بحوث قسم الجغرافيا ونظم المعلومات باللغة الانجليزية

Morphological Changes of Damietta Branch's Meanders using GIS and remote sensing from Al-Qanatir to Benha,

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الملخص

يمثل التعرج في الأنهار الرسوبية ظاهرة ديناميكية تعتمد على عدة عوامل. تنقسم هذه العوامل إلى عوامل هيدرولوجية : مثل حجم تصريف النهر ، وقوة تدفقه ، وحمولته من الرواسب. وكذلك خصائصه المورفولوجية : مثل عدد التعرجات ، أطوالها ، نصف قطر تقوسها ، معدل تعرجها ، ومتوسط عرض قناة النهر. ويتأثر شكل التعرجات في منطقة الدراسة في المقام الأول ببناء السد العالي بأسوان ، مما أثر بصفة عامة على الخصائص الهيدرولوجية والمورفولوجية لنهر النيل في مصر ، وتزداد فعالية هذا التأثير مع توجهنا نحو المصب ، حيث يتناقص حجم تصريف النهر وسرعة تدفقه وقدرته على النحت ويميل إلى التعرج ، وقد اهتمت الدراسة الحالية بدراسة العوامل المؤثرة في تعرج القطاع الجنوبي من فرع دمياط من القناطر الخيرية إلى بنها حيث أمكن التعرف علي شكلين من أشكال الهجرة الثنيات وهي : الثنيات المتقدمة الدورانية والثنيات المتسعة جانبياً .

Abstract

Meandering in alluvial rivers is a dynamic changing feature that depends on several factors affecting this change, these factors are divided into hydrological factors: such as the volume of river discharge, its velocity of flow and Annual sediment load. and its morphological characteristics: such as the number of meanders, their lengths, Radius of curvature, Sinuosity and average width of the river channel. The morphology of the meanders in the study area is primarily affected by the construction of the Aswan High Dam, which affected the hydrological and morphological characteristics of the Nile River in Egypt in

general, the effectiveness of this effect increases as we head towards the estuary, where the volume of the river's discharge, its velocity and its ability to erosion decreases The current study was concerned and tends to meander. with studying the factors affecting the meandering of the southern sector of the Damietta branch from Qanatir al-Khairia to Benha, where two forms of meanders migration can be identified: Advanced rotation meanders and Lateral extension meanders.

keywords: Meanders. Morphology. Hydrology. Damietta branch. meanders migration.

1- **Introduction**:

The meandering alluvial rivers is a curving extension of the river, this curvature ranges from slight curvature to severe curvature. Usually meandering rivers are mobile, as it is possible for the river to migrates part of its watercourse and increase the erosion on one side of the meander and deposit on the other side so that the end result will increase the meandering , producing significant contribution to change of river morphology. This occurs on varying timescales . The meandering rivers are single channels with a sinuous planform comprising a series of loops, frequently depicted as regular and simple in form and size, but in reality often having some irregularity, asymmetry, and complexity They are differentiated from braided channel patterns, which have multiple channels or multiple free bars within the course, and straight channels, which have very low sinuosity, though this lower limit of meandering is somewhat arbitrary. Thresholds and conditions for development of different types of pattern have been much investigated. Meandering courses are found not only in fluvial rivers and in bedrock channels but also in tidal flows, on glaciers, in oceanic currents, and in submarine and Martian environments. This implies intrinsic characteristics of fluid flows, but debate still surrounds the basic question of why rivers meander (Hooke, 2013).

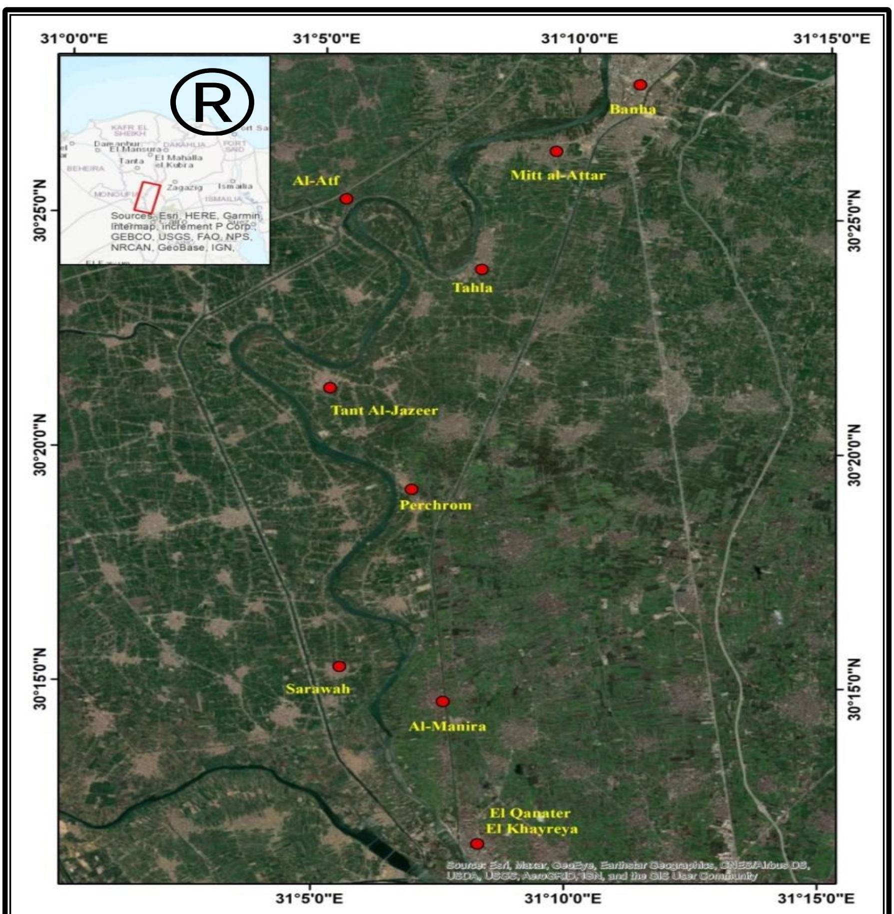
The meanders are one of the most common river patterns in different environments. The straight river is rare, so the river meandering is a form of river balance, where the presence of the slight meanders are linked to the river in the maturity stage, the more the river progresses in the stage of maturity to reach the old age stage the meanders become sharper .

It is necessary to identify the factors affecting why a river has a meandering pattern, there are many factors that affect the meandering of the river, as Planform classifications, flow strength, Topographical characteristics of the river channel, sediment supply, river Banks erodibility, Frequency of floods and human interventions

2- Study Area

North of Cairo, about 23 km, the Nile River divides into two branches, the Damietta branch and the Rosetta branch, the Damietta branch is one of the most important erosion factors affecting the morphology of the Nile River Delta, and even the most active erosion factor, due to its long-term impact.

The current study focuses on the changes in river meanders at Damietta branch in the sector, from Qanater al-Khairiya to Benha. The study area located between latitude of 30° 11′ 53″ , 30° 27′ 57″ N and a longitude of 31° 02′ 55″, 31° 10′ 41″ E extending for 49.3 km (Figure 1), characterized by very active river processes, especially in meanders , where the Nile River was affected by the construction of The Aswan High Dam, Topographical characteristics or the river's load of sediments, the Nile River is still striving so far, especially at the downstream



region, to reach a new equilibrium that fits with the changes that occurred after the construction of the Aswan High Dam .

Source: Esri, Maxar, GeoEye,
Earthstar Geographics, CNES/Airbus
DS. USDA, USGS, AeroGRID,
IGN, and the GIS User Community
& ASTER GDEM Version 2

Fig.1 Location of The study area

3- Material and Methods

This study relied on many data sources e.g.(satellite images , maps of different scales and field study) .

3.1 satellite images:

In the current study, Landsat satellite images were used, ranging from Landsat 3 of 1984 to Landsat 9 OLI/TIRS images of 2022 covering areas of Damietta branch . Five bands (Blue Band, Green Band, Red Band, Near-Infrared Band and SWIR 1 Band) out of eleven bands (Coastal / Aerosol, Blue, Green, Red, NIR, Short Wavelength Infrared 1, Short Wavelength Infrared 2, Panchromatic, Cirrus, Long Wavelength Infrared1, and Long Wavelength Infrared2) were used for all classification and interpretation techniques.

3.2 Maps

A large set of maps were used in this study, from historical maps to large-scale maps. The most important of those maps used are the following:

- French campaign maps of Egypt at a scale of 1:100,000 for the year 1798: 1801.

- Topographic maps, Egyptian General Survey Authority, 1:100,000 scale, survey in 1914, 1936 and 1971.
- Topographic maps, Egyptian General Survey Authority, 1:50,000 scale, survey in 1925 and 1991.
- Topographic maps, Egyptian General Survey Authority, 1:25,000 scale, survey in 1927 and 1944.
- Hydrotopographic maps, Hydraulics Research Institute, 1:5,000 survey in 2005 and 2013.

All of these maps contributed to identifying the morphological changes that the study area had undergone

3.3 Filed study

The field study was relied upon to identify the general characteristics of the study area, in addition to taking some notes about river banks erosion and islands merging into the flood plain and taking photos that represent these features.

4- Discussion

4.1 Hydrological Characteristics

4.1.1 volume of Damietta branch discharge

River discharge can be defined as the volume of water flowing through a river channel at a certain point, the river discharge is measured in cubic meters per second (m^3/s) .
the volume There is also a clear direct relationship between of river discharge and the its flow strength and, accordingly, the ability of the water flow to carry and transport river sediments and to erode its bed and banks, taking into account temporal discharge variation

dispositions and floods . ,

The volume of discharge in Damietta branch witnessed clear changes. These differences included two main periods. The first period is the period before the construction of the Aswan High Dam. This period was characterized by clear fluctuations in the water revenue of the Nile River in general, and the Damietta branch in particular. The second period, which is the period after the construction of the Aswan High Dam, was characterized by water control the river as a result of water storage control.

Table (1) and Figure (2) show monthly and annual average of Damietta branch discharge volume before and after the construction of the Aswan High Dam, from it the following can be concluded.

