for the whole country was collected from the National Population Commission State Office Jos and Sentinel-2 image (10m resolution) was downloaded from Glovis-USGS free download site.

Field Observation: The reliability of satellite images was verified by ground measurements using a 30m Surveyor's tape on four bridges that cross River Kaduna at Nasarawa, near Ahmadu Bello Stadium, the one popularly known as Yakowa Bridge and the Gadan Danbushiya at Unguwan Rimi. The measurements obtained, were compared with correspondent measurements on the satellite image and found that the ground measurements and the measurements on both SPOT and Sentinel images were close. Hence, the measurement of the river parameters from satellite images could be reliable. The photograph on Plate IV shows measurement being taken on the Nasarawa Bridge.

A Montana Garmin 650 handheld Global Positioning System (GPS) was used for logging the start point and endpoint of each bridge. A 30m Surveyor tape was laid in iterations until the entire width of the river was covered, and then the total width of the bridge was obtained by summing up all iterations and their excesses. The ground measurements and their corresponding measurements on the images are presented in Table 3.

Table 3: Ground Measurements and Their Corresponding Measurements on The Images							
Bridge	Start point of bridge		End point of bridge		Ground Measurement	SPOT Image	Sentinel-2 Image
	Eastings Coordinates	Northings Coordinates	Eastings Coordinates	Northings Coordinates			
Nasarawa	324125	1158982	324185	1159228	254.8	254.29	253.21
Stadium	327154	1160926	327345	1161033	215.4	218.34	218.92
Yakowa	331592	1161972	331766	1161705	322.54		318.69
Unguwar Rimi	333047	1165344	333273	1165250	247.55		244.77

3.3 Data Processing

Topographic maps and satellite images were processed to extract spatial data on the river planforms. The detailed methodology of the processes employed is discussed as follows:

3.3.1 Processing Topographic Maps

To extract data from topographic maps for analysis the relevant analogue maps were scanned to convert to digital format. When scanning of paper maps is carried out the resultant maps lose spatial reference and can't be subjected to analysis in Geographic Information System (GIS) domain. To analyze the scanned maps, spatial reference through the process of georeferencing were provided. Georeferencing the scanned maps define their location using map coordinates by assigning the coordinate system of the data frame to selected control points. This process allows the georeferenced raster data to be viewed, queried and analyzed with other geographic data. After georeferencing, a measure of the error-the residual error is returned. The error is the difference between where the "from point" ended up as opposed to the actual location that was specified that is, the "to point". The total error is automatically computed by taking the root mean square (RMS) sum of all the residuals. This value describes how consistent the transformation is between the different control points.

3.3.2 Image Processing

The satellite images utilized for this study were pre-processed as of the time of acquisition, that is, all forms of corrections, enhancement and georeferencing had been carried out on them. However, further processing was required for the images to be analyzed and this post-processing included subset, mosaic and re-projection processes.

3.4 Data Analysis

In order to characterize the various planform variables on River Kaduna, nine reaches were selected on the portion of the river upstream of the Shiroro Reservoir. The reaches that were selected for the studies and their locations geographically defined as:

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

The river bank limits for the study reaches were traced from the topographic maps and the satellite images. Further GIS analyses performed on the delineated bank limits involved the establishment of the centerline, based on which the channel length, sinuosity index, channel width and channel migration were calculated. Other calculations that were based on the extracted bank limits are the braiding index.

3.4.1 Analysis of Topographic Maps and Satellite Images

The channel outlines or bank limits of the defined segments of the river were delineated from the scanned georeferenced maps and satellite images using ArcGIS 10.3.1. Each of the digitized reaches was stored in a separate shapefile using procedures (Downward et al., 1994). Errors of exaggeration and generalization were avoided so that such errors do not yield misleading results. Based on the delineated bank limits further analyses were carried out to determine changes in planform of River Kaduna following the procedures (Clerici and Perego, 2016).

3.4.2 Characterization of Channel Planforms Variables

To describe the river channel planform variables the procedures of Clerici and Perego were adopted (Clerici and Perego, 2016). After delineating the bank limits the procedure is concentrated on the establishment of the centerline. The centerline was defined by joining a set of points that are plotted at equidistance from the opposite banks, created from successive iterations of parallel lines from the opposite banks of the river. The channel width is commonly defined as the length of the line from bank to bank orthogonal to the channel centerline. The same procedure as described in the script was used by Clerici and Perego and is adopted in this work for calculating river width, Sinuosity Index, Braiding Index and Channel Lateral Migration (Clerici and Perego, 2016). The rest of the procedure explains; Parallel lines tracing from bank limits in a series iteration, Centerline extraction, Equidistance point setting on the centerline, Orthogonal transect tracing on the centerline.

4. RESULTS AND DISCUSSION

The natural and anthropogenic processes acting on the river that brought about changes in the planform variables for the period 1962 to 2017 are presented and discussed under channel width, sinuosity index, braiding index, channel migration and channel length.

4.1 Changes in Channel Width

The derived statistics for the changes in channel width are shown in Table 4 and 5 for meandering and straight reaches respectively. In 1962 the average width of the channel in the meandering reaches 1, 2 and 3 were 69.81m, 192.65m and 218.01m respectively. In 2005 the average width of the same reaches were 65.91m, 107.38, and 143.21m respectively, and in 2017 the average widths of the reaches were 55.09m, 88.42m and 154.99m respectively. These values indicate a progressive reduction in the average width of the meandering reaches. The statistics show that in 1962 the straight reaches 1, 2, and 3 had values of average width as 97.41m, 74.86m and 193.17m respectively; in 2005 the values were 77.62m, 59.63m and 122.68m for reaches 1, 2 and 3 respectively. The same reaches in 2017 had 62.82m, 58.69 and 118.07 respectively. These results portrayed a continuous reduction in the average width of the straight reaches.

