Original Research Article

CHANNEL PLANFORM DYNAMICS ALONG DISTRIBUTARY CHANNELS: CASE STUDY OF THE RIVER NUN A MAJOR DISTRIBUTARY OF THE RIVER NIGER

Abstract

Channel planform dynamics were analyzed for the River Nun; a major distributary of the River Niger from 1985 to 2015 using GIS and Remote sensing applications. Satellite imagery of the area from 1985, 1995, 2005, and 2015 were analyzed by means of GIS and used to determine the planform characteristics and changes in width, sinuosity, and shoreline migration rates. The channel planform dynamics were determined by comparing sequential changes in the position of the shorelines in these years. Sinuosity adjustments during the study were small and range between 1.74–1.76. The initial sinuosity (1.74 in 1985) increased to 1.75 in 1995 and then increased to 1.76 in 2015. Channel expansion is observed to be the dominant planform process, owing to periodic floods within the study area. The river's channel width barely expanded from 1985 to 1995 (by 0.1 %). However, there is a constant increase in expansion within the study years that by 2005-2015 expansion had increased to 9%. The bank erosion was prevalent. Mean erosion rates ranged from 0.7m/year in 20 years (1985-2005) to 2m/year in 30 years (1985-2015). In the 1st 10 years (1985-1995) less than 0.1m of deposition was observed. The mean erosion rates ranged from 1.3 to 1.6 m/year on the left side and 2.8 to 3.8 m/year on the right side of the channel. Mean accretion rates of 1.2 m/year on the left side and 1.8 m/year on the right side were observed. The channel is observed to move generally towards the east (right).

Keywords: River Nun, Channel planform dynamics, Channel shifting, erosion.

1. INTRODUCTION

Understanding the planform dynamics of river channels has important implications for maintaining biodiversity (Naiman et al., 1993; Hughes, 1997; Ward et al., 1999) and minimizing flood damage (Holburt, 1984). In the recent decade, the River Nun, a major distributary of the River Niger has experienced episodes of intense flooding in response to man-made events such as frequent dam openings. Although floods tend to rehabilitate large areas of ecologically important riparian vegetation (Glenn et al., 1996, 2001; Stromberg, 2001), they can cause property damage worth millions of dollars (Holburt, 1984). Investigations of historical channel change provide insight into how stream channels respond to such flood events. With this information, land and resource managers are able to make decisions that minimize social costs (e.g., flood damage to life and property) and maximize the ecological benefits of flooding (e.g., rehabilitating riparian vegetation and deterring the proliferation of exotic species).

The application of GIS to aerial photographs in order to explore geomorphic change and the dynamics of fluvial landforms is a recent ploy by researchers to enhance the utility of historic aerial photographic data and readily quantify channel changes through time (Gurnell et al., 1994, 1998; Graf, 2000; Winterbottom, 2000). Given the constantly changing character of fluvial systems, Winterbottom (2000) takes into consideration the importance of discerning between gradual changes occurring within fluvial systems in a state of dynamic equilibrium and alterations in channel form and pattern (e.g., sinuosity, braiding index) that constitute a departure from equilibrium.

River channel changes such as bank erosion, downcutting and bank accretion are natural processes for an alluvial river. However, regional developments such as sand mining, infrastructure construction on the riverbank, artificial cutoffs, bank revetment, reservoir construction, and land use alterations have changed the natural geomorphologic dynamics of rivers (Surian 1999; Kesel 2003; Surian and Rinaldi 2003; Batalla et al. 2004; Vanackeret al. 2005; Wellmeyer et al. 2005) with no exception to the River Nun. Therefore, channel stability is often threatened. Such human activities may even become stronger forces for change than natural events such as floods and droughts. The resulting channel changes cause various environmental and socioeconomic consequences in terms of navigation, loss of riparian land and infrastructure, flood hazards, and the alteration of aquatic and riparian ecosystems.

