



GEOSPATIAL ASSESSMENT OF CHANNEL PLANFORM AND MIGRATION IN THE LOWER REACH OF RIVER GONGOLA, ADAMAWA STATE, NIGERIA

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Channel migration is the process by which stream channels move and shape floodplains through time. The river channel of the lower reach of River Gongola between Kiri dam and the inlet to River Benue has been subjected to channel migration since the impoundment of Kiri reservoir in 1984. In this study, temporal changes in river channel parameters such as width, area, perimeter, sinuosity and channel bars, as well as the channel migration of the lower reach of River Gongola were assessed. Landsat MSS image of 1975 (nine years before the commissioning of Kiri reservoir) and Google maps of 1975, 1984, 1989, 1999, 2009 and 2019 were acquired, processed and analyzed for the changes in channel parameters and migration in each of the six selected years. Overlay method in ArcGIS 10.5 software and appropriate formula were used to obtain the values of the channel parameters as well as that of channel migration. The result of the study reveals that all the channel parameters have been subjected to changes. The channel width was widest in 1975 when the dam was not constructed. The largest channel bars in 1989 recorded positive impact on the channel width, perimeter, length and sinuosity as all these parameters covered the highest land area in the same year. The sinuosity index ranged from 1.22 to 1.26 which fall within the "sinuous" class and hence, the channel is currently in sinuous stage. Areas covered by erosion were more prominent in the river channel than areas with deposition. The initial vertical incision before and shortly after the impoundment of the reservoir has changed to lateral erosion which leads to channel widening. It was recommended that geospatial techniques should be applied in the temporal monitoring of river channels for reliable and accurate data for monitoring of river channels.

1.0 Introduction

River channel is the physical confine of a river consisting of a bed and river banks (AEDA 2014). River channels are important in two major ways; firstly, it is the custodian of ecosystem, that is, the habitat to flora and fauna. Secondly, river channels are important to man in several ways; sources of water, food resources (animals and plants) and means of livelihood like fishing and irrigation agriculture. Despite the importance of these river channels, and due to constant interference of man through various activities, river channels are frequently modified through dam construction, irrigation, channelization/dredging and flood control strategies. River channels are subjected to land degradation due to river flow and regulations and pressure on land uses, hence, land utilization in the floodplains often leads to decreases in water quality, loss of wildlife habitats, and an increase in severity and frequency of flood losses (Shimin et al., 2016, Matylda et al., 2020). The lower reach of River Gongola between Kiri dam and the inlet to River Benue is one of the numerous river channels in Nigeria which becomes a subject of attraction for study because of the changes in the area since the impoundment of Kiri reservoir.

Kiri reservoir was constructed by the Federal Government of Nigeria (FGN) under the management of the Upper Benue River Basin Development Authority (UBRBDA). In the report of Shallangwa et al. (2014), Zira et al. (2015), the construction of Kiri reservoir started in 1976 and was completed in 1982 mainly to supply water for irrigating over 6,000 hectares of sugarcane estate of the Savannah Sugar Company Limited (SSCL) which is now known as SSCL (Dangote Groups). As far back as 1984, Olofin (1984) has argued that the construction of major dams on savanna streams would usually escalate fluvial processes on the valley side and the downstream. Tukur and Mubi (2002); Tukur et al. (2006) have carried out extensive studies of the changes in the lower reach of the Gongola River since the construction of Kiri dam. Some of their findings revealed that after the Kiri dam was constructed, the downstream flood peaks dropped from 1,420 cubic metres per second (50,000 cu ft/s) to 1,256 cubic metres per second (44,400 cu ft/s). Secondly, the flows in drier seasons increased from 5.7 cubic meters per second (200 cu ft/s) to 21 cubic meters per second (740 cu ft/s). Furthermore, the channel bank full and riverbed widths also reduced by 38.3% and 72.2% respectively while at the downstream were narrow valleys and less sinuous (winding). There were fewer separate channels and reduction in the overall channel width, concave bank erosion and emergence of vegetation in some of the reaches. Finally, natural activities like vertical and lateral erosion, flooding and deposition of debris among others also result into modifications of river channels. When river channels are modified, one of the most common outcomes is channel migration. Channel migration is the process by which stream channels move and shape floodplains over time (Shimozono et al., 2019). The rate and severity of channel migration depends on several factors such as amount and frequency of rainfall, topography, land use and vegetation cover. Channel migration is a threat on land uses by the riparian communities, infrastructure and human livelihood (Jatan et al., 2017). Other related problems include difficulty in growth and development due to constant loss of properties and cost of flood and erosion control measures (Legg and Olson, 2014). The effect of changes of the Gongola channel due to the construction of the dam on the livelihood of the inhabitants as highlighted by Igidi (2020) include loss of residential and agricultural lands to floods and reduction in fishing activities as 'sedimentation and siltation in the river have shrunk the fishing community of about 120 to just about 40 households, most of them now living in poverty'.