River Kaduna is a natural alluvial river characterized by channel boundary roughness. Its hydraulic geometry is determined by the stability of the channel banks, the availability of sediment for transport, and vegetative cover, in addition to the magnitude and variability of flow (Singh, 2003). The boundary conditions of the river provide the friction needed to reduce the viscosity of flow and slow down the lift and drag processes of the river thereby affecting the movement of sediments (bed and bank material, and cohesive material). In the absence of scouring of the riverbed the slope of the river is gradually reduced by deposition thereby affecting the flow velocity. The types of sediments being transported have also influenced the amount of deposition. Very fine sediments are carried in suspension, which can be seen in the brown colour of water during flood flows in River Kaduna, but the coarse sands and gravels are moved by lift and drag processes that rely much on the Stream Energy.

Thus, rather than River Kaduna widening regularly in response to floods or as a long-term change due to increases in surface water runoff resulting from upland development or climate change according to Konrad, assertion or in response to riparian vegetation removal from agricultural activities as asserted by the channel width was narrowing due to deposition that follows the reduction in Stream Energy (Konrad, 2012; Brooks et al., 2003; Eaton, 2006). On June 20th, 1990, the Shiroro Dam was inaugurated and this further impacted on the velocity of the river. The

decrease in Stream Energy that resulted from these processes further reduced the capacity of the river to transport its load, thereby increasing sedimentation (narrowing the channel) and reducing the capacity of the river to cope with flood flows.

The situation experienced in the reaches during the period of study was exacerbated by human intervention through various forms of agricultural activities upstream as well as urbanization. The agricultural activities expose the land cover that should naturally reduce sediment yield in the basin. Particularly, meander reaches 2 and 3, straight reach 3 and braided reaches 2 and 3, had to cope with the effect of urbanization, as high runoff from the Kaduna metropolis added to the water and sediment load transported by the river. Hence, the narrowing of these reaches during the period of study is explained by sedimentation. The narrowing channel implies that more of the discharge of the river is converted to storage which results in flooding. Tiegs and Pohl examined the planform channel response of a portion of the Upper Colorado River Delta in the United States America using aerial photography and Geographic Information System analysis, while Velcu and Morosanu studied the dynamics of the minor river bed of Teslui River Romania, in relation to human factors, and they got similar results in their analyses (Pohl, 2005; Velcu and Morosanu, 2015).

Table 4: Statistics of Average Width of Meandering Reaches in meters

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

Table 5: 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

4.2 Changes in Sinuosity Index

The results in Tables 6 and 7 show that sinuosity index values for meandering reach 1 in 1962, 2005 and 2017 were 1.24, 1.25 and 1.25 respectively. For meandering reaching 2 the values in 1962, 2005 and 2017 were 1.50, 1.50 and 1.49 respectively and in the years 1962, 2005 and 2017 the sinuosity index values for meandering reach 3 were 1.24, 1.24 and 1.24 respectively. The results indicate that for the 56 years being examined there were no significant changes in sinuosity in all the three meandering reaches. For straight reach 1 in 1962, 2005 and 2017 sinuosity index values of 1.03, 1.06 and 1.09 respectively were obtained. For the same years in straight reach 2 the sinuosity values were 1.02, 1.05 and 1.06 respectively, while sinuosity values of 1.01, 1.00 and 1.00 respectively were obtained for straight reach 3 for the same period.

The results of the sinuosity index show no significant changes in sinuosity for all the reaches studied not even in straight reaches 1 and 2 that developed meandering thalweg and the river at those reaches was beginning to erode material from the outer bend and depositing them in the inner bend. This process was not significantly active in any of the reaches studied as the sediment yield to the channel was mainly of watershed/hill slope origin. However, those sinuosity values that were analyzed for both meandering and straight reaches agreed with the sinuosity ranges proposed by Sapkale and Chougule for both meandering and straight reaches (Sapkale and Chougule, 2014).

A group researchers carried out experiments to detect the effects of the changing slope and changing sediment discharge to river patterns (Petrovski et al., 2014). They observed that slope is related to sediment discharge; and that a river will be straight if the slope and sediment discharge are low. If the slope, the water and sediment discharge increase, the river starts to meander or could become braided. It starts with the development of a meandering thalweg, and then a real meandering channel evolved, with the sinuosity of at least 1.3. Previous observations had shown that the slope reduced but sediment yield did not reduce, and the results show that the sinuosity index did not change for all the reaches. As observed by Tiegs and Pohl in their study of planform channel response of a portion of the Upper Colorado River Delta in the United States America, sinuosity adjustments were also limited during the timeframe of their study, the Upper Colorado River Delta did respond with large adjustments in channel width. River Kaduna responded by narrowing its channel (Tiegs and Pohl, 2005).