Table (1) monthly and annual average of Damietta m3/day) during the branch discharge volume (million period (1948-2015)

Period / Months	1948-1963	1980-2015
January	12.95	7.85
February	15.55	7.45
March	13.20	12.25
April	12.35	12.00
May	15.15	14.75

June	29.30	22.15
July	37.05	25.15
August	129.50	22.10
September	197.00	16.35
October	123.50	13.70
November	79.00	13.25
December	48.90	8.65
Sum	712.45	175.65
Annual average	109.61	14.64

Source: Nile Research Institute (NRI), Egypt, unpublished data

- April recorded the lowest volume of water discharge during the period preceding the construction of the Aswan High Dam (1948-1963), reaching 12.35 million $^{m3/d}$. While the months of August, September and October represent the height of the flood in the Damietta branch during this period, where the average volume of discharge during the third months reached 150 million $^{m3/d}$, which is a large average close to the total annual water revenue of the Damietta branch after the construction of the Aswan High Dam.

- The volume of water discharge of Damietta branch has become largely balanced largely balanced after the construction of the Aswan High Dam, with not great differences as a result of the control of the river's water. The month of February recorded the lowest discharge volume amounting to 7.45 million $^{m3/d}$, while the discharge volume average during the flood months (August, September and October) was 17.38 million $^{m3/d}$.

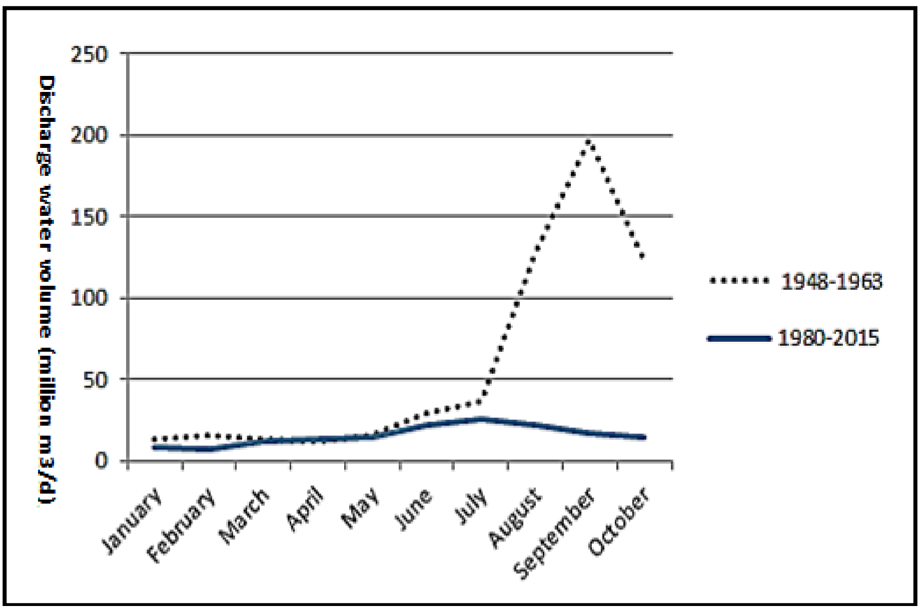


Figure (2) monthly and annual average of Damietta branch discharge volume (million $^{m3/day}$) during the period (1948-2015)

4.1.2 Flow velocity

The velocity of water flow in study area ranged between 0.341$^{(m/s)}$ in north of the Delta barrages, specifically at Darawa island, and 0.736$^{(m/s)}$ at Sarawa Meander, approximately 8 km north of the Delta barrages table (2).

On the horizontal level, the flow velocity varies from one sector to another in the study area, as follows:

- The flow velocity in the first sector, north of the Delta barrages, ranged between 0.364$^{(m/s)}$ on the eastern side of Damietta branch and 0.30$^{(m/s)}$ on the western side of it, while the velocity of water flow in this sector is the lowest in the study area, this is due to the presence of a group of stone heads directly north of the delta barrages, as well as the two islands of Darawa. The increase in flow velocity on the eastern side compared to the western side is due to the prevailing westerlies (anti-trades) winds, which push the flowing water towards the east, and thus the velocity of the water flow increases in the east and decreases in the west.

- In the two meanders of Sarawa and Tant Al-Jazira, the velocity of the flow increases in the concave side of both meanders. We find that the velocity is increased on the eastern (right) side of the Sarawa Meander, which is the concave side, while the velocity increases on the western (left) side of the Tant Al-Jazira Meander, which is also the concave side of the meander.

The velocity of flow water varies vertically, so it is the most rapid from the surface and decreases towards the bed to reach its slowest velocity near the bed as a result of intensity of friction and an increase in sediment concentration in the lower layer of water

Table (2) The velocity of flow water in the study area

	astern side		Midstream		Western side	
	pth (m)	ow ocity n/s)	epth (m)	w city /s)	epth (m)	Flow locity m/s)
North of the Delta Barrages	Zero	0.46	Zero	.46	zero	0.41
	-0.5	0.46	-0.5	.46	-0.5	0.40
	-1.5	0.45	-1.0	.46	-0.8	0.36
	-3.0	0.43	-2.0	.42	-0.95	0.32
	-4.5	0.38	-3.0	.37	-1.6	0.01
	-5.25	0.36	-3.25	.33		
	-6.0	0.01	-4.0	.01		
	verage	0.364	verage	359	verage	.300
	verall erage			0.341		
sarawh Meander	Zero	1	Zero	)8	zero	).95
	-0.5	)8	-0.5	)7	-0.5	).87
	1.25	)5	-1.25	9	-1.25	).83
	-2.5	33	-2.5	79	-2.5	).81
	3.75	76	-3.75	57	-3.75	).76
	4.25	53	-4.25	55	-3.9	).69
	-5.4	)1	-4.7	)1	-4.2	).01

	‌ʼerage	66	Average	39	average	).703
	verall 'erage			0.736		
[ant Al-Jazeera Meander	Zero	)3	Zero	)6	zero	1.10
	-0.5	)3	-0.5	)5	-0.5	1.09
	-0.9	34	-1.35	)7	-1.35	).95
	-1.8	72	-2.9	31	-2.9	).83
	-2.7	56	-3.75	56	-3.75	).56
	3.25	11	-4.0	)1	-4.0	).01
	‌ʼerage	82	Average	10	average	).76
	verall 'erage			0.716		

Source: Nile Research Institute (NRI), Egypt, unpublished data

4.1.3 Annual sediment load

It is important to appreciate that sediment production and sediment delivery vary markedly in the major tributary basins and marked spatial and temporal (annual and seasonal) variability in suspended sediment flux is a key feature of the fluvial geomorphology of the basin. Suspended sediment concentrations and loads are subject to considerable annual variation. The annual sediment load of the Nile at Aswan has varied between 50 and 228 million tons. Due to the erodible upland terrains, high sediment supply and high runoff, much of the suspended sediment load measured at Aswan derives from the highlands of

Ethiopia. In fact, together the Blue Nile and Atbara contribute on average about 97 % of the Nile's annual suspended sediment load (with about 72 % from the Blue Nile and 25 % from the Atbara) and the White Nile the (Woodward et al., 2007). remaining 3.0 %

The annual load of sediments in the Damietta branch was affected by the construction of the Aswan High Dam in southern Egypt, where the Aswan High Dam holds the sediments in front of it. Table 3 shows the discrepancy in the annual load of sediments for Damietta branch before, during and after the construction of the Aswan High Dam, which amounted to 51.76 million tons before the construction of the Aswan High Dam. While it reached 14.43 million tons during the construction period of the Aswan High Dam, which was characterized by partial water, the sediment load decreased to control of the river's 4.4 million tons after the construction of the Aswan High Dam and full control of the water flow in the Nile River north of the Dam.

Table (3) Annual sediment load for Damietta branch before, during and after the construction of the Aswan High Dam

Period		Annual sediment load (million t/Y)
Before	1964	51.76
During	1967	14.43
After	1973	4.40

Source: F. Marwa, 2016 "in Arabic"

4.2 Morphometric characteristics of meanders

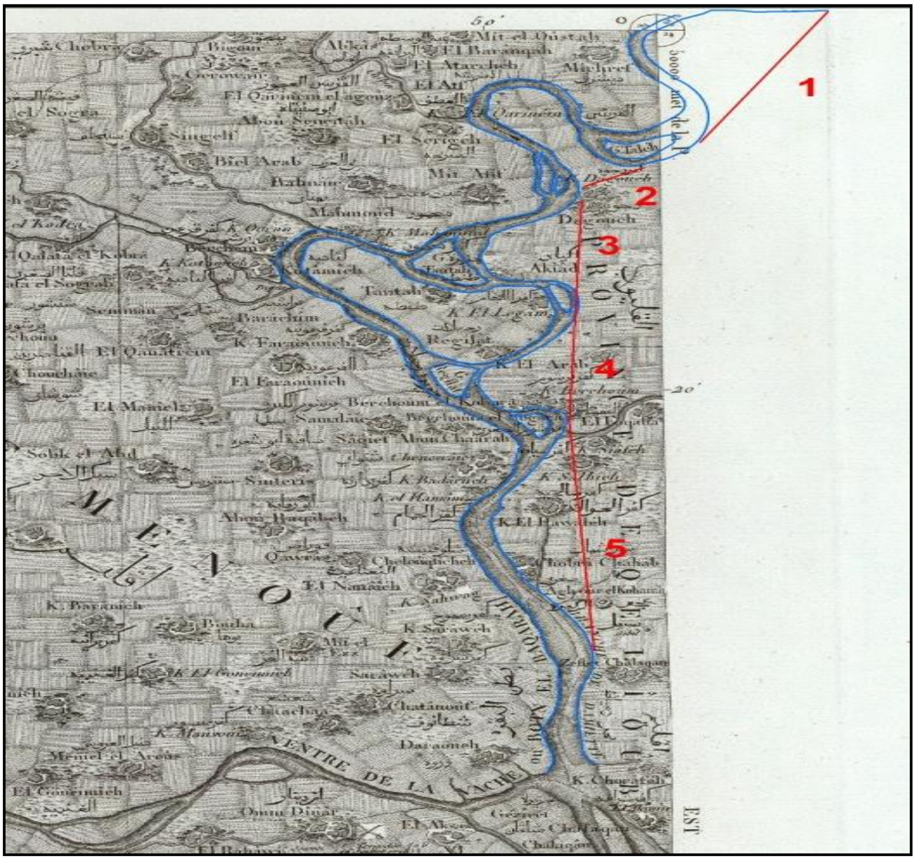
The construction of the High Dam is a pivotal point that affected the morphology of the meanders in general, as it can be clearly distinguished between two periods of the contemporary history of the morphological changes of the Nile River in Egypt, which are the period before the High Dam, it is the period that can be geographically dated from the maps of the French campaign to the topographic maps with a scale of 1: 25,000 edition in 1952. The second period is the period after the construction of the High Dam and extends to the present day.

