Application of Remote Sensing and GIS in Sinuosity and River Migration Analysis of the Lower Parts of River Niger in the Niger Delta

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Abstract
Sinuosity and river migration analysis of the lower parts of the River Niger in Niger Delta from Onitsha to the coast has been done using various Landsat images during 1985 to 2015. The transect method was used for the river shifting measurement. The study area consists of a stretch characterized by uneven meandering and migration. Consequently, the adjacent areas are susceptible to flooding that causes significant losses of crops, property, livestock, and human lives. During the study period, the channel pattern moved from a sinuous-straight to straight-sinuous pattern with sinuosity reducing in the upper portions of the channel. It was found that in the upper portions of River Niger, the west bank of the channel was subjected to more erosion and that the river is migrating towards the west. In the lower portions of the River Niger, the east bank is subjected to more erosion and thus the channel is migrating towards the east. The width of the meander belt ranged from less than 1km to 4.9 km with an average of about 2km. Based on the findings of this study, it is suggested that the flood protection structures are crucial for the west bank in the upper reaches and the east bank in the lower portions of the channel in the study area. It is further suggested that these structures be constructed outside the meander belt of the river.
Keywords: Sinuosity. Channel migration. Meander belt. Channel pattern. GIS. Landsat images.

1. Introduction

Rivers are important not only as the conveyor of the products of continental denudational processes to the major sinks (oceans and lakes), but also as a natural resource for a wide range of human activities and uses especially transportation, recreation, irrigation, fishing, water and energy supply. Knowledge of the forms, energetics and dynamics of rivers, therefore, is of importance as such an understanding can assist land and natural resource managers in taking necessary measures to minimize damage (e.g., alterations of aquatic and riparian ecosystems, damage to property) conserve biodiversity (Gilvear et al. 2000) and plan for sustainable utilization. Rivers are naturally sinuous for much of their lengths, and it has been widely reported that the distance any river is straight does not exceed ten times its width at that point (Leopold and Langbein, 1966). Attempts have been made, therefore, to classify streams based on the degree to which a river departs from a straight line, its sinuosity.

Most rivers such as the River Niger, show significant change in sinuosity through time and hence their planforms reflect not only the geomorphic history but the geological controls such as active tectonics, tributary contributions and other factors affecting valley slopes (Burnett and Schumm 1983; Wyzga 2006). The study of the sinuosity index of a drainage line helps in evaluating the effect of terrain over river course and vice-versa (Panda and Bora 1992). Gillespie and Giardino (1997) evaluated the river sinuosity of Brazos river of Texas and found that the size of the river bends is influenced more by the composition of the river channels than by the peak flows. Similarly, Timar (2003) revealed that remarkable sinuosity changes have been found to correlate with discharge and sediment load changes at the interflow of tributaries. Rawat et al. (2011) studied the relationship among the sinuosity index, morphometric factors and natural hazard potential of third-order river basins of Kossi river basin in Lesser Himalayas. Harvey (2007a) identified three types of high sinuosity bedrock channels from the Almeria region of southeast Spain, and suggested that their distributions are related to gradient increase during incision in response to (1) regional tectonics, (2) local tectonic deformation, (3) tectonically-induced drainage ponding and breaching, (4) river capture and (5) eustatic sea level change. Even the smallest changes in the topography affect the sinuosity of low-gradient rivers (Holbrook and Schumm 1999), providing hints on on-going microtopographic changes. Nathan (2005) observed that the unusually high degree of sinuosity exhibited by the American River near its confluence with the Rubicon River is related with the coincidence of hinge zone of moderately to steeply plunging asymmetric folds with the axis of the meanders. Barbour et al. (2009) evaluated a quantitative relationship between regional climatology and sinuosity, and it has been