Table 6: Statistics of Channel Sinuosity of Meander Reaches

	Year	Valley Length	Straight Length	Sinuosity
Reach 1	1962	10172.17m	8231.33m	1.24
	2005	10325.31m	8234.25m	1.25
	2017	10267.01m	8232.00m	1.25
Reach 2	1962	8708.30m	5820.70m	1.50
	2005	8599.74m	5752.06m	1.50
	2017	8628.86m	5778.45m	1.49
Reach 3	1962	14108.35m	11380.78m	1.24
	2005	14062.40m	11318.21m	1.24
	2017	14034.86m	11335.48m	1.24

Table7: Statistics of Channel Sinuosity of Straight Reaches

	Year	Valley Length	Straight Length	Sinuosity
Reach 1	1962	3837.29m	3713.54m	1.03
	2005	3926.95m	3702.53m	1.06
	2017	4023.99m	3701.03m	1.09
Reach 2	1962	4880.66m	4786.63m	1.02
	2005	4846.15m	4622.34m	1.05
	2017	5117.58m	4817.24m	1.06
Reach 3	1962	4313.06m	4286.38m	1.01
	2005	4298.65m	4281.54m	1.00
	2017	4298.97m	4282.71m	1.00

4.3 Changes in Braiding Index

The results of changes in braiding are shown in Figures 2 - 4 and the derived statistics for changes in braiding are shown in Table 8. The statistics in Table 8 shows that in 1962, 2005 and 2017 in the braided reach 1, the braided index values were 0.12, 0.53 and 1.45 respectively and for the same period, in braided reach 2 the values were 0.02, 1.16 and 6.25 respectively, while for the same period in braided reach 3 the index values were 0.39, 2.79 and 9.74 respectively.

In braided reach 1, braiding as observed in 1962 was in the form of isolated few bars occurring within the channel, transforming from a more or less straight channel to a braided one. As observed in 2005 and 2017

the reach developed more alternate bars with sinuous thalweg. This is what was referred to as river metamorphosis (Schumn, 1985). The explanation for this change is that there has been an increase in peak discharge, sediment size, and sediment load causing the river to deposit its load. In braided reach 2, the river channel was quite broad in 1962 with few lateral and longitudinal bars. In 2005 and 2017 it was observed that portions of the reach had developed islands that were more than three times the width of the channel, referred to as anabranching (Schumn, 1985). Braided reach 3, showed multiple channel systems in portions of the reach that separate and rejoin the main channel to form a network. The channels were separated by islands that are more than three times the width of the channels and are therefore anastomosing (Schumn, 1985).

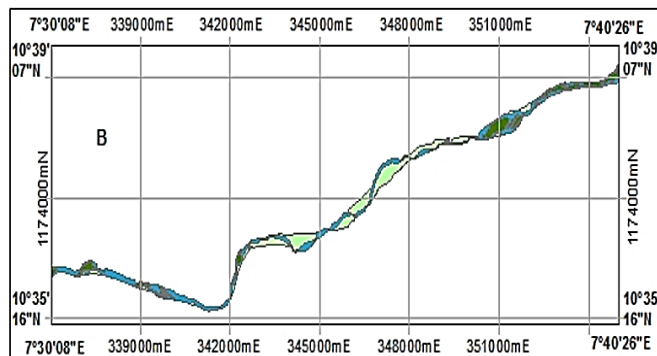
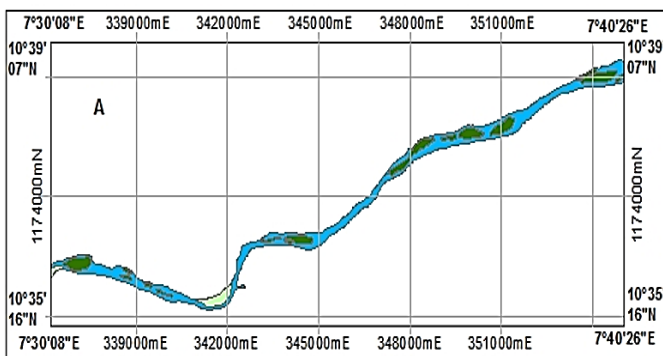
The reason for the braiding is that the reaches are laden with bedload, and the slope, velocity and the stream power have reduced resulting in more deposition of sediment. In addition to the sediments generated from various agricultural activities upstream and the runoff and sediment discharge from Kaduna metropolis, dam construction is another human activity that has affected the flow of the river. It was observed that the backwater effect of the Shiroro reservoir has reduced the velocity particularly, in braided reach 3 intensifying the braiding of the river in that reach. Braiding changes channel geometry so rapidly, thereby modifying the channel boundaries and floodplains. Issues and problems of braiding channels have presented management challenges particularly as economic and ecological considerations and the desire to reduce hazards (flooding) are competing.

Management strategies that have been proposed for controlling braided rivers include protecting the developed floodplain by engineered structures, mining gravel from braided channels, regulating sediment from contributing tributaries, and afforesting the catchment. Sand mining and quarry activities were already taking place in few places in braided reach 2. Sand mining could help in reducing braiding because the mined areas serve as sediment traps. When sand is mined the river deposits some of its load in the mined area and that reduces braiding and clogging of the channel. This activity leaves very deep borrow pits that serve as flood flow collection points. During floods, a considerable amount of water is trapped in the pit and this helps in reducing the effect of flooding because it increases the lag time of floods.

These results agree with those of Tiegs and Pohl who observed that channel planform response during their study was mainly channel narrowing (Tiegs and Pohl, 2005). The results also agree with the studies in which increased braiding was observed (Scorpio et al., 2015). The same causes identified for sinuosity are also responsible for braiding (Petrovszki et al., 2014). As the slope increase and the water and sediment discharge increase, the river starts to meandering became braided with time.