The research presented here focuses on this latter type of change on the River Nun from 1985 to 2015. It uses repeat aerial photography managed in a GIS, to describe the planform geometry and migration behavior of confined meandering section of the River Nun and to relate the channel-migration rate of this river to basic hydrologic and geomorphic controls. Although the data presented here are clearly of scientific interest to those seeking to understand the dynamics of migration, they are also significant to practical issues such as predicting channel-migration rates for engineering and planning purposes. This fundamental geomorphic information has particular utility in the River Nun as it is a major distributary of the River Niger and drains the oil prolific Niger Delta where a majority of oil installations and infrastructure are located and thus must be protected to prevent catastrophic environmental problems. However, protection cannot proceed without a sound understanding of the type and magnitude of channel response that can be expected from flood flows, as well as where such changes will occur. This study provides the historical, geomorphic context needed to discuss desired changes to the form, and function of the River Nun.

The River Nun (Figure 1) lies within the southern part of Nigeria and is considered as a continuation of the River Niger. The Nun begins after the bifurcation of the River Niger into 2 at about 32km downstream from Aboh in the Niger Delta. The Nun flows through sparsely settled zones of freshwater and mangrove swamps and coastal sand ridges before completing its about 180-km south-southwesterly course to the Gulf of Guinea, through a wide inlet of the Atlantic Ocean, at Akassa. The Nun with a total length of 190km and average width of 370m, the Nun River is considered the largest in Bayelsa State (FPD, 1980). Large dams and reservoirs such as the Lagdo Dam in Cameroon (began operation in1982), Kainji Dam (began operation in 1968) and Jebba Dam (began operation in 1984), have increasingly controlled the River Niger discharge and attenuated water and sediment yields in the River Nun. The River Nun which drains a major part of the Niger Delta has been exposed to flooding within the last couples of years, this is a result of the flooding of its parent channel (River Niger) within the study period. Thus, the channel planform in the River Nun is influenced by both natural flooding and human management and hence its implications on the River Nun are examined. We conducted this research on the entire length of the River Nun.

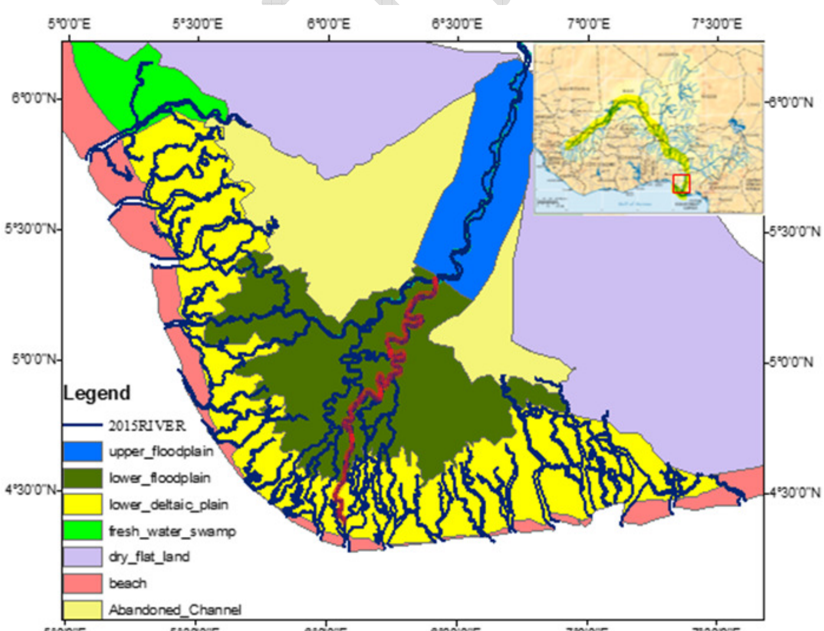

Fig. 1. Geologic map of Niger Delta denoting study location and major sedimentary environments as defined by the fluvial, tidal and wave-related processes

2. MATERIALS AND METHOD

In this study, a time series of georeferenced data were developed using Landsat TM images. Polygons were created that depicted the active stream channel from these mosaics and compared the active channel width, sinuosity, and channel area for three different periods between 1985 and 2015. The starting date (1985) provides the earliest data available for the study reaches. The most recent available imagery was obtained in 2015. Using these polygons, the historical changes in the river's position, channel area, and erosion and accretion rates were described, and the patterns of variation were characterized in these.

