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Ali Williams Butu
Department of Geography, Nigerian Army University Biu, Borno State

Chukwudi Nnaemeka Emeribe
2National Centre for Energy and Environment, Energy Commission of Nigeria, University of Benin, Edo State, emeribe.c@ncee.org.ng

Dewingong Columbus Leke
Department of Geography, Faculty of Arts and Social Sciences, Nigerian Defense Academy, Kaduna, Nigeria

Mamman Shaba Jibril

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Effect of urbanization on channel platforms of River Kaduna from 1962-2017, Kaduna State, Nigeria

Ali Williams Butu[1], Chukwudi Nnaemeka Emeribe[2], Dewingong Columbus Leke[3], Mamman Shaba Jibril[3], Benjamin Julius Ananya[1]

[1]Department of Geography, Nigerian Army University Biu, Borno State
[2]National Centre for Energy and Environment, Energy Commission of Nigeria, University of Benin, Edo State,
[3]Department of Geography, Faculty of Arts and Social Sciences, Nigerian Defense Academy, Kaduna, Nigeria

E-mail: emeribe.c@ncee.org.ng

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Abstract. *The study investigated changes in channel planforms of River Kaduna. Topographic maps were complimented with Mosaic of SPOT 5 satellite and Sentinel-2 images. Results showed that except for sinuosity index and channel length, channel width, braiding and channel migration exhibited considerable changes. These changes were evident in reduced velocity and stream energy, the type of sediment being transported, the silt materials being transported in suspension and the coarse sand and gravels being moved by lift and drag processes which are easily deposited, thus causing the channel to contract and braid. Channel migration occurred as gradual bend shifts leaving no evidence of lateral abrasion. Similarly, channel length did not change significantly to affect the sinuosity index. The result further revealed there was little lateral abrasion and the channel are relatively stable, implying that the materials being transported and deposited must have originated from the watershed. Anthropogenic factors such as urbanization, deforestation and agriculture activities contributed significantly to the observed channel alteration. There is a need to encourage mining gravel and sand from braided channels to provide sinks for sediments that otherwise would be deposited downstream. Afforesting the catchment area is required to create canopies to exposed surface and reduce sediment supplies.*

Keywords*: braiding, channel migration, channel planforms, channel width, remote sensing*

1. Introduction

During the International Symposium on "Man's Role in changing the Face of the Earth" in 1952, scholars convened to discuss the reality of human impacts on Earth, and the question explored at that symposium was: "What has been, and is, happening to the earth's surface as a result of (humans) having been on it for a long time, increasing in numbers and skills which are unevenly distributed at different places and times?" (Fejos, 1956). In this regard, what comes to mind is the disturbing and noticeable modification of stream channel morphology, including water quality and discharge characteristics. The impact of human activities in changing river channels is reported to have begun more than 4,000 years ago. However, it was until late 1960's that greater attention was shifted to the dynamics and consequences of this modification (Gregory, 2006). Modification and degradation of the urban stream due to urbanization is known to have serious consequences. These include flooding, loss of life and property, disruptions of the entire stream ecosystem with enormous implications for aquatic life and biodiversity as shown by Aliyu (2014).

According to Paul and Meyer (2001), the seriousness of urbanization and its impact on urban stream channels (a phenomenon known as urban stream syndrome), has prompted many studies across the globe. These studies have all demonstrated that urbanization of a catchment results in irreversible consequences that produce delirious changes on runoff characteristics; channel morphology; hydraulic geometry and to the stream ecosystem (Wolman 1967; Paul & Meyer 2001; May *et al*., 1997; Jeje & Ikezeato, 2002; Hession *et al.* 2003, Roesner & Bledsoe, 2003; Nabegu, 2014).

Kaduna City is one of the settlements in the northern Nigeria with the fastest urbanization speed, rapid industrialization and population explosion. The rapid urbanization has resulted in a series of changes to the river systems, hence persistent seasonal flooding problems along the river floodplain and encroachment into the traditional flood-prone areas of the Kaduna River, coupled with other ecological and environmental issues.

In recent years, there are serious concerns about the ecological impacts of river system modification, especially with a growing fear of climate change and population expansion around the catchment. According to the National population census of 2006, approximately 10,245,930 people are living in and around the Kaduna River basin with about 1,139,578 living in Kaduna North, Kaduna South and Chikun Local Government Areas respectively (National Population Commission, 2009). Agricultural activities are also operational along the Kaduna River, upstream of the Shiroro Reservoir. For any meaningful water resources development in the study area, there is a need for an adequate understanding of the temporal and spatial patterns of changes in the channel's morphology, as well as where interventions are required.

Such understanding can help to develop appropriate management schemes for urban rivers in Nigeria, especially as variations within channels dictates that different strategies may be required for different channel segments to handle spatially distributed response mechanisms as well as decision making as to appropriate restoration plan, even if the magnitude of change cannot be predicted precisely (Neller, 1989, May *et al.*, 1997; Chin and Gregory, 2005). Thus, the present study aims to investigate for changes in the channel planforms of Kaduna River upstream of the Shiroro Reservoir, which is hypothesized to have witnessed modification arising from heavy land-use activities around the floodplain.

2. Methodology

2.1. Study Area

The study area is Kaduna River, upstream of the Shiroro Reservoir. Geographically the study area is located between latitudes 9°52′38″N and 10°39′07″N and between longitudes 6°52′33″E and 8°28′50″E (Fig. 1). Rainfall in the study area is governed by the annual passage of the Inter-Tropical Convergence Zone (ITCZ), the meeting point of a dry northeastern low-pressure air mass and a moist southwestern high-pressure air mass (Udo & Okujagu 2014).

The northeastern movement of the ITCZ and the rain-bearing winds that accompany the movement marks the onset of the rainy season, while the southwestward movement and the accompanying harmattan winds marks the beginning of the dry season. Annual rainfall and its reliability decrease from the south northwards with rainfall ranging from a minimum value of 897mm to a maximum value of 1600mm (Butu et al., 2020). Wet season across the basin ranges from 5 months in the north to more than 8 months in the south. The highest temperatures occur in March and April just before the rainy season, with mean monthly temperature reaches 28°C in March and drops to 23.2°C in December.

The basin is underlain by a complex of igneous and metamorphic rocks of mainly Jurassic to Precambrian age (Bennett *et al.,* 1979). The younger (Quaternary) lavas overlie this basement in the south-eastern parts. The only recent sediments are various colluvial and alluvial deposits and wind-blown material (drift). Laterite caps are associated closely with crestal sites throughout the Kaduna Basin, particularly in the northern part of the Basin. They are believed to be residual from a more extensive and level late-Tertiary, lateritized surface that has since been gradually eroded by the present river systems. The Basement Complex rocks are essentially granites, gneisses, migmatites, schists and quartzites. The soil of the basin is essentially ferruginous tropical soils. These soils are generally characterized by a sandy surface horizon overlying a weakly structured clay accumulation and have low base-exchange capacity, but their base saturation and pH values are relatively high. They are sensitive to erosion and have low water-holding capacity (Mohamed-Saleem, 1984).

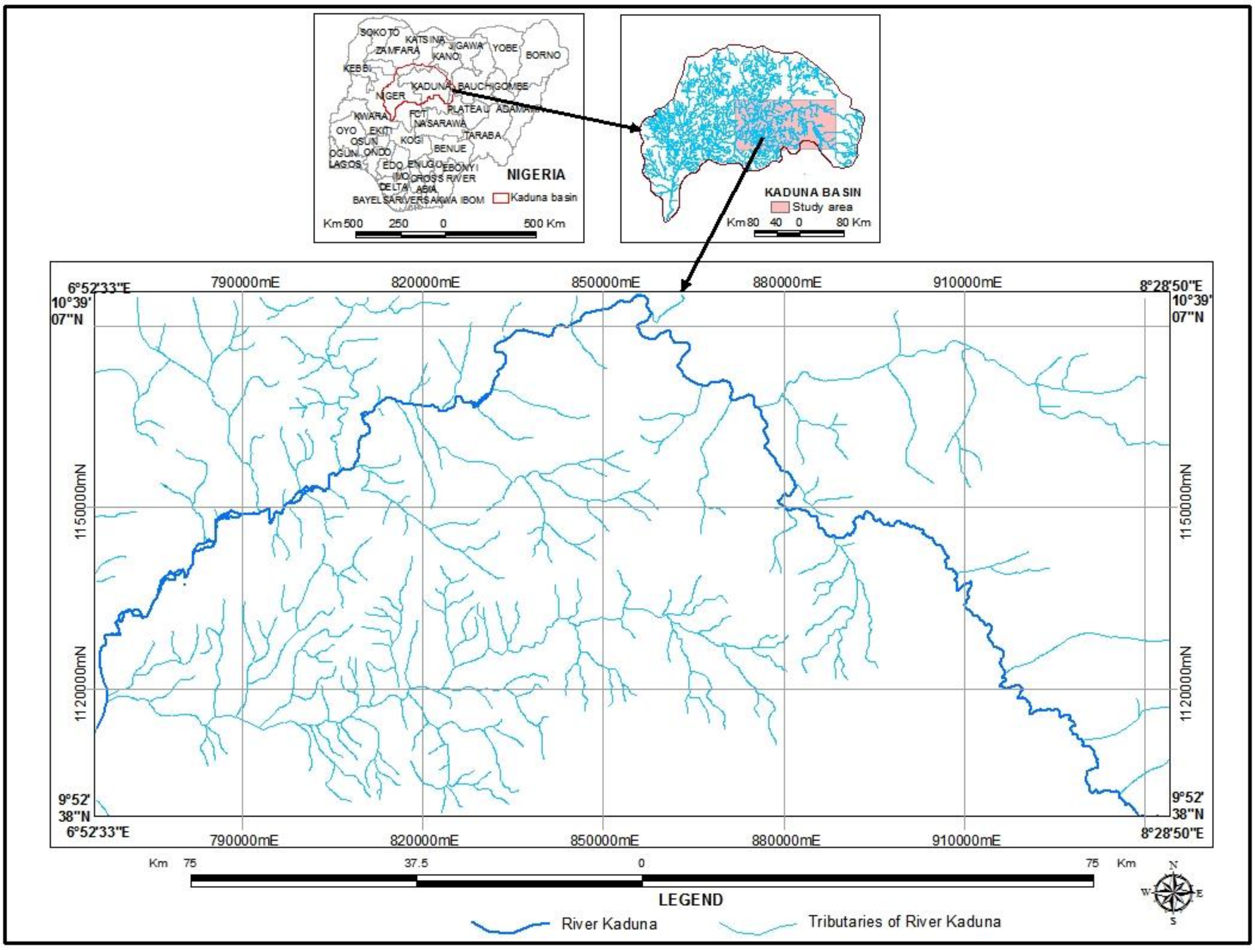


Figure 1. The Study Area

2.2. Data

Information on channel planform characteristics of River Kaduna was obtained from topographic maps of 1:50000 scale covering the entire course of the river. The maps were obtained from the Federal Survey Map Depot in Kaduna for 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. The topographic maps provided information for earlier periods of the study for which satellite images were not available. To complement the archival maps, multi-temporal satellite images were used including the Mosaic of SPOT 5 satellite images (5m resolution) of 2005, which was collected from the National Population Commission State Office Jos. Sentinel-2 image (10m resolution) was downloaded from Glovis-USGS free download site.

