Research Article

A remote sensing-based evaluation of channel morphological characteristics of part of lower river Niger, Nigeria

M. O. Ibitoye[1]

Received: 1 May 2020 / Accepted: 14 January 2021 / Published online: 17 February 2021

Abstract
River bank erosion, accretion and lateral channel migration are important geomorphological processes, which attract a great deal of attention of river engineering scientists in many parts of the world. The present study assesses the morphological characteristics of parts of the lower section of River Niger, where field data are scarce and difficult to access for security and cost implications. Multi-date (1990, 2002 and 2017) Landsat imageries were used for the study, the imageries were corrected for geometric and radiometric errors, classified and analysed for changes in major land cover classes within the river channel, to assess river planform, riverbank pattern, channel width, bankline migration and centreline using ArcGIS software. The results revealed a decrease in water body and riparian vegetation by 27.64% and 9.77%, respectively, between 1990 and 2017. Sediment yield, however, increased by 75.61%. In addition, the river channel exhibited significant spatial changes within the study period; centreline at left flange shifted eastwards by about 1347.3 m at the upper section but westward at the lower section by 123.1 m. The bankline shifted prominently eastwards at right flange and westwards at the right flange. The study concluded that the studied channel had actually undergone some critical morphological changes greatly affected by erosion and accretion processes that are easily captured with remote sensed imageries.

Keywords Remote sensing · Niger River · Morphology · Channel planform · Bankline

1 Introduction

River morphology refers to the field of science that deals with changes of river planform and cross section due to sedimentation and erosion processes [1–3]. Every river channel has its own unique characteristics, but variation in river channel morphology is a result of an expansive range of hydrological conditions, sediment characteristics and geologic histories of the river [4]. The continuous fluvial processes of erosion and sedimentation patterns have reportedly reduced the capacity of river to contain incoming flow from the upstream, under different conditions [3, 5, 6]. Consequently, sedimentation and degradation are enhanced in river beds causing alteration and instability in river channel system [4, 5]. Changes in river channel may be slow and progressive or rapid in a sense of geologic time, due to natural and anthropogenic influences [7, 8]. Given increasing human activity affecting river basins, at global scale, studies of channel morphology have interested relevant spatial scientists [8–10]. Urbanization, grazing and faming activities have impacted severely on river basins, causing instability in river channels, and consequently threatening livelihoods within river basins [7–11].

Over the years, the downstream morphology of River Niger has been a subject of great concern to environmentalists and vulnerable residents in the basin. River Niger plays an important role in water transportation, supply, and it is a backbone for wet and dry season faming in the

✉ M. O. Ibitoye, moibitoye@futa.edu.ng; geomattim@gmail.com | [1]Department of Remote Sensing and Geoscience Information System (GIS), Federal University of Technology, Akure, Nigeria.

SN Applied Sciences (2021) 3:340 | https://doi.org/10.1007/s42452-021-04215-1

area [12]. The Niger River basin is so important that the Nigerian government in 1999 under the Petroleum Trust Fund directed an Ecological endowment for the dredging of 573 km distance (00 m width by 2.5 m depth) of its lower section, while a number of inland ports (such as Idah, Lokoja, Baro and Onitsha) along the river bank were targeted for improvement [13]. The river channel has been severely impacted by sedimentation, which has reduced its carrying capacity and created many channel planforms.

Morphological analysis of river streams is required for planning purposes for both disaster preventive and predictive measures, including ensuring navigation safety and appropriate allocation of intake structures and scour calculations at bridges. It also plays an important role in the basin delineation and planning for sustainable management [14]. In the field of fluvial geomorphology, river channels are typically studied with measurements of widths and water volume, both variables that are dynamic (vary temporally) but which are difficult to measure without appropriate field and safety equipment [1, 4]. On the other hand, the study area (River Niger channel) being an important component of the drainage system in Nigeria and West Africa [4, 12, 15] deserves studying in some details to enhance river basin management in the region. There is, however, little or no coordinated study of the morphological characteristics of River Niger and many other rivers in Nigeria, except those of Jeje and Ikeazota [16], and Fashae and Faniran [4] on Ekulu and Ogun rivers in East and Western Nigeria, respectively. These studies are too few, and their conclusions may not be generalized to a larger river like Niger, whose influence is beyond Nigeria, since it flows through some other West African countries. In addition, given the improvement in computer and spatial systems that has resonated the importance of remote sensing as a sound complement in environmental analysis, the present study is privileged over the previous studies that have involved a limited use of the technology in their studies. Also, there have been cases of persistent flood with severe impact on communities around the Niger basin, and a study as this will provide decision-support information for environmental planning in the area.

The use of remote sensing-based decision-support information is an improvement over the essentially localized and strictly equipment-based assessment of river channel conditions [17, 18]. Remote sensing and geographical information system (GIS) are evolving in Nigeria and other African countries, and they have been found to be very useful for hydrological and geomorphological studies [8, 19, 20]. Several authors including [3, 8, 21–23] have applied the techniques in parts of River Nile, Qingjiang River basin in China, Brahmaputra–Jamuna River, Bangladesh, and in many other countries of the world, the techniques found to be reliable and capable to providing improved information for planning purpose. Application of the techniques in this study will therefore project a template for more studies, especially given the fact that the imageries are mostly free and accessible to most researchers, and that software for geographical information analysis are available in both proprietary (e.g. ArcGIS, IDRIS and MATLAB) and open-source (e.g. QGIS and Scilab) types. Consequently, specific objectives of this study are to evaluate selected morphological characteristics of part of lower Niger River from multi-date satellite imageries. Results from the study will provide decision-support information to relevant governmental and non-governmental agencies as well as relevant individuals that are concerned with blue economy development agenda of the United Nations Sustainable Development Goals (SDG 14) [24, 25].

2 Study area

River Niger is the third longest river in Africa, after the Nile and the Congo [26], covering 4,180 km. The river flows from its origin in the Fouta Djallon highlands in Guinea through Mali, Niger, Benin Republic before reaching Nigeria [27]. The portion earmarked for the study is the lower part of the river, below the confluence of rivers Niger and Benue where erosion and deposition processes are obvious and regarded as problem in terms of flooding occurrence and inability to serve as an economic hub of the government and local communities along the river channel. The study area covers a distance of about 11.5 km (Fig. 1). This portion of the river channel forms the boundary between Ajaokuta and Ofu Local Government Areas, Kogi State. Major towns and villages around the channel are Ajaokuta town, Okene, Egayin Ogwoawo, Gbake and Okpo and Okokenvi villages located at the left and right of the river bank, respectively. The river is a major source of economic activities for inhabitants across the river banks and a natural habitat for aquatic animals. River Niger is a source of water for irrigation, and water supply, power production for both industrial and community uses and water transportation; it also has many fishing points for surrounding communities.