4.2.1 Number of meanders

The number of meanders is one of the dynamic features that changed during the period before the construction of the High Dam and until the present day.

- **before the High Dam**

From the maps of the French campaign, the number of meanders in Damietta branch stream before the construction of the High Dam reached five (Fig. 2).



Jacotin, **M**. (**1818**). **Carte topographique** :**Source de Égypte Et de plusieurs parties des pays limittrophes**, **Levée pendant l'expedition de l" armée Françise**,

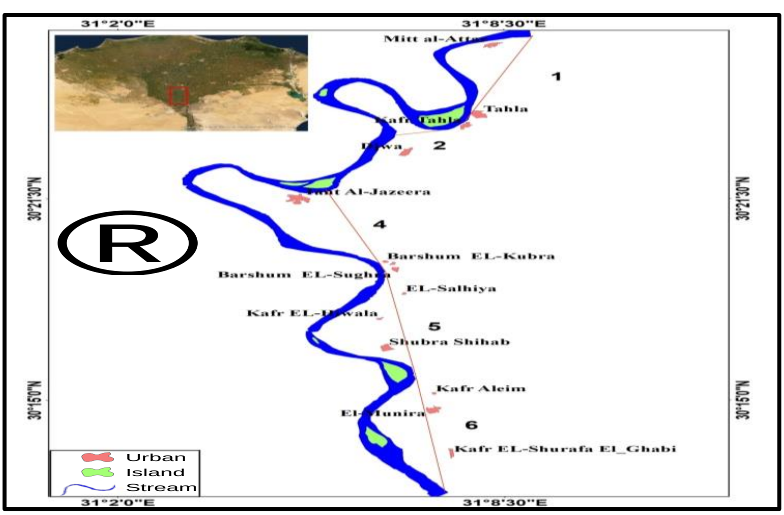
Fig. 2 The number of meanders in the study area during the period 1798: 1801

From the topographic maps scale 1:25000 edition in 1927 and it was issued as a second edition between 1945 and 1947 and also published as an enhanced edition in 1952. It is noted that the number of meanders has changed in the study area, where there is a clear change in the morphology of the river channel in the area between the beginning of the nineteenth century and the middle of the twentieth century, the eastern channel of the Damietta branch was separated in the Tant al-Jazira region and appeared as a blind river, which led to the disappearance of the meander No. 3with the emergence of a new meander in the southern part of the study area, the meander No. 6. Overall, the disappearance of meander and the appearance of another did not affect the total number of meanders, but rather their distribution (Fig. 3).

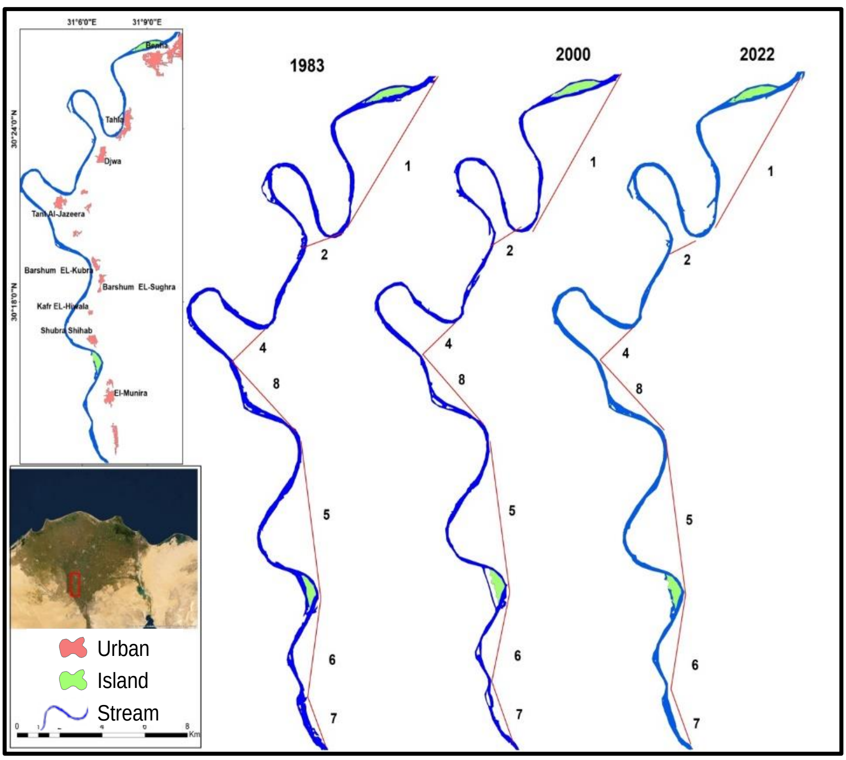
topographic maps scale 1:25000 enhanced editions :Source in 1952

Fig. 3 The number of meanders in the study in 1952.

- **After the High Da**



The number of meanders increased during the period after the construction of the High Dam, where it increased from 5 meanders to 7 meanders s can be attributed ’during 1984, 2000 and 2022,. It to the decrease in water supply in addition to the merging of Abu Hajjaj Island, south of Sarawah Island with the west bank, just north of Qanatir al-Khairiya, which led to the division of meander No. 6 into tow meanders No. 6 and 7 (Fig. 4) .



Landsat images for 5 TM in 1984, **7 ETM in 2000** :**Source and 9 OLI/TIRS in 2022**

Fig.4. The number of meanders in the study area in 1984, 2000 and 2022.

4.2.2 Meander lengths

The lengths of the meander have been studied from two aspects: the actual length of the meander, which is the length of the middle course of the river, and the length of the meander axis, which is the straight distance between two successive peaks. Table (4) shows the meander lengths in the study area. From 1952 to 2022, meander length in the study area was characterized by change, which generally tended to decrease, except for meanders No. 1 and 2.

Table (4) Meander lengths in the study area (km), .period 1952: 2022

		Meander No.								
		1	2	3	4	5	6	7	8	Average
1952	Meander length	8.9	7.3	-	11.8	8.9	7.7			8.9
	Meander axis length	7.2	0.6	-	4.6	5.9	6.8			5.0
1984	Meander length	9.1	7.5	-	8.1	8.4	5.1	4.4	4.9	6.8
	Meander axis length	7	0.6	-	2.3	5.8	3.1	2.8	3.9	3.6
2000	Meander length	9.2	7.6	-	7.9	8.5	4.9	4.3	4.8	6.7
	Meander axis length	7	0.6	-	2.1	5.8	3.1	2.7	3.8	3.6
2022	Meander length	9.2	7.6	-	7.8	8.3	4.8	4.3	4.9	6.7
	Meander axis length	6.9	0.6	-	2.1	5.9	3.2	2.7	3.8	3.6

١:٢٥٠٠٠topographic maps scale Measured from:Source and Landsat images for 5 TM in ١٩٥٢enhanced editions in 1984, 7 ETM in 2000 and 9 OLI/TIRS in 2022 .

Meander lengths of meanders No. 1 and 2 were affected by the merger of the islands with the floodplain, where the island of Ulama, which was dividing the channel before the construction of the High in 1952 Dam into two streams, main and secondary(Fig.5), merged with the eastern bank of the river, thus erosion focused on the concave side of the channel in the east bank, and on the other side, the island of Buqtur merged with the west bank of the river (Fig. 6).

The length of the meander axis of meanders was characterized by decreasing after the construction of the High Dam in all meanders in the study area due to the change in the morphology of the river channel, where meander No. 4 was divided into two meanders in 1984, and mender No. 6 was divided into two separate meanders, in addition to the merger of many islands on the floodplain , such as the islands of Ulama , Buqtur, Bein El-Bahrein El-Kebera, , Bein El-Bahrein El-Saghira, Sarawa and Darwa .