The reliability of satellite images was verified by ground measurements using a Montana Garmin 650 handheld Global Positioning System (GPS) was used for logging the start point and endpoint of each bridge and 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 it was 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. Data and satellite imagery processing operations such as scanning, geo-referencing, image processing, image re-projection, image mosaic and transformation were carried out in the GIS environment to aid raster data viewing, querying and other spatial analysis, corrections, ensure proper scaling and comparison of data sets (i.e. 1962 and 2005 and 2005 and 2017).

All spatial data were projected and transformed to the same datum and spheroid, the World Geodetic System of 1984 (WGS 84) Datum and Spheroid which are commonly used for most mapping in the country were adopted for this study. Details of the topographic maps, satellite images (The SPOT 5 images and Sentinel-2 images) and the ground measurements with their corresponding measurements on the images are shown in Table 1 and Table 2, respectively.

Table 1. Details of the Topographic maps and Satellite Imageries

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

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

Table 2. 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

2.3. 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 as follows (Table 3 and Figure 2):

Table 3. Nine reaches of the river upstream of the Shiroro Reservoir

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

The riverbank 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 centreline, 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.

For these topographic and satellite images to be used in the GIS environment, the topographic maps and satellite images were first processed to extract spatial data on the river planforms. The processes involved first processing of topographic to extract data from topographic maps for analysis. First, of 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 not be subjected to analysis in Geographic Information System (GIS) domain. To be able to analyze the scanned maps, they were provided spatial reference through the process of geo-referencing. Georeferencing the scanned maps define their location using map coordinates by assigning the coordinate system of the data frame to selected control points.

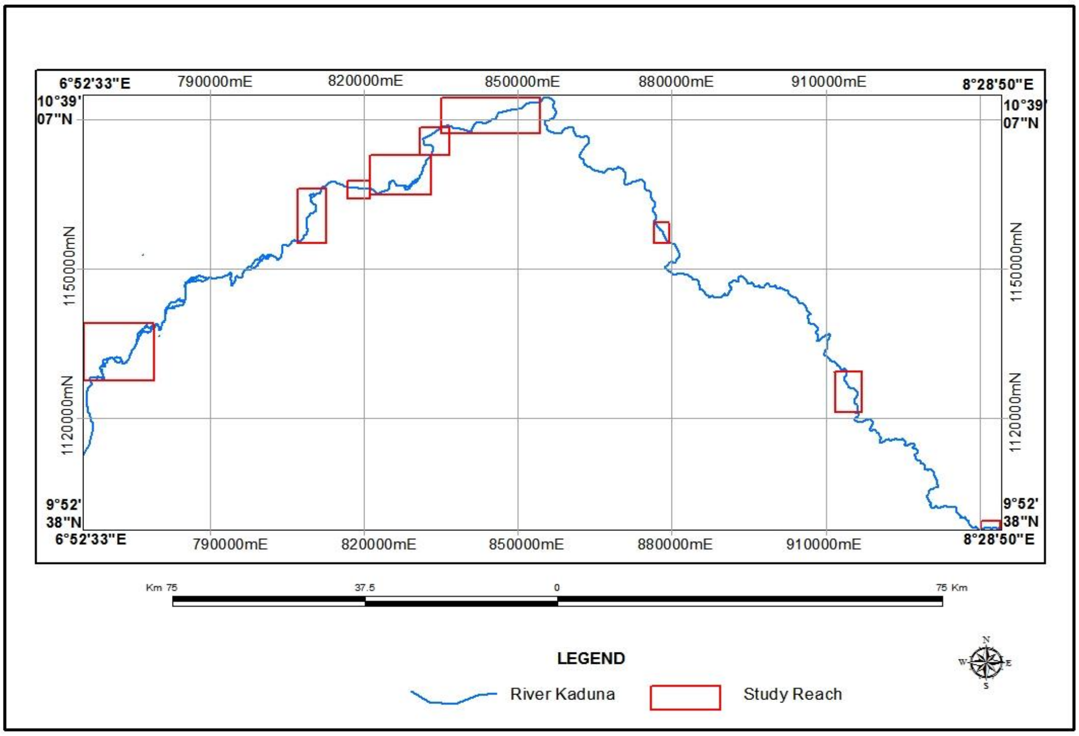


Figure 2. The Selected Study Reaches

2.3.1 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 geo-referenced maps and satellite images using ArcGIS 10.3.1. Each of the digitized reaches was stored in a separate shapefile and according to the method used by 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 by Clerici & Perego (2016). The procedures involve creating the centre line or flow line of the river. This step is important because it eases the calculation of stream length and enables comparison of other data that were based on the centre line.

To describe the planforms of the river for the year 1962, the bank limits of the river were delineated from the scanned and geo-referenced topographic maps of scale 1: 50,000. This was done for the meandering and straight reaches. For the braided segment, the bank limits, as well as the lateral and longitudinal bars, were delineated. Bank limits for the year 2005 were delineated from SPOT-5 images of 2005 to describe the planform of the river. The bank limits and the lateral and longitudinal bars were also delineated for the braided reaches. Similarly, the same procedure was carried out on the Sentinel-2 images of 2017. To describe the planform of the river for the year 2017. To use the satellite imagery for analysis the following processes were carried out.

Image Processing: The satellite images utilized for this study were pre-processed as of the time of the acquisition, that is, all forms of corrections, enhancement and geo-referencing were 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.

Image Subset: Subsets of the study reaches for the year 2005 were extracted from a larger mosaic of SPOT 5 image of the whole country. The Subset Utility tool in Earth Resources Data Acquisition System (ERDAS) software was used to create a subset of the study area from a mosaic of SPOT 5 image of the whole country.

Image Re-projection: The mosaic of SPOT 5 images Nigeria was in geographic coordinate system and rest of the spatial data for the project were in Universal Transverse Mercator (UTM) system. In order to ensure proper scaling and comparison of data sets, the subset SPOT 5 images were re-projected from geographic coordinates (latitudes and longitudes) in degrees, to Universal Transverse Mercator (UTM) in metres using the re-project command in ERDAS imagine.

Image Mosaic: When the study area covers a larger area than a single scene or image tile can cover, two or more scenes or image tiles may be merged to form one continuous image that covers the Area of Interest (AOI). Usually, the outcome of a mosaic process is a new image that is larger than that required for the study area, so for the same reasons of saving disk space and processing time, a subset is done to reduce the mosaic image to the limits of the AOI. A mosaic process was carried out on Sentinel-2 images to obtain images of the study reaches for the year 2017. The Mosaic Utility tool in (ERDAS) software was also used to assemble two tiles of Sentinel-2 images to obtain a contiguous image covering the AOI for the year 2017.

Projection and Transformation: The results of the processing performed on the scanned map and the satellite images could be adversely affected if the projection and transformation are not carefully managed, for example, a change in channel position could be evident as a result of poor projection and transformation rather than an actual migration in reality. To avoid this all spatial data were projected and transformed to the same datum and spheroid, the World Geodetic System of 1984 (WGS 84) Datum and Spheroid which are commonly used for most mapping in the country were adopted for this study.

2.3.2 Characterization of Channel Planforms Variables

River channel planform variables were determined using the procedures of Clerici & Perego (2016) which is based on establishing a centreline. A centreline 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. Since each of the two parallels lines traced out from each iteration are equidistant from the pertaining bank line, their intersection defines points that are equidistant from the banks. The line joining these intersection points defines the channel centreline. The length of the centreline is assumed to be the length of the channel at the particular reach.

2.3.3 Channel width

Based on algorithms utilized by Pavelsky and Smith, (2008) and Fisher et al., (2013) channel width was automatically computed along the lines orthogonal to the pixels forming the computed raster centreline. A Python script has described the calculation of channel width at regularly-spaced transects, orthogonal to the channel centerline according to the method by Casagrande *et al*., (2011). The same procedure as described in the script was used by Clerici & Perego (2016), and this method was adopted in this work for calculating river width. In this method, the sum of all orthogonal transects for each reach and each epoch was calculated by adding all the transect legs. The average width of the river for all the reaches and all the epochs was calculated by dividing the sum of all orthogonal transects by the number of transects.

2.3.4 Calculation of Sinuosity Index

To determine sinuosity index, the river valley was subdivided into rectilinear segments. River valley segmentation introduces a certain degree of subjectivity, especially where the valley shows a curvilinear path. Based on that, Casagrande, *et al.*, (2011) suggested that to reduce the degree of subjectivity, a fixed-length value should be used for the valley segmentation. The determination of the centreline eliminates that subjectivity. In this study, the river valley was ignored and only the channel centreline was used. The length of the channel centreline encompassed in the valley segment was then divided by the length of the straight line valley segment, that is, the straight line joining the start point and the endpoint of the segment. To calculate the length of the centreline a ‘length' field was created in ArcMap to allow the system to automatically update the values of this field to geometric values.