3 Materials and methods

Secondary data such as multi-temporal Landsat imageries of 30 m resolution obtained from the United States Geological Survey (USGS) Agency (https://www.usgs.gov/) were used. The data which include Landsat 5 TM (1990), Landsat 7 ETM + (2002) and Landsat 8 (OLI) (2017) were images corresponding to the dry season of the year (January and December). The dry season image data for

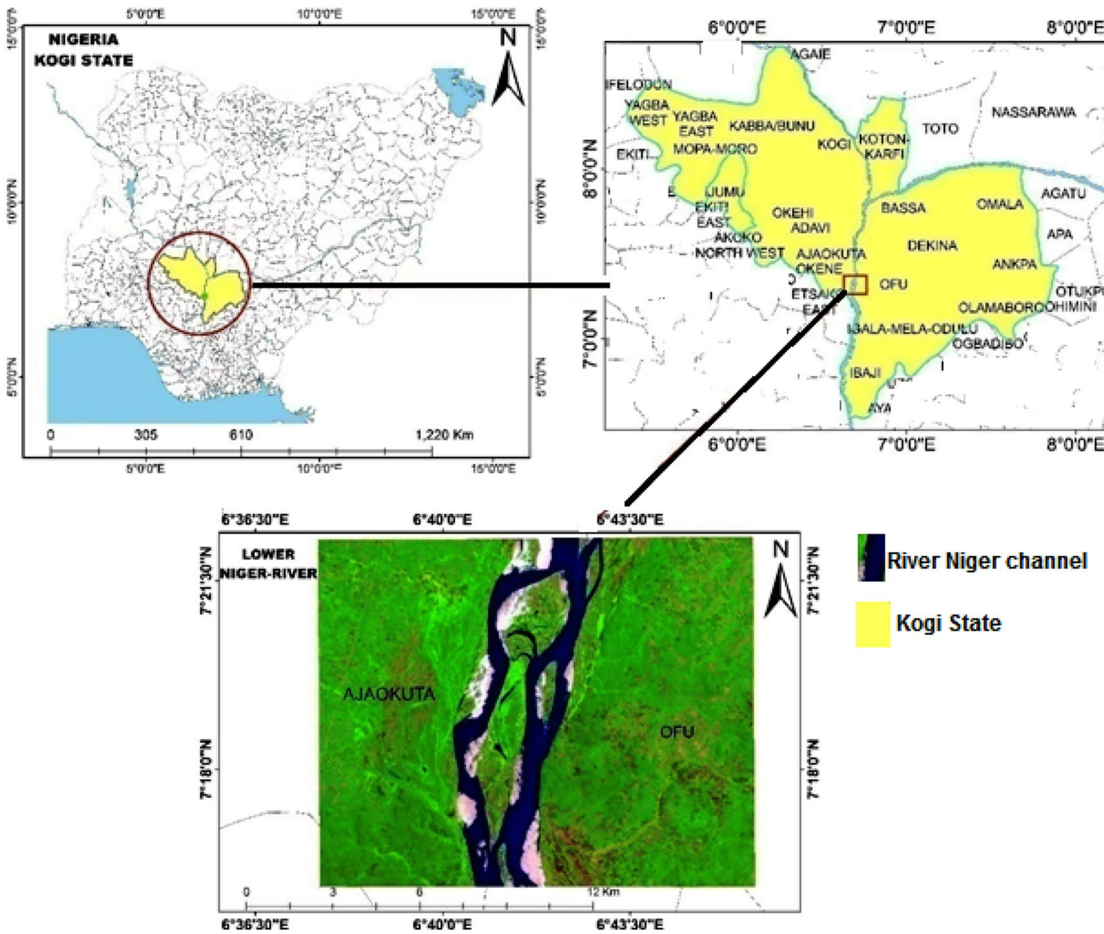

Fig. 1 Map of the study area

Table 1 Description of the secondary data used

Image	Resolution	Date of acquisition	K/J scene path/row
Landsat 5	30 m	01/01/1990	189/55
Landsat7 ETM+	30 m	12/01/2002	189/55
Landsat 8 OLI	30 m	12/12/2017	189/55
Administrative map	–	2017	–

the three years (1990, 2002 and 2017) were adopted as a result of the assurance that such data will be free of cloud cover and also to avoid seasonal variations of topographic details such as vegetation cover and land use cover. In addition, the Nigeria administrative map of Scale 1:5,000,000 was used to extract a shape file for the study area (Table 1).

Landsat imageries were downloaded from the archive of the United State Geological Survey (USGS.gov), while the administrative map was obtained from the office of the Surveyor-General of the Federation of Nigeria.

3.1 Image processing and classification

The Landsat images used for the research were restricted to study area only and in that instance; the image files were reduced and extraneous data in the file were not only eliminated, but speeds up processing due to the smaller amount of data to process. Band combinations adopted for the false composite images were 5, 4 and 3 and were used in the identification of the features of interest. The choice of these combinations was as a result of the importance of bands 4 and 3 in the definition of the land/water interface and in differentiating vegetation.

The images were projected to Universal Traverse Mercator (UTM) coordinate system Zone 31 N using World Geodetic System (WGS) 1984 datum for uniformity and to correct for radiometric and geometric errors with the view of bringing the location of element on the images to ground equivalence. The corrections were conducted using calibration tool and Fast Line-of-Sight Atmospheric Analysis of Hypercubes (FLAASH) algorithm in ENVI 5.1 software environment [28, 29] and also were the original digital number (DN) of the raw Landsat images were converted to top-of-atmosphere reflectance values. Through image visual interpretation and ground-truthing approaches, different land use/land cover types were identified. Forty (40) training sample sites were selected from each land use and classified to produce land use/land cover maps for the study periods using supervised classification approach in the maximum likelihood classification algorithm, where land coverage is classified into areas of similar spectral characteristics for the study period [8]. The analysis classified land use/land cover in the study area into four broad groups, namely sedimentation, vegetation (riparian), bare surface and water body. A confusion matrix analysis was carried out on all the images used to assess the accuracy of the classification.

3.2 Morphological change detection

The change estimation technique was used to identify the change of land cover and quantify the rates and magnitudes of change. The changes among the various land use types as classified for 1990, 2002 and 2017 were identified and quantified based on the spectral characteristics and was estimated on annual basis. The extent of erosion and accretion-related changes in the channel were assessed and the phases of exchange between the related classes were deducted from the results. The persistent change in each of the land use classes was noted through the period of study.