2.1 Data and Image Processing-. Satellite images from 1985, 1995, 2005 and 2015 (Landsat TM-resolution 30 m) covering the study area, was used for assessing planform changes in the channel over a period of time. All images were from the October. All datasets were geometrically corrected and resampled to bring to the same scale (Lillesand and Kiefer 2000).

Delineation of channel boundaries-. Nicoll and Hickin (2010) digitized channel outlines using the water boundary to denote the edge of the channel because this boundary is clearly defined in Landsat images. Changes in the water level can, therefore, lead to large changes in the positions of the channel boundaries. To avoid this problem, the river channel was defined as an elongated area in which streamflow occurred with sufficient frequency, force, and duration to discourage the presence of vegetation; as a result, 90 % or more of this area is bare ground or water (Lawler 1993; Tiegs and Pohl 2005).

Defining the stream channel by the absence of vegetation rather than using a strictly geomorphologic approach was used successfully by Gurnell (1997) and Winterbottom (2000). Several other studies have used the limit of vegetation or changes in vegetation type to denote channel boundaries (e.g., Richard et al. 2005). This method of active channel delineation effectively eliminates inconsistencies in channel planform measurements that might occur as a result of varying water levels (Gurnell 1997).

In the GIS software, continuous polygons were created to represent the stream channel in each year using the image (map) data. These polygons were digitized on the screen at a scale of 1:30000, and methodological consistency was maintained by having a single operator perform all polygon delineations. Using these techniques, a georeferenced polygon coverage of the active channel was created for each image (Fig. 2).

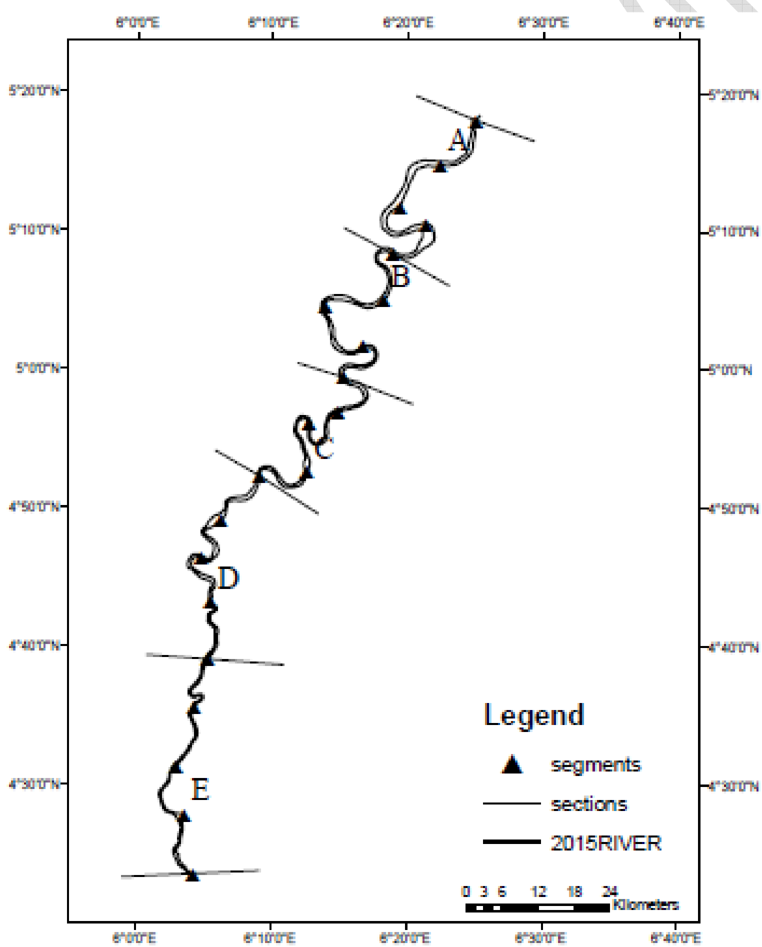

Fig. 2: Channel course of the river Niger denoting transverse sections and segments

2.2 Change in Morphology-. The digitized river channels of 1985 were divided into five equal segments(A–E) of 38km each (Fig.2) for River Nun. The starting point was designated as section a-a and the channel reach between section a-a and section b-b was designated as segment A, and so on. A combined map was prepared by superimposing the digitized river channels of all years to assess changes during different time periods. Changes in morphology were assessed by visual inspection of digitized channels. A typology mainly based on the methods proposed by Goswami et al. (1999) for planform changes was established. It was used as a base to classify the geomorphological changes observed. The different types of planform changes recognized were: changes in channel width; changes in channel length and progressive shifting of the meander bends.