2.3.5 Calculation of Braiding Index

The bank-full channel limits and the limits of longitudinal and lateral bars, as well as ponds, were delineated from topographic maps for 1962 and satellite images for 2005 and 2017. Different indexes have been proposed by various authors to express the degree of braiding of a river Thorne (1997). Among them, the channel count index is the most commonly used, since it is simple to calculate and is the least sensitive to river-stage effects (Ashmore, 1991; Egozi, & Ashmore, 2008). It is simply expressed as the number of active sub-channels along a channel transect of a large alluvial river. Lalit *et al.,* (2018) calculated braiding index using an approach that utilizes a fraction of area covered by Sand bars, the number of mid-channel bars and the maximum width of the reach. The approach is expressed as:

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

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 the formulation of the method, the following points were considered: (a) River or reach with more fraction of area by bars has more braiding value. (b) In the case of the same fraction of area by bars, the number of mid-channel bars will influence braiding value. (c) Braiding of rivers or reaches with the same fraction of area by bars and the same number of mid-channel bars will differ by maximum width. (d) Length is used in the denominator to get a dimensionless value of the braiding index. This approach was adopted in calculating braiding was adopted in the present study.

2.3.6 Channel Lateral Migration

To understand channel migration black arrows were drawn pointing in the flow direction of the river and migration was examined by overlays of the centreline for 1962, 2005 and 2017 for both meandering and straight reaches. The space between the centrelines of two dates represents the channel migration for those dates. In defining the amount of lateral migration between dates; the procedure used for obtaining channel width which involves the construction of the channel centreline was adopted. The centrelines between dates were obtained and orthogonal transects were constructed for both meandering and straight reach.

3. Results

The results of changes in channel width are shown in Figures 3, 4 and 5 for meandering reaches 1, 2 and 3 and Figures 6, 7 and 8, for straight reaches 1, 2 and 3. The derived statistics for the changes in channel width are shown in Table 4 for meandering and straight reaches respectively. In 1962, average width of the channel in the meandering reaches 1, 2 and 3 were 69.81m, 192.65m and 218.01m respectively. In 2005, average width for the same reaches were 65.91m, 107.38, and 143.21m respectively, while in 2017, 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.

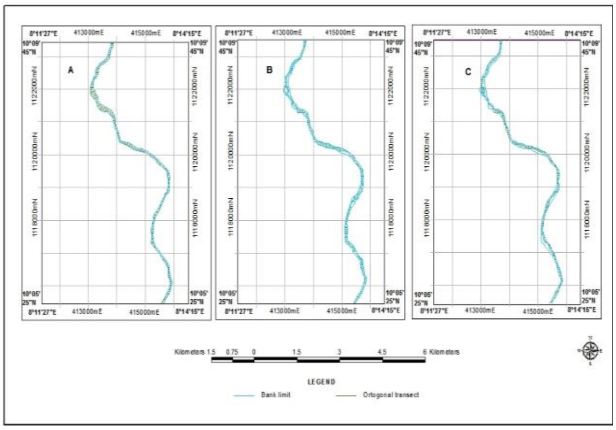


Figure 3. Changes in Channel Width for Meandering reach 1: A-1962, B-2005 and

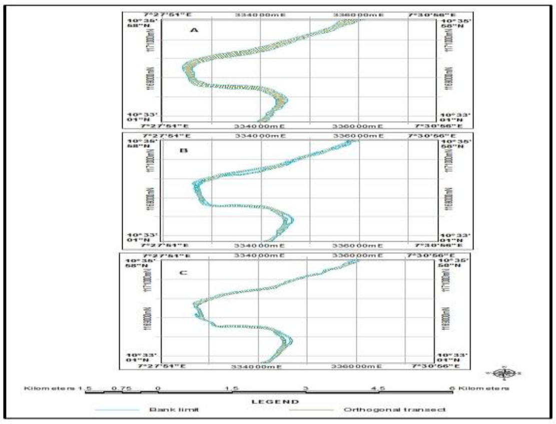
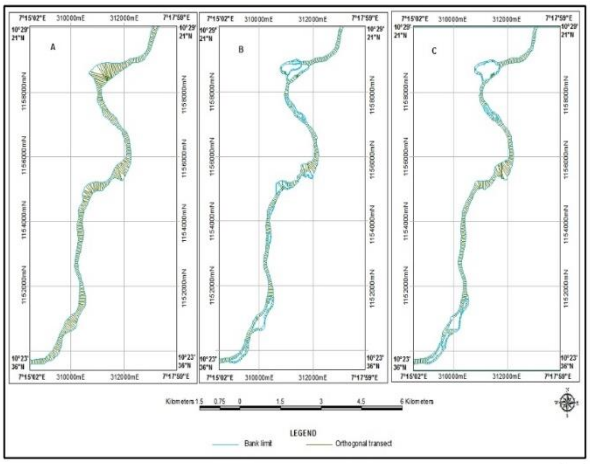
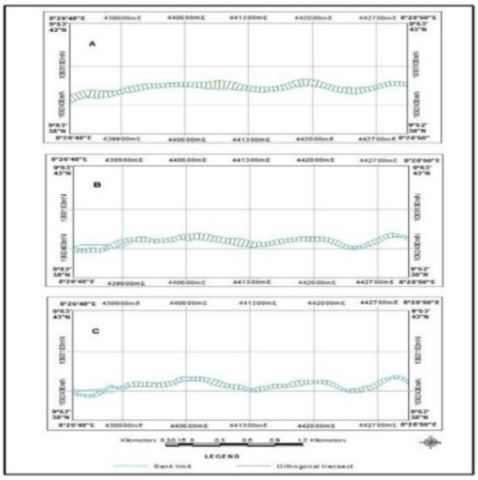
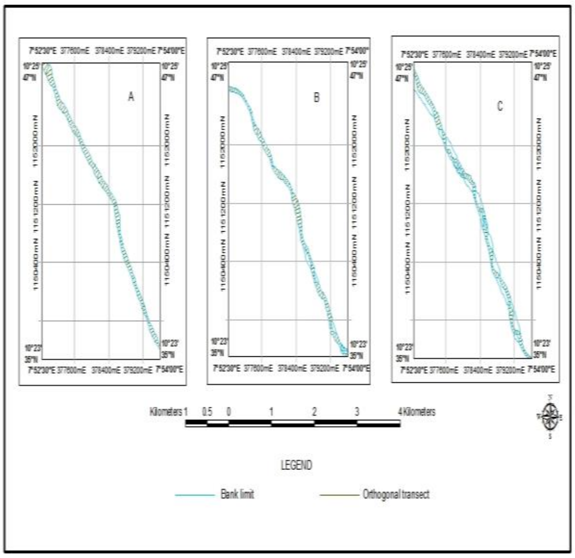


Figure 4. Changes in Channel Width for Meandering reach 2: A-1962, B-2005 and C-2017







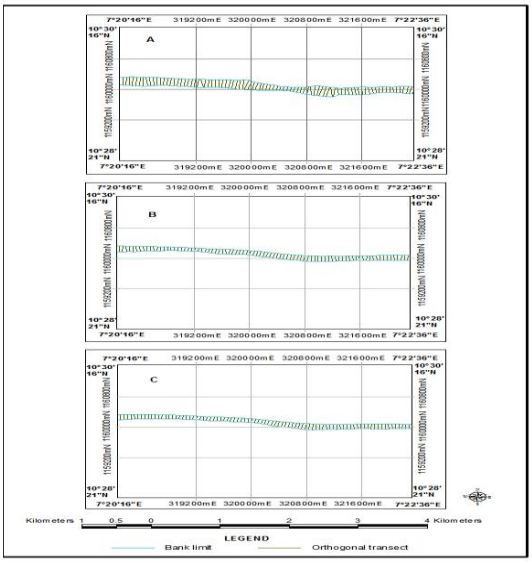


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Figure 7. Changes in Channel Width for Straight reach 2: A-1962, B-2005 and C 2017

Figure 8. Changes in Channel Width for Straight reach 3: A-1962, B-2005 and C 2017

Tables 4 and Table 6 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 reach 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 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.

Table 4. Statistics of Average Width of Meandering and straight Reaches in Metres

Width of Meandering Reaches			
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
Straight Reaches			
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

Table 5. 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

Table 6. 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

The results of changes in braiding are shown in Figures 9, 10 and 11 and the derived statistics for changes in braiding are shown in Table 7. The statistics in Table 7 show 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.

Table 7. 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

In braided reach 1 (Figure 9), 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. In braided reach 2 (Figure 10), 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, a feature referred to as anabranching according to Schumn (1985). A photograph of Lateral Bars, Longitudinal Bars and Active Channel on braided reach 2 is shown in Plate I.

Plate I: Lateral Bars, Longitudinal Bars and Active Channel

Plate II: Sand Mining Activities on the River near Gidan Danbushiya Bridge at Unguwar Rimi

Plate III: Quarry activities near Yakowa Bridge

Braided reach 3 (Figure 11) 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 as asserted by (Schumn, 1985).

Figures 12, 13 and 14 show overlay of centrelines for meander reaches 1, 2 and 3, in 1962, 2005 and 2017 respectively. The overlay in Figures 15, 16 and 17 relates the centrelines of straight reaches 1, 2 and 3, in 1962, 2005 and 2017 respectively, while Figures 18, 19 and 20 show overlay of centrelines of braided reaches 1, 2 and 3, in 1962, 2005 and 2017 respectively. From these overlays, channel migrations for all the reaches are visually appreciated from the comparison of the centrelines. 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 statistics for meander reaches 1, 2, and 3, those for the straight reach the statistics for braided reaches are shown in Table 8.

