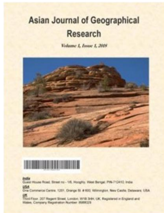

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Development of Chute Cutoff in the Lower Course of River Mayo-Inne, Yola South, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author DJI designed the study, performed the Field measurements, wrote the protocol and wrote the first draft of the manuscript. Author EY managed the analyses of the study, prepared the study area maps, contributed in the discussion and conclusion. Both authors managed the literature searches, read and approved the final manuscript.

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ABSTRACT

The study investigates the development of chute cutoff in the lower course of River Mayo-Inne, Yola South LGA, Adamawa State, Nigeria. The study employed the integrated approach of Remote Sensing, Geographic Information System, Field Survey, Laboratory Analysis, Oral Interview and Personal Observation in examining the influences of some relevant channel planform parameters (Sinuosity Index, Cutoff Ratio and Braiding Index), land use/land cover, channel bank materials, water stage and channel depth on the development of the chute cutoff over a period of Twenty five years (1990-2015). Results revealed the drastic reduction of Sinuosity Index from 1.57 in 1990 to 1.46 in 2015, changing the channel from meandering to the straight pattern. The analysis of changes in cut-off ratio unveiled the development of chute cutoff in bend II, which ultimately separated the river flow, forming a weak braided channel with a braiding index of 0.43. These developments were attributed to incessant flooding in the study area and floodplain characteristics such as floodplain elevation, bank strength and changes in vegetal cover.

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Keywords: Floodplain; chute cutoff; sinuosity index; braiding index; flooding; land use/land cover.

1. INTRODUCTION

The occurrence of cutoffs in river systems is sporadic and a key component in the complex dynamics of meandering rivers [1]. Chute cutoff is one of the most significant geomorphic features of the meandering channel that reduces bend growth and channel sinuosity and are essential in understanding the dynamics of physical habitat [2]. Besides its geometrical significance in limiting the complexity of meandering rivers, chute cutoff also plays a vital dynamical role by generating intermittent noise capable of influencing the spatiotemporal dynamics of the whole river [1].

Cutoffs develop when erosion cuts across a point bar or low areas of floodplains, redistributing water and sediment through the chute channel, abandoning the original meander before eventually infilling [3,4,5,6,7]. The initiation and development of chute cutoffs have been a topic of debate among fluvial geomorphologists. [8], argued that "chute initiation takes place when the overbank flow is diverted from the main channel towards the point bar where the riverbank strongly turns away from the downstream flow path." [9] opined that the initiation and development of chute cutoffs depend on the characteristics of floodplains, especially bank strength, floodplain elevation, sediment composition, and the presence of vegetation. [10] further emphasized that chute cutoffs are associated with small agricultural streams characterized by higher return periods of overbank flow and the combined influences of embayment, nick point formation, weathering, mass wasting and earth worm's activity. They further clarified that the degree of dominance of the aforementioned activities depends on the nature of the overbank flow return periods, kind of floodplain and land use, discharge, vegetation cover, meander properties and channel bank properties. From the preceding, it can be deduced that the initiation and development of chute cutoff are associated with floodplain characteristics and triggered by flood events. This entails that chute cutoff development requires high water level, non-vegetated point bar, non-cohesive bank materials and high rates of bedload transport and deposition.

Chute cutoffs are mostly associated with weakly meandering rivers that developed on young floodplains that are on the transition from meandering single thread to braided pattern [11,12,13,14,9]. [7] categorically state's that 'chute and neck cutoff are not conceptually related, they define neck cutoff as the self-interception of an evolving meander bend'. There are two fundamental types of chute cutoff which are defined by their formation on the floodplain [9]. They are scroll-slough cutoffs and bend cutoff: A scroll-slough form cutoff through sloughs on point bars while a bend cutoff across the point bar by incision taking advantage of gradient [12].