postulated that the rivers, which have more relative variance in discharge, tend to have greater lateral mobility. Decrease in flood plain storage and stream power levels higher than the channelization also control the geometry of sinuosity. Constantine and Dunne (2008) suggested that the size frequency distribution of oxbow lakes within the flood plains can be predicted using channel sinuosity studies. While quantifying the geomorphology of Doodhganga stream in Kashmir Himalaya, Hussain and Pandit (2011) emphasized that the anthropogenic intervention may alter the river sinuosity. Stanistreet et al. (1993), after studying the river channels on the Okavango Fan, recorded that bed load meandering and low-sinuosity fluvial channel systems are possible where vegetation is sufficient to produce confining peat levees. Investigations carried out by Ebisemiju (1994) in the Elemi river basin, southwestern Nigeria suggested that small intermittent streams in the seasonally wet humid tropics have a tendency to develop very sinuous channels characterized by compound and highly convoluted loop. He also presented that the dominant factor controlling the degree of sinuosity is channel bank resistance to lateral erosion as influenced primarily by the nature of riparian vegetation and secondarily by the percentage silt/clay in channel bank sediment. Fashae et al. (2015) investigated downstream morphologic characteristics of the alluvial section of the lower River Ogun, Nigeria and revealed that the ratio of stream channel length to down valley distance (sinuosity) indicated the stream type and how it would respond to channel and valley slope adjustments. Tukur et al. (2003) through studies carried out in River Gongola north-eastern Nigeria, comparing it's pre-dammed and post dammed geomorphic characteristics suggests a reduction in sinuosity and increased braiding in rivers which have been dammed.

Channel dynamics represent an integral component in the evolution of vast alluvial floodplains as well as the disturbance regime vital for floodplain patterns. Alluvial rivers are inherently dynamic in nature, responding to the variation in water and sediment inputs (Yang et al. 1999). Alterations in these inputs either natural or anthropogenic result in changes in the planform/channel pattern, sinuosity, and braiding index (Knighton 1984).

Scientists have also discussed the response of alluvial channels to tectonically-induced gradient changes, especially in terms of channel pattern responses (Burnett and Schumm 1983; Schumm et al. 2000). The consensus appears to be that tectonically induced gradient steepening may lead to heightened channel activity, resulting in accelerated erosion either by incision or by lateral erosion, and an increase in sinuosity (Keller and Pinter 1996). With larger rivers and lower gradients, lateral activity might dominate leading to floodplain formation and there is a switch from a bedrock channel to an alluvial channel within a confined rock valley (Harvey 2007b).

Remote sensing is an active tool to interpret not only the structural controls (Ramasamy 2006; Youssef et al. 2009; Madani and Emam 2011), channel migration (Ramasamy et al. 1991; Gilvear et al. 2000; Yang et al. 1999) delineate water potential zones (Edet et al. 1996;) but also the tectonic controls in river sinuosity (Jain and Sinha 2004; Jain and Sinha 2005). Hassan and Klein (2002) by using aerial photographs studied the fluvial characters of Jordan River and remarkably concluded that the sinuosity of the river has been increased by 25% due to the drop in the mean sea level of Dead Sea. Allen (1964 and 1970) used aerial photographs to delineate the lateral extent of the various mega and sub sedimentary environments in the Niger Delta. The use of GIS in combination with remote sensing is widely applied in the delineation of ground water potential zones within basement complexes S-W Nigeria with most zones falling within the medium groundwater potential zone which are generally underlain by medium-porphyritic granite, biotite-hornblende granite and granite gneiss bedrock settings (Edet et al. 1996). Ebisemiju et al. (1994) investigated sinuosity in River Elemi S-W Nigeria and concluded that sinuosity of the stream channels increases with increase in channel bank resistance to lateral erosion but decreases as channel gradient increases. River sinuosity studies within Nigeria are scarce, outdated and focuses mainly on rivers within the S-W of the country. This work focuses on the use of aerial photography and Geographic information system to determine the sinuosity trend of the River Niger, in the Niger Delta basin S-S Nigeria.

2. Study Area

The River Niger is Africa's third longest river (4,200 km), after the Nile and the Congo (Anderson et al., 2005). It is located between the meridians of 11°30' west and 15° east, from Guinea to Chad; and between the parallels of 22° north and 5° north, from the Hoggar Mountains to the Gulf of Guinea. It drains a large portion of Western Africa and discharges its waters and sediment load into the Atlantic Ocean through the southern part of Nigeria which leads to the building of the complex, fragile and active Niger Delta. The Niger River encompasses six hydrographic regions, each of which is distinguished by unique topographic and drainage characteristics. The Upper Niger River Basin headwaters are in the Fouta Djallon Massif, Guinea. From there the river flows northeast, traversing the Inland Delta, a vast spreading floodplain (averaging 50,000 square kilometers) that dissipates an appreciable portion of its potential hydraulics through absorption and evaporation. When it reaches the fringes of the Sahara Desert, the Niger River turns back by forming a great bend and flowing south and east as the Middle Niger River section, then as the Lower Niger, to the Niger Delta at the Gulf of Guinea, which it reaches after being joined by its largest tributary, the Benue River (Anderson et al. 2005). The Niger Delta