The temporal assessment of channel migration areas is important for monitoring the channel at different periods and for documentation of the changes and what cause such changes which can be sources of relevant data for the general management of river channels. Jatan et al. (2017) opined that channel migration is an agent of environmental change. In this study, geospatial techniques were integrated with remotely sensed and other geospatial data to assess the channel migration at the lower reach of the Gongola River channel before and after the construction of Kiri dam.

2. Materials and Methods

2.1 The Study Area

River Gongola is the largest among the right-bank tributaries to River Benue. Gongola River takes its source from Jos plateau and flows north-easternly towards River Benue through Plateau, Bauchi, Gombe and Adamawa States with an approximate distance of 602 km (Adeniyi and Adedeji, 2007). The channel of River Gongola between the Kiri dam and the confluence to River Benue constitute the study area. It lies between latitude 9° 29' and 9° 41' N and longitude 12° 01' and 12° 04' E (Fig. 1) with a total length of about 26.9 km. The four riparian LGAs to this part of the channel are Demsa, Guyuk, Numan and Shelleng. The relief of the area is generally low; ranging from 170 to 172 m above sea level (Figure. 1).

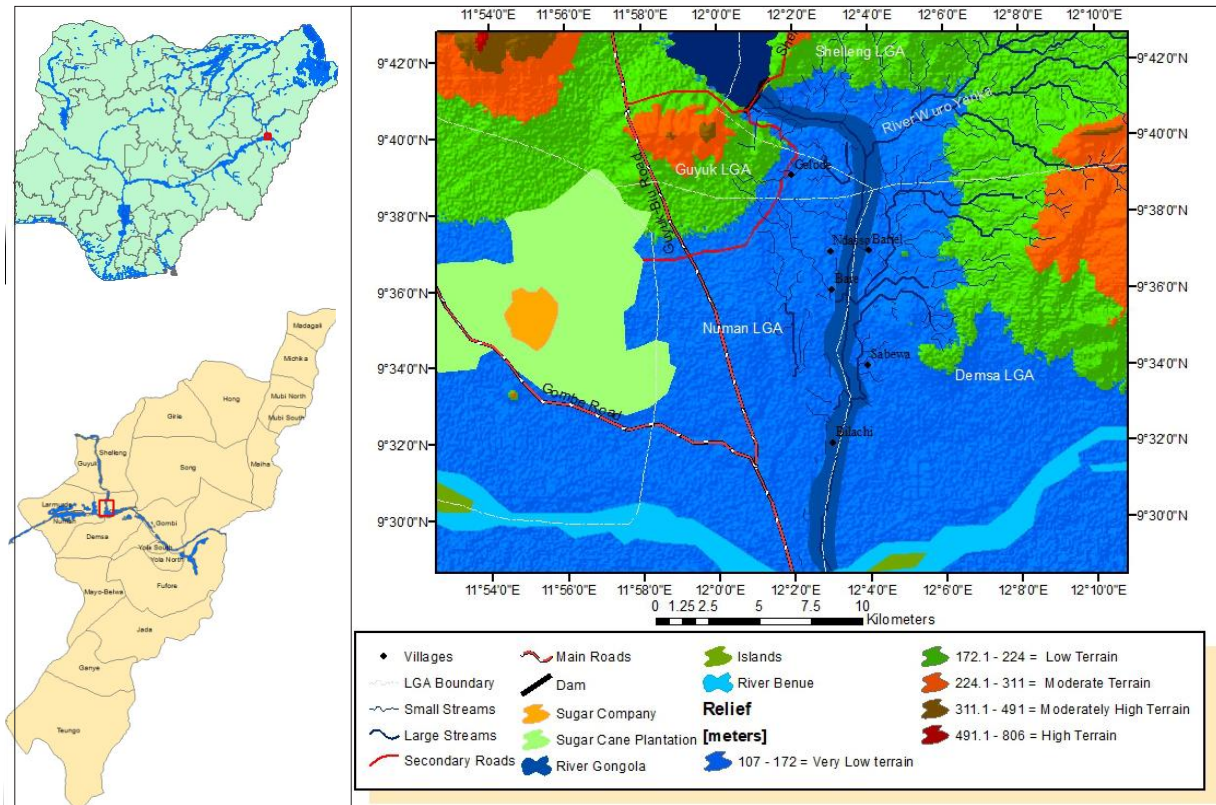


Figure 1. The Study Area

The soil of the area is mainly Gleyic Cambisols (Ray, 2020) made of loam, sandy loam, silt loam or loamy sand. The major tributary to River Gongola in the study area is River Wuro Yanka with its numerous tributaries. According to Ikusemoran (2022), mean annual rainfall of the southern part of the river channel (from the inlet of River Benue to about 9.30°N is 961.93 mm, while the northern part upwards to the outlet of Kiri reservoir (about 9.42°N) is 896.91 mm. Mean annual temperature within the area ranges to 27.29 to 29.06 °C. The study area falls in the Southern Guinea Savanna zone; characterized by shrubs, scattered trees (*Daniellia oliveri* (most abundant), *Lophira lanceolata*, *Azalia*) and tall grasses such as *Andropogon*, *Hyppathenia* and *Pennisetum*. The area has few settlements and road network due to its swampy nature. The few communities in the area are Bare, Bilachi, Gelode, Ndasso, Kapalakan, Imburu and Sabewa. Farming and fishing are the main occupation of the people in the area.

2.2. Methods

The two data sets that were used for this study are (i) Landsat MSS image of 05/12/1975 (ii) Google Earth Pro maps of December 1984, 1989, 1999, 2009 and 2019; an average of ten years. 1975 (nine years before the commissioning of the dam) was selected as the base year for the study because the earliest available Landsat image of the area was in that year. 1984 was also selected because the dam was commissioned in the year and hence the need to examine the condition of the dam from the onset. The selection of subsequent 10 year period from 1989 to 2019 was because Google Earth data of the area in the same month (December) was only available during this period. Short period of assessment (five year after the dam's impoundment) was considered because most of the changes that took place were likely to have occurred within the first five years after construction and after which stabilization of the changes might have taken place.

2.2.1 Mapping of Channel Migration