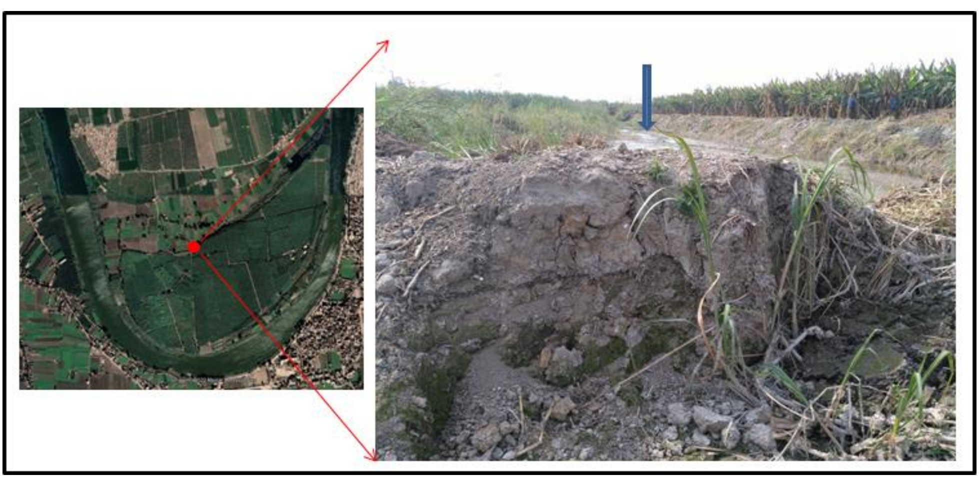
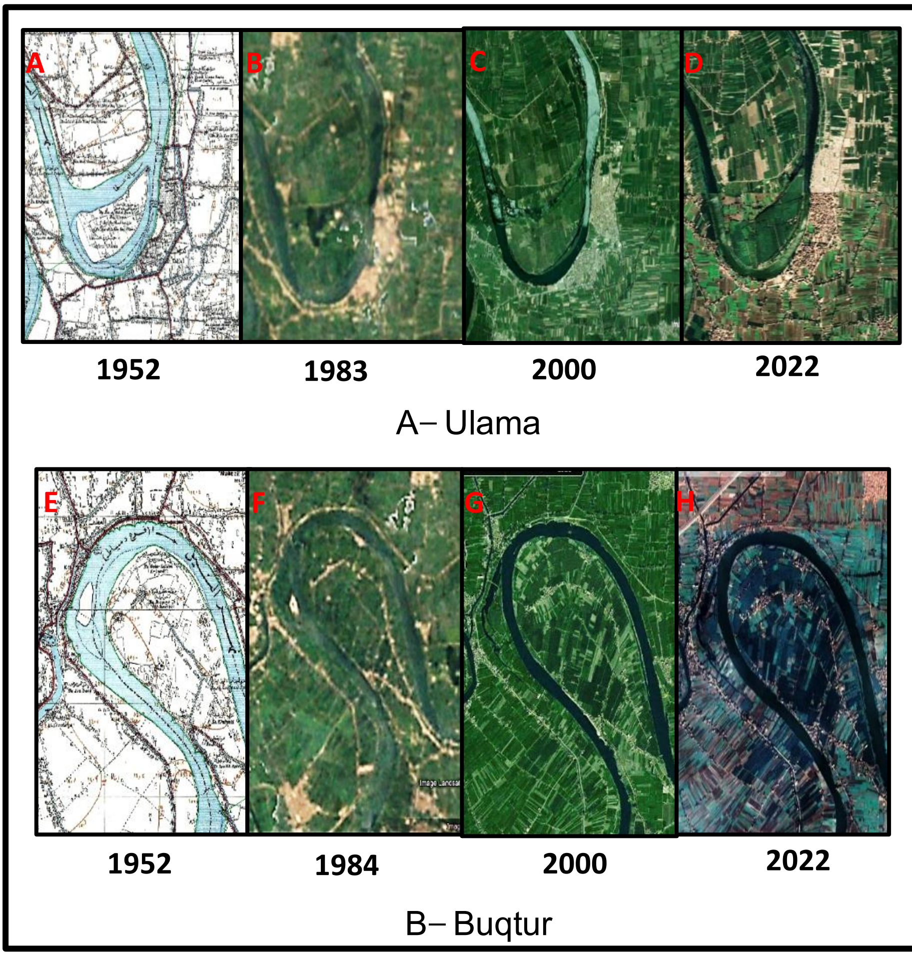


Fig.5. The merging of Ulama Island Into the floodplain.

*Note the presence of a short river arm separating the Island and the floodplain



:Source

enhanced ١:٢٥٠٠٠topographic maps scale A and E from ١٩٥٢editions in

B and F Landsat images 5 TM, 1984.

C and G Landsat images 7 ETM, 2000.

D and H Landsat images 9 OLI/TIRS, 2022.

Fig.6. The merger of the islands of Ulama and Buqtur with the floodplain during (1952 : 2022).

4.2.3 average width of the channel

The average channel width was calculated by measuring the cross-sections perpendicular to the flow direction at equal distances (1 km). Table (5) shows of meanders in study average width of the channel area. From 1952 to 2022, the following was found:

- The width of the channel in the study area was affected by the change in the volume of water discharge before and after the construction of the High Dam. The average width of the channel in all the meanders of the study area in 1952 was 328.3 m, this average decreased in the years after the construction of the High Dam (1984, 2000 and 2022) to be 243.1 m, 197.7 m and 195.8 m, respectively.
- The islands play a dual role in determining the width of the channel. Before the construction of the High Dam, and with a large volume of discharge and an abundance of sediments, the river

is capable of eroding its banks and widening its course, this appears from the 1952 maps in the influence of the cannel's width on the islands' locations. After the construction of the High Dam, the volume of drainage and the sediments carried by the water decreased as a result of the partial and then total control of the river's water. The river's energy and ability to erode its two opposite banks to the islands decreased (Fig.7), and with some human interventions in Backfilling of the secondary channels, some islands merged with the floodplain, which led to a decrease in the width of the channel in these places. (Fig.6) and (Fig.8).

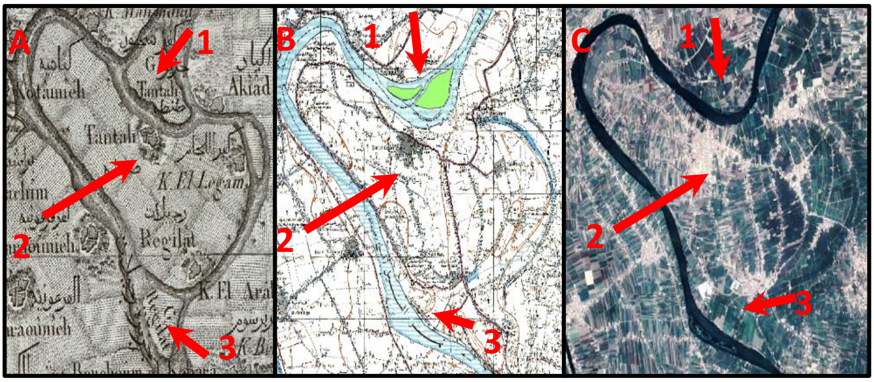
of meanders in the Table (5) the average width of the channel .study area (m), period 1952: 2022

	Meander No.								
	1	2	3	4	5	6	7	8	Average
1952	288.3	300.7	-	301.6	260.1	490.8			328.3
1984	211.5	240.9	-	209.3	213.5	255.3	315.6	255.4	243.1
2000	190.7	203.2	-	191.3	194.5	186.2	205.4	209.4	197.7
2022	189.2	201.9	-	188.7	193.8	184.7	203.5	208.7	195.8

Source: Measured from topographic maps scale ١:٢٥٠٠٠ enhanced editions in ١٩٥٢ and Landsat images for 5 TM in 1984, 7 ETM in 2000 and 9 OLI/TIRS in 2022 .

Fig.7 Decreased water level in the western stream northwest of Ramlh Island.

*Note the merging of some modern islands into the floodplain

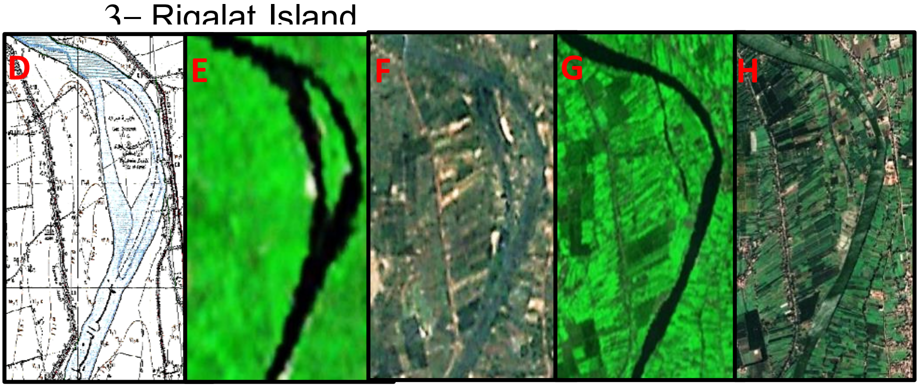


1798: 1952 2022

1- Bein El-Bahrein El-Kebera and Bein El-

2- Tant Al-Jazira

3- Rigalat Island



2°19 1972 1984 2000 2022

Sarawa

Source:

French campaign maps of Egypt at a scale of A from 1:100,000 for the year 1798: 1801.

١:٢٥٠٠٠topographic maps scale B and D from ١٩٥٢enhanced editions in

E from image us geological survey 1972

F from Landsat images 5 TM, 1984.

G from G from Landsat images 7
ETM, 2000.
C and H from Landsat images 9
OLI/TIRS, 2022.
the merger Fig.8. Width of meander channels affected by of the islands into the floodplains.

4.2.4 Meanders' Radius of curvature

Radius of curvature (r) is a measure of size by fitting circles to individual meander bends, Hooke (2013). Table 6 shows the values of Meanders' Radius of curvature in meters. From it, the following is clear:

Table 6; the values of Meanders' Radius of .curvature in the study area (m), period 1952: 2022

	Meander No.								Average
	1	2	3	4	5	6	7	8	
1952	1318	750		912	840	507			865.4
1984	1305	749		796	832	468	210	487	692.4
2000	1301	749		789	832	466	208	482	689.6
2022	1294	749	-	787	833	465	207	481	688.0

١:٢٥٠٠٠topographic maps scale Measured from:Source and Landsat images for 5 TM in ١٩٥٢enhanced editions in 1984, 7 ETM in 2000 and 9 OLI/TIRS in 2022 .

- The radius of curvature in the study area ranged between 865.4 m in 1952 and 688 m in 2022. This is due to the emergence of modern meanders in the period following the construction of the High Dam, namely meanders 7 and 8, which affected the calculation of the average radius of curvature in the total meanders.
- The radius of curvature is affected by the Meander's length, as the relationship between the length of each meander and the value of its curvature radius is strong positive relationship that ranged between 0.73 and 0.987.

4.2.5 Sinuosity index

Sinuosity is typically discussed as a consequence of channel migration processes in meandering rivers (1–9), where flow through a channel with modifiable boundaries and a curved planform sets up internal flow instabilities that drive spatial patterns of bank erosion and accretion, which change planform curvature (Lazarus and Constantine 2013). Generally stream sinuosity indexes are usually derived by dividing the length of a reach as measured along a channel by the length of a reach as measured along a valley (Muller, 1968).

The channel pattern can be classified in terms of Sinuosity index as shown in Table 7.

Table 7: Classification of Channel Pattern in terms of Sinuosity Index

Type	Sinuosity
Straight	< 1.05
sinuous	1.05 : 1.5
meandering	> 1.5 : 2
anastomosing	> 2

Source: Morisawa, 1985, p.91

Table (8) shows Meanders' Sinuosity values in study area. From 1952 to 2022, the following was found:

Table 8: Meanders' Sinuosity values in the study area (1952–2022)

	Meander No.								Average
	1	2	3	4	5	6	7	8	
1952	1.2	12.2	-	2.6	1.5	1.1			3.7
1984	1.3	12.5	-	3.5	1.4	1.6	1.6	1.3	3.3
2000	1.3	12.7	-	3.8	1.5	1.6	1.6	1.3	3.4
2022	1.3	12.7	-	3.7	1.4	1.5	1.6	1.3	3.4

١:٢٥٠٠٠topographic maps scale Measured from:Source and Landsat images for 5 TM in ١٩٥٢enhanced editions in 1984, 7 ETM in 2000 and 9 OLI/TIRS in 2022 .