Table 8: Values for Changes in 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 = X.N*W/L
1962_1	6.23	1.72	0.28	16	579.37	21074.99	0.12
2005_1	4.36	2.34	0.54	25	838.60	21330.17	0.53
2017_1	5.15	2.76	0.54	35	1635.09	21381.21	1.45
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	2041.31	18314.80	6.25
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



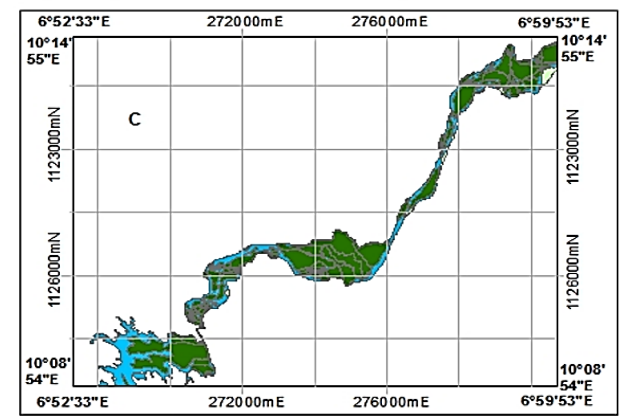
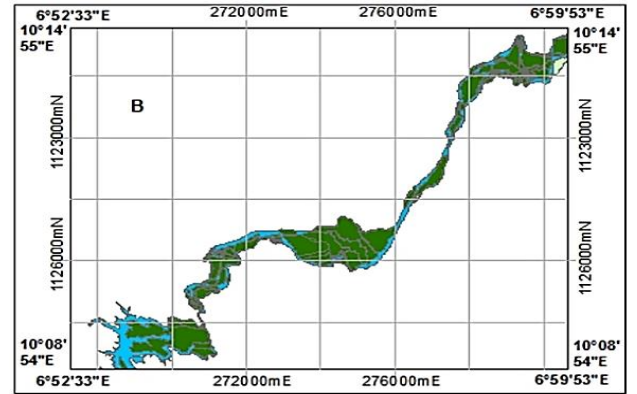
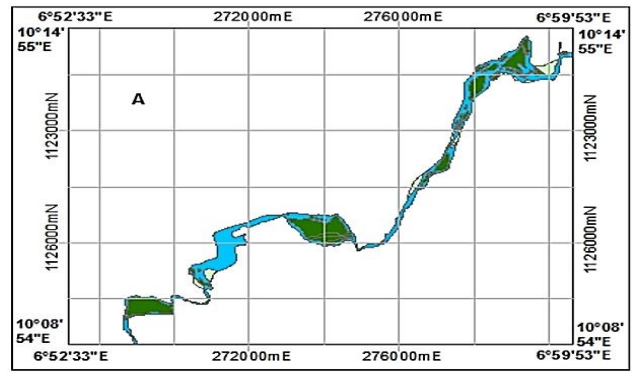
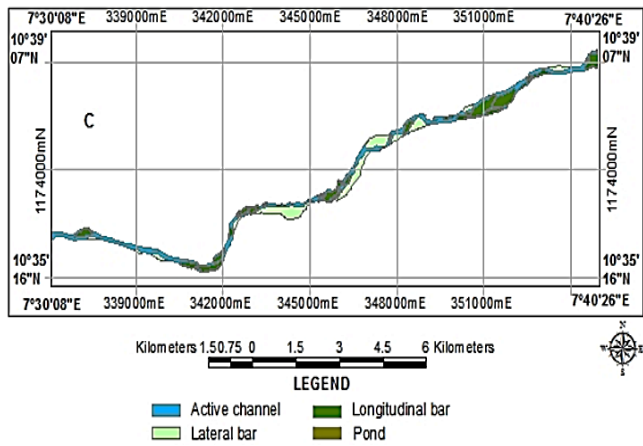


Figure 2: Changes in Braiding for Braided reach 1: A-1962, B-2005 and C 2017

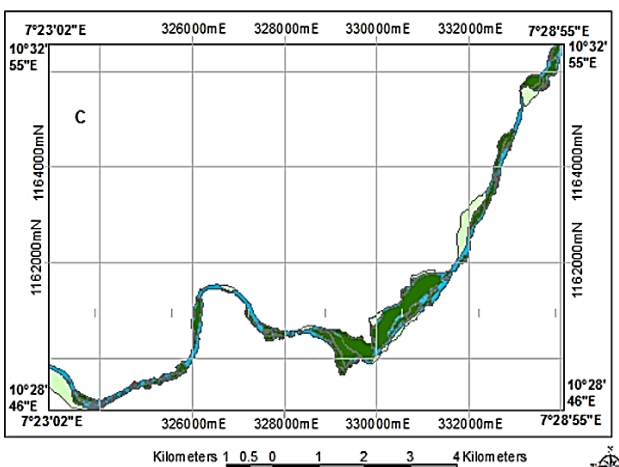
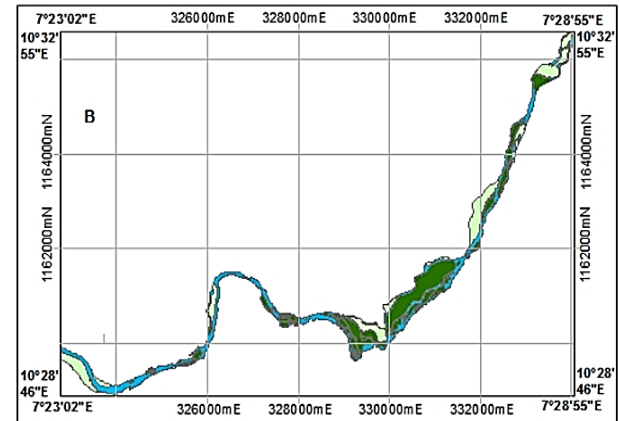
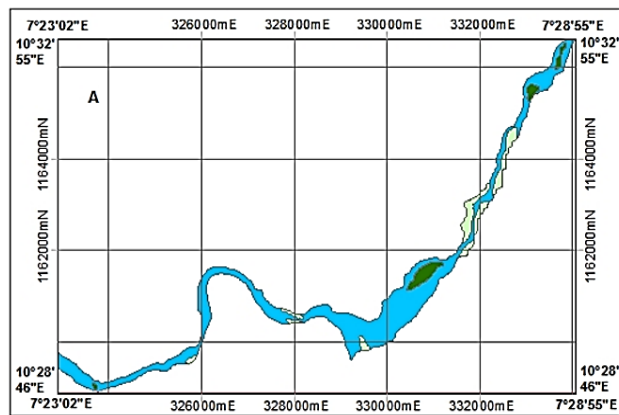