(Fig.1) is one of the largest regressive deltas in the world with an area of 300,000km² onshore and offshore (Kulke, 1995) and about 500,000 km3 volume of sediment deposit (Hospers, 1965). The Niger Delta is also the sixth largest oil producing delta in the world (Reijers, 1996). It is located between latitude 4°31'N-5°20' N and longitude 3°E - 9°E (Asseez, 1989). The on-shore part of the delta covers about 70,000 km2 and is characterized by an axial distance of 221 km from the northern apex at Onitsha to its coastal margin apex at River Nun. River Niger joins River Benue 230 km before entering the Niger Delta basin at Onitsha (Allen, 1965a). The Niger bifurcates into Nun and Forcados branches about 100km from Onitsha and discharge into the eastern and the western flanks of the delta respectively (Andersen et al. 2005; Whiteman et al. 1982).
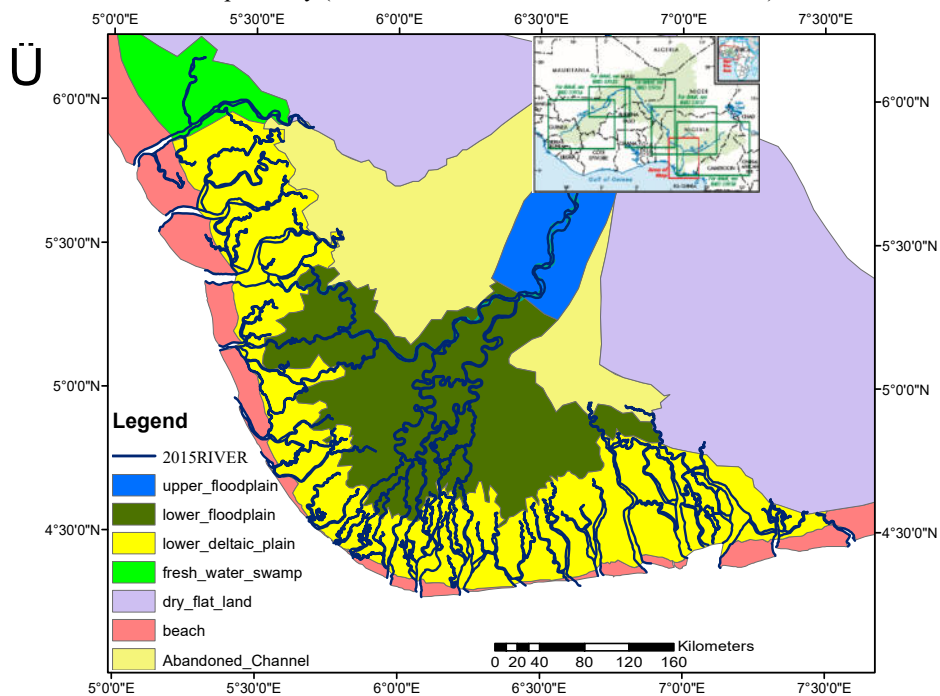

Figure 1: Geologic map of Niger Delta showing major sedimentary environments as defined by the fluvial, tidal and wave-related processes

3. Methodology

Satellite images of 1985, 1995, 2005, 2015 (Landsat TM—resolution 30 m) were used for assessing planform changes in channel over a period. All datasets were geometrically corrected and resampled to bring to the same scale (Lillesand and Kiefer 2000). Processing and interpretation of satellite imagery to delineate various geomorphic units, channel characteristics and analysis of the dataset was achieved using ESRI ArcGIS 10.3 and ArcView 3.5 computer software using spatial analyst, data management, editor, conversion and split tools. The procedures were tailored towards extracting qualitative and quantitative parameters from the channels using geoprocessing operations. The parameters estimated from the Channel parameters include apex to toe length, reach length, reach sinuosity and channel bed.