Most studies on the long-term changes in meandering rivers have thus far focused on the development of chute cutoff in large rivers outside Nigeria [15,9]. This study, however, takes into cognizance the development of chute cutoff in the lower course of River Mayo-Inne, a third order tributary of River Benue in Adamawa State Nigeria.

1.1 Study Area

The lower course of River Mayo-Inne, Yola South L.G.A, Adamawa State, is the study area for this investigation. The river which is a third order tributary in the Benue catchment takes it source from an undifferentiated basement complex (Jangani Hills) in Ganye Local Government Area. It is located between latitude 9º16ʹ and 9º26ʹ North and between longitude 12º12ʹ and 12º20ʹ East of the Greenwich Meridian (Figs. 1 and 2).

The climate is a savanna type with rainy seasons usually starting from May to October with annual total rainfall amounts ranging between 800 and 1100mm, while the dry seasons commence from November to April. The vegetation of the study area can be classified as Sudan Savannah type that covers most parts of the northern states [16,17].

The types of soils characterizing the study area include Luvisols, Cambisols, and alluvial soil [18]. The relief falls within the plains of the Benue trough that range in height between 311.1 and 140m above sea level. The drainage pattern is said to be dendritic at the upper course. However, flowing down current to the middle course at Tullabenbi, where the river cut across a different geological formation, the drainage pattern changed in parallel. At the lower course, the river flow, meander and joined the River Benue which serve as a local base level.