In order to calculate the changes that have occurred in the channel width over selected years, the channel length was divided into 8 lines in E-W aligned at right angle (90°) from North to South ([8, 30]. The channel widths were measured at bankfull (bank to bank) using Cartesian coordinate method in ArcGIS where the coordinates of the right and left channel edge positions in the section lines were measured and the bankfull widths were calculated from the coordinates using basic geometry [8, 31]. The river centreline was obtained from the respective images for the study period with reference to major channel (channel exhibited a dominant flow path) [8] using an external extension on ArcGIS called the Polygon to centreline. As shown in the images (Fig. 3), two major channels formed dominant flow path, (referred to in this study as left and right flange centreline). The given images were automatically converted from raster format to polygon using raster to polygon algorithm in ArcGIS to enable the delineation of the midpoint from top to bottom of the river channel. The water surface was extracted from the classified image and converted from raster to polygon using raster to polygon conversion tool in ArcGIS. Reason for converting to polygon was that the "Polygon to centreline" only recognizes a shape file to produce the centrelines which were either right or left flange of the river channel. After delineation of the centrelines, they were digitized on screen manually to produce maps of the centrelines both right and left flanges of the river channel. The distances of channel migration between the centreline of two consecutive years (1990–2002; 2002–2017) were calculated using $Dm = T1 - T2$; where Dm is the distance of channel migration, and T1 and T2 are the time period of the successive channel migration [32].

The occurrence of erosion along the channel bankline was estimated from the coordinates of each section of the bankline on the images and compared with bankline migration positions in the three images covering the study period (1990, 2002 and 2017) [33]. In the same vein, lengths of deposition along the bankline were estimated from the coordinates of the positions of the bankline. When the shifting of the channel is negative value, it indicates that the shifting is due to erosion and when the value is positive, it indicates a shifting due to deposition [20, 23]. The schematic diagram of the method used for this study is presented in Fig. 2.

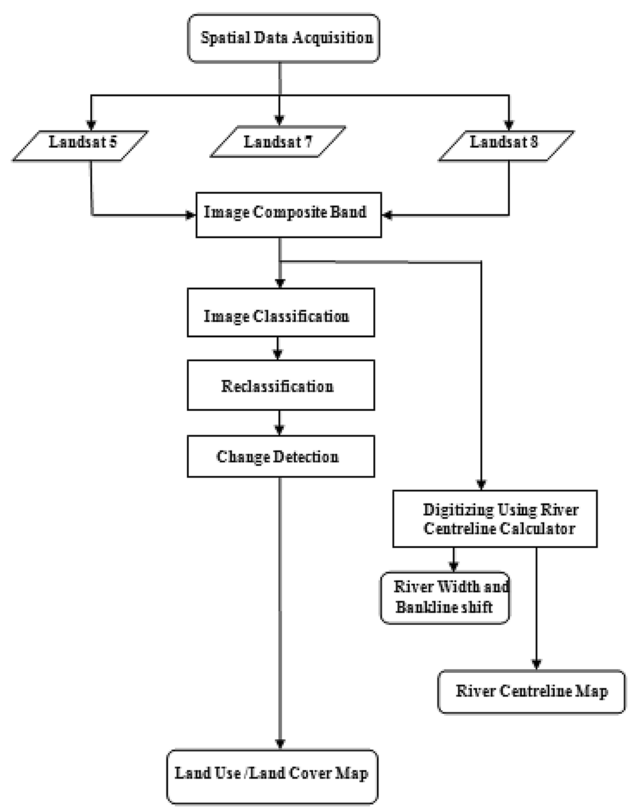

Fig. 2 Procedure for analysis of the image data

4 Results and discussion

4.1 Spatio-Temporal pattern of land cover between 1990 and 2017

The results of land cover analysis of the channel are presented in Table 2. As shown in Table 2, four (4) land cover types were identified, namely bare surface, sediment, vegetation (riparian) and water body. In the table, water body takes the largest proportion of the channel with a total area of 21.71 km^2 (62.49%) in 1990, while in 2002 and 2017, the proportion reduced to 16.15 km^2 (46.58%) and 15.71 km^2 (42.66%), respectively. There was considerable decrease of 5.56 km^2 in the water body between 1990 and 2002 and a further decrease of 0.44 km^2 between 2002 and 2017. The total loss of water body to other categories of land (channel) cover was 6.0 km^2 which translated to the annual decrease of 0.2 km^2 /year. The riparian vegetation occupied 8.19 km^2 (23.57%) in 1990 and decreased to 7.03 km^2 (20.28%) in 2002 but increased to 7.39 km^2 (20.07%) in 2017. However, notwithstanding the increase (0.36 km^2) observed between 2002 and 2017, there was an overall decrease of 0.8 km^2 (1990 and 2017) which translated to an annual decrease of 0.03 km^2/year.

In 1990, the sediment occupied 4.68 km^2 (13.48%) but increased drastically to 7.89 km^2 (22.76%) and 8.22 km^2 (22.32%) in 2002 and 2017, respectively. Between 1990 and 2002, the increase was 3.21 km^2 (0.267 km^2/year), while between 2002 and 2017 there was an increase of 0.331 km^2 (0.02 km^2/year). The overall increase (1990–2017) was 3.54 km^2 (0.13 km^2/year). The bare surface cover had a total area of 0.16 km^2 (0.46%) in 1990 but astronomically increased to 3.60 km^2 (10.38%) in 2002 and 5.50 km^2 (14.94%) in 2017. This pattern shows that in the space of 27 years, the bare surface has an overall increase of 5.34 km^2 (0.2 km^2/year) about 33 times the value in 1990.

The land cover pattern observed in the study channel as shown in Table 2 revealed that the increase in the proportion of the bare surface and sediment land cover in all the years (1990–2002, 2002–2017) accounted for the decrease observed in the water body in the same years. The changes observed in this period are not unexpected as similar studies by Ashrafi, et al. [23], Mahammad et al. [8] confirmed a decrease in water body as a result of increase in deposition within a channel reach. In addition, the huge deposition at the middle of the channel indicated a greater degree of obstruction to flow path of the river (Fig. 3), thus, diverted river flow sideways that resulted to river bank erosion in the adjourning land/flood plain as observed by Takagi et al. [30] and Mohammad, et al., [8]. Though with marginal decrease, the riparian vegetation particularly those within the channel reach (Fig. 3) not only encouraged high rate of sedimentation but served as a break to water flow and thus hold back the particles (sediments) to a place and encouraged the stabilization of the sediment [8]. In addition, the high rate of deposition in the study area may be attributed to the aftermath of large floods that occurred in the lower section of river Niger in 2012 where greater portion of the channel were left with huge sediments after a flooding occurrence [34]. The large portion of mid-channel bar cum riparian vegetation no doubt obstructed the flow path which consequently diverted sideways, thus leading to increase in bank erosion and widening of the channel corridor (Fig. 3). Generally, the development of riparian vegetation in this study may be a result of the nutrients and seeds deposited along with the sediments that supported the growth of plants and trees in the study channel. This lends credence to the observation made by Mahendra et al. [35] that carried out a similar study along the Kuzuryu River, Japan, and reported a strong interaction between ecological dynamics of riparian areas and sediment transportation in river systems. Thus, confirmed sediment as one of the major factors that contributed to the channel dynamics and pattern changes in the study area [36].