3.1 Computation of sinuosity parameters

Sinuosity parameters of the River Niger and River Nun were measured using the procedure outlined by Friend and Sinha (1993). In this procedure, the stretch was divided into equal-length reaches. The mid channel and overall channel belt length was measured and then the sinuosity equation was applied. The Landsat images of the years 1985, 1995, 2005 and 2015 were used in this study (Fig. 2a–d). For sinuosity analysis, the river stretch was divided into a series of continuous reaches, each having a length of 70km for River Niger.
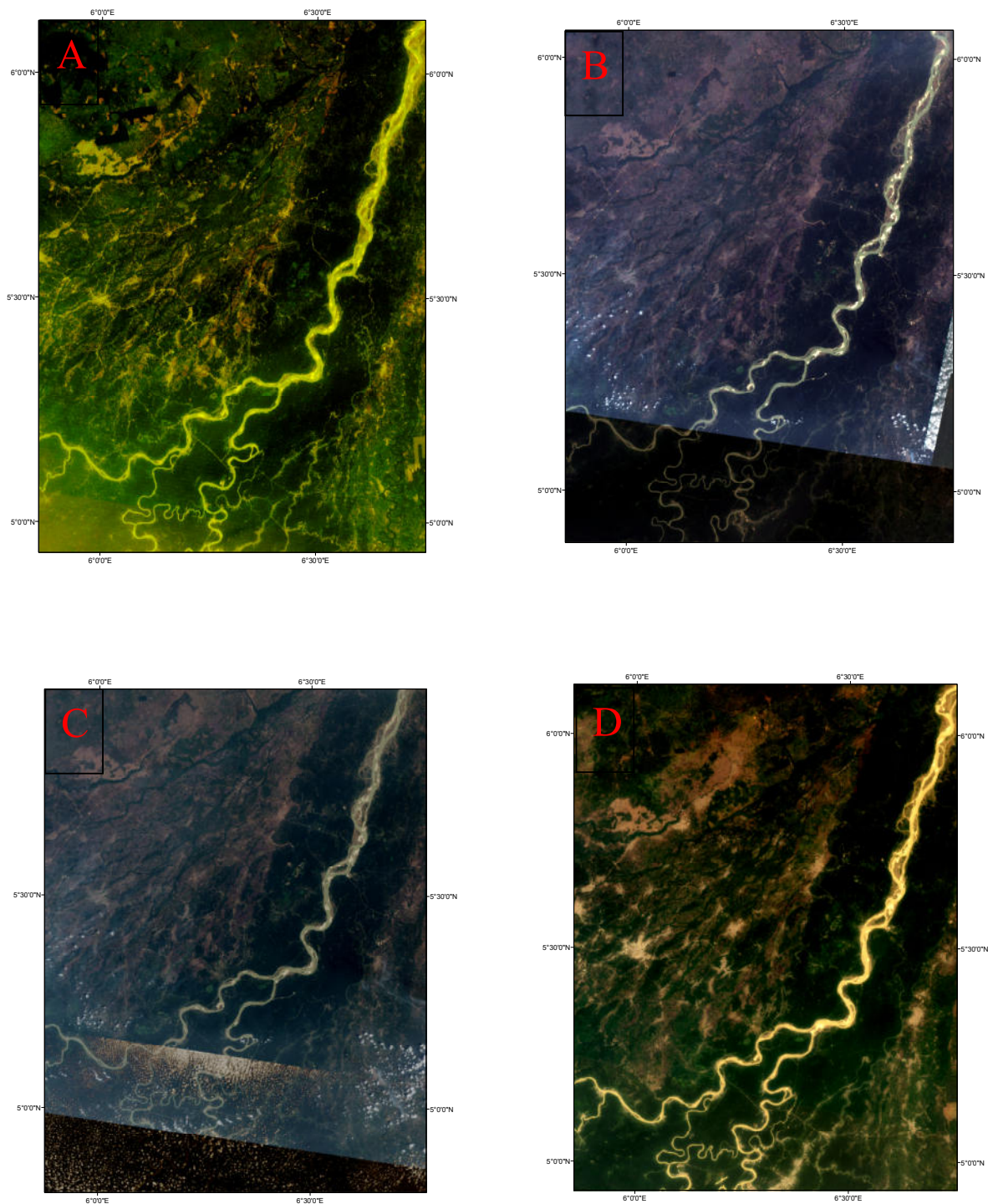
Figure 2: Floodplain and channel boundaries of the River Niger. A) 1985, B) 1995, C) 2005, D) 2015.
The overall length of the channel and the main channel length were measured using ArcGIS. The sinuosity was computed using the following equation for each reach:

$$P = {Lmax}/{LR}$$

here P is sinuosity, Lmax is the length of the midline of the channel (in single-channel rivers) or the widest channel (in multi-channel rivers) of the reach and LR is the overall length of the reach.