2.3 Amount of Bankline Shift-. Each of the five segments was further divided into two equal parts, and the amount of bank line shift was measured at 11 transverse sections.

2.4 Changes in Channel Length, Channel Area and Sinuosity-. Channel length was measured along the line equidistant and parallel to the left and right banks of the channel polygon. Active channel area was determined for each polygon in GIS, excluding vegetated mid-channel islands as adopted by Tiegs and Pohl (2005). The line used to determine channel length was also used to measure sinuosity (channel length/straight-line valley length). The channel length, area and sinuosity, were determined for the entire river channel, for all the assessment periods as well as for each segment.

3. RESULTS

3.1 Planform Changes in the River Nun-. The digitized river Nun channel of 1985, 1995, 2005 and 2015 was divided into five equal segments (A–E) of 32km each. The starting point was designated as section a-a and the channel reach between section a-a and section b-b was designated as segment A and so on. Each segment showed a variation of change between the study years. During the assessment period, four cases of straightening of the river course due to bank detachment occurred. In segments A (1985-1995; 2005-2015) the straightening decreased the length of the river by 1.3km (3%) and 1.2 (3%), segment B (1995-2005) by 0.2km (1%); segment D (1985-1995) 0.1km (<1%) and in segment E (1985-1995) by 0.2km (1%) (Table 1). An overall increase in the channel length between 1985 and 2015 was recorded (Table 1). In the study period between 1985 -1995 a total of three segments experienced straightening as compared to one each recorded in the following assessment periods. The channel is observed to be entering its meandering stage as channel length gradually increases during the study period irrespective of the straightening observed in some parts of the channel.

Table 1. Channel length at different segments of the River Nun from 1985 to 2015

	LENGTH KM						
	YEAR						
SEGMENTS	1985	1995	% change	2005	% change	2015	% change
A	38.2	36.9	-3.4	37.1	0.5	35.9	-3.1
B	36.4	38.1	4.6	37.9	-0.5	38.7	2.1
C	36.9	37.2	0.9	37.5	0.7	37.8	0.9
D	36.9	36.8	-0.2	36.8	0.0	37.0	0.6
E	36.8	36.6	-0.6	36.7	0.3	36.8	0.3
Total	**185.2**	**185.6**		**185.9**		**186.2**	

Changes in Channel Width-. In addition to the increase in channel length, there were also cases of channel widening and narrowing. The period between 1985 and 1995 registered three instances of channel widening in segments A, B and C. In the period between 2005-2015 four instances of widening were observed. In 1995-2005 only one case of widening was identified in segment A, which also represent the maximum case of channel widening in the entire time frame of the study. The widening was due to migration of bankline or development of mid-Channel Islands. During the assessment periods of 1985–1995 and 2005–2015, only two and one cases of narrowing, respectively, were recorded. The period between 1995 and 2005 registered channel narrowing in all segments except segments A while the period 1985-1995 registered channel narrowing in segments D and E. The last assessment period (2005-2015) registered two instances of channel narrowing in segments B and E. In the period between 1895-2015 three instances of channel widening were identified in segments A, C and D whereas, segments B and E were observed to be narrowing.

3.2 AMOUNT OF BANKLINE SHIFT

Assessment period 1985-1995-. There was a substantial negative shift of the east banking during 1985-1995, maximum apparently being 27m at segment C and 25m in segment D. The west bankline had a maximum negative shift of 58m in segment A and 55m in segments B (Table 2). The large negative shift at segment B toward the west caused a marked increase in channel width between segments B and C as there was a large amount of positive shift (deposition) of 28m on the same west bankline in segment C. Positive shifts in the west bank line was recorded in segments D (32m) and C (28m). The East bankline is observed to have positive shifts in segments A (43m) and B (49m). These shifts recorded in the east bankline represented the greatest extent of positive shifts within the period. It is generally observed that during the study period segments that displayed negative shifts in one bankline had an almost equal amount of positive shift in the opposite bankline. This behaviour is associated with meandering rivers where bank cutting and point bar development is prominent.