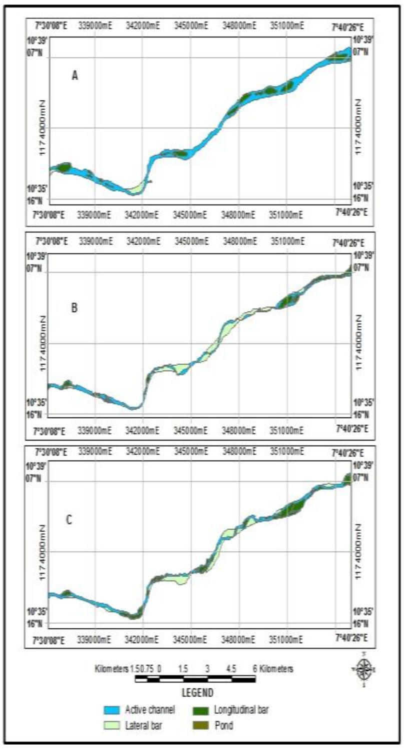


Figure 9. Changes in Braiding for Braided reach 1: A-1962, B-2005 and C 2017

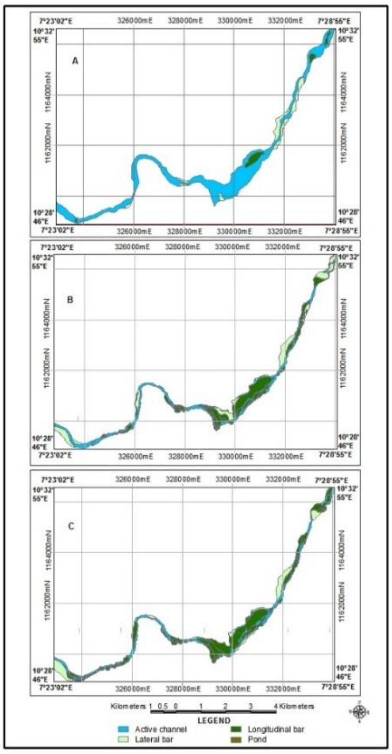


Figure 10. Changes in Braiding for Braided reach 2: A-1962, B-2005 and C 2017

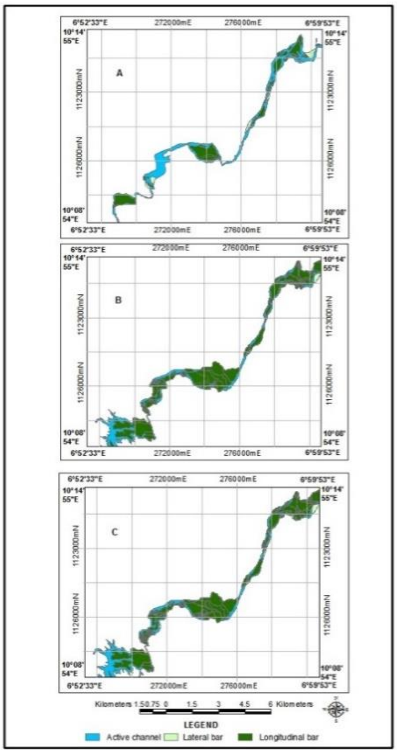


Figure 11. Changes in Braiding for Braided reach 3: A-1962, B-2005 and C 2017

The result in Figures 21 and 22 revealed channel migration between 1962 and 2005, and between 2005 and 2017 respectively, for meandering reach 1. Channel migration between 1962 and 2005, and between 2005 and 2017 for meandering reach 2 are shown in Figures 23 and 24, respectively, while channel migration between 1962 and 2005 and between 2005 and 2017 for meandering reach 3 are shown in Figures 25 and 26 respectively. Figure 27 and 28 show 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 are shown in Figures 29 and 30, respectively, and channel migration between 1962 and 2005 as well as between 2005 and 2017 for straight reach 3 are shown in Figures 31 and 32 respectively.

Figures 33 and 34 show 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 are shown in Figure 35 and 36, respectively, and channel migration between 1962 and 2005 as well as between 2005 and 2017 for braided reach 3 are shown in Figures 37 and 38 respectively. The statistics in Table 8 show 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.

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 (Table 8). 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. 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 (Table 8).

Figures 12, 13 and 14 show gradual channel migration for meandering reaches 1, 2 and 3 respectively while figures 18, 19 and 20 revealed gradual channel migration for braided reaches 1, 2 and 3 respectively. Channel position shift was negligible in straight reach 3 as shown in Figure 16 but very pronounced in straight reaches 1 and 2 particularly from 1962 to 2005 as shown in Figure 15 and 16. 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.

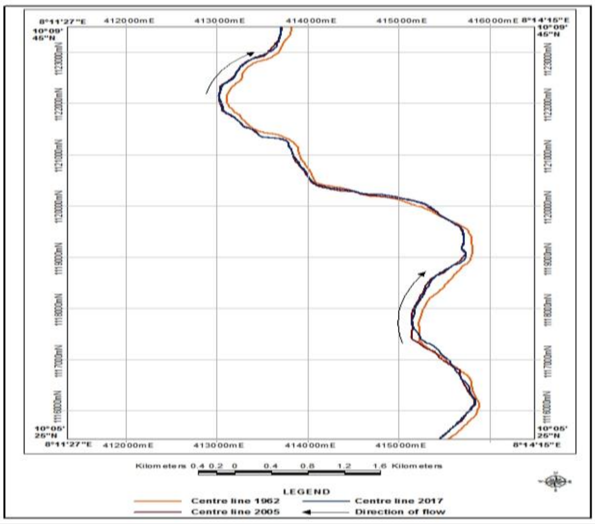


Figure 12. Changes in Channel Migration from 1962 to 2017 for Meandering Reach 1

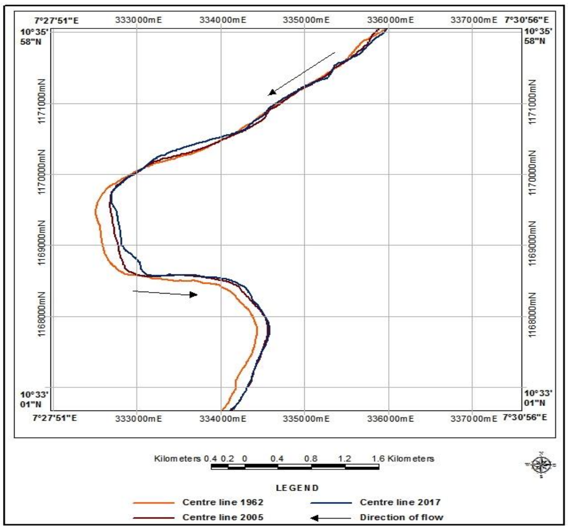
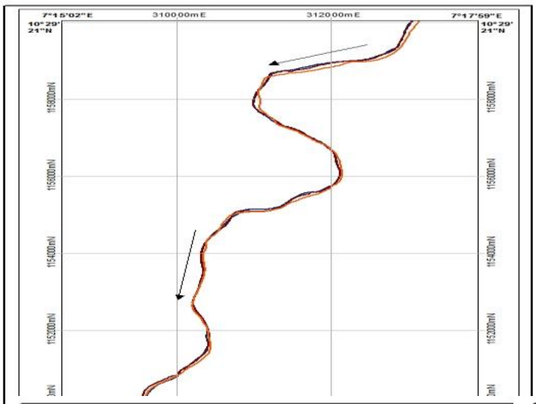
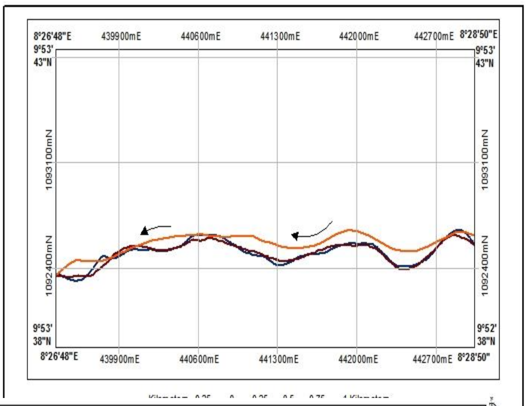