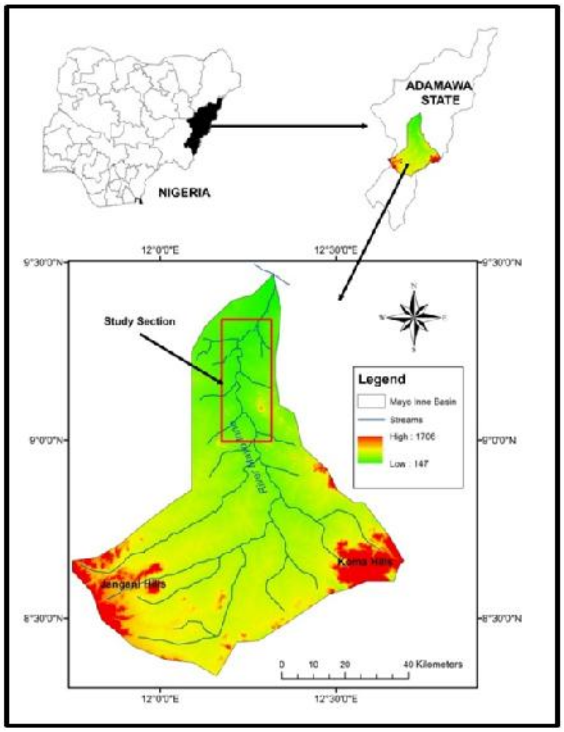

Fig. 1. Study area

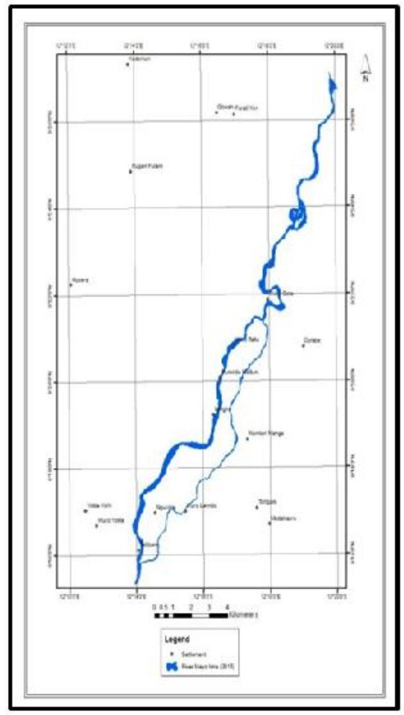

Fig. 2. The study river section

2. MATERIALS AND METHODS

The study was carried out using an integrated approach of remote sensing, geographic information system (GIS) and field survey. Satellite imageries used for the study included Landsat MSS of 1990 and Landsat ETM+ of 2015. The images were subjected to coordinate system verification, spatial image extent, georeferencing, resampling and re-projection, image filter and sub-setting and composite color development among others. From each of the respectively processed satellite imageries, the river channel was digitized, and the sectional stream lengths and valley lengths were measured. Lengths of bends and their corresponding chords, as well as the lengths of islands, were also measured from the processed river channel imageries in the ArcMap environment of ArcGIS 10.1. Land use/land cover change detection by both supervised and unsupervised classification was also conducted in the ArcMap environment of the same software.

The relevant channel planform parameters measured from the two critical meander bends included:

i. **Sinuosity Index:** The degree of meandering or winding of river channel computed as the ratio of the Stream length to the Valley length [19], expressed as:

$$S_i = \frac{S_L}{V_L}$$

Where:

S_i is Sinuosity index; S_L is Stream length, and V_L is Valley length

ii. **Cut-off Ratio:** The ratio of the Length of the bend to the Length of the chord [20], expressed as:

$$C_R = \frac{L_B}{L_c}$$

Where:

Cut-off Ratio is C_R; Length of the bend is L_B, and Length of the chord is L_c

iii. **Braiding Index:** The ratio of the length of island or bar to that of the cross-sectional reach [21] expressed as:

$$B_i = \frac{2L_{Bar}}{L_{Reach}}$$

Where:

Braiding Index is B_i; Length of Island or Bar is L_{Bar}, and Length of the reach is L_{Reach}

Field survey involving observations and measurements ascertained the floodplain characteristics. The coordinate of each of the sampling points in Fig. 3 was obtained using Garmin 76S handheld GPS. This was used to track the exert sample point on the channel profile. A total of 28 Bank material samples were collected by scooping from both the right and left banks of the river channel for particle size analysis in the Soil Science Laboratory of Modibbo Adama University of Technology, Yola. The textures were determined using the USDA textural triangle.Water-stage data were obtained from Upper Benue River Basin Development Authority, Yola.

3. RESULTS AND DISCUSSION

Measurements were carried out for stream length and valley length on 1990 and 2015 satellite imageries. The computed sinuosity indices (S_i) as provided in Table 1 showed distinctive variation within the two study periods.

Table 1. Sinuosity Index for River Mayo-Inne

S/No	Year	Sinuosity	Channel pattern
1	1990	1.57	Meandering
2	2015	1.46	Straight

Source: Satellite image analysis (2016)

The Table 1 revealed that in 1990 the sinuosity index stood at 1.57; this sort of channel is classified according to [19] as a meandering river. However, the S_i value drastically reduced from 1.57 (in 1990) to 1.46 (in 2015) changing the channel from a meandering state to a slight straight pattern. The analysis of changes in the cut-off ratio for the two critical bends in Figure 4 indicated that Bend I rose from 3.43 in 1990 to 4.09 in 2015. However, bend two experienced a drastic decrease to 1.53 in 1990 as shown in Table 2.

Table 2. Cut-off ratio and braiding index for river mayo-inne

S/N	Year	Cut-off ratio bend I	Cut-off ratio bend II	Braiding index
1	1990	3.43	1.53	Nill
2	2015	4.09		0.43

Source: Satellite image analysis (2016)

The period of 2015 revealed the development of chute cutoff in bend II, which ultimately separate the river flow, forming a weak braided channel with a braiding index of 0.43. The flow separation enhanced the development of three in-channel erosional bars located at the right bank, in the middle of the channel and at the left bank. The sandbar at the right bank had a length of 864 m, while the middle and the remaining bank bars had 319 m and 264 m respectively. The reduction in sinuosity index, which changed the channel pattern from meandering to a straight one as indicated in Table 1, may not be unconnected with the development of chute cutoff in bend II of the study channel. The result of this analysis conforms with the findings of [2].