Assessment Period: 1995–2005-. During the 1995–2005 period, the instances of negative shifting were observed mainly on the East bankline. The maximum negative shift within the period is seen in the east bankline of segment E (133m). Other negative shifts were observed to be in segments C (5m) and D (2m), however, the only negative shift associated with the west bank line was observed in segment B (4m). Positive shifts (deposition) are associated more with the west bankline in this period as all segments with the exception of segment B recorded positive shifts. Segments A (20m) and E(19m) recorded the maximum positive shift within the study period. The East banklines also registered positive shifts (deposition) within the study period. These shifts are observed in segments B (11m) and A (3m). Segments A, B and D experience narrowing whereas segment E is observed to be widening within the study period. The east bank line appears to be more unstable and contributes more to the widening of the channel (Table 2).

Assessment period: 2005-2015-. The west bankline is observed to have the most frequent amounts of negative shifts as compared to the east bankline (Table 2). The west bankline shows a maximum negative shift of 28m in segment C which causes a remarkable difference in the channel width between segments B-C. During the assessment period, the west bankline is observed to be more unstable recording four of the five segments with negative shifts in their banklines. Although the highest negative shift is observed in the east bankline, segment (E) both banklines contribute to the widening of the channel at segment E. The channel is observed to experience an equal spread of negative shifts in the banklines with very minimal deposition observed.

Assessment period 1985-2015-. During this assessment period, the maximum number of negative shifts were registered by the east bankline. The East bankline also recorded the highest value of negative shift in segment A (212m) within the assessment period. Other notable negative shifts of the east bankline include 54m, 53m, 29m in segments D, C and E respectively. During this period the west bankline experienced only 2 segments with negative shifts; segment A (24m) and B (25m). The east bankline displayed a maximum number of negative shifts (4) segment in the assessment period. the negative shift of 25m in segment A during this assessment period (Table 2). The east bankline also recorded the highest positive shift of 38m in segment B, whereas, the west bankline recorded high positive shifts of 37m and 20m in segments E and C respectively. There is a general migration of the upper sections of the River Nun channel to the West, while the lower sections of the channel are migrating towards the East. Thus, infrastructure located in the migration directions would be at high risk of destruction if all conditions observed during this study remain constant.

Table 2. Shift in position of banklines (M) of the River Nun between 1985-1995, 1995-2005, 2005-2015 and 1985-2015 (DIR- Direction, W-West, E- East, Ave- Average).

SEG	1985-1995			1995-2005			2005-2015			1985-2015		
	WEST-BANK	EAST-BANK	DIR	WEST-BANK	EAST-BANK	DIR	WEST-BANK	EAST-BANK	DIR	WEST-BANK	EAST-BANK	DIR
A	-57.6	43.4	W	20.0	3.4	E	-14.4	-26.4	E	-25.4	-212.3	E
B	-54.8	48.5	W	-3.8	11.3	W	1.3	-44.8	E	-24.3	38.0	W
C	28.0	-26.8	E	6.3	-5.3	E	-28.0	22.3	W	19.8	-53.3	E
D	31.5	-25.0	E	6.3	-2.3	E	-26.8	23.0	W	20.3	-54.3	E
E	16.6	4.2	E	19.4	-133.0	E	-12.8	-57.8	E	36.5	-29.4	E
AVE	-7.3	8.9	W	9.6	-25.2	E	-16.1	-16.7	E	5.4	-62.2	E