Figure 13. Changes in Channel Migration from 1962 to 2017 for Meandering Reach 2





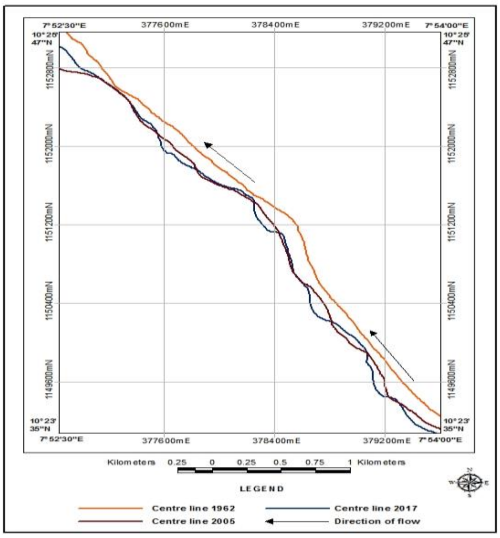


Figure 16. Changes in Channel Migration from 1962 to 2017 for Straight Reach 2

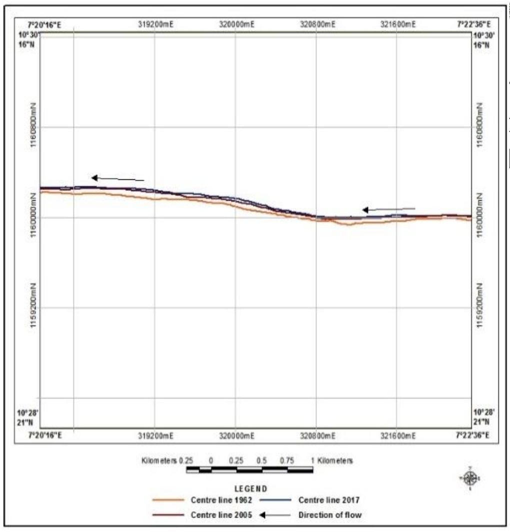


Figure 17. Changes in Channel Migration from 1962 to 2017 for Straight Reach 3

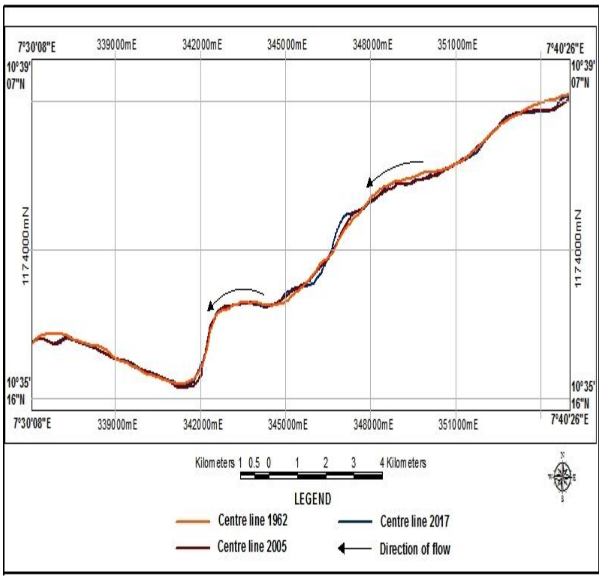


Figure 18. Changes in Channel Migration from 1962 to 2017 for Braided Reach 1

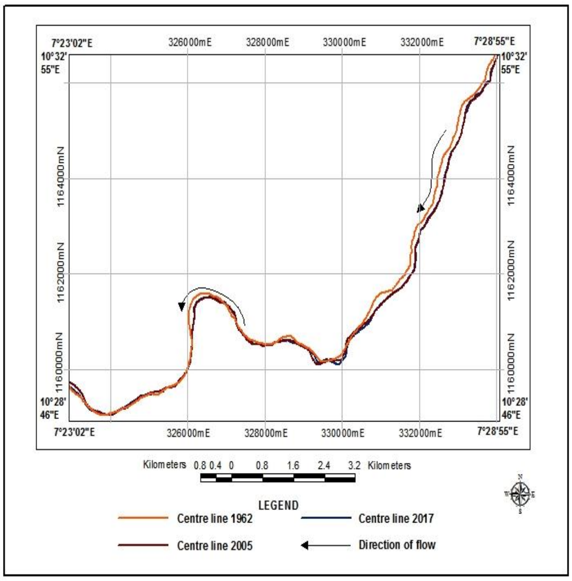


Figure 19. Changes in Channel Migration from 1962 to 2017 for Braided Reach 2

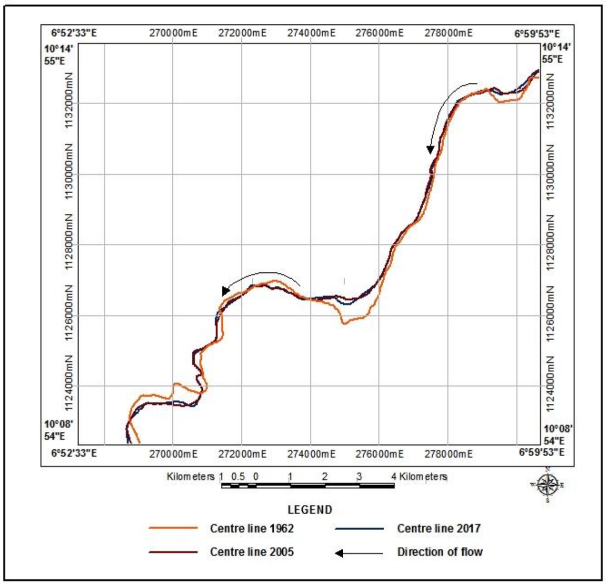


Figure 20. Changes in Channel Migration from 2005 to 2017 for Braided Reach 3

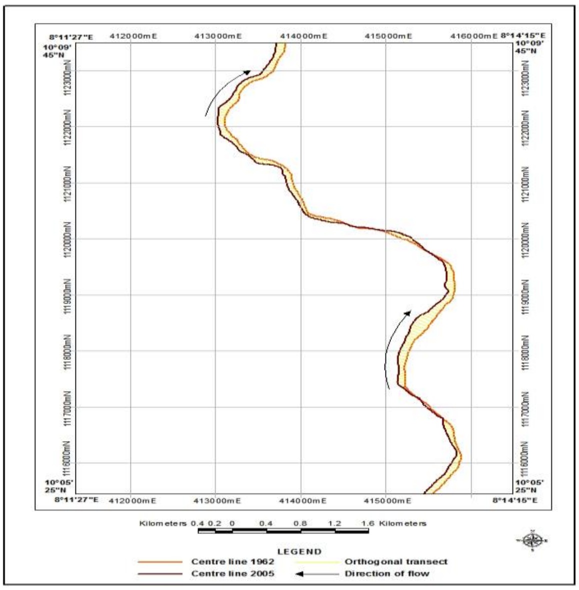


Figure 21. Changes in Channel Migration Between 1962 and 2005 for Meandering Reach 1.

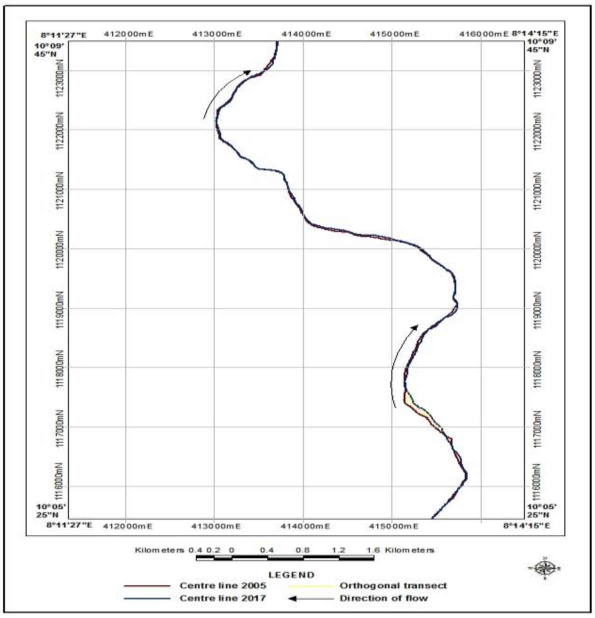


Figure 22. Changes in Channel Migration Between 2005 and 2017 for Meandering Reach 1

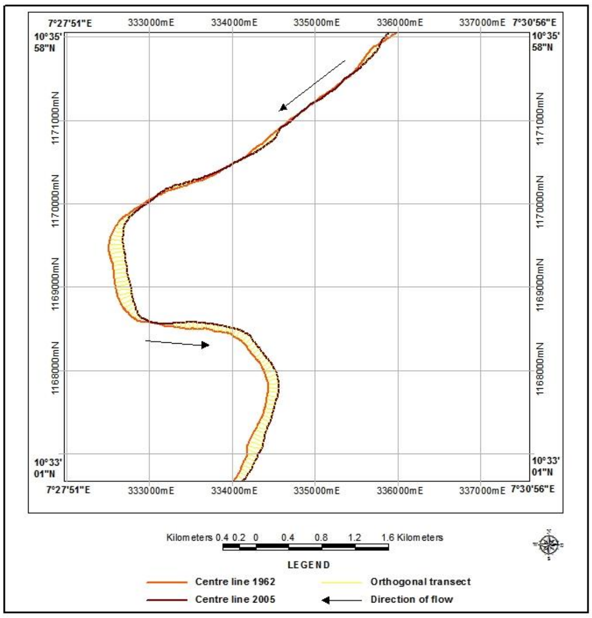


Figure 23. Changes in Channel Migration Between 1962 and 2005 for Meandering Reach 2

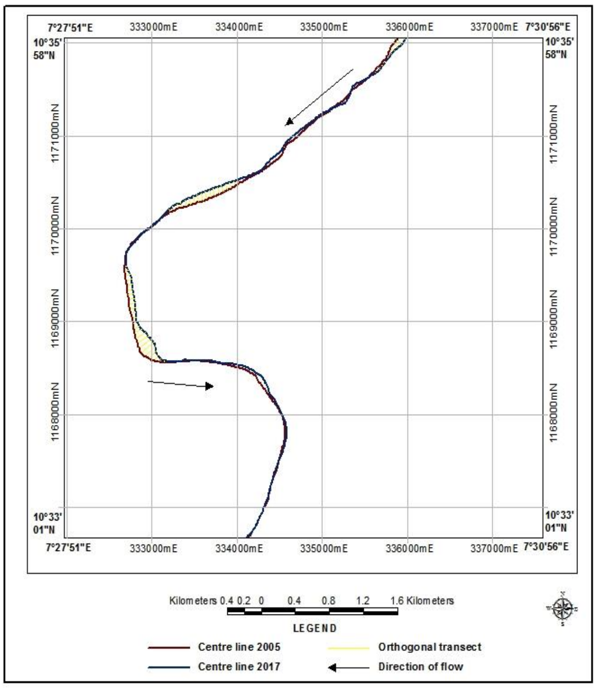


Figure 24. Changes in Channel Migration Between 2005 and 2017 for Meandering Reach 2.

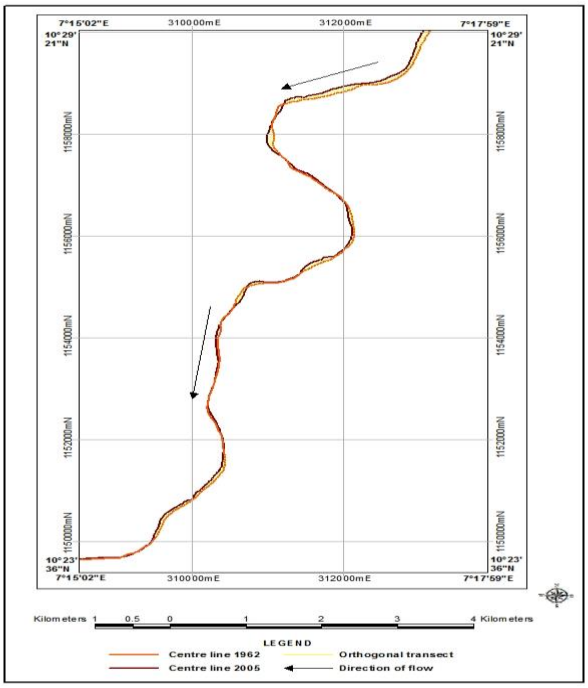


Figure 25. Changes in Channel Migration Between 1962 and 2005 for Meandering Reach 3.