The changes observed in the bare surface land cover in the study area, 0.46%, 10.38% and 14.94% in the three years period (1990–2017), predominantly fell within the riparian vegetation land cover. This suggests human activities responsible for the removal of the vegetation

Table 2 Land Cover types of the study area

Class	Area (Km^2)			Diff (Km^2)		Changes per km^2/year
	1990	2002	2017	1990–2002	2002–2017	1990–2017
Bare surface	0.16 (0.46%)	3.60 (10.38%)	5.50 (14.94%)	3.44	1.90	5.34 (0.2 km^2/y)
Sediment	4.68 (13.48%)	7.89 (22.76%)	8.22 (22.32%)	3.21	0.33	3.54 (0.13km2/y)
Vegetation	8.19 (23.57%)	7.03 (20.28%)	7.39 (20.07%)	−1.16	0.36	−0.80 (0.03km^2/y)
Water Body	21.71 (62.49%)	16.15 (46.58%)	15.71 (42.66%)	−5.56	−0.44	−6.00 (0.2 km^2/y)
	34.74 (100%)	34.67 (100%)	36.82 (100%)			

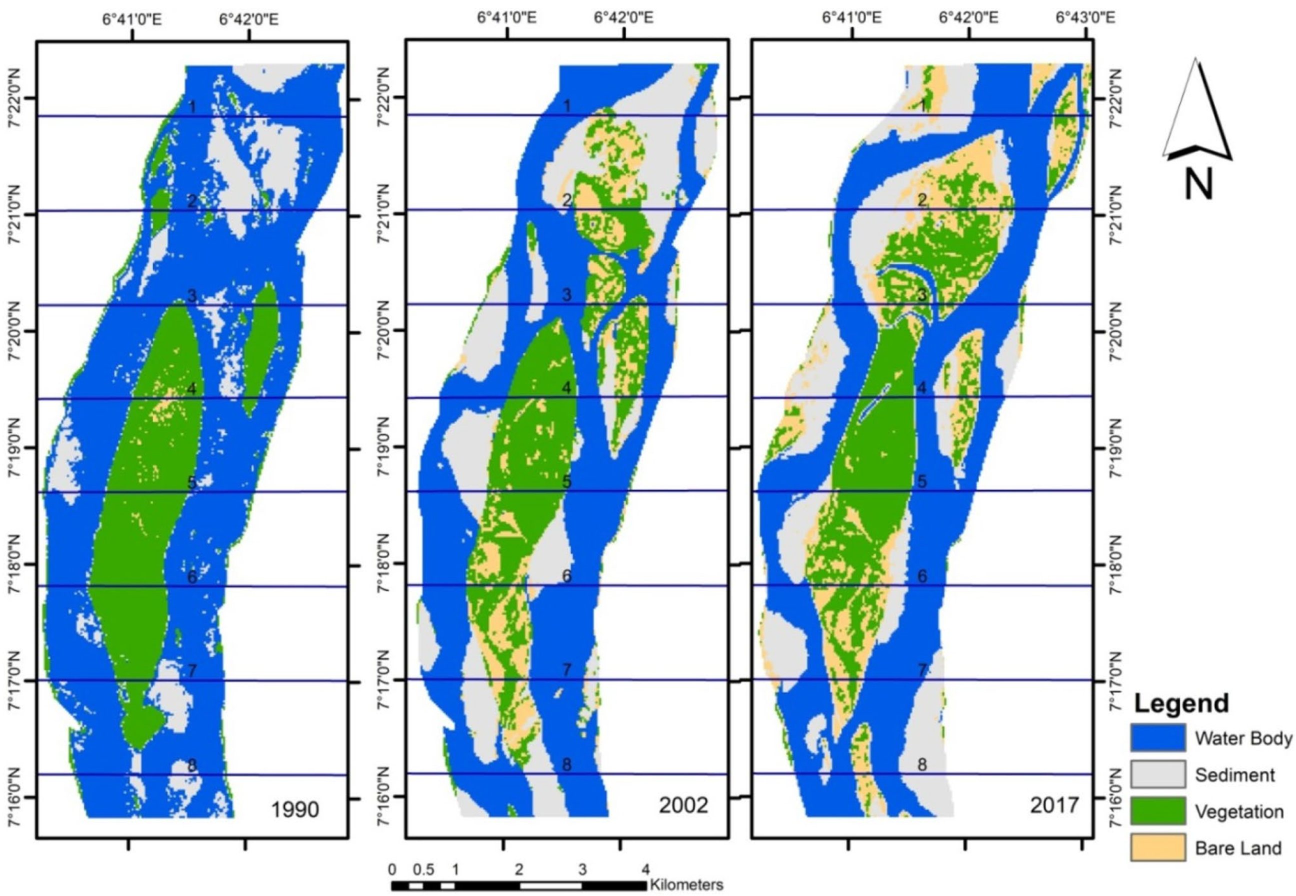

Fig. 3 Land cover classification over the study period

for farming activities bearing in mind that this section was the most fertile portion of the channel [37]. Dillaha et al. [37] reported that worldwide, agriculture is probably the largest contributor to the decline of riparian quality and functioning. He concluded that some of the most fertile soils are often located in riparian areas and that the areas also provide a convenient source of water for irrigation of adjacent cropland. The reliability of the classification of the four land use types is shown in Table 3 and the result showed a strong agreement between the classified images and the ground truth for the three years period (1991, 2002 and 2017) with overall accuracy values ranged between 92.5 and 97.5, while overall Kappa values ranged between 0.90 and 0.97. The result further explained that the ground-truthing and land use type selection was carefully done.

Table 3 Accuracy assessment of images used for land use/land cover classification in the study area

Accuracy assessment						
Land use/land cover	1990		2002		2017	
	Producer	User	Producer	User	Producer	User
Vegetation	100	91	90	90	100	100
Water body	90	82	100	100	100	91
Sediment	100	90	100	91	100	100
Bare surface	80	100	90	100	90	100
Overall accuracy	92.5		95		97.5	
Overall Kappa	0.90		0.93		0.97	

4.2 Channel bankline migration between 1990 and 2017

The evidence of lateral migration of river bank positions for the left and right flanges is shown in Tables 4 and 5, respectively. As revealed in the tables (Tables 4 and 5), there was considerable migration in the channel as evident in the shift observed at the bankline on both flanges of the channel. For instance, in Table 4, between 1990 and 2002, the left flange (east) of the channel was dominated with a eastwards shift in the bankline ranged from 6 m (point 6) to 128 m (point1), with a total distance shift of 315.25 m, while only point 3 shifted westwards by 382.5 m. Between 2002 and 2017, the left flange (east) of the channel also exhibited shift in both directions. For instance, a westwards shift ranged from 0.01 m (point 6) to1348m (point 1) with a total distance shift of 2636.8 m, while the eastwards shift ranged from 0.01 m (point 8) and 360 m (point 2) with total distance shift of 809.1 m.