Figure 3: Changes in Braiding for Braided reach 2: A-1962, B-2005 and C 2017

Figure 4: Changes in Braiding for Braided reach 3: A-1962, B-2005 and C 2017

4.4 Channel Lateral Migration

The results in Figures 5 - 7 show overlay of centerlines for meander reach 1, straight reach 2 and braided reach 3 from 1962 - 2017. From these overlays, channel migrations for all the reaches are visually appreciated from the comparison of the centerlines. The statistics of the average distance of channel migration derived when successive years were overlaid in each of the reaches represent changes in channel migration between the years. The statistic for meander reaches 1, 2, and 3 are shown in Table 9, those for the straight reaches are shown in Table 10, while Table 11 shows the statistics for braided reaches. The result in figure 5 shows channel migration between 1962 and 2005, and between 2005 and 2017 respectively, for meandering reach 1. There was also channel migration between 1962 and 2005, and between 2005 and 2017 for meandering reach 2 respectively, while channel migration between 1962 and 2005 and between 2005 and 2017 for meandering reach 3 were also noticed.

The result in figure 6 shows channel migration between 1962 and 2005, and between 2005 and 2017 respectively, for straight reach 1. Channel migration between 1962 and 2005, and between 2005 and 2017 for straight reach 2 and channel migration between 1962 and 2005 as well as between 2005 and 2017 for straight reach 3. The map in figure 7 shows channel migration between 1962 and 2005, and between 2005 and 2017 respectively, for braided reach 1. Channel migration between 1962 and 2005, and between 2005 and 2017 for braided reach 2 and channel

migration between 1962 and 2005 as well as between 2005 and 2017 for braided reach 3. Channel positional change did not take any particular pattern since the direction of migration varied randomly. The nature of migration is likened to the pendulum of a wall clock which oscillates from the left to right bank of the reach (Mongaldip et al., 2015).

The statistics in Table 9 shows that for meander reach 1 between 1962 and 2005 the average distance of channel migration was 82.35m and between 2005 and 2017 the distance was 61.88m. For the same period meander reach 2 had average channel migration distance of 97.01m and 69.47m respectively, while meander reach 3 had average channel migration distance of 50.06m and 36.87m respectively. The statistics in Table 10 shows that in straight reach 1 the average distance in channel positional shift between 1962 and 2005 was 79.91m and between 2005 and 2017 was 23.35m. For straight reach 2 the average distance in channel positional shift between 1962 and 2005 was 122.22m and 55.28m between 2005 and 2017. The statistics in Table 11 shows that in braided reach 1 between 1962 and 2005 was 99.70m and between 2005 and 2017 was 86.06m.

The average channel migration distance for braided reach 2 between 1962 and 2005 was 110.64m and was 50.11m between 2005 and 2017, while braided reach 3 had average channel distance of 173.63m between 1962 and 2005, and 56.36m between 2005 and 2017. In all meandering and braided reaches studied there was no evidence of channel expansion and bend cutoffs this was because there was minimal lateral abrasion in most of the reaches. The dominant process responsible for channel migration was the gradual migration of channel bends (Knighton, 1998). Figures 5 - 7 show gradual channel migration for meandering and braided reaches 1, 2 and 3 Channel position shifts was negligible in straight reach 3 but very pronounced in straight reaches 1 and 2. It was observed that lateral abrasion was active in straight reaches 1 and 2 which implied that slope and Stream Energy were higher being in the upper course of the river.

It was further observed that meandering thalweg developed in these reaches particularly from 2005 to 2017. Rapid vegetation removal, constant erosion and deposition of sediton from high flow discharge during floods as well as anthropogenic influences particularly agriculture favoured channel migration in the reaches. The results obtained from this study are comparable with those of Velcu and Morosanu who studied the dynamics of the Minor Riverbed of Teslui River in relation to the human factor in Romania; those of on river channel adjustments and implications for channel recovery in Southern Italy; those of on Bank Erosion and Migration Nature of the Hooghly River in India; those of on Assessment of Anthropogenic Factors and Floods using Remote Sensing and GIS on Lower Regimes of Kangshabati-Rupnarayan River Basin in India; those of who studied the Geomorphological processes and river migration in Bangladesh and the studies of Barman and Goswami who evaluated sinuosity index of Dhansiri (South) River Channel and Bank Erosion in India using Geographic Information System (Velcu and Morosanu, 2015; Scorpio et al., 2015; Mongaldip, et al., 2015; Lovric and Totic, 2016; Das et al., 2013; Barman and Goswami, 2015).

Velcu and Morosanu attributed the channel migration to human intervention which followed the construction of a dam for irrigation (Velcu and Morosanu, 2015). The confluence points for the river Teslui and Olt were moved and this triggered a migration to the new position of the confluence. A group researcher considered channel migration to have emanated from the natural process of erosion which was attributed to limited woody riparian vegetation along the channel (Scorpio et al., 2015). For migration occurred as a normal natural fluvio-geomorphic phenomenon resulting from continuous siltation and fluvial erosion (Mongaldip et al., 2015; Lovric and Totic, 2016; Das et al., 2013; Barman and Goswami, 2015).