- The average of Sinuosity values for the studied meanders was 3.8 for the year 1952, 3.3 for the year 1984 and 3.4 for the years 2000 and 2022. However, it should be noted that these values should not be relied on in describing the studied meanders, as this rate was affected by an anomaly value for meander No. 2, which is approximately four times the largest of the other values.
- Most of the meanders in the study area belong to the sinuous and meandering types, except for meanders 2 and 4, which belong to anastomosing type.

- In general, it can be observed that the Sinuosity values increased from 1952 to 2022, except for meanders No. 5 and 6. This is due to the merging of some islands into the floodplain , in addition to an increase in the erosion rate on the concave side of the meander.

5- Results

5.1 Erosion and sedimentation dynamics

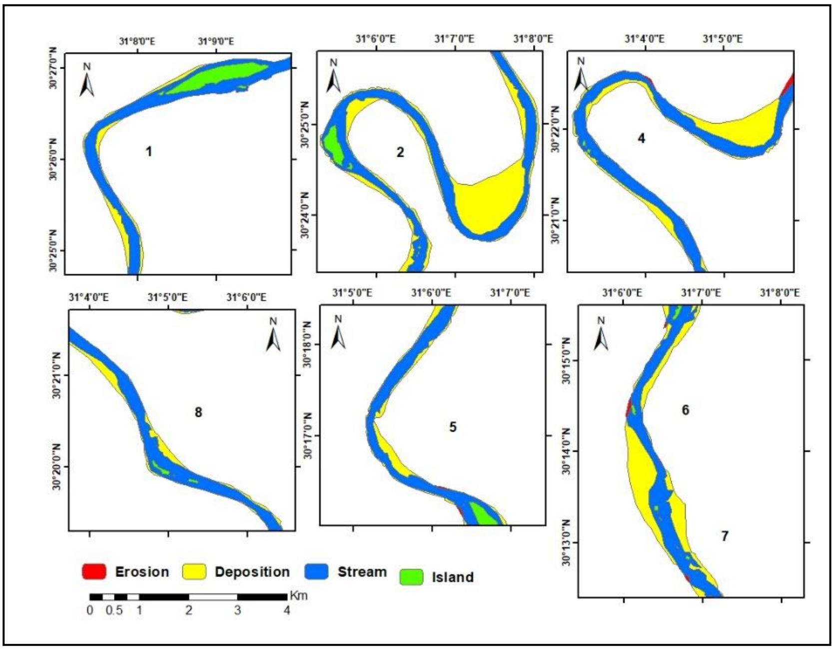
The dynamics of erosion and sedimentation is one of the clearest manifestations of morphological change in rivers. The processes of erosion and anchorage are divided into two types, horizontal and vertical. Here we are interested in studying the effect of the two patterns on the morphology of the Damietta branch in the study area.

5.1.1 Horizontal erosion and sedimentation dynamics

The comparison was made between two successive periods, :as follows

- **1952–1984**

This period was characterized by the predominance of sedimentation processes, and it is considered the most obvious period of morphological change in the study area, as it is the transitional period between before the construction of the Aswan High Dam and after its construction, in addition to reaching the stage of total control of the river water, so the sedimentation process prevails over the erosion process (Fig. 9), where the area added to the flood plain - sedimentation area - reached 8,676 square meters as the water receded from the shallow areas near the banks, which led to its appearance as part of the flood plain, while the rate of erosion was 1,136 square meters.

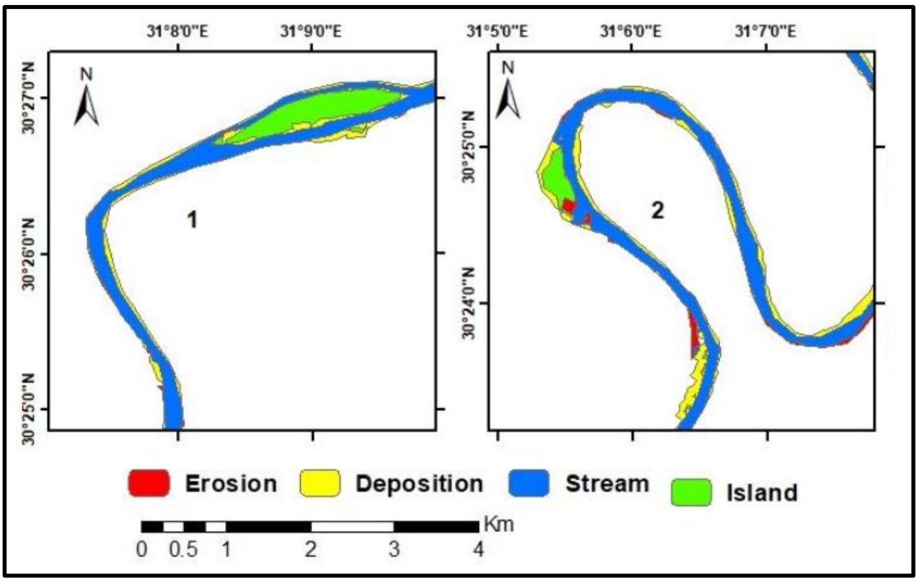


١:٢٥٠٠٠topographic maps scale Source:
and Landsat images ١٩٥٢enhanced editions in
for 5 TM in 1984.

Horizontal erosion and sedimentation Fig.9.
4.١٩٨in the study area, the period of 1952:

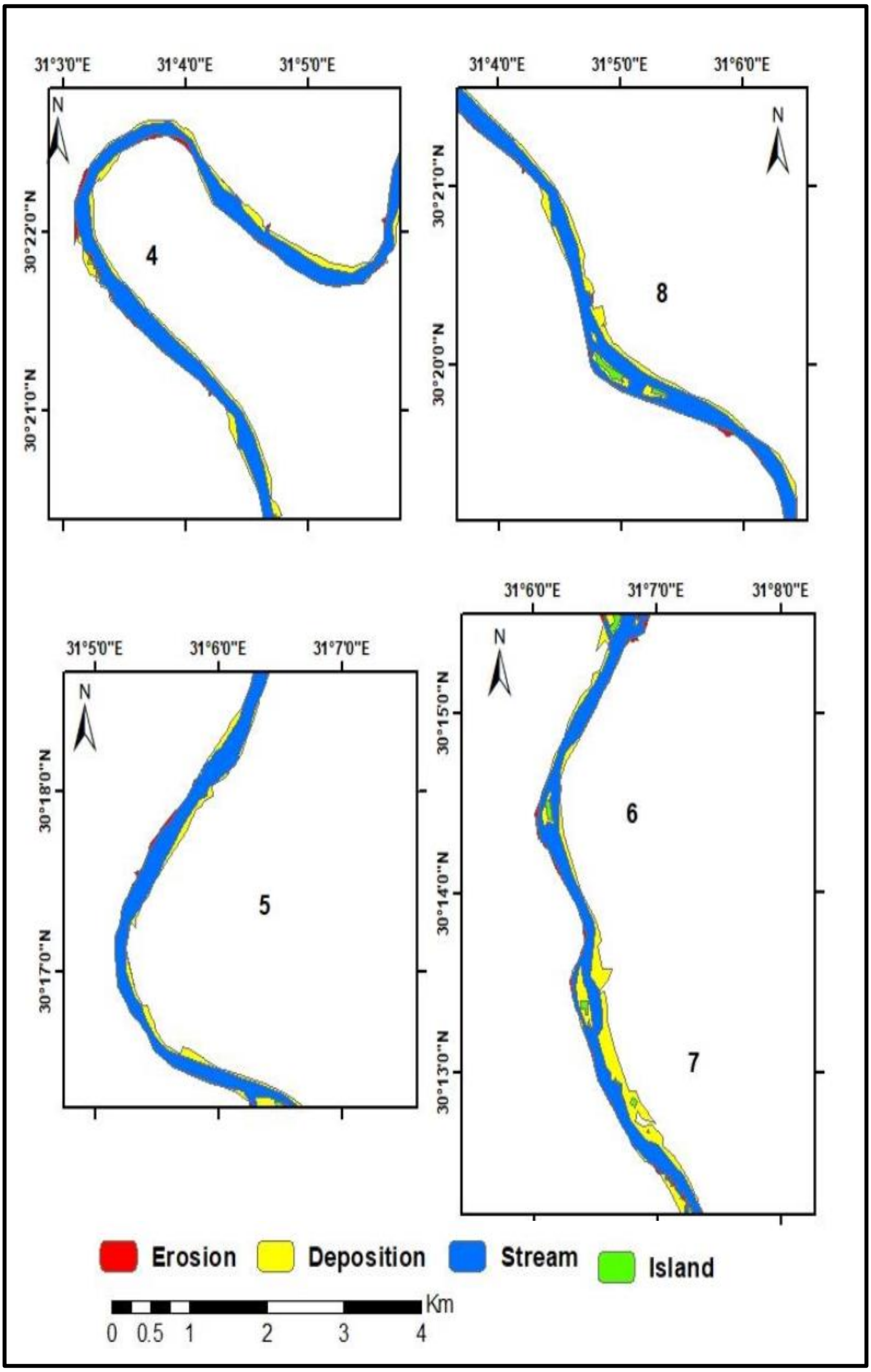
- **1984–2000**

During this period, sedimentation conditions continued to prevail, but less severely than the period preceding (Fig. 10), where the sedimentation rate reached 3245 square meters while the erosion rate decreased to 605 square meters due to the decrease in water revenue in the Damietta branch as a result of the total control of the Nile water in Egypt and the inability of the river to erosion especially near its mouth, , as this period was characterized by an increase in the rate of sedimentation around the islands, as well as the concentration of sedimentation on the eastern side of the Damietta branch.



Landsat images for 5 TM in 1984 and Source: 7 ETM in 2000.