Similarly, at the right flange (west) of the channel, considerable shift to either westwards or eastwards was observed (Table 5). From Table 5, between 1990 and 2002, there was a prominent westwards shift ranged from 20.9 to 378.1 m with a total distance shift of 707.57 m. All the other points at the right flange for the year (1990–2002) exhibited eastwards shift ranged from 9.0 to 248.9 m, with a total distance shift of 428.1 m. Between 2002 and 2017, there were minimal eastwards shifts but with a very high value of 689.3 m at the lower section of the channel, specifically, at point 8. It is also worth to mention that there was stability at points 1 and 2 sections of the bankline. Studies (e.g. [20, 23, 38]) observed that the negative values depict a shift due to

Table 4 Positional coordinates of section of the bankline points along the left flange (east) of the study channel in 1990–2017

Sect	Northings (m)	Eastings (m)			Difference in lateral shift (m)/annual migration rate		
		1990	2002	2017	1990–2002	2002–2017	1990–2017
1	814,669.051	244,916.036	244,788.025	246,136.373	128.011 (10.67)	−1348.348 (−89.89)	−1220.337 (−45.20)
2	813,176.959	244,436.029	244,368.503	244,008.932	67.526 (5.63)	359.571 (23.97)	427.097 (15.82)
3	811,677.474	243,896.077	244,278.657	243,949.002	−382.580 (−31.88)	329.655 (21.98)	−52.925 (−1.96)
4	810,195.881	243,206.030	243,169.939	243,978.967	36.091 (3.01)	−809.028 (−53.94)	−772.937 (−28.63)
5	808,712.398	242,906.012	242,870.301	242,750.439	35.711 (2.98)	119.862 (7.99)	155.573 (5.76)
6	807,234.678	242,936.035	242,930.256	242,930.264	5.779 (0.48)	−0.008 (−0.00)	5.771 (0.21)
7	805,743.073	242,966.021	242,930.230	243,409.649	35.791 (2.98)	−479.419 (−39.95)	−443.628 (−16.43)
8	804,250.533	243,386.034	243,379.693	243,379.685	6.341 (0.53)	0.008 (0.00)	6.349 (0.24)
				Westwards shift (−ve)	∑=382.58	∑=2636.803	∑=2489.827
				Eastwards shift (+ve)	∑=315.25	∑=809.096	∑=594.70

The negative value indicates westward direction of shift; positive value indicates eastward direction of shift. Values in bracket are lateral shift per year

Table 5 Positional coordinates of section of the bankline points along the right flange (west) of the study channel in 1990–2017

Sect	Northings (m)	Eastings (m)			Difference in lateral shift (m)/annual migration rate		
		1990	2002	2017	1990–2002	2002–2017	1990–2017
1	814,669.051	247,556.060	247,934.201	247,934.166	−378.141 (−31.5)	0.035 (0.002)	−378.106 (−14.0)
2	813,176.959	247,166.045	247,364.906	247,364.899	−198.861 (−16.57)	0.007 (0.00)	−198.854 (−7.36)
3	811,677.474	246,956.033	246,795.590	246,885.279	160.443 (13.37)	−89.689 (−5.98)	70.754 (2.62)
4	810,195.881	246,656.000	246,765.627	246,675.726	−109.627 (−9.14)	89.901 (5.99)	−19.726 (−0.73)
5	808,712.398	246,176.000	246,166.286	246,256.236	9.714 (.081)	−89.950 (−5.99)	−80.236 (−2.97)
6	807,234.678	245,725.838	245,716.835	245,746.850	9.003 (0.081)	−30.015 (−2.00)	−21.012 (−0.78)
7	805,743.073	245,726.020	245,477.107	245,417.245	248.913 (20.74)	59.862 (3.99)	308.775 (11.44)
8	804,250.533	245,695.935	245,716.877	245,027.628	−20.942 (−1.75)	689.259 (45.95)	668.317 (24.75)
				Westwards shift (−v)	∑=707.571	∑=209.654	∑=697.934
				Eastwards shift (+v)	∑=428.073	∑=839.064	∑=1047.846

The negative value indicates westward direction of shift; positive value indicates eastward direction of shift. Values in bracket are lateral shift per year erosion process along the channel bankline, while the positive values indicate shifting due to deposition.

The study further revealed that erosion was more dominant along the left flange of the channel in all the time period for this study (1990–2002, 2002–2017) with the higher value of 2636.8 m recorded in the 2002–2017 time period (Table 4). At the right flange (west), erosion was dominant in the time period 1990 and 2002 with a total length of 707.6 m as compared to 428 m total length covered by deposition process. By 2002–2017 time period, erosion covered a total length of 209.6 m, while deposition covered 839 m which was about 4 times the value of erosion (Table 5). As much as the total lengths of the shift (inner or outer) along the channel were significant when compared with deposition of 32 m–640 m recorded by Mohammad, et al. [8], yet the values were far below 2678 m and 3378 m recorded as erosion and deposition, respectively, at two different sections along the right bank side of river Jamuna, Sirajganj district, Bangladesh [23]. However, the total area covered by the deposition due to eastwards shift of bankline was not determined in this study, but has no doubt contributed, no matter how negligible, to the overall percentage of sediment land cover type for the study channel. This observation thus confirmed that bank erosion is an important source of sediment yields in lowland catchments [39]. The study further confirmed observations of some scholars [8, 30, 40] that rates of bank erosion and deposition were variable depending on the position of the channel bend, sediment and vegetation characteristics of the channel. If the migration continues in this pattern for decades, there is every possibility that the river channel will eat into the surrounding floodplain.