3.2   Computation of river shifting parameter

There are two main methods of river migration measurements, they are; polygons method and transects method (Rapp and Abbe 2003). The transects method was used in this study and is explained below:

- i.   The first step: Determine the source channel (i.e the origin channel); the main channel of 1985 was considered the origin channel in this study.
- ii.   The second step: Divide the flood plain into transects; the floodplain of 1985 was divided into transects of 22 km length each.
- iii. The third step: Overlay the center line of the origin channel (main channel) on all years of the flood plain transects in ArcGIS.
- iv.   The final step: Measure the changes in the position of the intersection of the main channel centerline with flood plain transects (migration distance) in ArcGIS for all the periods, and the direction of channel migration.

Migration rate is the outcome of dividing the migration distance by the number of years between various images used and the base image. Accordingly, the migration rates were computed and analyzed in the subsequent sections.

4.   Results and Discussion

4.1   Analysis of sinuosity of meanders

In 1985, the River Niger averagely was a straight-sinuous channel with a sinuosity parameter less than 1.5 for most of its segments. From 1995 till the end of the study period (i.e., 2015), the sinuosity of the River Niger is observed to increase as the years progress moving it to a predominantly sinuous channel with portions of braiding in some sections (Figure 3; table 1). In 2005, the sinuosity parameters were relatively high compared to those of the other years, there seems to be a gradual increase in sinuosity from 1985 to 2005. However, in 2015, the sinuosity parameters are observed to display a minute decrease in the sections, although the average still categorizes the Niger as being sinuous as the sinuosity index value is greater than 1.5. This subtle drop in the sinuosity index 2015 may be indicative of a gradual change in the river channel from its sinuous nature to a more braided form.
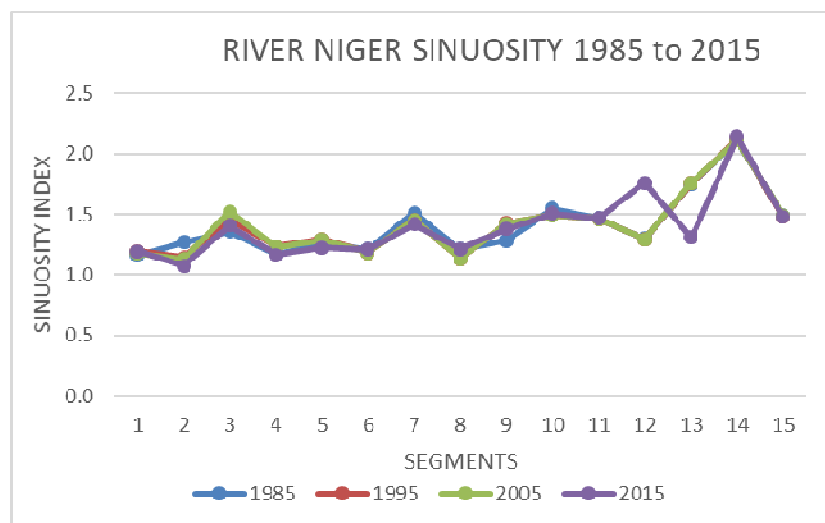

Fig. 3 Sinuosity of the River Niger 1985 -2015.

Table 1: Sinuosity values of different segments of the river Niger from 1985 to 2015.

SEGMENT	SINUOSITY			
	YEAR 1985	YEAR 1995	YEAR 2005	YEAR 2015
A	1.2	1.2	1.2	1.2
B	1.3	1.1	1.1	1.1
C	1.4	1.5	1.5	1.4
D	1.2	1.2	1.2	1.2
E	1.3	1.3	1.3	1.2
F	1.2	1.2	1.2	1.2
G	1.5	1.5	1.5	1.4
H	1.2	1.1	1.1	1.2
I	1.3	1.4	1.4	1.4
J	1.5	1.5	1.5	1.5
K	1.5	1.5	1.5	1.5
L	1.3	1.3	1.3	1.8
M	1.7	1.8	1.8	1.3
N	2.1	2.1	2.1	2.1
O	1.5	1.5	1.5	1.5