The river channel of each selected year in Google Earth map was digitized as polygon and exported to ArcGIS 10.5. The “collapse dual lines to centerline” tool of the Cartography-Generalization module of the Arc toolbox of ArcGIS 10.7.1 was used to generate the center

line or the mid channel length of the river channel. The pattern of channel migrated areas was achieved by overlay of channel migration for two-time period of study at a time, that is, 1975/1984-1984/1989, till 1999/2009-2009/2019; a total of four maps were generated. To determine the lateral migration, the centerlines of the river channels for each of the four overlaid maps were used. Each polygon of the four maps was transformed into polygon through the “feature to polygon” tool of the feature module in the data management tools of the Arc Toolbox in Arc GIS 10.7.1. The attribute tables of the four generated migration polygons, shows the eroded, deposited and the static areas. Each of the polygons was calculated using the area calculation tool of ArcGIS.

Table I. Methods of generating the channel parameters

Parameters	Description	Methods
Channel Area	The total land area of the channels in km ²	Use of area calculation module of Arctool box in ArcGIS 10.5 to calculate the generated channel of each study years
Channel Perimeter	The perimeter of the channel area	Use of perimeter calculation module of Arctool box in ArcGIS 10.5, to calculate the perimeter of the generated channel area (polygon) of each study years
Channel Length	The length of a center line that passes through middle of the channel	The center line was generated through the use of collapse lines to centerline of the cartography module of ArcGIS 10.5 on each of the study years. The length of the center line (Channel length) was derived by the use of the length calculation module of ArcGIS 10.5.
Average Channel Width (ACW)	Expressed as a ratio of the channel area to the channel length (Kou et al., 2017, Ezekiel et al., 2020)	Channel width = Ac/Lc where: Ac = Channel area, and Lc = Length of the center line (channel length) (Kou et al., 2017, Ezekiel et al., 2020).
Changes in Channel Width	The differences between the width in the initial year and that of the latter year	Subtraction of the width of latter year from the initial year
Percentage changes in Channel Width.	Percentage change in the width between an initial year and the latest year e.g 1975&1984.	Channel width of the latest year minus the width of the initial year divided by the width of the initial year multiplied by 100. Represented by formula $[ACW_2-ACW_1/ACW_1*100$ (Kenton, 2019, Ezekiel et al., 2020)
Sinuosity Index	The ratio of each stream channel and their corresponding stream channel length	It is expressed as: $SI = Ls/Lv$. Where: SI = Sinuosity Index, Ls = measured Stream length (centerline length) and Lv = valley length (straight line measurement of the entire valley) (Young et al., 2018, Ezekiel et al., 2020)
Migration Area	The area of migration polygon was derived from the center lines of two study periods when converted to polygon using ArcGIS 10.5	The area calculation module of ArcGIS was used calculate both the area and perimeter of the converted polygon in ArcGIS 10.5 environment.
Magnitudes of Migration	The total land area over which the stream has migrated within a study period	It is expressed as $A/(0.5*P)$. Where A = the area of the migrated polygon, and P is the corresponding perimeter of the area (Kenton, 2019).
Annual rate of migration	Annual rate of the channel lateral migration	This is expressed as Rt/N . Where: Rt = Magnitudes of migration and N is the number of years within the study period.