Table 9: Statistics of Average Distance of Channel Migration of Meander Reaches in meters.		
Reach	Between 1962 and 2005	Between 2005 and 2017
1	82.35m	61.88m
2	97.01m	69.47m
3	50.06m	36.87m

Table 10: Statistics of Average Distance Channel Migration of Straight Reaches in meters.		
Reach	Between 1962 and 2005	Between 2005 and 2017
1	79.91m	23.35m
2	122.22m	55.28m
3	38.45m	14.25m

Table 11: Statistics of Average Distance Channel Migration of Braided Reaches in meters.		
Reach	Between 1962 and 2005	Between 2005 and 2017
1	99.70m	86.06m
2	110.64m	50.11m
3	173.63m	56.36m

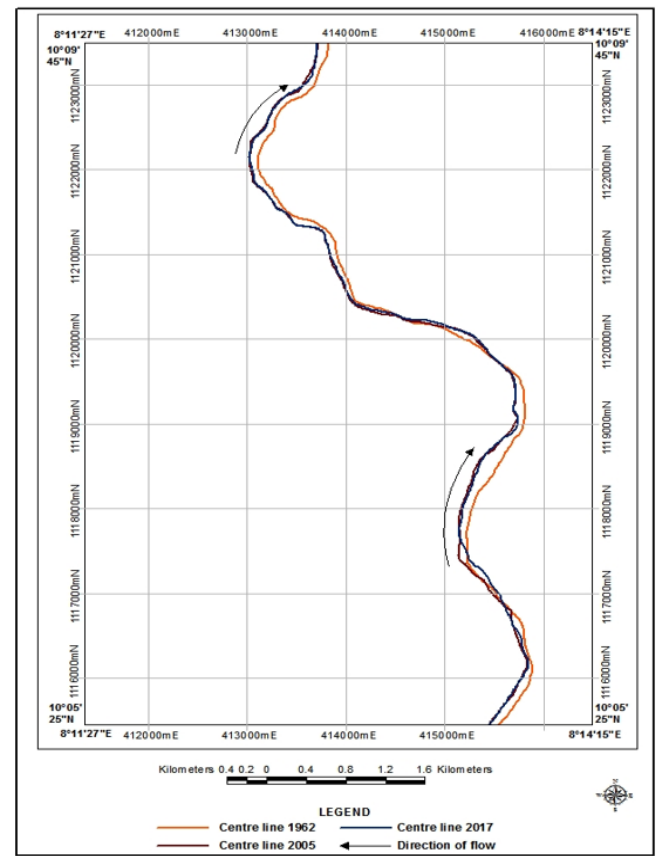


Figure 5: Changes in Channel Migration from 1962 to 2017 for Meandering Reach 1

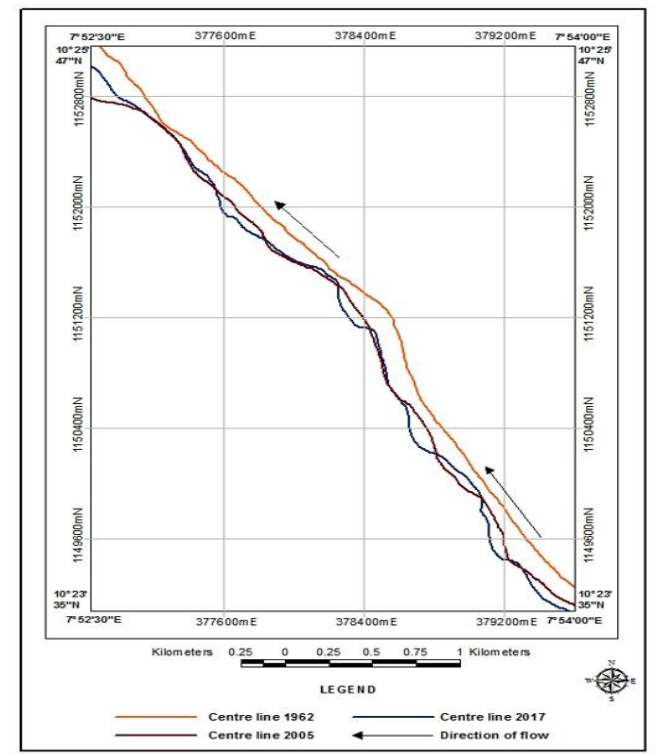


Figure 6: Changes in Channel Migration from 1962 to 2017 for Straight Reach 2.

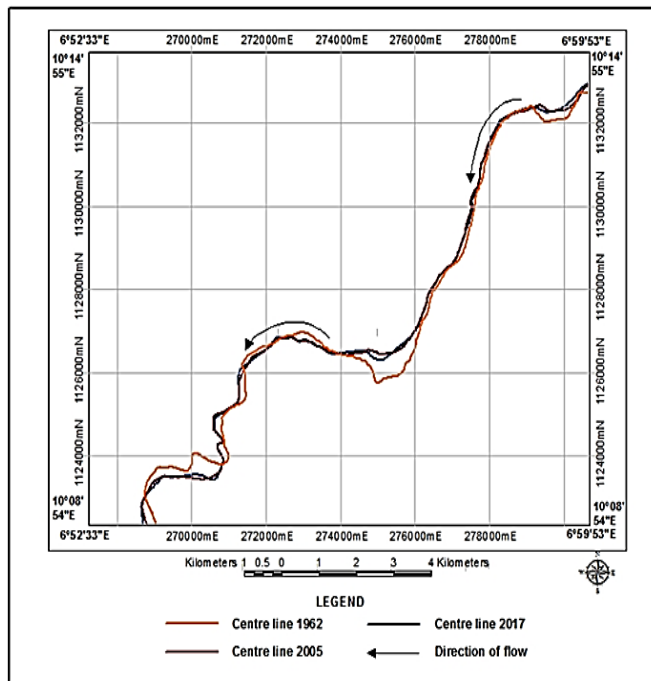


Figure 7: Changes in Channel Migration between 1962 and 2005 for Braided Reach 3.