4.3 Lateral shifting of the channel centreline 1990–2007

The lateral shifting (directional) of the centreline of the channel is shown in Table 6. As previously revealed, the study channel has dual centrelines due to effect of deposition and consequent development of riparian vegetation

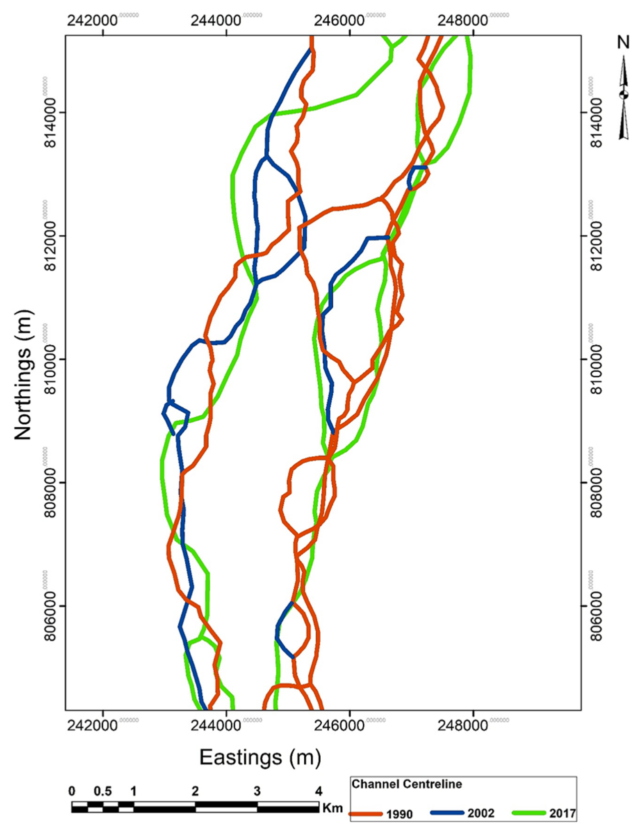

Fig. 4 Lateral shifting of the channel centreline between 1990 and 2007

Table 6 Lateral shift of the centreline of the left and right flanges of the study channel between 1990 and 2017

Sect	1990–2002				2002–2017			
	Left flange shift		Right flange shift		Left flange shift		Right flange shift	
	Dist (m)	Direction	Dist (m)	Direction	Dist (m)	Direction	Dist (m)	Direction
1	208.829	west	80.121	west	−1347.299	East	−722.098	East
2	529.38	west	−223.601	East	375.708	west	107.084	west
3	−2.912	East	56.976	west	226.146	west	123.308	west
4	250.958	west	−67.475	East	−732.898	East	89.287	west
5	452.907	west	63.479	west	129.219	west	−414.03	East
6	−110.463	East	−57.741	East	144.602	west	25.317	west
7	339.318	west	112.023	west	−387.468	East	393.595	west
8	87.577	west	151.105	west	−123.111	East	568.27	west
	Σ = 1868.969	West	Σ = 463.704	West	Σ = 875.675	West	Σ = 1306.86	West
	Σ = 113.375	East	Σ = 348.792	East	Σ = 2590.776	East	Σ = 414.03	East

that bifurcated the channel into two major water flow paths (Fig. 4). In all the time period 1990–2002 and 2002–2017, there were noticeable variations in the centreline shift. For instance, between 1990 and 2002, at the left flange of the river flow path, there was high centreline shift with a total length of 1868.969 m towards the left hand side of the river as against 113.375 m that shifted towards right of the channel. During the same period (1990–2002) at the right flange of the river flow path, migration length was prominence at the either side of the centreline with 463.704 m (left shift) and 348.792 m (right shift). By the 2002–2017 time period, the shifting pattern at the left flange of the river flow path was quite different when compared with the pervious time period (1990–2002), as there was high rate of shift with a total length of 2590.776 m towards the right hand side of the centreline as against total length of 875.675 m that shifted left of the centreline. At the right flange of the channel, a shift of 1306.861 m was recorded at left side of the centreline, while a total length of 414.03 m was recorded at the right side of the centreline (Table 6). The lateral shifting experienced in the centreline of the two river flow paths in the study area may be attributed to the erosion and accretion activities at the river banks and bends as observed by many scholars [8, 30]. These activities have a consequent effect on the positional stability of the river centreline [41]. As exhibited in Fig. 3, the study area was characterized with braided channels which occurred as a result of deposition at some river/channel bends. However, this pattern was not unexpected as the study area falls within the lower course of River Niger where geomorphological process was dominantly depositional as a result of weak in the carrying capacity of sediment load within the channel [30, 40].

4.4 The river width morphology

The temporal and spatial changes of the channel width over the study period are shown in Table 7. The temporal changes of the width along the channel reach in 1990 ranged from 2309.9 m at Sect. 8 (lower part) to 3449.97 m at Sect. 4 with a mean value of 2876.2 m. By 2002, the width had an increase ranged from 2337.184 m at Sect. 8 (lower part) to 3595.688 m at Sect. 4 with mean value of 2,902.728 m. In 2017, there was a decrease in the width ranged from 1647.943 m at Sect. 8 (lower part) to 3505.797 m at Sect. 5 with mean value of 2595.59 m. The result of the temporal width changes revealed very minimal change in all the years similar to the observation of Takagi, et al. [30] on the braided-belt channel width of Brahmaputra River, Bangladesh. However, there are significant spatial changes observed at each section of the channel reach in 1990–2002 and 2002–2017 time periods. For instance, between 1990 and 2002, there was consistent increase in the channel widths, though varied in distances along the river reach (26 m –506.2 m), except at Sect. 3 that a decrease of 543.0 m was observed (Fig. 5). Between 2002 and 2017, channel widths increased significantly in some sections, i.e. Sects. 2, 3 and 5, while the channel widths at Sects. 1,4, 7 and 8 exhibited significant decrease ranged from 539.3 to 1348.4 m, along the channel reach (Fig. 5). Considering the time period 1990 and 2017, the channel widths exhibited significant increase at Sect. 2 (625.9 m) and Sect. 5 (235.8 m), while Sects. 1,4, 7 and 8 exhibited significant decrease ranged from 123.7 m at Sect. 3 to 842.2 m at Sect. 1of the channel reach. Specifically as shown in Fig. 4, in 1990–2002 time period, the width exhibited though with varied length, increase at Sects. 1,2,4 and 7 but exhibited notable decrease in length at Sect. 3. In 2002–2017 and 1990–2017 time periods, there was prominent decrease in width length at Sects. 1,4, 7 and 8, while positive length increase was observed at Sects. 2 and 3.