Channel Floor	The changes in the shapes of the channel floor	A line was drawn at the center line of each of the years' channels. The "show elevation profile" module of Google Earth was used to draw a longitudinal profile of each of the study years which shows the floor of the channel.
Channel Bars	Channel bars result from deposition of sediment (bed load or suspended load) in a high thawed sinuosity.	Extraction of River channel from the main River valley using GIS technique

Source: Researchers' compilation (2023)

2.2.2 Determination of other Channel Planform features

Other planform features like channel area, width, perimeter, length, average channel width, changes in channel width, percentage change of channel width, sinuosity index, migration area, magnitude of migration and annual rate of migration were determined through their respective formula as shown in Table 1. Sinuosity index table which is the standard for the determination of channel sinuosity is shown in Table 2

Table 2. Sinuosity Index table

Sinuosity Index	Channel Class
<1.05	Straight
1.05 – 1.30	Sinuuous
1.30 – 1.50	Moderate Meandering
>1.50	Meandering form

Source: Yong (2018) in Yonnana et al. (2020)

3. Results and Discussion

3.1 Changes in the channel parameters

Table 3 shows the trends in the changes of the channel parameters from 1975 to 2019. While channel width, perimeter, length, average channel width were reported in km/km², the area coverage as well as the perimeter of channel bars were measured and reported in km² and km respectively. Percentage change of channel width were in percentages.

Table 3. Changes in the channel parameters from 1975-2019.

Years	Channel Width (km ²)	Channel Perimeter (km ²)	Channel Bars (km ²)/perimeter (km)	Channel Length (km)	Average Channel Width (km)	Magnitude of Change of Channel Width (km)	Percentage Change of Channel Width (%)	Sinuosity Index
1975	17.73	82.90	2.44(18.19)	28.41	0.62	-	-	1.25
1984	11.92	86.32	2.80(22.18)	28.22	0.42	-0.02	-32.26	1.24
1989	11.82	89.59	3.11(22.61)	28.62	0.41	-0.01	-2.38	1.26
1999	13.71	79.44	2.14(16.52)	28.33	0.48	0.07	17.07	1.25
2009	19.67	65.77	0.54(5.46)	28.03	0.70	0.22	45.83	1.23
2019	18.28	67.13	0.52(6.57)	27.84	0.66	-0.04	-5.71	1.22

Source: Calculated from the generated maps using the calculation module of ArcGIS software

3.1.1 Channel's Width

Table 3 revealed that before the construction of the reservoir (1975), the width of the channel of River Gongola was wide (17.73km²). However, about 30 years after the impoundment of the reservoir, (between 1984 and 1999), the channel's width was narrower than the initial width of 1975. In the last two decades (from 2009 to 2019), the width of the channel has been widening- wider than that of 1975. This finding is in line with the work of Tukur and Mubi (2002) on the same lower reach of River Gongola that a narrow channel has replaced the large pre-dam channel due to the changes brought about by the regulation of the flow of the river channel. The increase in width at the downstream as observed in 2009, has been attributed to

the composition of the bed and bank materials of the river channel which could be linked to removal of the riparian vegetation by human activities (Fashae and Faniran, 2015). Further findings by Tukur et al. (2006) revealed that regulation of the Gongola river flow by damming has indeed affected the resilience of the downstream environment, resulting into changes in the wetlands scenario of the pre-dam periods. Negative magnitudes of changes in channel width were recorded in 1984, 1989 and 2020, while 1999 and 2009 had positive changes. The period between 1975 and 1984 recorded the highest negative percentage changes of channel width per annum, while the highest positive change per annum occurred between 1999 and 2009 (Table 3). The continuous widening of the channel since 1999 has led to vegetation depletion in the area (Ikusemoran 2022) which exposes the channel to both soil erosion and flood hazards.