4.5 Changes in Channel Length

In this study, the length of the centerline was considered as the valley length of the river at the various reaches. The statistics in Table 6 and Table 7 show the valley lengths for meandering and straight reaches respectively. The length of the river in meander reach 1 in 1962, 2005 and 2017 was 10172.17m, 10325.31m and 10267.01m respectively. For the same period, the length of the river for meander reach 2 was 8708.30m, 8599.74m and 8628.86m while for meander reach 3 the length of the river was 14108.35m, 14062.40 and 14034.86m respectively. The length of the river in straight reach 1 for 1962, 2005 and 2017 was 3837.29m, 3926.95m and 4023.99m respectively. For straight reach 2 in the same period the length of the river was 4880.66m 4846.15m and 5117.58m respectively and for straight reach 3 in the same period the length of the river was 4313.06m, 4298.65 and 4298.97m respectively.

A strong link exists between sinuosity and channel length such that as sinuosity decreases, the length of the channel decreases. For instance, sinuosity decreases to a minimum when an avulsion or a series of cutoffs straightened a channel. Such changes may be related to major changes of sediment load or an increase of peak discharge, but they may also be due to a progressive increase of sinuosity-with an accompanying reduction of channel gradient- to the point that aggradation and cutoffs or avulsion results. There were no significant changes in sinuosity for all the reaches studied and consequently, there were no significant changes in channel length. Velcu and Morosanu experienced a decrease in the length of the study river and explained that it was due to the migration of the confluence point of the rivers Teslui and Olt (Velcu and Morosanu, 2015). The migration of the confluence point had the effect of a meander cut-off judging from the relics of abandoned river arms and oxbows of the old river course. Barman and Goswami found that a neck cut-off had resulted in a shortening of the channel course, as it was observed that the river course in 2008 became shorter than that in 1999 (Barman and Goswami, 2015).

5. CONCLUSION

The results of the analysis of changes in channel planform of River Kaduna have shown that there have been significant changes. There has been a considerable amount of contraction in the meandering and straight reaches that have greatly altered the width of the river and there has also been an increase in braiding. The hydraulic geometry as expressed by Singh (2003) asserts that there is a direct relationship between channel width and discharge. The reduction in the width of the river has adversely affected the discharge pattern of the river which is manifested in an increase in water storage (floods) and erosion. Also, there is huge deposition of finer sediments in the river and this has adversely reduced the water retention potentials of the river which can result in flooding as experienced in similar locations.

REFERENCES

- Abowei, J.F.N., and Sikoki, F.D., 2005. Water Pollution Management and Control, Double Trust Publication Co., Port Harourt, Pp. 236.
- Aisuebeogun, A.O., and Ezekwe, I.C., 2014. Channel dynamics and hydraulic geometry of two tropical deltaic catchments in Southern Nigeria. *Landform Analysis*, 27, Pp. 3-13. doi: <http://dx.doi.org/10.12657/landfana.027.007>
- Barman, P., and Goswami, C.D., 2015. Evaluation of Sinuosity Index of Dhansiri (South) River Channel and Bank Erosion, Assam in GIS. *International Advanced Research Journal in Science, Engineering and Technology*, 2 (5).
- Brooks, A.P., Brierley, G.J., and Millar, R.G., 2003. The long-term control of vegetation and woody debris on channel and flood-plain evolution: insights from a paired catchment study in southeastern Australia. *Geomorphology*, 51, Pp. 7-29.
- Clerici, A., and Perego, S., 2016. A Set of GRASS GIS-Based Shell Scripts for the Calculation and Graphical Display of the Main Morphometric Parameters of a River Channel. *Intern. Jour. of Geosciences*, 7, Pp. 135-143.
- Conniff, K, Molden, D., Peden, D., Awulachew, S.B., 2012. Nile Water and Agriculture: Past, Present and Future. In Awulachew, Seleshi Bekele; Smakhtin, Vladimir; Molden, David; Peden D. (Eds.). *The Nile River Basin: water, agriculture, governance, and livelihoods*. Abingdon, UK: Routledge - Earthscan. Pp. 5-29.
- Das, D., Kar, K.K., and Deb, M., 2013. A case study of Geo-Morphological Processes and River Migration in Bangladesh. *American Journal of Remote Sensing*, 1 (4), Pp.72- 76.
- Downward, S.R., Gurnell, A.M., and Brookes, A., 1994. A methodology for quantifying river channel planform change using GIS, *Variability in Stream Erosion and Sediment Transport*. Proceedings of the Canberra Symposium. IAHS Publ. Pp. 224.
- Eaton, B.C., 2006. Bank stability analysis for regime models of vegetated gravel bedrivers: *Earth Surface Processes and Landforms*, 31, Pp. 1438-1444.
- Fashae, O.A., and Faniran, A., 2015. Downstream Morphologic Characteristics of the Alluvial Section of Lower River Ogun, Nigeria. *Journal of Environmental Geography*, 8 (1-2), Pp. 1-10.
- Garde, R.J., 2006. *River Morphology*, New Delhi, New Age International (P) Ltd, Pp. 11-33.
- Grande River Estuary, Argentina. 2004. *Estuarine, Coastal and Shelf Science*, 62, Pp. 301-312. <http://dx.doi.org/10.1016/j.ecss.2004.09.018>.
- Holburt, M.B., 1984. The 1983 high flows on the Colorado River and their aftermath. *Water International*, 9, Pp. 99-105.
- Hughes, F.M.R., 1997. Floodplain Bio geomorphology. *Progress in physical geography*, 21 (4), Pp. 501-529.
- Jagers, H.R.A., 2003. Modeling planform changes of braided rivers. Print Partners Ipskamp B.V., Pp. 1-314.
- Knighton, D., 1998. *Fluvial form and processes A New Perspective*. London: Arnold.
- Kondolf, G.M., Piegay, H., and Landon, N., 2002. Channel response to increased and decreased bedload supply from land use change: contrasts between two catchments. *Geomorphology*, 45, Pp. 35-51.
- Konrad, C.P., 2012. Reoccupation of floodplains by rivers and its relation to the age structure of floodplain vegetation: *Journal of Geophysical Research*, 117, doi: 10.1029/2011JG001906.
- Larsen, E.W., and Greco, S.E., 2002. Modeling channel management impacts on river migration: A case study of Woodson Bridge State recreation area, Sacramento River, California, USA. *Environmental Management*, 30, Pp. 209-224.
- Lord, M.L., Germanoski, D., and Allmendinger, N.E., 2009. Fluvial Geomorphology: Monitoring Stream Systems in Response to a