Fig.10.a. Horizontal erosion and sedimentation in the study area, the period of 1984:2000

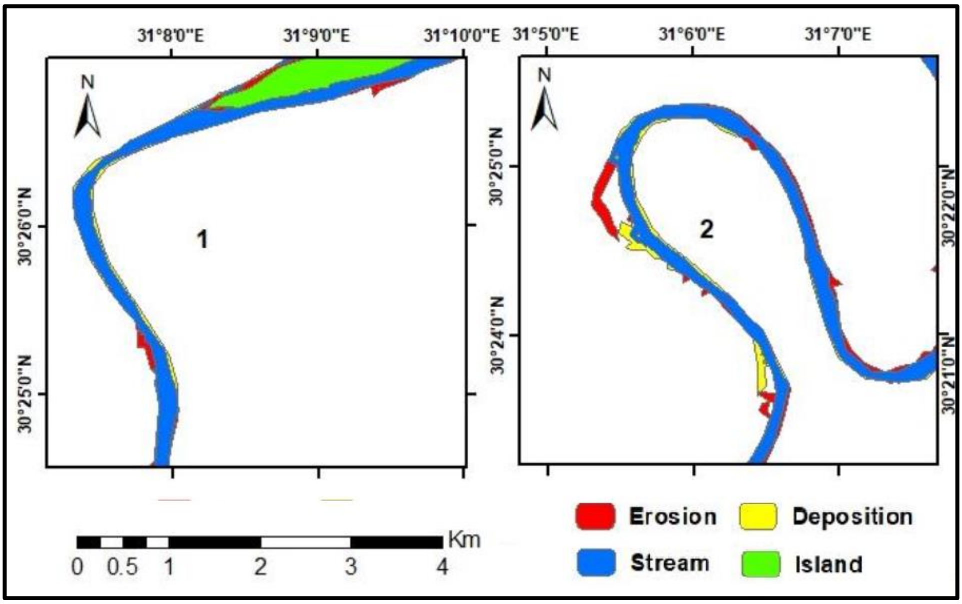

31°3'0"E
31°4'0"E
31°5'0"E
30°22'0"N
30°21'0"N
4
31°4'0"E
31°5'0"E
31°6'0"E
30°21'0"N
30°20'0"N
8
31°5'0"E
31°6'0"E
31°7'0"E
30°18'0"N
30°17'0"N
5
31°6'0"E
31°7'0"E
31°8'0"E
30°15'0"N
30°14'0"N
30°13'0"N
6
7
N
Erosion
Deposition
Stream
Island
Km
0 0.5 1 2 3 4

Landsat images for 5 TM in 1984 and Source:
7 ETM in 2000.

Fig.10.b. Horizontal erosion and sedimentation in the study area, the period of 1984:2000

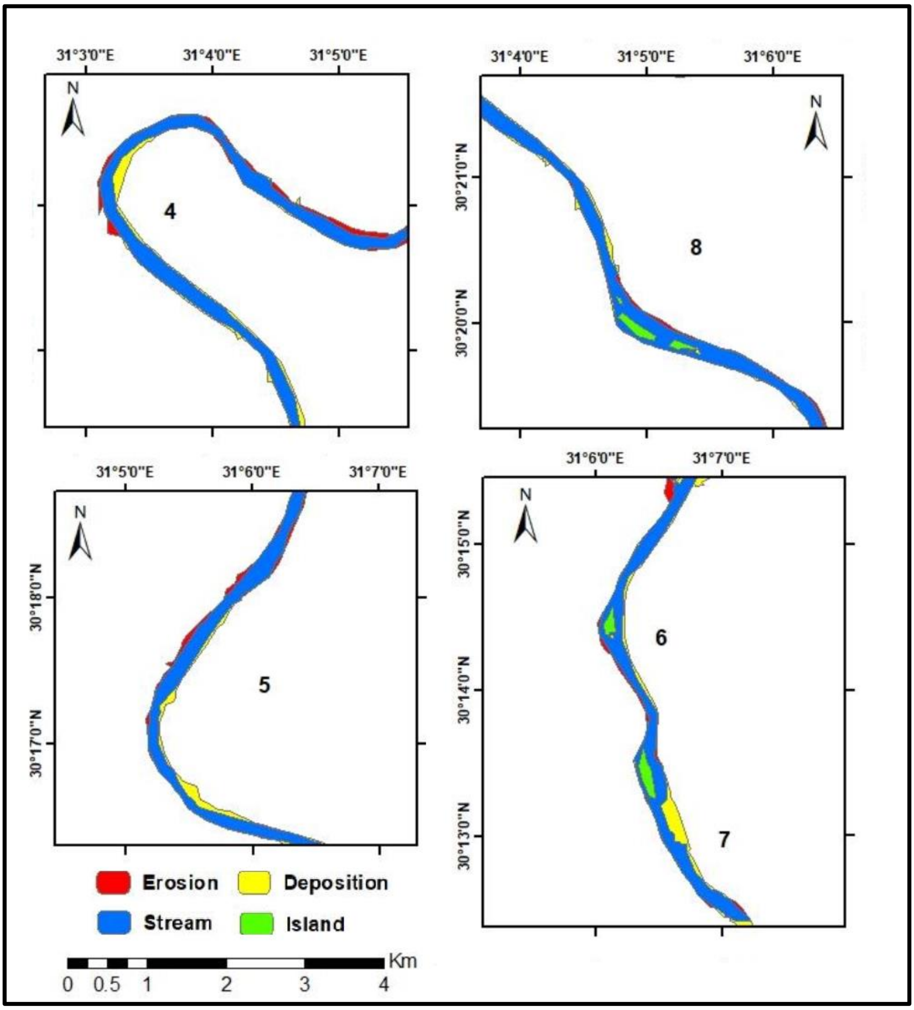
- **2000–2022**

This period is characterized by a balance between the erosion and sedimentation processes, where the sedimentation rate was 1559 square meters, while the erosion rate was 1250 square meters (Fig. 11). This balance is due to passing the period of scarce floods which drained nearly 70 billion between 1979 and 1987 cubic meters of Lake Nasser's reservoir, followed by an attempt to compensate for the loss of lake water by increasing the storage rate until the period of high floods between 1998 and 2002, when large quantities of water were pumped into the river to absorb those floods as well as the 2016 floods and the period of high floods In 2020 and 2021, all of this led to a relative balance between the erosion and sedimentation processes



Landsat images for 5 TM in 1984 Source:
and 9 OLI/TIRS in 2022.

Horizontal erosion and Fig.11.a.
sedimentation in the study area, the period of 2000:2022.



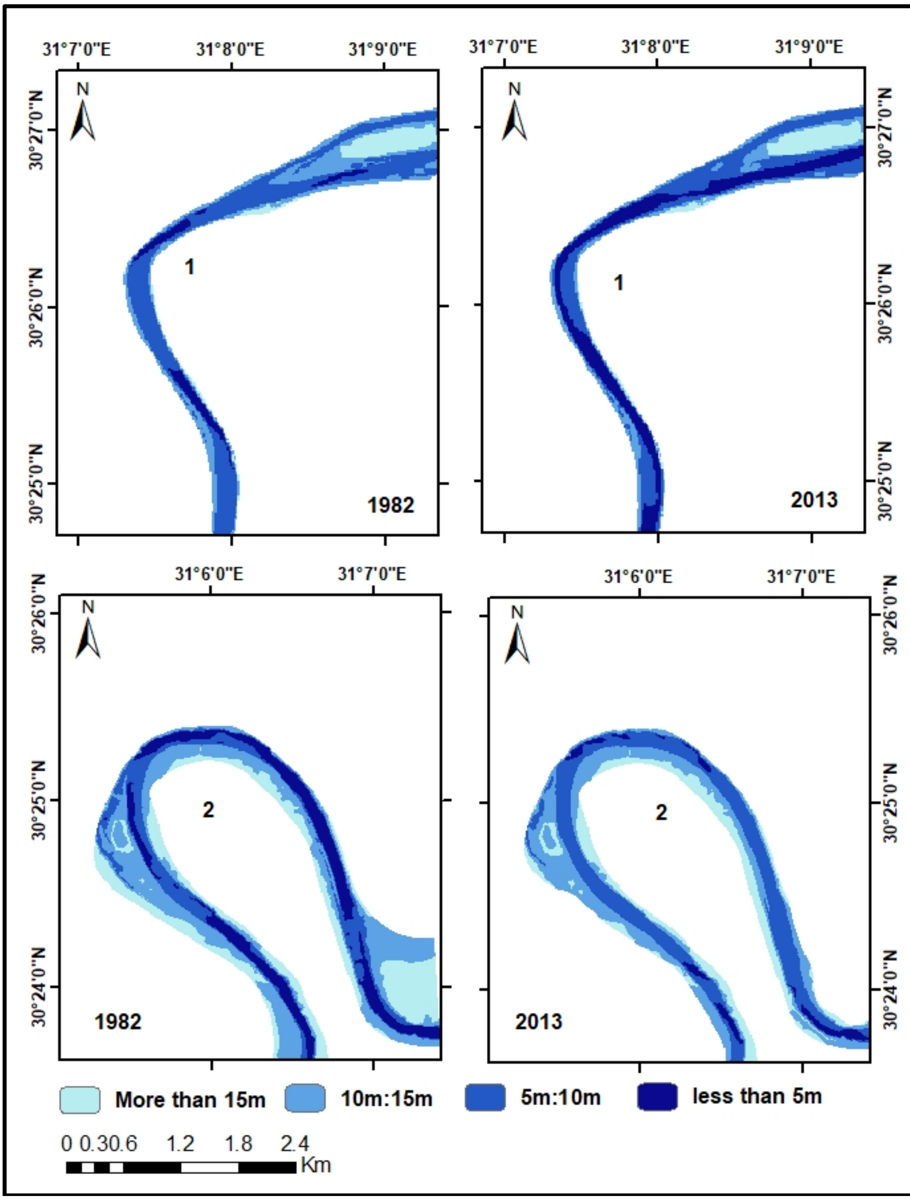
Landsat images for 5 TM in 1984 and Source:
9 OLI/TIRS in 2022.
Horizontal erosion and Fig.11.b.
sedimentation in the study area, **the period of**
2000:**2022**.