3.1.2. Channel Bars

Fig. 3 shows the nature of the numerous channel bars in each of the study period. The area in kilometers square of the channel bars and their corresponding perimeters are shown in Table 3. There were increase in area coverage and perimeter of the channel bars after the dam's impoundment (from 1984 to 1989) but the channel bars recorded its largest land area coverage and perimeters in 1989 (Table 3). The presence of large channel bars during this period (1989) has impacted on the entire perimeter, length and sinuosity of the channel as the three parameters recorded their highest values in 1989 (Table 3) This finding agrees with that of Hudson, (2007) that channel bars result in a high thawed sinuosity. Deposition of sediment (bed load or suspended load) results in channel bed aggradation (vertical adjustment), and the formation of channel bars (lateral adjustment). However, the areas and the perimeters of braided bars were found to drastically decrease from 1989 to 2019 which could be connected to the sinuous formation of the river channel. The transformation of the stream channel from meandering to sinuosity is clear evidence of soil erosion at play, while the sinuous (straight) channel increases water velocity which exposes the channel to flooding.

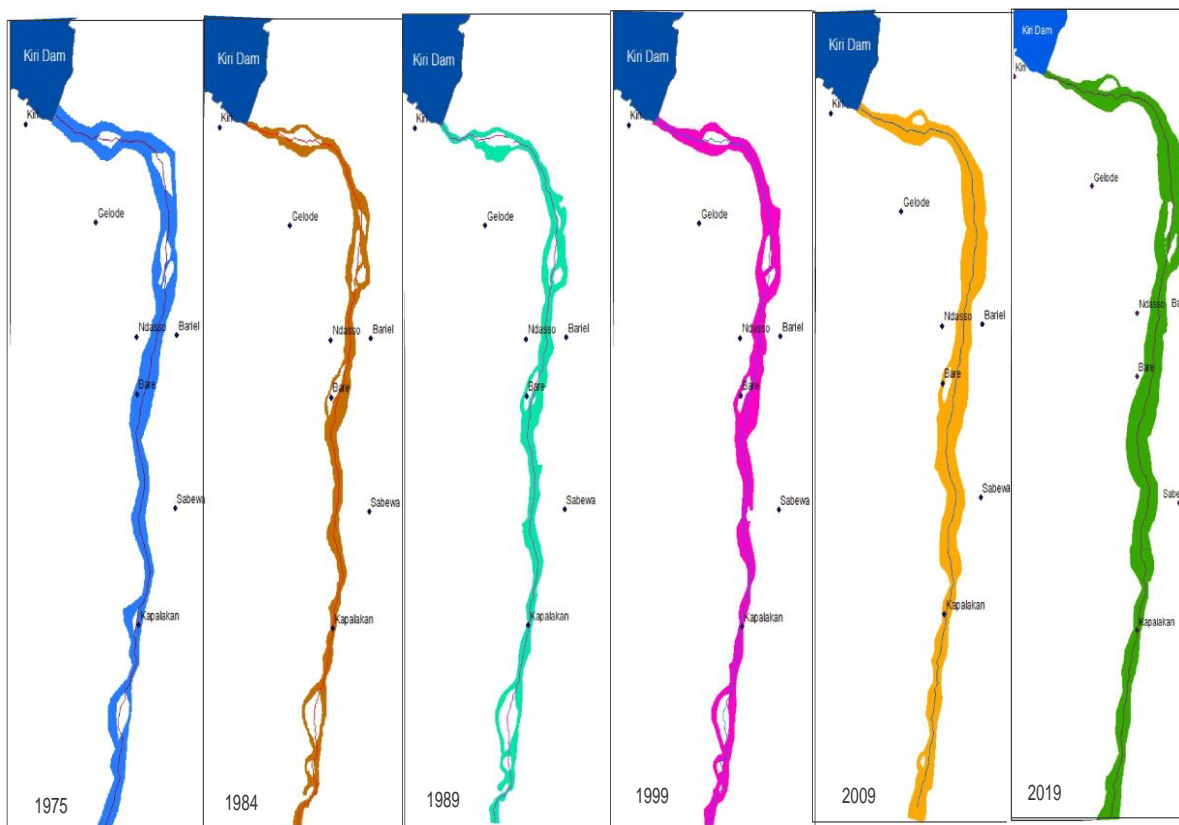


Figure 2. Channel Bars along the lower reach of River Gongola

3.1.3. Channel Perimeter

The impact of channel bars on channel perimeters especially after the dam's impoundment was identified in Table 2. The periods with largest channel bars coincides with the period with the largest channel perimeter. For example, 1989 and 2019 recorded the highest and the least land area of channel bars respectively and which also are the same periods with the highest and the least channel perimeters. This relationship between channel bars and perimeter has been reported by Pickup (1976). Therefore, reduction in channel perimeter means less channel width which also increases flooding as the channel width might not easily contain stream runoff.