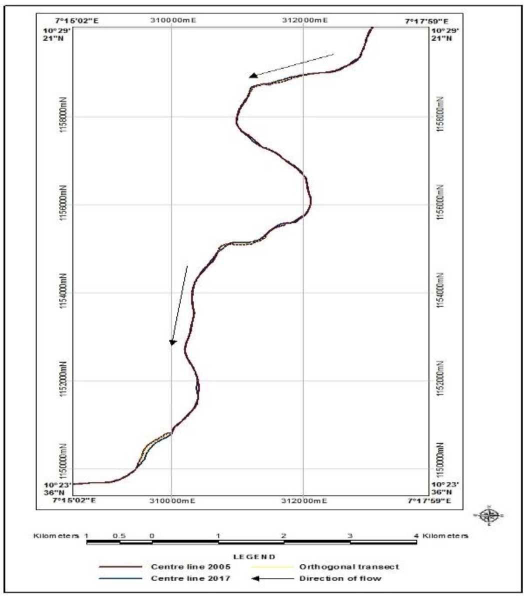


Figure 26. Changes in Channel Migration Between 2005 and 2017 for Meandering Reach 3

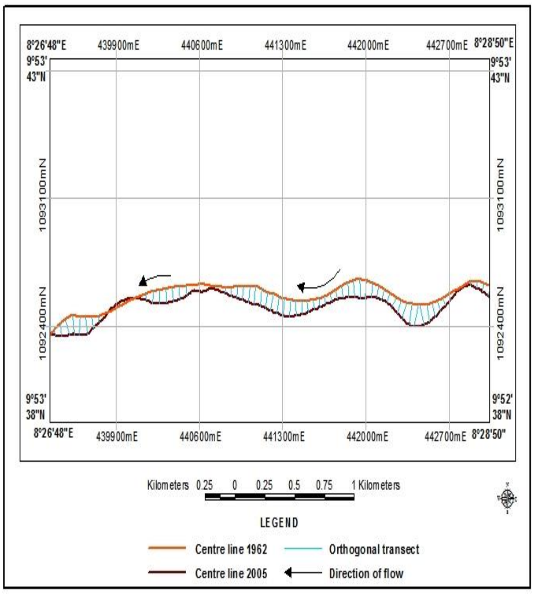


Figure 27. Changes in Channel Migration Between 1962 and 2005 for Straight Reach 1

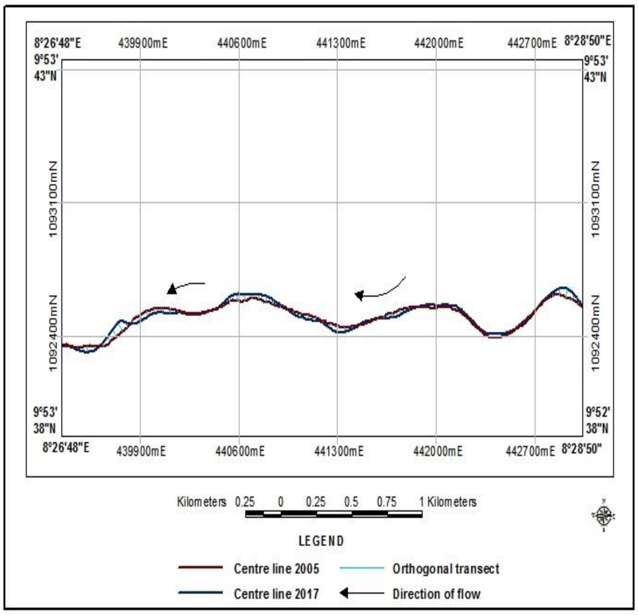


Figure 28. Changes in Channel Migration Between 2005 and 2017 for Straight Reach 1

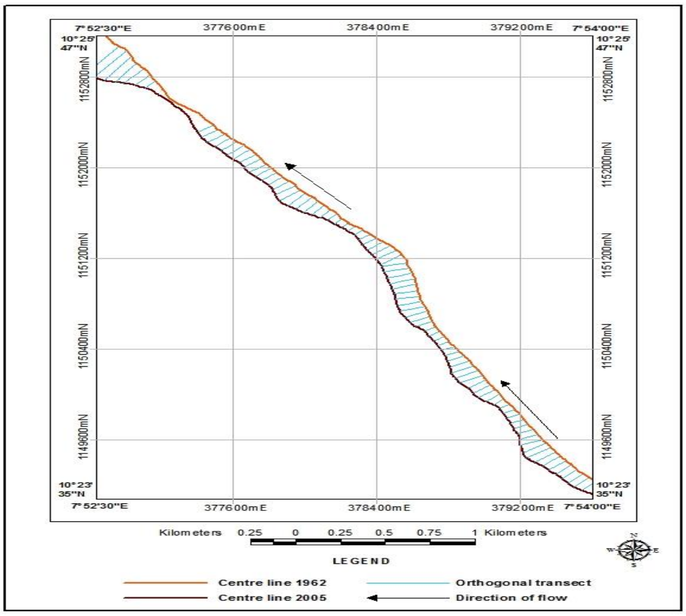


Figure 29. Changes in Channel Migration between 1962 and 2005 for Straight Reach 2

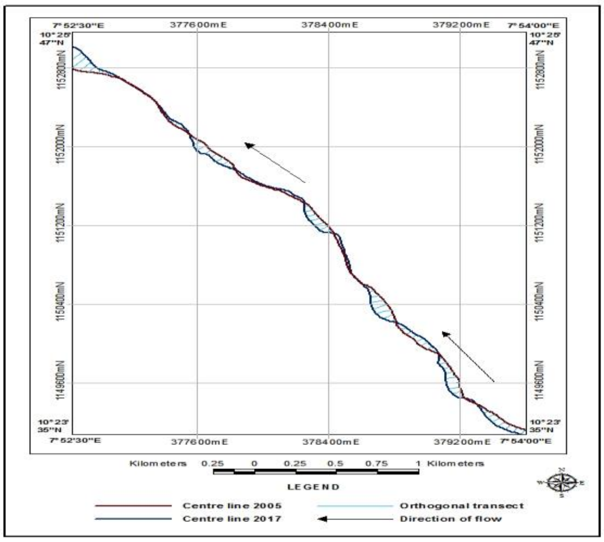


Figure 30. Changes in Channel Migration between 2005 and 2017 for Straight Reach 2

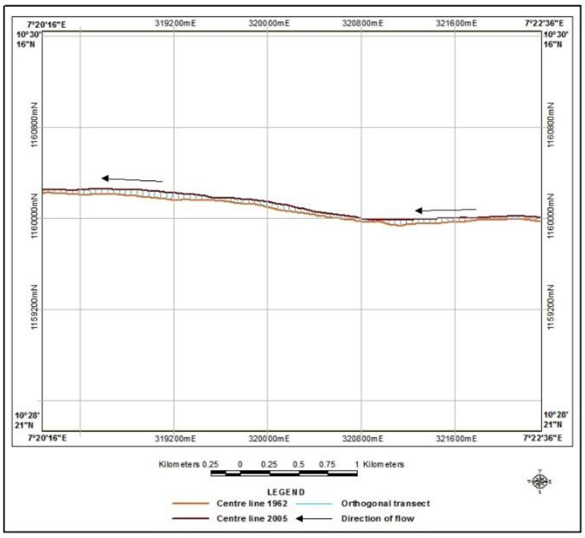


Figure 31. Changes in Channel Migration between 1962 and 2005 for Straight Reach 3

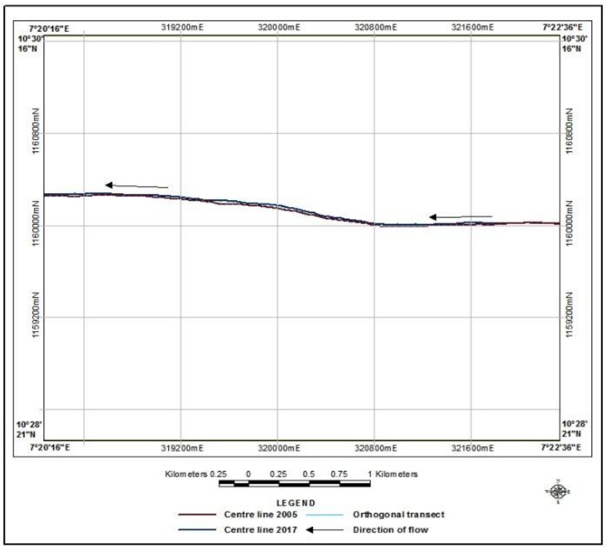


Figure 32. Changes in Channel Migration between 2005 and 2017 for Straight Reach 3

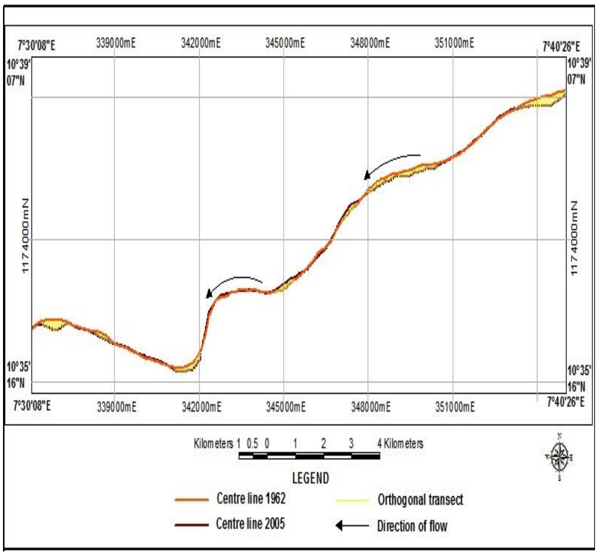


Figure 33. Changes in Channel Migration between 1962 and 2005 for Braided Reach 1