4.2   Analysis of shifting behavior

Landsat images of the years 1985, 1995, 2005, and 2015 were used in river shifting analysis. The migration distances were measured at 61 points with 5km intervals and then divided to 15 segments (A-O). The source channel was overlaid with each main channel of other years. Distances between centerlines at every section were measured and migration distance for different periods were calculated. The results of the rate of river shifting, the shifting direction and the type of change occurring i.e widening (erosion) or narrowing (deposition) during all four periods are given in Table 2 and Table 3. During the first period (1985–1995), the river was shifting to the east except some parts of the lower reaches. During the second (1995–2005) and third period (2005-2015), some parts of the reaches between sections G and H and the reach between sections J and O were shifting to the west; the other reaches kept shifting in the east direction. In general, the upper sections of the River Niger are observed to be shifting to the west and the lower sections are observed to be shifting towards the east during the study period. The higher values of erosion are observed at the upper sections of the channel. These sections include sections A-F (Figure 4) and thus infrastructure located at these locations on the Delta are at high risk of destruction if conditions observed during this study remain the same.

Table 2: Rate of migration (shift) of the various segments of the Niger River during the 30year study span (Negative values indicate erosion).

SEGMENT	MIGRATION RATE (m/ YEAR)		
	1985-1995	1985-2005	1985-2015
A	-40.2	-17.3	-6.2
B	52.0	25.4	-2.1
C	16.6	4.0	-14.3
D	100.2	22.4	-4.5
E	-40.3	-20.5	-4.4
F	-78.3	-42.1	-23.4
G	-24.6	-12.1	-7.2
H	-37.2	-18.9	-3.3
I	-33.2	-16.2	-9.8
J	-13.5	-8.6	-9.3
K	-18.8	-8.4	-0.8
L	78.3	39.6	25.7
M	46.7	23.8	15.7
N	63.1	34.8	-5.0
O	-4.6	-5.4	16.6

4.3   Delineation of meander belt

The channel belt refers to the zones in which the channel has been active. According to this definition, channel delineation depends on locating the areas which were occupied by the river during the previous years. As parts of

Table 3: Type of shift and direction during all four periods within study area. (SEG- Segment; DIR- Direction of migration).

| SEG	1985-1995	DIR	1995-2005	DIR	2005-2015	DIR	1985-2015	DIR
A	WIDENING	EAST	NARROWING	WEST	WIDENING	WEST	WIDENING	EAST
B	WIDENING	EAST	WIDENING	WEST	WIDENING	WEST	WIDENING	WEST
C	WIDENING	EAST	WIDENING	WEST	WIDENING	WEST	WIDENING	WEST
D	NARROWING	EAST	WIDENING	WEST	WIDENING	EAST	WIDENING	WEST
E	WIDENING	WEST	WIDENING	WEST	WIDENING	EAST	WIDENING	WEST
F	WIDENING	WEST	WIDENING	WEST	WIDENING	EAST	WIDENING	WEST
G	WIDENING	WEST	WIDENING	WEST	WIDENING	WEST	WIDENING	WEST
H	WIDENING	WEST	NARROWING	WEST	WIDENING	WEST	NARROWING	WEST
I	WIDENING	WEST	WIDENING	WEST	WIDENING	WEST	WIDENING	WEST
J	WIDENING	WEST	NARROWING	WEST	WIDENING	WEST	WIDENING	EAST
K	NARROWING	EAST	NARROWING	EAST	WIDENING	EAST	WIDENING	EAST
L	NARROWING	EAST	NARROWING	EAST	WIDENING	WEST	WIDENING	EAST
M	WIDENING	WEST	WIDENING	EAST	WIDENING	EAST	WIDENING	EAST
N	NARROWING	EAST	NARROWING	EAST	NARROWING	WEST	NARROWING	EAST
O	NARROWING	EAST	NARROWING	WEST	NARROWING	WEST	NARROWING	EAST
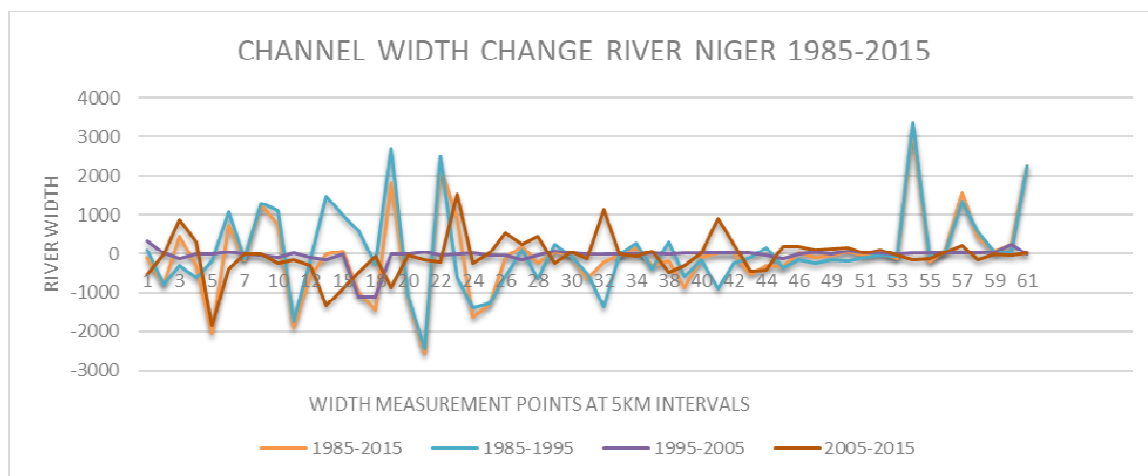
Figure 4: River Niger Migration of the four periods within the Niger Delta.