3.1.4. Channel widening

The average channel width in 1975 (seven (7) years before the completion of the dam) was 0.62 km. However, in 1984 (2 years after the commissioning of the dam), the average width had reduced to 0.42 km, that is, a difference of 0.2 km. The largest channel width during the study period was recorded in the last decades, that is, between 2009 and 2019. Mubi (2002) and Tukur et al. (2006) have also reported the reduction of the channel width during this period. Human activities which might be linked to the reduction include: like irrigation, expansion of human settlements and sand mining are all practiced along the channel especially in places like Bare, Bilachi, and Ndasso as observed during the field work. Reduction in stream width leads to flood vulnerability and vertical erosion. For instance, reduction in stream width between 2009 and 2019 as recorded in Table 3 might be a catalyst to the frequent flooding in the area especially in 2012, 2015 and 2018 (Ikusemoran, 2022).

3.1.5. Channel Sinuosity.

Channel sinuosity is the meandering of a stream channel (Novica and Radislav, 2016, Jatan et al., 2017, Ezekiel et al., 2020). It is determined through sinuosity index which is derived from the ratio of the respective stream channel length to the valley length (Ezekiel et al., 2020). The channel at the downstream of Kiri reservoir was found to be initially in a meander form but gradually becomes straightened especially from 2009 (Figure 2). The sinuosity index decreased from the pre-dam (1975) to early post-dam era (1984) as shown in Table 3. This reduction in sinuosity at this period was also reported by Tukur et al. (2002) that the post-dam channel became less sinuous. The sinuosity index was highest in 1989 (the year with highest rainfall), when channel perimeter and channel length recorded the highest value Table 2). The general sinuosity index was obtained from sinuosity class types as shown in Table 2.

Since the sinuosity index ranged from 1.22 to 1.26 and which all fall within the "sinuous" class (Table 2), it was concluded that the channel at the downstream of Kiri reservoir has been at sinuous stage. Fig. 2 proves the current sinuosity stage of the channel because the channel has gradually moved away from the meandering nature through bend-cutting, disappearance of channel bars among others to slightly straight channel which all results from soil erosion. The reduction of the sinuous index value since 1989 shows that the channel is becoming more sinuous, which has increased flood hazards in the channel area.

3.1.6. Channel Migration

When River channels move or migrate laterally across their floodplains, it is called channel migration. Channel migration occurs when a river erodes a bank side and deposits the eroded sediments on the opposite side of the eroded bank. Channel migration can also occur as an abrupt shift of the channel to a new location, called an avulsion, which may happen during a single flood event (Steve, 2020). Table 4 shows the land area, perimeter, total rate as well as the annual rate of channel migration in the lower reach of Kiri reservoir.

Table 4. Area, perimeter, magnitudes and annual rate of migration (1975-2019)

Years	Migration Area (km ²)	Perimeter of Migration Area (km)	Magnitudes of Migration (m)	Annual Rate of Migration (%)
1975-1984	2.48	53.13	93.38	10.38
1984-1989	1.39	56.09	49.64	9.93
1989-1999	1.83	53.92	67.78	6.78
1999-2009	2.77	37.68	146.81	14.68
2009-2019	1.55	37.80	81.87	8.19

Source: Research measurement (2020)

Reduction in the land area of channel migration was noticed at the initial stage of the impoundment of the reservoir (1984-1999). However, despite the increase in the size of migration area between 1999 and 2009, reduction in the migrated land area was recorded in the last decade (2009-2019) which might be attributed to the decreasing rainfall in the area as represented by the -21.1 mm in the rainfall trend equation in the catchment (Ikusemoran, 2022). The 1999-2009 periods had the highest total rate of channel migration with 14.68% per year. Channel migration has been said to be influenced by both natural and anthropogenic factors (Novica and Radislav, 2016, Jatan et al., 2017, Ezekiel et al., 2020). Erosion, deposition and other land areas during the period is shown in Figure 3.