Changes in Sinuosity and Channel length-. Values of sinuosity oscillated considerably in the segments during different assessment periods. In 1985, all segments of the channel had sinuosity values ≥ 1.5 indicating a sinuous/meandering pattern except in segment E which displayed a sinuosity value of <1.5 (Table 3). In the subsequent assessment period (1995), the channel sinuosity character remained the same with segments A-D being highly sinuous and segment E having the lowest sinuosity values in the period. Segments A and B are observed to display an increase of sinuosity by 5% and 1% respectively. Segments D and E retained their initial sinuosity values whereas segment A showed a decrease in sinuosity by 3%. The maximum gain, 5%, was registered in segment B. In the next assessment period (2005), sinuosity remained unchanged in segments D and E, it reduced in segment B and increased in segment C. However, a 1% increase was observed in segment A. During the period of 2015, the sinuosity increased in segments B (2%) and C (1%) and decreased only segments A (3%). Segments D and E remained unchanged. A gradual increase in sinuosity is observed in segments B and C whereas segment A shows a decrease through the study period.

Considering the entire stretch of the River Nun, changes in channel configuration led to an overall increase in sinuosity by 1% in 30 years i.e., from 1985 (1.74) to 2015 (1.76). The most significant period responsible for this loss was during 2005–2015 (see Table 2). The river dynamics also influenced the channel area during different periods of assessment. The channel length ranged from a minimum of 36.4km during 1985 (segment B) to 35.9km in period 2015 (segment A). A maximum gain of 5% occurred during the period of 1985–1995 in segment B. The gain could be attributed to an increase in the sinuosity and therefore the meandering nature of the channel. The River Nun registered an overall net gain of 1% in channel length over 30 years.

Table 3. Sinuosity values of different segments of the River Nun from 1985 to 2015

SEGMENTS	SINUOSITY			
	1985	1995	2005	2015
A	1.81	1.75	1.76	1.70
B	2.04	2.15	2.14	2.19
C	2.12	2.14	2.15	2.17
D	1.45	1.45	1.45	1.45
E	1.28	1.28	1.28	1.28
AVERAGE	1.74	1.75	1.76	1.76

3.3 Change in Channel Width-. In addition to the increase in channel length, there were also cases of channel widening and narrowing. The period between 1985 and 1995 registered two instances of channel widening in segments A and B (Table 4). The widening was due to migration of bankline or development of mid-Channel Islands. During the assessment period of 1995-2005, only one case of widening was identified in segment E with all other segments narrowing. However, in the 2005–2015 period, all segments were observed to widen and no case of narrowing was recorded in the period. During 30 year assessment period (1985-2015), two cases of channel narrowing were registered (segments B and E).

Table 4. Summary table denoting type of shift in positions of banklines in River Nun between 1985 - 2015. (DIR- Direction, W- West, E- East)

SEG	1985-1995	DIR	1995-2005	DIR	2005-2015	DIR	1985-2015	DIR
A	Widening	W	Narrowing	E	Widening	E	Widening	E
B	Widening	W	Narrowing	W	Widening	E	Narrowing	W
C	Narrowing	E	Narrowing	E	Widening	W	Widening	E
D	Narrowing	E	Narrowing	E	Widening	W	Widening	E
E	Narrowing	E	Widening	E	Widening	E	Narrowing	E

4. DISCUSSION

This study on the dynamics of the River Nun generated valuable baseline information on channel characteristics and planform changes over a period of 30years. The variation of the width of the river Nun between study years was considered to establish the rate of erosion and deposition along its course and invariably the migration rate of the channel. Within the River Nun erosional fluctuations are observed throughout the channels with the upper reach experiencing the highest level of erosion. This change may be as a result of the variation in annual precipitation; as precipitation is said to be on an increase since 2005 within the study area (Abaje et al., 2015) as compared with the reduction in precipitation observed by Odjugo (2005) between the years 1990–2001. The recent constant yearly release of water from the Ladgo dam in Cameroon into the river Benue has led to the constant yearly flooding of the River Niger (Azuwike et al., 2011) causing a chain reaction flooding of the study area. This flooding, in turn, plays a part in defining the change observed within the study area. A general narrowing of the channel is observed with the lower portions displaying minor erosional evidence as compared to its upper reaches. This plays into Mount (1995) elucidations; that with the increase in the frequency of the flooding in a channel, at its lower reaches depositional, rather than erosional, processes act to expand the channel capacity. Generally, River Nun is observed to have an increase in negative change (erosion) during the assessment period with erosion increasing to an average of 9% in the period between 2005-2015 from an average of 3% in the previous years between 1995-2005 (Table 5). The River Nun 1st study period of 10 years (1985-1995) no change in the channel was recorded, however in the 2nd study period spanning 20 years (1985-2005) and 3rd study period spanning 30 years (1985-2015) a 3% rate of erosion at approximately 1m/year and a 12% rate of erosion at 2m/per respectively was observed (Table 6). The impact of the change in land cover and an increase in the use of land surrounding the River Nun plays into the susceptibility of the area to erosion as an increase in settlements and infrastructure is observed during the study period. The character of water is known to be changing worldwide and there has been growing concern as to the direction and effects of these changes on settlement, infrastructures and the environment (Adejuwon, 2011) as illustrated in results established in this work, erosion is on the rise within the study area.