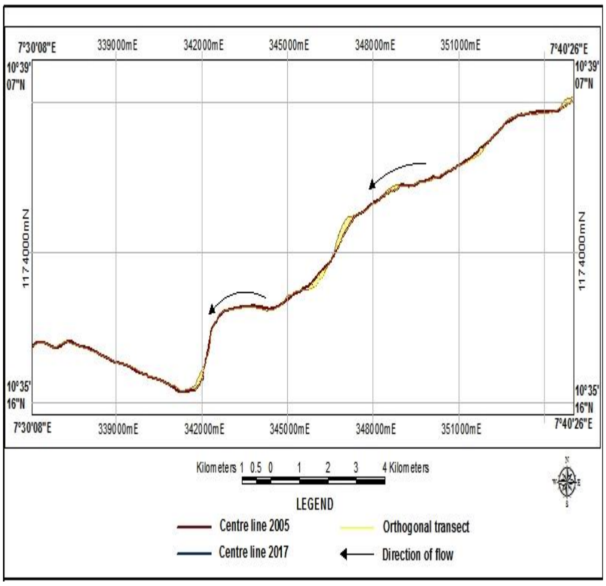


Figure 34. Changes in Channel Migration between 2005 and 2017 for Braided Reach 1

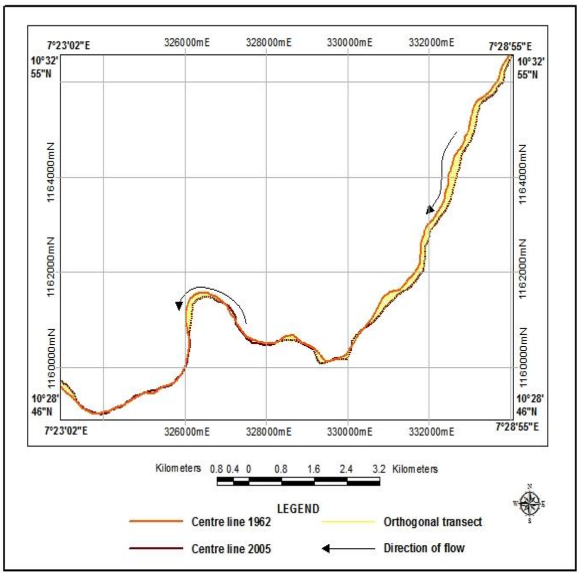


Figure 35. Changes in Channel Migration between 1962 and 2005 for Braided Reach 2

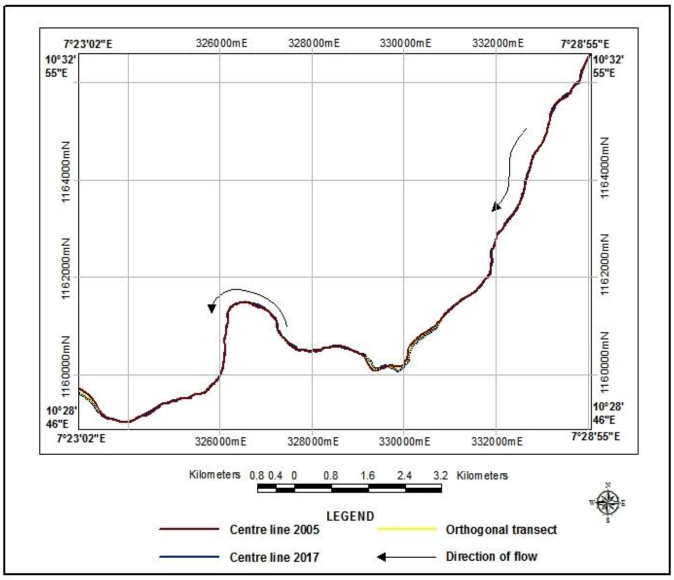


Figure 36. Changes in Channel Migration between 2005 and 2017 for Braided Reach 2

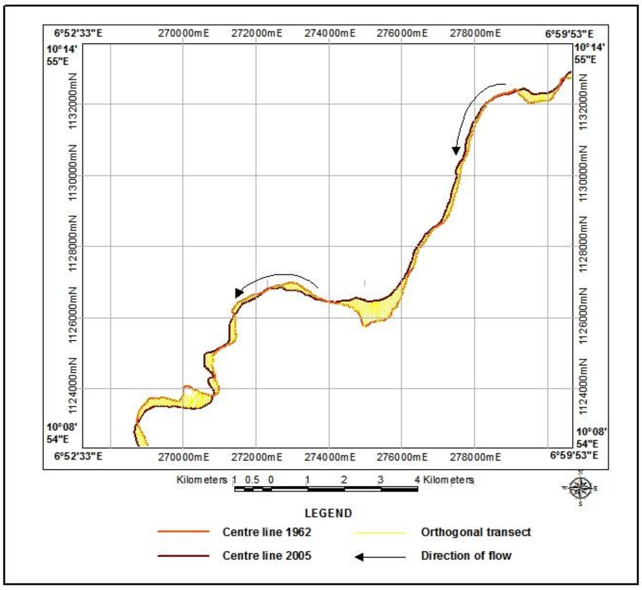


Figure 37. Changes in Channel Migration between 1962 and 2005 for Braided Reach 3

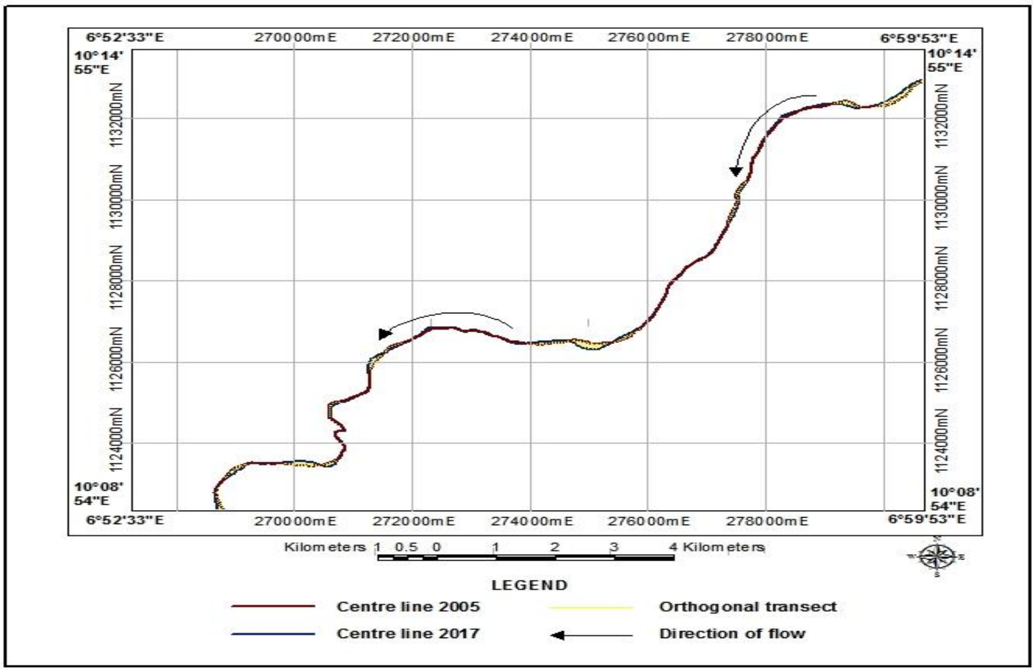


Figure 38. Changes in Channel Migration between 2005 and 2017 for Braided Reach 3

Table 8. Statistics of Average Distance of Channel Migration of Meander, Straight and Braided Reaches in Metres

Meander Reaches in Metres		
Reach	Between 1962 and 2005	Between 2005 and 2017
1	82.35m	61.88m
2	97.01m	69.47m
3	50.06m	36.87m
Straight Reaches in Metres		
Reach	Between 1962 and 2005	Between 2005 and 2017
1	79.91m	23.35m
2	122.22m	55.28m
3	38.45m	14.25m
Braided Reaches in Metres		
Reach	Between 1962 and 2005	Between 2005 and 2017
1	99.70m	86.06m
2	110.64m	50.11m
3	173.63m	56.36m

Table 8 illustrates 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.

4. Discussion

The results in Figs 6-8 for reach 1, 2 and 3 and the statistics in table 4 depict 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 according to (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 river bed 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 as seen from the study. 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 (2012), assertion or in response to riparian vegetation removal from agricultural activities as asserted by Brooks *et al.*, (2003); and Eaton (2006), instead the channel width was narrowing due to deposition that follows the reduction in stream energy.

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 could have been 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 (Figures 3 and 4), straight reach 3 (Figure 8) and braided reaches 2 and 3 (Figures 9 and 10), 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 & Pohl (2005) 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 & Morosanu (2015) 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.

On the whole, 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 were in agreement with the sinuosity ranges proposed by Sapkale & Chougule (2014) for both meandering and straight reaches. Petrovszki, *et al.*, (2014) carried out experiments to detect the effects of the changing slope and changing sediment discharge to river patterns. 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 meandering or could become braided.

As observed by Tiegs & Pohl (2005) 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. In Figs 9 &10 braiding pattern 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. However, 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.

Figure 11, illustrate 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 as asserted by (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 as shown in Plate II and III. 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. Plate III shows blocks of rocks that have been extracted from a rock outcrop close to the bank of the river in braided reach 2. 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 & Pohl (2005) who observed that channel planform response during their study was mainly channel narrowing. The results also agree with the studies by Scorpio, *et al.,* (2015) in which increased braiding was observed. The same causes identified in Petrovszki *et al*. (2014) for sinuosity are also responsible for braiding. As the slope increase and the water and sediment discharge increase, the river starts to meandering became braided with time.

Results of channel migration between 1962 and 2005 and between 2005 and 2017 shows that 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 as asserted by Mongaldip (2015). In all meandering and braided reaches showed there was no evidence of channel expansion and bend cut-offs and this could be attributed to the fact that there was minimal lateral abrasion in most of the reaches. The dominant process responsible for channel migration was the gradual migration of channel bends as asserted by Knighton (1998). However, Figures 12, 13 and 14 show gradual channel migration for meandering reaches 1, 2 and 3 respectively while Figures 18, 19 and 20 revealed gradual channel migration for braided reaches 1, 2 and 3 respectively.