The development of chute cutoff in bend II can also be attributed to incessant flooding in the study area and floodplain characteristics such as floodplain elevation, bank strength, sediment composition, and vegetation. Data acquired from Upper Benue River Basin Development Authority (UBRBDA), Yola, revealed that the average water stage of the river is 2.63 m, while field measurements revealed an average channel depth of 2.15 m.

From the above, it can be deduced that incessant flooding occurs every year in the study area; this is because the average water stage is higher than the average channel depth. Oral interview with some of the inhabitant of the study area confirmed this and further pointed out that that increase in water stage has over time led to submergence of farmlands, especially those adjacent to the river channel. To this effect, the channel form responds by chute incision and head cut propagation on the point bar to form a chute channel.

The result from particle size analysis revealed that the channel bank material varies in textural characteristics along the channel profile Table 3.

The percentage composition of bank material samples collected from the right and left banks of the channel along the sample stations revealed that sand constituted an average of 58.85%, while silt and clay accounted for 29.11% and 12.04% respectively. This observation thus places the bank material and soils of the study area in the categories of sandy, sandy loam, loam, sandy clay loam, and silty loam. The result thus revealed channel bank material in the study area as having low cohesion owing to low clay content which serves as a binding agent on one hand and high percentages of sand content, on the other side, thus, highly susceptible to chute incision and head cutoff across point bar by fluvial processes.

The land use/land cover change detection analysis showed that significant changes had taken place within the period of study (Fig. 5 and Table 4).

Vegetation, which constitutes the major land cover class that significantly influences the development of chute cutoff, reduced from 6.36% in 1990 to 3.62% in 2015. Changes in vegetal cover, especially riparian vegetation influence the development of chute channel; this is because vegetation increases the shear strength of bank material and reduces lateral mobility and migration rates, making river channels to become more stable. Reduction in riparian vegetation thus, makes the banks to be susceptible to widening and development of chute cutoff across a point bar or low areas of floodplains by fluvial processes.