TABLE 5 Summary table showing average channel width change and average percentage change of River Nun in 10 years (1985-1995, 1995-2005, 2005-2015), 20 years (1985-2005) and 30 years (1985-2015) intervals. (Negative values indicate erosion).

River Nun	1985-2015	1985-2005	1985-1995	1995-2005	2005-2015
Average change (m)	-58.5	-13.8	0.0	-13.9	-44.7
% change	12.0	3.0	0.0	3.0	9.0

TABLE 6 Summary table showing average migration rate of River Nun in 10 years (1985-1995), 20 years (1985-2005) and 30 years (1985-2015). (Negative values indicate erosion).

SEGMENT	MIGRATION RATE m/year		
	1985-1995	1985-2005	1985-2015

A	-1.3	-6.8	-8.2
B	-0.6	-0.2	0.5
C	-0.4	0.2	-1.3
D	0.6	0.5	-1.2
E	1.4	2.2	0.0
AVERAGE	0	-0.8	-2.0

A notable finding of the present study was that despite certain sections of the channel displaying straightening which can be attributed to the effects of flooding (Mitra et al. 2005; Mount 1995), an overall increase in sinuosity value coupled with an increase in the channel length is observed. The analysis revealed an overall 1% net increase in the channel length over the 30year assessment period with all the individual assessment periods showing a <0.5% increase in channel length. This meager positive change in length and sinuosity could be interpreted as an attempt of the channel to revert the negative effects the constant floods have exerted on it. The sinuosity increases and a corresponding increase in channel length show that there is a direct relationship existing between the two parameters as seen in Lazarus et al, 2013.

The analysis distinctly revealed the general eastward movement of the channel during the assessment periods between 1985-2015 with the upper reaches of the channel moving towards the west in 1985-1995 However, the upper reach of the channel is observed to be swinging back towards the east in the last assessment period. Generally, the upper and lower reaches of the channel is migrating eastwards whereas, the upper mid-section is observed to move westwards during the combined 30year assessment period. This multidirectional shifting behavior is common in rivers within tropic regions like the Ganga (Dhari et al 2014) and is attributed to the varied weaknesses of the channel banks at different sections of the channel. As the East bank of the Nun succumbs to erosion since it is observed to be more unstable than the west bank, the overall migration trend of the river channel is seen to be shifting eastward; this puts all flood protection structures on the east bank under high flood risk..

5. CONCLUSIONS

The present study amply indicates that the River Nun has undergone changes in 30 years between 1985 and 2015 and that its equilibrium is being disturbed continuously. The significant changes correspond to increased instability in terms of increased channel length (1%), increased sinuosity (1%), and multidirectional migrations. The River Nun has migrated generally toward the east with its east bankline being more unstable although large negative shifts of the western bankline were also observed in certain segments of the channel. The maximum channel shift observed was approximately 133 m in the eastern bankline over the 30-year assessment period. The river Nun channel has experienced altered dynamics making the future of habitats and environment within the Niger Delta precarious and thus causing huge economic losses. Extensive deforestation and exploration activities since the 1960s in the catchment area are presumed to have severely disturbed the equilibrium of the River Nun. Floodplain management plan is the need of the hour for the Niger Delta Basin which could guarantee the conservation of the river and adjacent ecologically important habitats while minimizing risk to the inhabitants and supporting the sustainable development of the floodplain.

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