Considering the morphological and land cover observed in the study, the channel revealed some impacts of human activities as well as climate change and overall degradation, thus confirmed that the river was not in its natural state. The implication of increased sediment both

Table 7 River widths at various sections along the channel in 1990, 2002 and 2017

sections	Channel widths (m)			Diff. in channel widths (m)		
	1990	2002	2017	1990–2002	2002–2017	1990–2017
1	2640.009	3146.176	1797.793	506.167	−1348.383	−842.216
2	2730.016	2996.403	3355.967	266.387	359.564	625.951
3	3059.956	2516.933	2936.277	−543.026	419.344	−123.682
4	3449.970	3595.688	2696.759	145.718	−896.929	−753.211
5	3269.988	3295.985	3505.797	25.997	209.812	235.809
6	2789.803	2786.579	2816.586	−3.224	30.007	26.783
7	2759.999	2546.877	2007.596	213.122	−539.281	−752.403
8	2309.901	2337.184	1647.943	27.283	−689.241	−661.958
Σ	23,009.645	23,221.825	20,764.718			
Mean	2876.205	2902.728	2595.590			

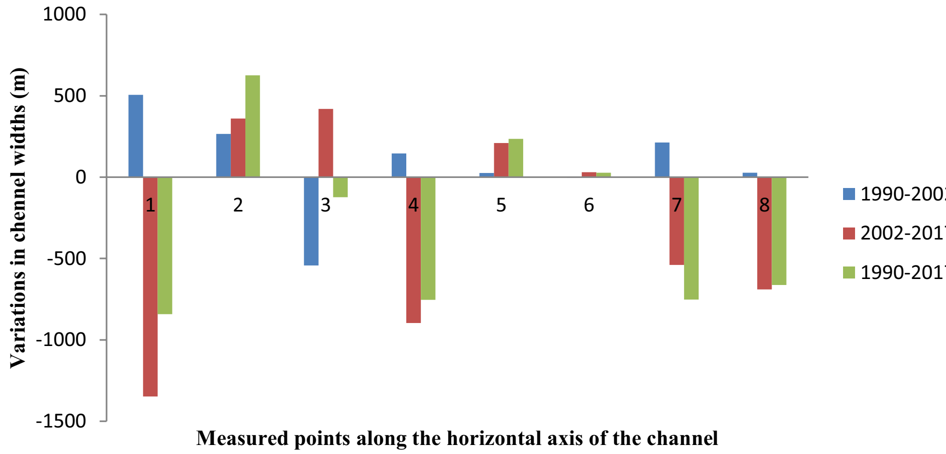

Fig. 5 Variations in channel widths between 1990 and 2017 along the measured sections

within and at the bank of the river channel will hinder the free flow of waterways transportation of goods and passengers, mostly traders, by ferry. Once sediment entered waterway, it is difficult and expensive to remove except through engineering solution. This therefore explains the reason why Federal Government committed billions of Naira (266 million US dollar) to the dredging of the lower part of river Niger few years ago. Going by the consistent reduction in the water component of the channel, most of the aquatic life such as Tilapia, Synodontis, Labeo and Cithafisnus to mention but a few, will be scarce and inaccessible to the local fishermen whose livelihood were limited to subsistent fishing similar to the observation of Solomon et al. [42] at Idah area of Kogi State, Nigeria. The lower channel of river Niger as revealed by this study did not portray a sustainable used of the channel as recommended by the United Nation in the Sustainable Development Goals 14 (SDGs 14) agenda that may eventually lead to sustainable inland waterways development and other blue economy development in Nigeria [43].

5 Conclusion

The study has revealed the morphology and land cover of lower course of river Niger in the past 27 years (1990–2017). The temporal assessment of the river morphology between 1990 and 2017 showed considerable changes in all the land cover and morphological attributes with conspicuous decrease in riparian vegetation and water body. The sediment in all the years increased greatly to the detriment of the water body. The river (channel) width also exhibited varied decrease and increase at various sections of the channel reach in all the time period. Furthermore, it was observed that the nature of the river channel centreline was not constant both at the left and right flange of the river flow paths throughout the years as the centreline shifted towards the east in the earlier years of study(1990–2002) but migrated greatly in the later years of study (2002–2017) in the westward direction.

The study further showed that remotely sensed data such as Landsat imageries which are freely available for research in developing countries like Nigeria played a prominent role in the analysis and evaluation of river channel morphology in terms of cost and time if field surveying techniques are to be used. In addition, remote sensing techniques clearly offer significant potential to facilitate a number of river related application for effective river management and water resource strategies. There is no doubt that the results of this study will contribute meaningfully to the strategies needed for effective river and ecosystem-based management model.

Acknowledgements The author acknowledges the contribution of Mr. N. K. Gimba of the Department of Remote Sensing and GIS, School of Earth and Mineral Science, Federal University of Technology Akure who assisted in the field work and analysis of the imageries.

Author contributions The author conceptualized and designed the research framework. He also supervised the research and wrote the manuscript.

Data availability The data used are satellite images from opened source and field observation.

Code availability ArcGIS from ESRI made available to the University was used.

Compliance with ethical standards

Conflict of interest There is no conflict of interest while carrying out this research.