5.1.2 vertical erosion and sedimentation dynamics

The hydrotopographical maps for the years 1982 and 2013 were relied upon in the study of vertical erosion and sedimentation of the meanders in the study area using the digital elevation maps method (Fig. 12), where it possible to calculate the areas of the elevation categories for the two years under study (Table 9), and then the possibility of identifying the supremacy of one process over the other and its impact on the morphology of the meanders.

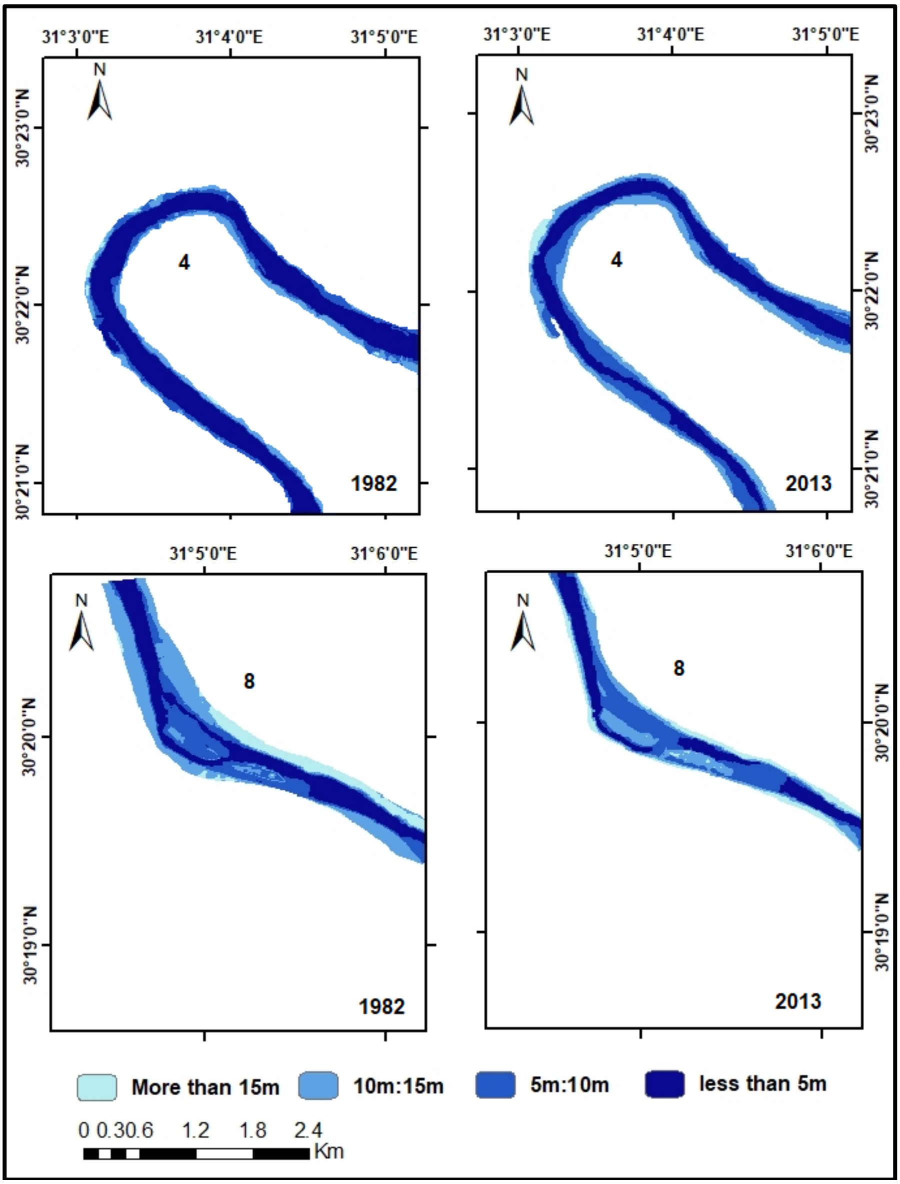
From Figure 12 and Table 9, it becomes clear that:

- Between 1982 and 2013, the area occupied by the elevation category (<5m) decreased in all studied meanders.
- In 1982, the percentage of the second and third categories combined ranged between 58.7% and 70.3%, and this percentage increased in 2013 to range between 83.5% and 89.4%.
- Between 1982 and 2013, the area occupied by the elevation category (>5 m) decreased in all studied meanders. This is not due to the vertical erosion process, either due to the merger of some islands with the floodplain, which represented the main strength of this category.



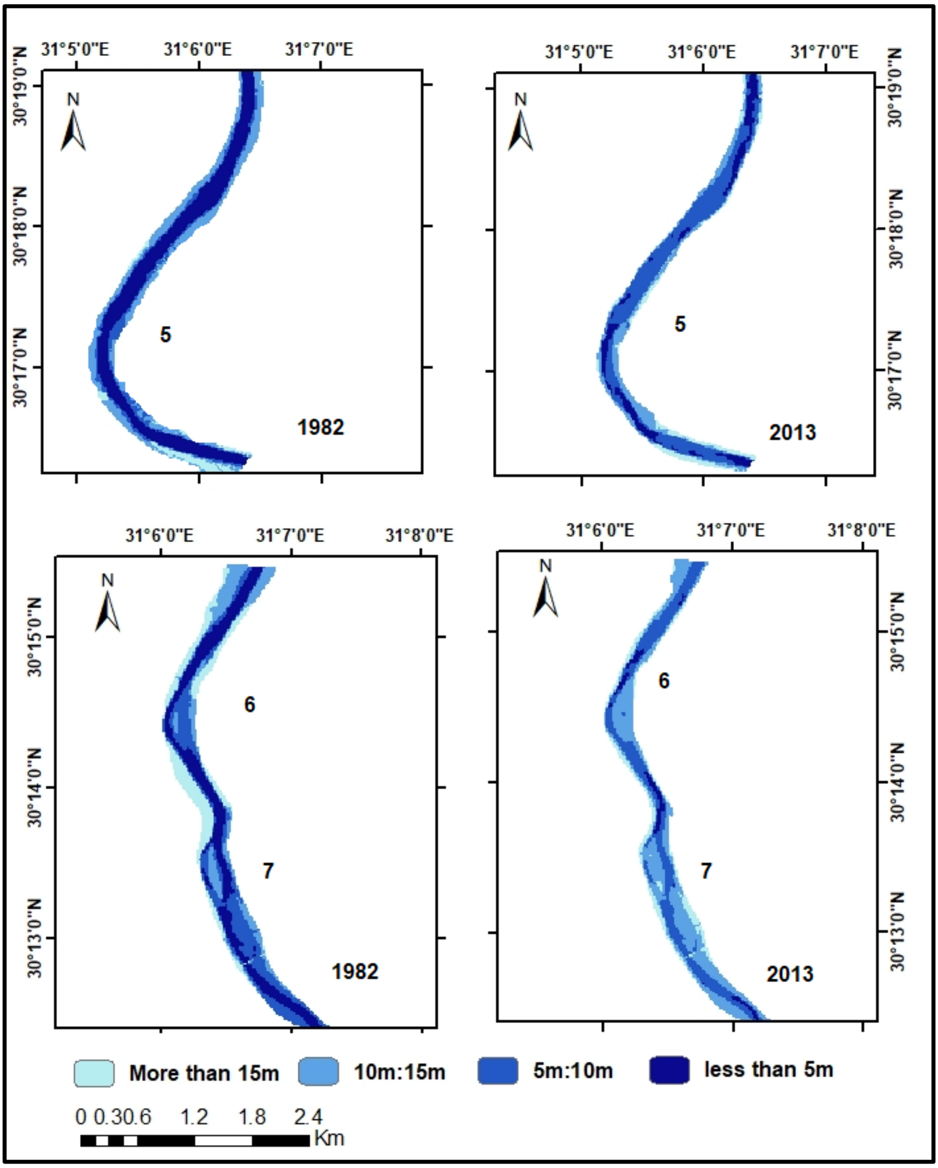
Source: Hydrotopographic maps scale1:5000, 1982 and 2013.

Fig.12.a. digital elevation maps of meanders in the study area.



Source: Hydrotopographic maps scale1:5000, 1982 and 2013.

digital elevation maps of meanders in the Fig.12.b. study area.



Source: Hydrotopographic maps scale1:5000, 1982 and 2013.

Fig.12.c. digital elevation maps of meanders in the study area.

It is clear from the previous presentation that the vertical sedimentation process prevails in the meanders of the study area. This is consistent with the hydrological, morphometric and hydrotopographical characteristics of the Nile River in the study area.

Table 9 Percentages of the studied meanders elevation categories.

	<5m		5:10m		10:15		15 m>	
Meanders No.	2013	1982	2013	1982	2013	1982	2013	1982
1	7.1	19.1	50.6	42.5	30.2	27.9	12.1	10.6
2	3.1	17.6	57.8	46.3	31.6	22.0	7.5	14.1
3	-	-	-	-		-	-	-
4	21.4	29.8	53.4	44.9	23.9	23.1	1.3	2.2
5	9.4	34.5	49.4	29.3	35.4	29.4	5.8	6.8
6 and 7	7.8	18.4	44.1	33.8	40.0	32.5	8.1	15.3
8	13.9	24.2	46.1	37.3	37.4	26.9	2.6	11.6

Measured from Hydrotopographic maps :Source scale1:5000, 1982 and 2013.

5.2 The Correlations between morphometric characteristics of meanders

From the study of the correlations between the morphological characteristics of meanders (Table 10), it is possible to divide them into three categories as follows:

Table 10. Correlations matrix between the morphological characteristics of meanders

		Length	Axis_Length	Width	Radius	Sinuosity
Pearson Correlation	Length	1.000	.453	-.426	.883	.216
	Axis_Length	.453	1.000	-.246	.620	-.651
	Width	-.426	-.246	1.000	-.525	.014
	Radius	.883	.620	-.525	1.000	.079
	Sinuosity	.216	-.651	.014	.079	1.000

The analysis was carried out using IBM SPSS version 25.

- Weak correlations

Weak correlations represent 40% of the total correlations between variables, which are the correlation between axis length and radius of curvature (-.25), the correlation between meander length and sinuosity (+.22), the correlation between meander width and Sinuosity (+.14), and the correlation between radius of curvature and Sinuosity (+.08).