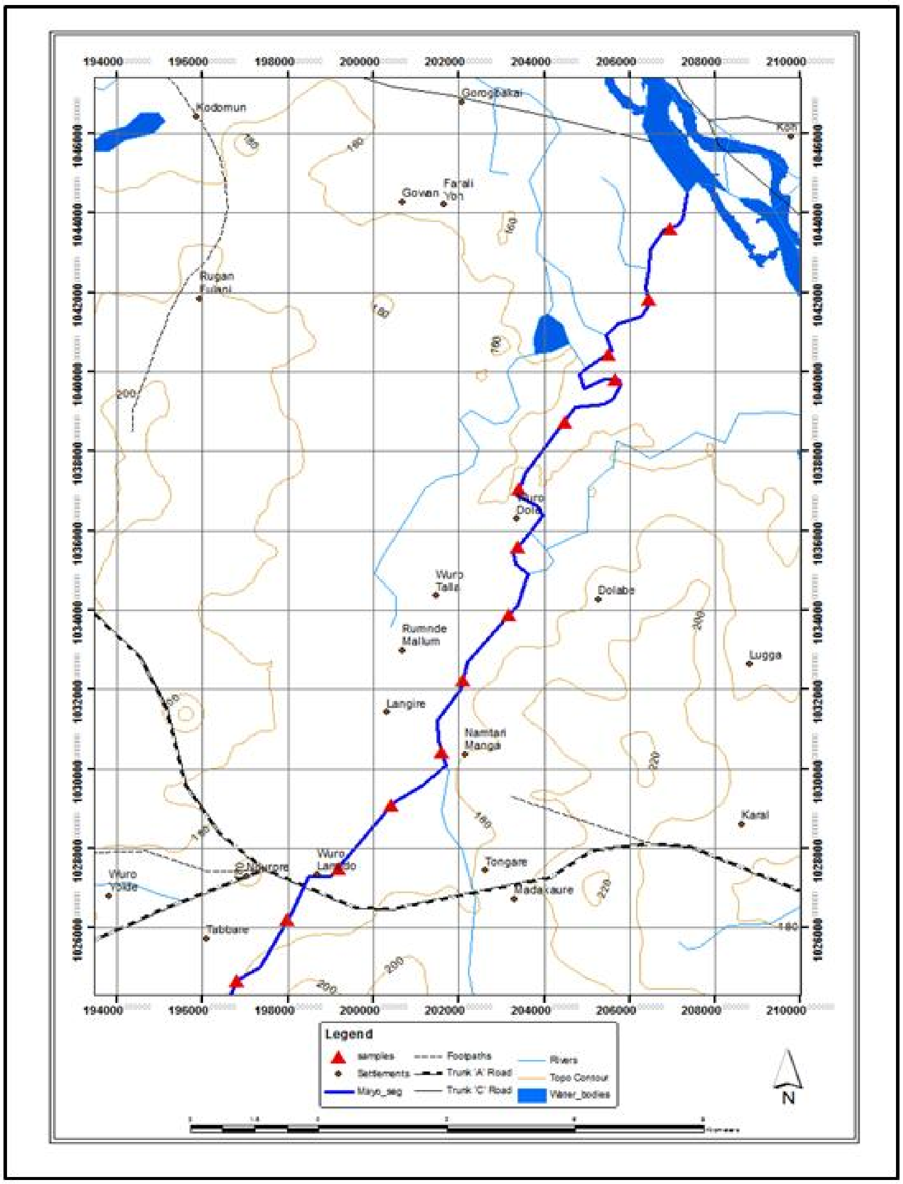

Fig. 3. Map of the study area showing sampling locations

Source: Adapted from topographical map prepared by federal ministry of survey (1970)