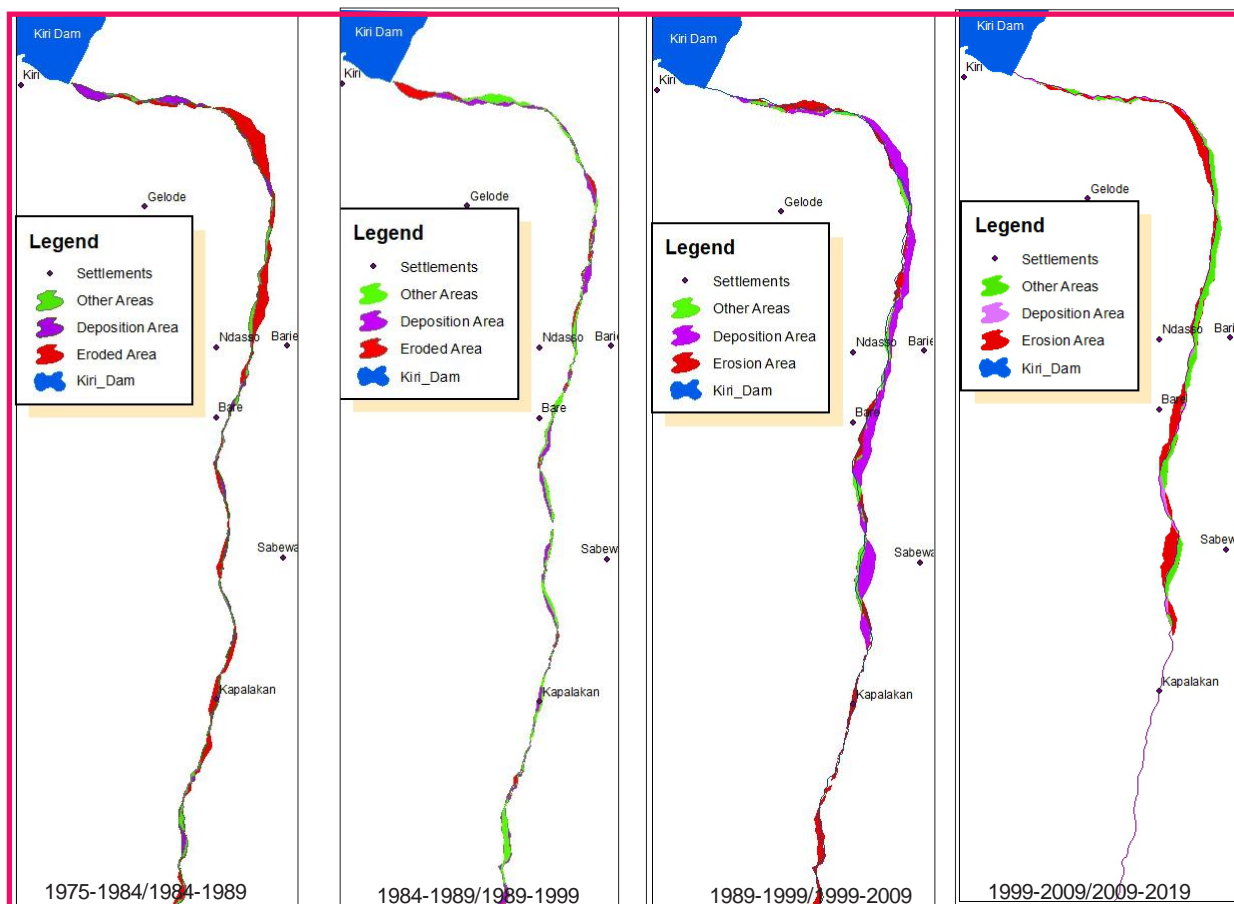


Figure 3. Erosion, deposition and other land areas (1975-2019)

Fig. 3 and Table 5 show the land areas (through overlay) that have been subjected to erosion, deposition and those that are not subjected to either erosion or deposition which are referred to as “other areas” within the study period.

Table 5. Area of the eroded, deposited and other areas within the channel migrated area

Years	Erosion (km ²)	Deposition (km ²)	Others (km ²)	Total (km ²)
1975/1984-1984/1989	2.45	0.95	0.47	3.87
1984/1989-1989/1999	1.35	1.18	0.69	3.22
1989/1999-1999/2009	1.80	2.37	0.43	4.6
1999/2009-2009/2019	2.75	0.31	1.26	4.32
Total	8.35	4.81	2.85	16.01

Table 5 shows that a total land area of 16.01 km² have been subjected to channel migration. Of the total land area under channel migration, 8.35 km² has been subjected to soil erosion, while 4.81 km² land area have been filled with deposition. The remaining 2.85 km² are static. This result show that erosion is more prominent in the river channel than deposition. Serious deposition along the channel in the lower reach is not expected because the river carries minimal debris due to the short distance between Kiri dam and the inlet to River Benue. The effects of soil erosion on the river channels include undermining houses, roads, and infrastructure, wash away properties, threats to lives and poses risks to public health in close communities like Bare, Ndasso and Bilachi.