The river in the study stretch is braided, the channel belt includes both active and abounded channels. The channel belts were delineated manually by drawing simple polygons covering the channel belt in the years 1985,1995, 2005 and 2015.The polygons (channel belts) were overlaid and merged together to get the overall channel belt. Figure5a shows the channel belt in various years and Fig.5b shows the meander belt of the River Niger in the study area. The overall belt widths were measured at all the sections, and the width varied from 0.3km to about 4.9km with an average value of about 2.2 km. The delineation of the meander belt is important as it has a direct bearing on the planning of flood protection works.
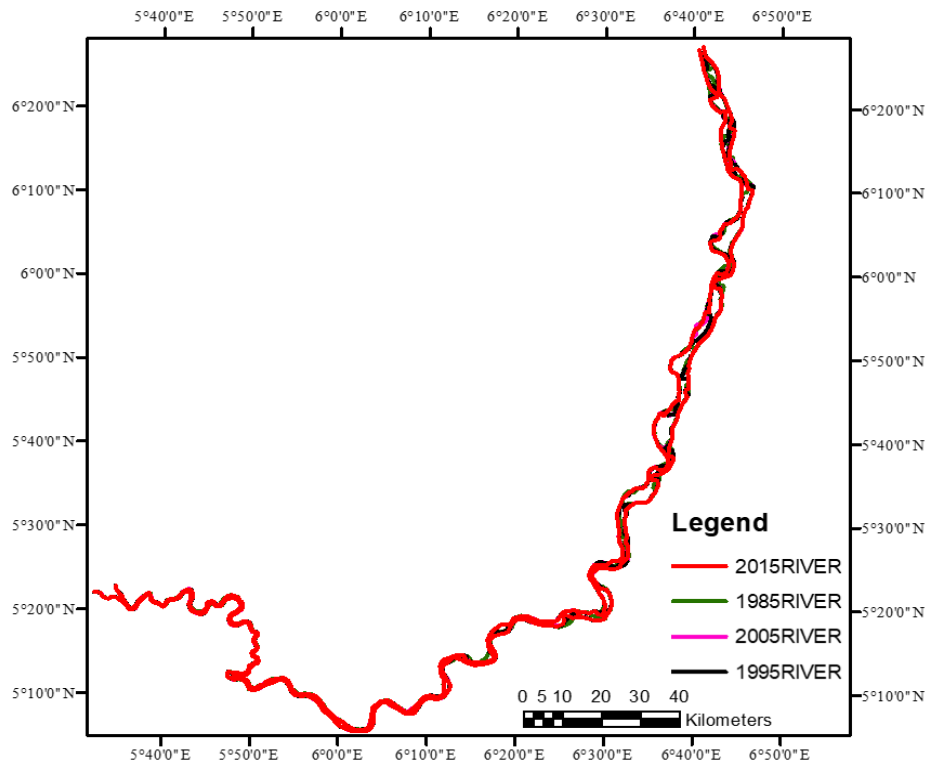
Figure 5a: Channel belts of the River Niger during the study period 1985-2015.
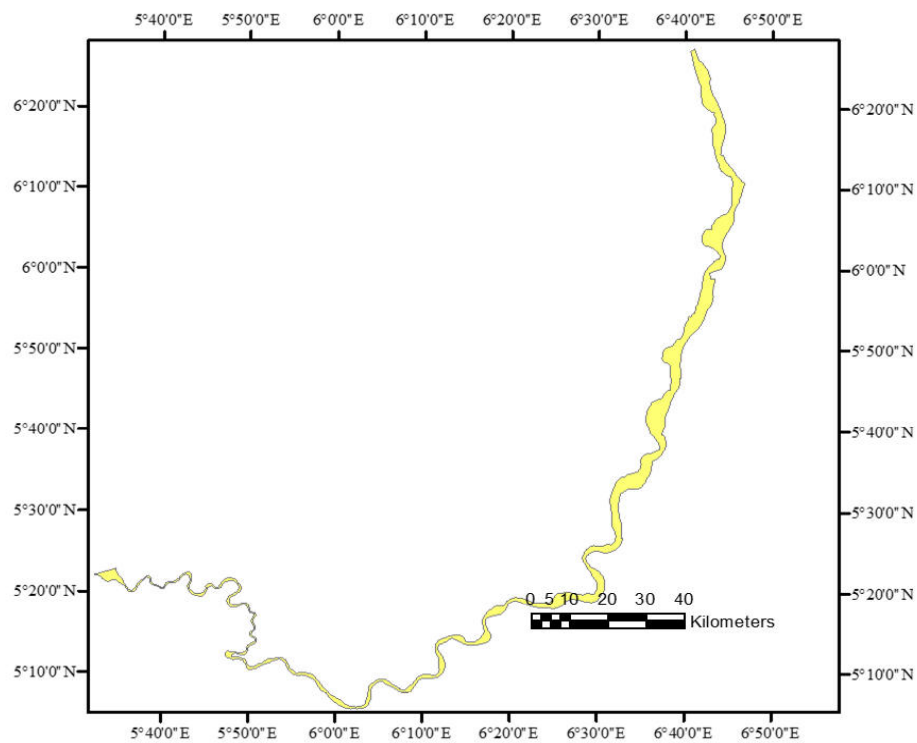