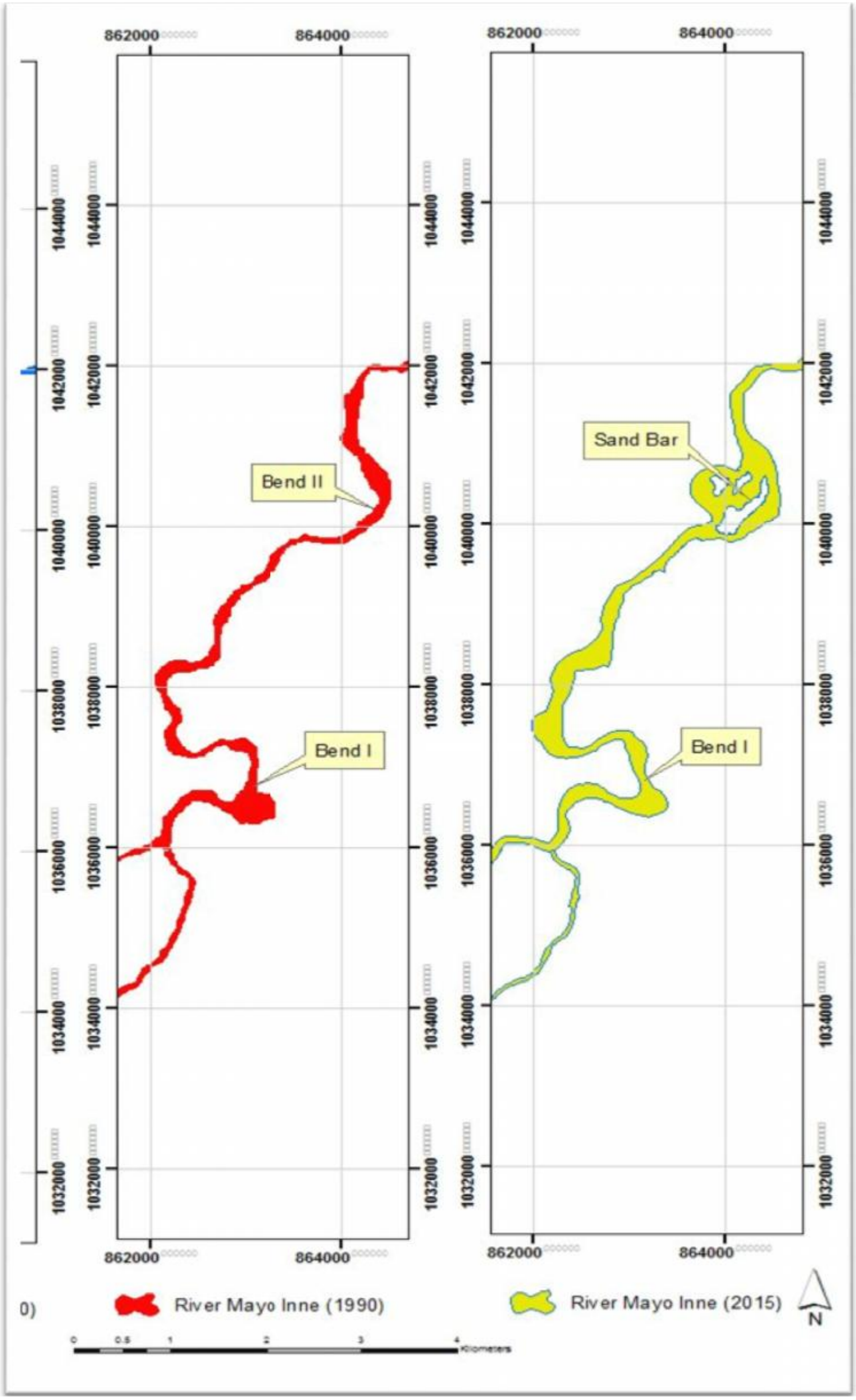

Fig. 4. Changes in meander characteristics in the study channel
Source: Satellite image analysis (2016)

Table 3. Soil textural characteristics of bank-material in the study area

Sample stations	Bank	%Sand	%Silt	%Clay	Textural classes
1	Right	95	03	02	Loam
	Left	51	25	24	Sandy loam
2	Right	53	41	06	Sandy
	Left	97	02	01	Sandy loam
3	Right	95	03	02	Sandy loam
	Left	37	49	14	Sandy
4	Right	37	39	24	Sandy loam
	Left	23	59	18	Loam
5	Right	53	35	12	Sandy clay loam
	Left	33	45	22	Loam
6	Right	61	29	10	Sandy loam
	Left	75	15	10	Loam
7	Right	71	27	02	Silty loam
	Left	89	05	06	Sandy clay loam
8	Right	71	23	06	Sandy loam
	Left	21	59	20	Silty loam
9	Right	79	19	02	Sandy loam
	Left	57	29	14	Loam
10	Right	43	39	18	Loam
	Left	93	05	02	Loam
11	Right	61	31	08	Sandy
	Left	47	37	16	Sandy
12	Right	59	19	22	Sandy clay loam
	Left	25	49	26	Sandy loam
13	Right	53	41	06	Sandy
	Left	59	15	26	Sandy loam
14	Right	39	49	12	Sandy loam
	Left	51	43	6	Sandy loam

Source: Field work and laboratory analysis (2016)

Table 4. Land use/land cover classification and change dictation analysis for 1990 and 2015

S/No	Land use/land cover	1990 (ha)	2015 (ha)	1990 percent area	2015 percent area	% Change 1990-2015
1	Vegetation	2288	1301	6.36	3.62	-2.74
2	Cropland	31320	33277	87.06	92.51	+5.45
3	Water Bodies	82	51	0.23	0.14	-0.09
4	Bare Surfaces	1501	451	4.17	1.25	-2.92
5	Marshes	412	258	1.15	0.72	-0.43
6	Built-up Areas	369	634	1.03	1.76	+0.73
7	Total Land Area	35972	35972	100%	100%	