Channel position shift was negligible in straight reach 3 16 but very pronounced in straight reaches 1 and 2 particularly from 1962 to 2005. It was observed that lateral abrasion was active in straight reaches 1 and 2 which implied that slope and stream energy were higher beings 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 sedition 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 & Morosanu (2015) who studied the dynamics of the Minor Riverbed of Teslui River in relation to the human factor in Romania;

those of Scorpio *et al.* (2015) on river channel adjustments and implications for channel recovery in Southern Italy; those of Mongaldip *et al.,* (2015) on Bank Erosion and Migration Nature of the Hooghly River in India; those of Lovric & Tosic (2016) on Assessment of Anthropogenic Factors and Floods using Remote Sensing and GIS on Lower Regimes of Kangshabati-Rupnarayan River Basin in India; those of Das et al., (2013) who studied the Geomorphological processes and river migration in Bangladesh and the studies of Barman & Goswami (2015) who evaluated sinuosity index of Dhansiri (South) River Channel and Bank Erosion in India using Geographic Information System. Velcu & Morosanu (2015) attributed the channel migration to human intervention which followed the construction of a dam for irrigation. The confluence point for the river Teslui & Olt was moved and this triggered a migration to the new position of the confluence. Scorpio *et al*. (2015) considered channel migration to have emanated from the natural process of erosion which was attributed to limited woody riparian vegetation along the channel. For Mongaldip *et al.* (2015); Lovric & Tosic (2016); Das *et al.* (2013) and Barman & Goswami, (2015), migration occurred as a normal natural fluvio-geomorphic phenomenon resulting from continuous siltation and fluvial erosion.

From Table 8, it can be seen that 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 cut-offs 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 cut-offs 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 & Morosanu (2015) 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 & Olt. 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 (2015) 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.

5. Conclusions

The results of the analysis of changes in channel planform of River Kaduna revealed that there have been significant changes in the channel planform variables investigated except for sinuosity index and channel length. 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 Leopold & Maddock (1953) and 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.

There are two possible reasons why there were no devastating floods in the past despite the irregularity in precipitation distribution; the first explanation is that the river channel then had the capacity to handle larger volumes of flood flows due to greater width and lower braided index. The second is that Kaduna city which has been hit by recent floods had not developed to the extent of generating the present volume of runoff and sediment loads that could necessitate clogging of the channel. From the analysis, it was observed that the channel width was reducing and the braided reaches were rapidly clogging. This phenomenon may continue to exacerbate with increasing urbanization and the effects of climate change, so sustainable measures have to be instituted, to cope with the issue of flooding in River Kaduna.

Dredging may appear to be a ready solution for reducing floodwater levels, but there are strong arguments against it. This is because dredging has tendencies to destabilize the banks of the river, destroy the aquatic ecosystem, and release unexpected flood flows that may have adverse effects on communities downstream. If it must be carried out, then it should be preceded by a robust impact assessment. Rather than dredging the following management strategies are recommended; (a) braiding could be controlled by protecting the developed floodplain by engineered structures (b) encourage mining gravel and sand from braided channels, this will provide sinks for sediments that otherwise would be deposited downstream to increase braiding and (c) afforesting the catchment area will create canopies to exposed surface and reduce sediment supplies.

References

Aliyu, B.N. (2014). Impact of Urbanization on Channel Morphology: Some Comments. *Journal of Environmental Science, Toxicology and Food Technology* 8 (4), 40-45.

Ashmore, P. (1991). Channel Morphology and the Bed Load Pulses in Braided, Gravel-Bed Streams. *Geografiska Annaler*, 73a: 37-52. http://dx.doi.org/10.2307/521212.

Barman, P & 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), 111-114.

Bennett, J. G., Rains, A. B., Gosden, P. N., Howard, W. J., Hutcheon, A. A., Kerr, W. B., Mansfield, J E., Rackham, L. J., & Wood, A. W. (1979). Land resources of central Nigeria *Agricultural development possibilities* 3 B. The Jema'a Platform.

Brooks, A.P., Brierley, G.J., & 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, 7–29.

Butu, A.W., Leke, D.C., Emeribe, C.N. and Jibril, M.S. (2020). Flood Frequency Analysis of River Kaduna, Kaduna State, Nigeria, using Precipitation Concentration Index Nigerian Research Journal of Engineering and Environmental Sciences 5(1), 139-156.

Casagrande, L., Cencetti, C., De Rosa, P., Fredduzzi, A., Martinelli, A. & Minelli, A. (2011). L'Utilizzo dei GFOSS nel Calcolo dell'Indice di Qualità Morfologica (IQM) dei Corsi d'Acqua. *Geomatics Workbooks*, 10, 57-78. http://geomatica.como.polimi.it/workbooks/n10/GW10-FOSS4Git_2011.pdf.

Chin A. & Gregory, K.J., (2005). Managing urban river channel adjustments. *Geomorphology* 69, 28–45.

Clerici A. & 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. *International* Journal *of Geosciences*. 7, 135143.

Das, D., Kar, K. K & Deb, M. (2013). A case study of Geo-Morphological Processes and River Migrating in Bangladesh. *American Journal of Remote Sensing.* 1(4), 72- 76.

Downward, S. R., Gurnell, A. M., & 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. no. 224.

Eaton, B.C., (2006). Bank stability analysis for regime models of vegetated gravel bedrivers: *Earth Surface Processes and Landforms*, 31, 1438–1444.

Egozi, R. & Ashmore, P. (2008): Defining and Measuring Braiding Intensity. *Earth Surface Processes and Landforms*, 33, 2121-2138. http://dx.doi.org/10.1002/esp.1658.

Fisher, G. B., Bookhagen, B. & Amos, C. B. (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.

Fejos, P. (1956). Forward. In: Thomas Jr., W.L. (Ed.), *Man's Role in Changing the Face of the Earth*. University of Chicago Press, Chicago, pp. vii–viii.

Gregory K.J. (2006). The Human role in changing river channels, *Geomorphology*. 79, 172-191

Henshaw, P.C. & D.B. Booth. (2000). Natural Restabilization of Stream Channels in Urban Watersheds. *Journal of the American Water Resources Association* 36(6), 1219-1236.

Ita, E. O. (1993). *Inland Fishery Resources of Nigeria*. CIFA Occasional Paper No 20. Rome, FAO. 1993, 120p.

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

Jeje, L.K. & Ikeazota, S.I. (2002). Effects of Urbanization on Channel Morphology: The Case of Ekulu River in Enugu, Southeastern Nigeria. *Singapore Journal of Tropical Geography* 23 (1), 37–51.

Lalit, S., Chandan, M. & Suranjana, B. B. (2018). A novel approach to calculate braiding of a large alluvial river, Research Communications, *Current Science* 115, No 6.

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

May, C.W., R.R. Horner, J.R. Karr, B.W. Mar, & E.B. Welch. (1997). *Effects of Urbanization on Small Streams in the Puget Sound Lowland Ecoregion*. Watershed Protection Techniques 2(4), 483-494.

Mohamed-Saleem, M. A. (1984). The Ecology, Vegetation and Land use of Sub-humid Nigeria. In: Von Kaufmann R., Chater S. and Blench R. (Eds), Livestock Systems Research in Nigeria's Subhumid Zone, *Proceedings of the Second II.A/NAPRI Symposium held in Kaduna*, Nigeria. International Livestock Centre for Africa Addis Ababa, Ethiopia

Mongaldip, M., Pintu, P & Kumar, N. B. (2015). Bank Erosion and Migrationing 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), 83-86.

Neller, R.J. (1989). Induced channel enlargement in smaller urban catchments, Armidale, New South Wales. *Environmental Geology and Water Sciences* 14, 167–171.

Paul, M.J. & J.L. Meyer. (2001). Streams in the urban landscape. *Annual Review Ecological. System.* 32, 333- 36.

Pavelsky, T. M. & Smith, L.C. (2008). RivWidth: A Software Tool for the Calculation of River Widths from Remotely Sensed Imagery. *IEEE Geoscience and Remote Sensing Letters*, 5, 70-73.

Petrovszki, J., Timár, G., & 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, 12271–12290 Grande River Estuary, Argentina. Estuarine, Coastal and Shelf Science, 62, 301-312. http://dx.doi.org/10.1016/j.ecss.2004.09.018.

Roesner, L. A. & Bledsoe, B. P. (2003). Are best-management-practice criteria really environmentally friendly? Journal of Water Resources Planning and Management-*American Society of Civil Engineers* 127, 150–154.

Sapkale, J. B. and Chougule V. A. (2014). Channel Pattern Variability and Stream Characteristics: A Study of Tulsi and Bhogawati River using Geo-informatics. *Indian Journal of Applied Research.* 4(7), 253-255.

Schumn, S. A. (1985). Patterns of Alluvial River, *Annual Review of Earth and Planet Science* 13, 5-27

Scorpio, V., Aucelli, P. C. P., Giano I. S., Pisano, L., Robustelli G., Rosskopf, C. M. & Schiattarella, M. (2015). River channel adjustments in Southern Italy over the past 150 years and implications for channel recovery. Geomorphology xxx.

Singh, V. P. (2003). On the Theories of Hydraulic Geometry. International Journal of Sediment Research, 18(3), 196-218

Tiegs, S. D. & Pohl, M. (2005). Planform channel dynamics of the lower Colorado River: 1976–2000. *Geomorphology* 69: 14–27.

Udo, I.A, & Okujagu, C. U. (2014). Assessment of Inter-Tropical Convergence Zone (ITCZ) Impact on Precipitation in Six Locations in Nigeria," *International Journal of Science and Research* (IJSR), 3 (6).

Velcu, G & 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.

Wolman, M.G. & Schick, A.P. (1967). Effects of construction on fluvial sediment: urban and suburban areas of Maryland. *Water Resources Research* 3 (2), 451–464.