Figure 5b: Delineated meander belt of the River Niger from Onitsha to the coast.

5. Conclusions

The River Niger is a highly active river which has changed its channel pattern from a sinuous-straight channel at

the beginning of the study period (1985) to a straight-sinuous channel at the end of the study period (2015); this may be due to discharge variability, urbanization and sediment load fluctuations caused by the frequent flooding occurring within the Niger Delta. In 1985, the sinuosity parameters were relatively high in segments G, J, K and M-O. The lower sections of the channel were observed to have sinuosity parameters greater than 1.5. In 1995 and 2005, the sinuosity parameter is observed to increase in segment C. The sinuosity pattern displayed in 1985 is carried through to 2005 with the lower reaches of the channel being more sinuous than the upper reaches. In 2015 sinuosity is observed to drop in most segments of the channel with sinuosity greater than 1.5 being observed in only 5 segments (J, K, L N and O) eluding to the straightening of the River Niger Channel. The River Niger migration was measured in the four periods; during the first period (1985–1995), the river generally migrated to the east except in the middle segments where it migrated westwards. In the second period (1995-2005) the upper reaches of the channel are observed to migrate westwards whereas the lower reaches are identified to move toward the East. The third period (2005–2015), displays a general migration to the west with a small section of the middle segments migrating towards the East. The final period which encompasses the total study period (1985-2015) the upper reaches of the channel are observed to migrate towards the west whereas, the lower reaches migrate towards the east. The west bank in the upper part of the River Niger channel is subjected to erosion and as a result, the river is shifting westward. However, this same phenomenon is affecting the east bank in the lower part of the River Niger channel. Hence mitigation processes and structures should be put in place to avoid further erosion of these banks. The channel belt width of the River Niger ranged from less than 1 km to about 4.9 km with an average of about 2 km. Belt width of about 2 km is normal for an active river like the Niger that practically single handedly drains the Niger Delta. As a result of the recurrent flooding in this region over the years, the present study will help the stakeholders in better planning and protection of the environment and infrastructure in this area.

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