3.1.7. Channel Incision.

Figure 4 shows the level of incision along the river channel since the impoundment of the reservoir. In 1984 (two years after the impoundment of the reservoir) vertical erosion was prominent especially at the upstream. In 1989, seven (7) years after impoundment, (the year with the highest rainfall (Ikusemoran, 2022), the channel floor that was initially incised became widen. In 1999 the channel became deeper again as a result of vertical erosion. However, in subsequent years (2009-2019), the channel was more of widening (lateral erosion) than deepening (vertical erosion). The reasons for the recent channel widening in this part of the river channel cannot be far-fetched; the flow strength at the lower course is generally weak and which also resists incision. Furthermore, the slope of the area is gentle or undulating (Figure 4) which is more prone to channel widening than incision as also observed by Beechie et al. (2008).

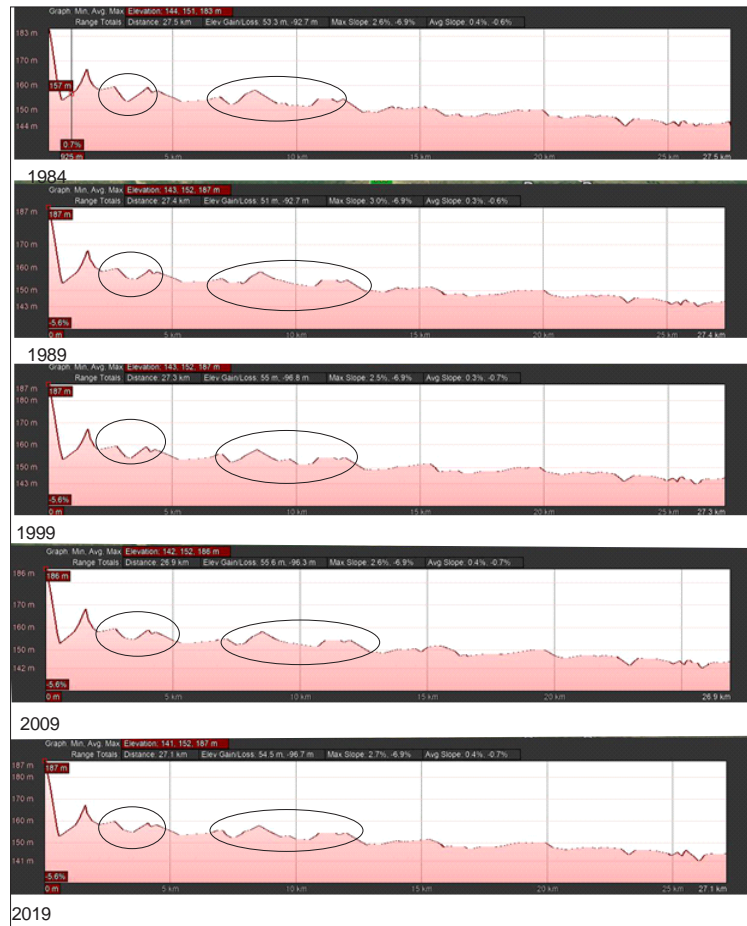


Figure 4. Trends in Channel Incision from 1984-2019

4. Conclusion and Recommendations

The temporal changes in the channel parameters as well as the changes in channel migration at the lower reach of River Gongola have been examined in this paper. All the channel parameters such as channel width, perimeter, length, incision and sinuosity as well as channel bars have been subjected to frequent changes. Eroded areas were found to cover larger areas than areas of deposition which suggests the presence of land degradation in the area. Based on the generated sinuosity, the area is now prone to lateral than vertical erosion which result into channel widening of the area and which might negatively affect the communities in terms of exposure to environmental hazards such as flood and soil erosion as well as their means of livelihood; farming and fishing. The effect of the channel migration on the inhabitants along the river channel is suggested for further studies.

Based on the findings of the study, the following recommendations were made;

- (i) Application of geospatial techniques to temporal monitoring of the channel should be imbibed so as to have a reliable and accurate data for frequent monitoring of the river channel in order to detect potential negative effects on man and the environment
- (ii) Creation of awareness on the effect of anthropogenic activities such as farming, grazing, sand mining and other activities that could aggravate land degradation along the river channel and the necessary control measures of each of the activities
- (iii) River channel control measures such as embankment, restriction of access to susceptible areas among others should be put in place where and when necessary to minimize the rate channel degradation in the area.

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