+ indicate an increase in land use/land cover and – report a decrease in land use/land cover
Source: Satellite image analysis (2016)

Other land uses such as cropland increase from 87.06% in 1990 to 92.51% in 2015. The change observed over the study period may not be unconnected with an increase in population and a corresponding increase in demand for food and raw materials from the surrounding urban settlements like Jimeta, Yola, and Numan. These activities mainly the arable type helps in loosening the bonds between soil particles, making them susceptible to an agent of erosion and transportation. To this effect, the loosed soils are subsequently transported and deposited in the river channel. This increases the bed elevation causing the river to shift to a new state of dynamic equilibrium. Water bodies, bare surfaces and built up areas also show significant changes as indicated in Table 4.

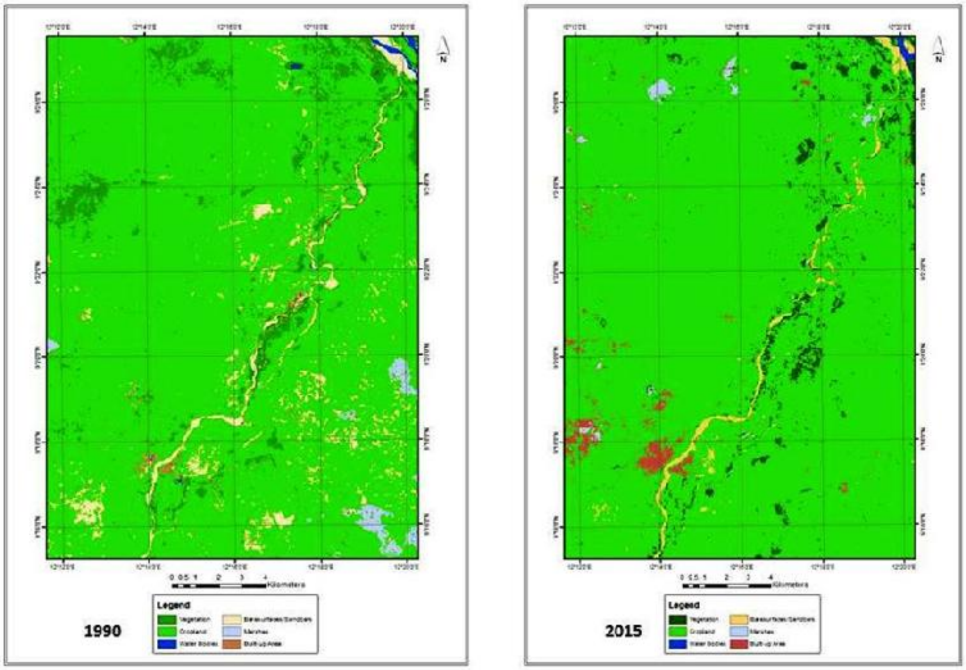

Fig. 5. Land use/Land cover images of the study area in 1990 and 2015, respectively
Source: United state geological survey

4. CONCLUSION

Study on the development of chute cutoff in the lower course of River Mayo-Inne was conducted with the aid of remotely sensed data, geographic information system, and field survey and laboratory analysis. The results revealed that chute cutoff developed in bend II of the study river; which is attributed to incessant flooding, changes in vegetal cover and cropland and composition of bank materials. To this effect, the channel sinuosity index and bend growth drastically reduced, changing the channel pattern from meandering to straight. With this channel straightening effect, the overflow (flooding) tendency of the channel section induced by meandering is reduced, thus posing a negative impact floodplain development and its agricultural benefits in the area. To improve this condition, there is need to minimize and checkmate adverse anthropogenic activities such as clearing of riparian vegetation, the building of houses close to the river channel, over cultivation, in-channel sand and gravel mining, and grazing along the river channel.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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