References

1. Manjusree P, Satyanarayana P, Bhatt CM., Sharma SVSP, Srinivasa RG (2014) Remote sensing and GIS for river morphology studies. National Remote Sensing Centre ISRO, Department of Space, Hyderabad 1–10. https://www.researchgate.net/publication/260317105
2. Novica L, Radislav T (2016) Assessment of bank erosion, accretion and channel shifting using remote sensing and GIS: case study—Lower course of the Bosna river. Quaestiones Geographicae 35(1):81–92
3. El-sayed RM, Abdelazim MN, Ghaly S, Ali KA (2017) Morphological variation of the Nile river fourth reach. Twentieth international water technology conference, IWTC20 Hurghada, 10p. https://www.researchgate.net/publication/310327662
4. Fashae OA, Faniran A (2015) Downstream morphologic characteristics of the alluvial section of Lower river Ogun,Nigeria. J Environ Geogr 8(1–2):1–10. https://doi.org/10.1515/jengeo-2015-0001
5. Surian N (1999) Channel changes due to river regulation: the case of the Piave River, Earth surface processes and landforms. John Willy Online Library, Italy. https://doi.org/10.1002/(SICI)1096-9837(199911)24:12%3C1135::AID-ESP40%3E3.0.CO;2-F
6. Haron NA, You GQ, Sulaiman MS, Yusuf B (2017) Abood MM (2017) evaluation of river stability by morphological assessment. Infrastruct Univ Kuala Lumpur Res J 5(1):11–20
7. Ghoshal S, James LA, Singer BM, Aalto R (2010) Channel and floodplain change analysis over a 100-year period: lower Yuba river, California. Remote Sens 2:1797–1825. https://doi.org/10.3390/rs2071797
8. Mohammad AH, Bhuiyan TK, Shigeyuki S (2014) Application of remote sensing and GIS for evaluation of the recent morphological characteristics of the lower Brahmaputra-Jamuna River, Bangladesh. Springer-Verlag, Berlin Heidelberg, p 18p
9. Adediji A, Jeje LK (2004) Channel erosion in the Opa Basin, Southwestern Nigeria. J Environ Hydrol 12:1–11
10. Ibitoye MO, Aboyeji OS, Adekemi SOA (2016) Spatio-temporal analysis of landuse dynamics in upper Opa catchment. Southwestern Nigeria. Ethiop J Environ Stud Manag 9(6):780–792
11. Eludoyin AO, Adewole AO (2019) A remote sensing-based evaluation of an unguaged basin in Southwestern Nigeria. Int J River Basin Manag. https://doi.org/10.1080/15715124.2019.1640226
12. Ali AD (2013) The colonial economy in the Lower Niger Region. Arab J Bus Manag Rev (OMAN Chapter) 2(7):47–54
13. , Akegbejo-Samsons Y (2017) The inner Niger Delta Project: environmental, social and economic consequences of dredging the Lower Niger river on the Communities. 10th international river symposium and environmental flows conference, Brisbane, Australia, 2–6
14. Moussa A, ElMoustafa A (2010) Morphological changes analysis for Nile Bed at Aswan Bridge area using GIS. Ain Shams J Civ Eng (ASJCE) 2:599–610
15. Porter MD, Masson TM (2004) Analysing changes in river channel morphology using GIS for Rio Grande Silvery Minnow habitat assessment. GIS/Spatial Anal Fish Aquat Sci 505:433–446
16. Jeje LK, Ikeazota SI (2002) Effects of urbanization on channel morphology: the case of Ekulu River in Enugu, Southeastern Nigeria. Singap J Trop Geogr 23(1):37–51
17. Thornton E, Neave M, Rayburg, S (2007) Hydraulic geometry in river channel networks as a method for the assessment of river condition. Proceedings of the 5th Australian stream management conference. Australian rivers: making a difference. Charles Sturt University, Thurgoona, New South Wales, pp. 401–406
18. Fuller I (2007) River and channel morphology: technical report prepared for horizons regional council, measuring and monitoring channel morphology. Messy University, New Zealand
19. Treitz PM, Howwarth PJ, Gong P (1992) Application of satellite and GIS technologies for land-cover and land-used mapping at the rural fringe: a case study. Photogramm Eng Remote Sens 58:439–448
20. Longoni L, Papini M, Brambilla D, Barazzetti L, Roncoroni F, Scaioni M et al (2016) Monitoring riverbank erosion in mountain catchments using terrestrial laser scanning. Remote Sens 8:241. https://doi.org/10.3390/rs8030241
21. Du Z, Linghu B, Ling F, Li W, Tian W, Wang H et al (2012) Estimating surface water area changes using time-series Landsat data in the Qingjiang River Basin, China. J Appl Remote Sens 6(1):063609–063609
22. Negm A, Elsahabi M, El-Sayed R, El-Basset NA, Ghaly S, Ali K (2016) Morphological variation of the Nile River first and second reaches using RS/GIS techniques. Nile River Hdb Env Chem. https://doi.org/10.1007/698_2016_126,©SpringerInternationalPublishingAG
23. Ashrafi TJ, Sikdar MS, Islam MK (2018) River change detection and bank erosion identification using topographical and remote sensing data. 4th international conference on advances in civil engineering, 19–21 December CUET, Chittagong, Bangladesh
24. World Bank (2016) Blue Economy development framework—Growing the Blue Economy to combat poverty and accelerate prosperity. http://pubdocs.worldbank.org/en/446441473349079068/AMCOECC-Blue-Economy-Development-Framework
25. United Nations Economic Commission for Africa (2016) Africa's Blue Economy: a policy handbook. Addis-Abba, Ethiopia
26. Mabogunje AL (2019) Niger River. Encyclopædia Britannica https://www.britannica.com/place/Niger-River/Hydrology. Last Updated: Dec 25, 2019
27. Meseko AA, Obieje DI, Karpenko O (2018) Tourism potential of the confluence between river Niger and river Benue in Nigeria: implication for project finance. J Glob Entrep Res 8(6):1–14
28. Hester DB, Cakir HI, Nelson SAC, Khorram S (2008) Per-pixel classification of high spatial resolution satellite imagery for urban land-cover mapping. Photogramm Eng Remote Sens 74:463–471
29. Lui GV, Coomes DA (2015) A comparison of novel optical remote sensing-based technologies for forest-cover/change monitoring. Remote Sens 7:2781–2807
30. Takagi T, Oguchi T, Matsumoto J, Grossma MJ, Sarker MH, Matin MA (2007) Channel braiding and stability of the Brahmaputra River, Bangladesh, since 1967: GIS and remote sensing analyses. Geomorphology 85:294–305
31. Mount NJ, Louis J, Teeuw RM, Zukowskyj PM, Stott T (2003) Estimation of error in bankfull width comparisons from temporally

sequenced raw and corrected aerial photographs. Geomorphology 56:65–77
32. Giardino JR, Lee AA (2011) Rates of channel migration on the Brazos River, Final report submitted to the Texas water development board, Texas A & M University, 8–9
33. Akhtar MP, Sharma N, Ojha CSP (2011) Braiding process and bank erosion in the Brahmaputra River. Int J Sed Res 26:431–444
34. Nwosu PC, Olayinka DN, Nwilo PC (2013) Generation of flood maps and drainage basin of Umueze Anam, Nigeria. Environment for sustainability, FIG working week, Abuja, 6–10 May, 1–15
35. Mahendra BB, Takashi A, Takeshi F, Senavirathna MDHJ, Guligena M et al (2019) Mechanism of riparian vegetation growth and sediment transport interaction in floodplain: a dynamic riparian vegetation model (DRIPVEM) approach. Water. https://doi.org/10.3390/w12010077
36. Church M, Rice SP (2009) Form and growth of bars in a wandering gravel-bed river. Earth Surf Process Landform 34:1422–1432
37. Dillaha TA, Reneau RBM, S, Lee, D, (1989) Vegetative filter strips for agricultural non-point source pollution control. Trans Am Soc Agric Eng 3:513–519
38. Hamid CHM, Ashraf M, Hamid Q, Sarwar SM, Saqib ZA (2017) Geospatial techniques for assessment of bank erosion and accretion in the Marala Alexandria reach of the River Chenab, Pakistan. Sains Malaysiana 46(3):413–420
39. Veihe A, Jensen NH, Schiøtz IG, Nielsen SL (2011) Magnitude and processes of bank erosion at a small stream in Denmark. Hydrol Process 25:1597–1613
40. Sarker MH, Thorne CR, Aktar MN, Ferdous MR (2014) Morphodynamics of the Brahmaputra-Jamuna River, Bangladesh. Geomorphology 215:45–59
41. Soar PJ, Wallerstein NP, Thorne CR (2017) Quantifying river channel stability at the basin scale. Water 9:133. https://doi.org/10.3390/w9020133
42. Solomon SG, Okomoda VT, Aladi SL (2012) Fish fauna in lower river Niger at Idah in Kogi state. J Agric Vet Sci 4:34–43
43. Elisha OD (2019) The Nigerian blue economy: prospects for economic growth and challenges. Int J Sci Res Educ 12(5):680–699