- Changing Environment. In Young, R., and Norby, L., *Geological Monitoring: Geological Society of America Boulder, Colorado*, Pp. 69–103.
- Lovric, N., and Tomic, R., 2016. Assessment of Bank Erosion, Accretion and Channel Migration Using Remote Sensing and GIS: Case Study – Lower Course of the Bosna River. *Questiones Geographicae*, 35 (1), Pp. 81-92.
- Métivier, F., Devauchelle, O., Chauvet, H., Lajeunesse, E., Meunier, P., Blanckaert, K., Zhang, Z., Fan, Y., Liu, Y., Dong, Z., and Ye, B., 2015. Earth Surface Dynamic. *Discussion*, 3, Pp. 1289–1316.
- Mongaldip, M., Pintu, P., and Kumar, N.B., 2015. Bank Erosion and Migration Nature of the Hooghly River at Sundalpurchar and Gosainchar Mouza, Ranaghat-I Block, Nadia District, West Bengal, India. *European Journal of Academic Essays*, 2 (7), Pp. 83-86.
- Naiman, R.J., Decamps, H., and Pollock, M., 1993. The role of Riparian Vegetation in Maintaining Regional Biodiversity. *Ecological Applications*, 3 (2), Pp. 209–212.
- Petrovski, J., Timár, G., and Molnár, G., 2014. Is sinuosity a function of slope and bankfull discharge? – A case study of the meandering rivers in the Pannonian Basin. *Hydrol. Earth Syst. Sci. Discuss.*, 11, Pp. 12271–12290.
- Petts, G.E., and Amoros, C., 1996. *Fluvial hydrosystems: London, Chapman and Hall*, Pp. 336.
- Ruiz-Villanueva, V., Diez-Herrero, A., Bodoque, J.M., and Blade, E., 2014. Large wood in rivers and its influence on flood hazard. *Cuadernos de investigacion Geografica*, 40 (1), Pp. 229-246.
- Russell, S., 2010. *Managing the Mekong: Conflict or Compromise. New security beat, Environmental Change and Security Program. Wilson Center ECSP.*
- Sapkale, J.B., and Chougule, V.A., 2014. Channel Pattern Variability and Stream Characteristics: A Study of Tulsi and Bhogawati River using Geoinformatics. *Indian Journal of Applied Research*, 4 (7), Pp. 253-255.
- Schumm, S.A., 1968. *River Adjustment to Altered Hydrologic Regimen Murrumbidgee River and Paleochannels, Australia 2031, USGS Prof. Pp. 598.*
- Scorpio, V., Aucelli, P.C.P., Giano, I.S., Pisano, L., Robustelli, G., Roskopf, C.M., and Schiattarella, M., 2015. River channel adjustments in Southern Italy over the past 150 years and implications for channel recovery. *Geomorphology xxx*.
- Selander, J.A., 2004. *Processes of knickpoint propagation and bedrock incision in the Oregon Coast Range. University of Oregon B.Sc. thesis, Eugene, Oregon.*
- Selander, J.A., 2015. *Influences on River Morphology in a Sediment-dominated system. Department of Geology University of California, Davis, Pp. CA 95616.*
- Singh, V.P., 2003. On the Theories of Hydraulic Geometry. *International Journal of Sediment Research*, 18 (3), Pp. 196-218.
- Tiegs, S.D., and Pohl, M., 2005. Planform channel dynamics of the lower Colorado River: 1976–2000. *Geomorphology* 69, Pp. 14–27.
- Velcu, G., and Morosanu, A.G., 2015. The dynamics of the minor riverbed of Teslui River in relation to human factors (1910-2008) - Case Study: Resca - Farcasele De Jos Sector.
- Ward, J.V., Tockner, K., and Schiemer, F., 1999. Biodiversity of floodplain river ecosystems: Ecotones and connectivity. *Regulated Rivers: Research and Management*, 15, Pp. 125– 139.
- Xiufang, Z., Yizhan L., Mui, L., Yaozhong P., and Peijun, S., 2013. Agricultural Irrigation in China. *Journal of Soil and Water Conservation*, 68 (6), doi:10.2489/jswc.68.6.147A
- Yearwood, K.I., 2010. *River Planform Change Downstream of the Sinclair Dam Oconee River, Georgia PhD Thesis University of Florida.*