- Moderate correlations

Moderate correlations represent 20% of the total correlations between variables, which are the correlation between the axis length and on the other hand the length and the width of meanders, respectively (+.45) and (-.43).

- **Strong correlation**

Strong correlations represent 40% of the total correlations between variables, where the correlations between the curvature radius and the rest of the variables were strong in addition to the correlations between axis length and sinuosity

Multiple regression models (Backward) were used to find the most influential variables on the meanders morphology (Table 11).

Table 11 Multiple regression model Coefficients

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	T	Sig.	Correlations Zero – order	Correlations Partial	Correlations Part
1	(Constant)	1.050	10.999		.095	.933			
	Axis_Length	.043	1.082	.039	.040	.972	.453	.028	.013
	Width	3.816	44.959	.034	.085	.940	–.426	.060	.027
	Radius	6.064	5.839	.863	1.039	.408	.883	.592	.326
	Sinuosity	.103	.454	.173	.227	.842	.216	.158	.071

2	(Constant)	.948	8.743		.108	.920			
	Width	4.533	33.696	.041	.135	.902	-.426	.077	.034
	Radius	6.274	2.127	.893	2.950	.060	.883	.862	.756
	Sinuosity	.086	.153	.145	.565	.612	.216	.310	.145
3	(Constant)	2.109	1.250		1.686	.167			
	Radius	6.123	1.569	.872	3.902	.018	.883	.890	.869
	Sinuosity	.088	.133	.148	.661	.544	.216	.314	.147
4	(Constant)	2.340	1.131		2.069	.093			
	Radius	6.205	1.474	.883	4.211	.008	.883	.883	.883

The analysis was carried out using IBM SPSS version 25.

From the table it is clear that the most influential variable on the morphology of the meanders is the radius of curvature, where the p-value of 0.008 is less than the acceptable alpha level of 0.05, meaning the correlation is statistically significant.

5.3 Meanders migration

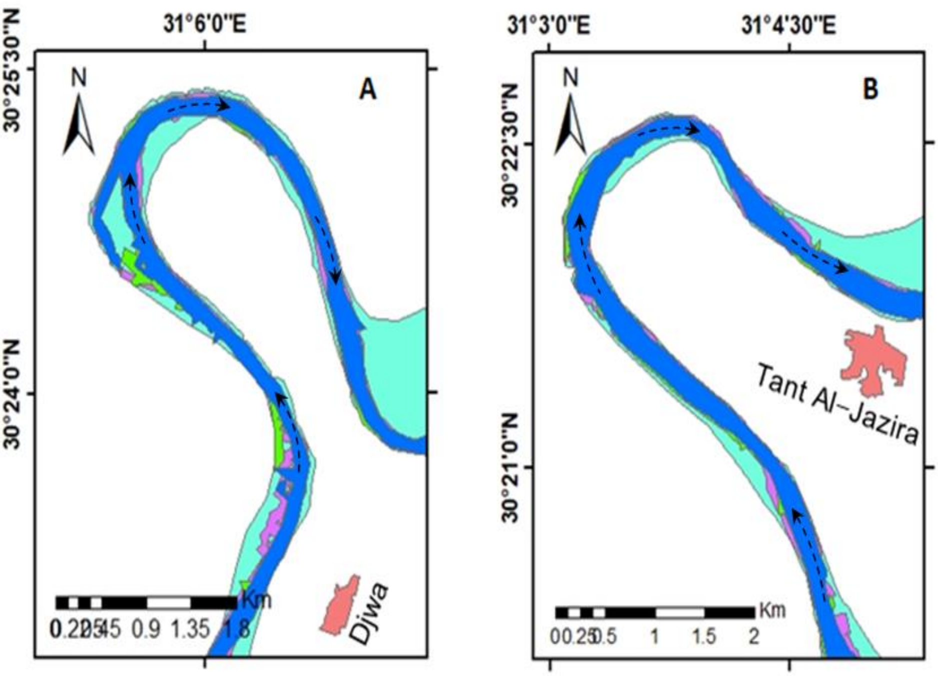
The impact of the construction of the Aswan High Dam significantly on the morphology of the Damietta branch's meanders, especially in the study area, where the discrepancy in the volume of drainage as well as the amount of sediments load, which in turn act as erosion shovels, led to a noticeable change in the morphometric and morphological characteristics of the meanders. In general, these changes are reflected in the meanders migration, where two types of meanders migration can be distinguished in the study area are advanced rotation meanders and lateral extension meanders:

5.3.1 Advanced rotation meanders

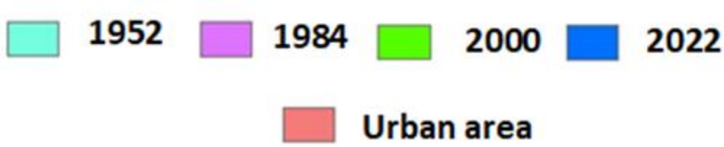
While the concave bank is subjected to a higher rate of erosion, the convex bank has more sedimentation processes, if the concave bank is towards the downstream, then with time the meander takes the form of advanced rotation meanders. These meanders are characterized by advancing downstream with a on the convex bank of the meander deposition obvious (Morisawa, 1985).

The study area includes only two meanders belonging to the advanced rotation meanders pattern are El-Atf and Tant Al-Jajira meanders as shown in (Fig.13) and (Fig.14).

Fig.13. Erosion on the western bank (concave) of Tana Al-Jazira meander.



B- Tana Al- A- El-Atf meander
Jazira meander



enhanced editions ١:٢٥٠٠٠ topographic maps scale Source: and Landsat images for 5 TM in 1984, 7 ETM in ١٩٥٢in 2000 and 9 OLI/TIRS in 2022.

Fig.14. Advanced rotation meanders in the study area.

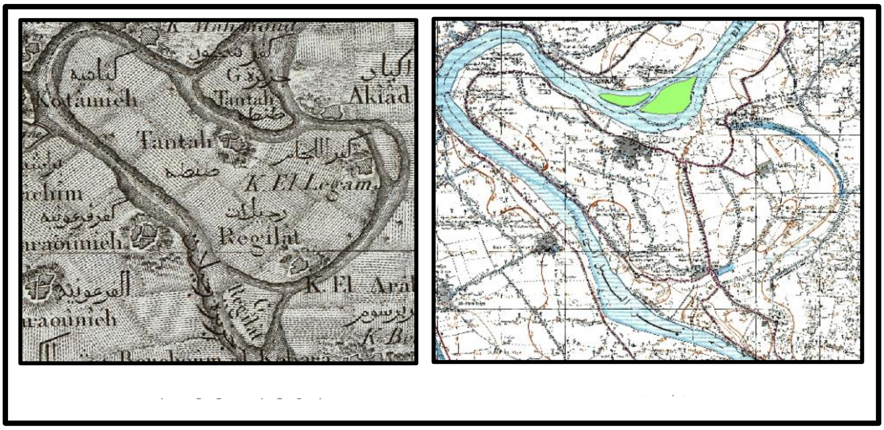
5.4 Lateral extension meanders

The development of Lateral extension meanders was associated with an increase in the rate of erosion on the concave bank and sedimentation on the convex bank in a direction parallel to flow direction.

The rest of meanders in the study area belong to the pattern of Lateral extension meanders, the development of these meanders was linked in the first place for two reasons:

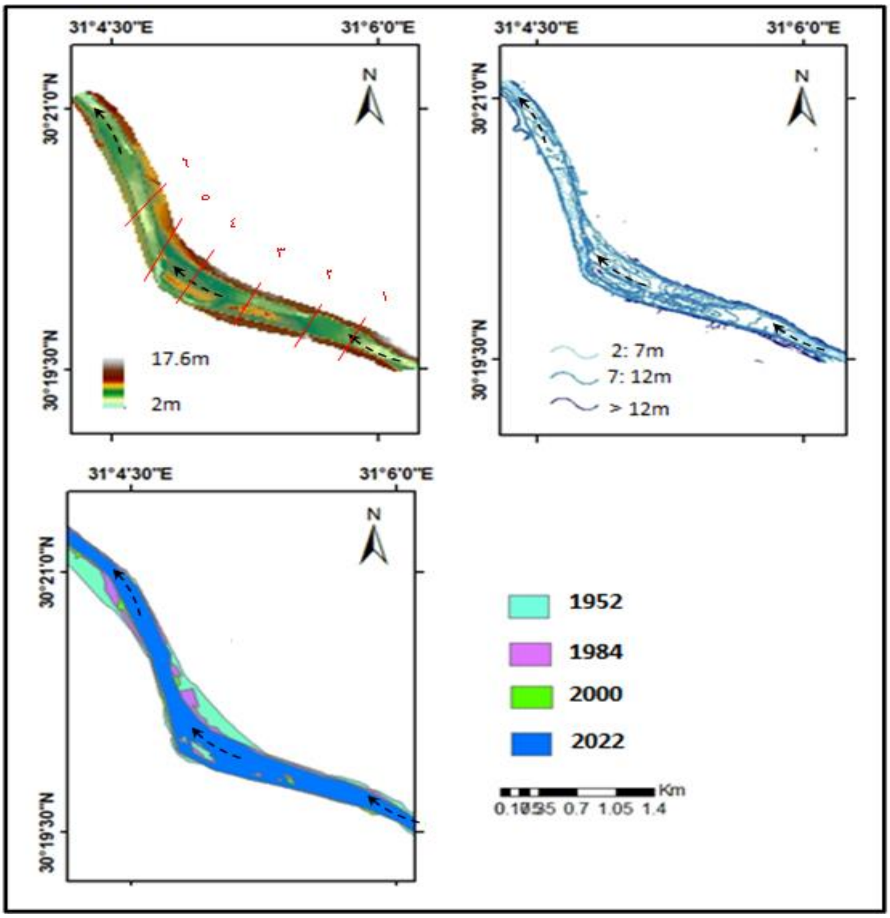
A- The merging of the islands with the floodplain of the convex bank to increase the width of the convex side and the rate of erosion on the concave side, and then the meanders migration in a direction parallel to the flow direction.

B- Local relief: its effect appears in only one meander No. 8, which was affected by the old island of Tant Al-Jazira, which in the past was a high area that the river near its mouth could not cross, so it was divided around the island, during the beginning of the last century, the eastern stream of the river separated from the main stream and the western side of the island becomes the eastern bank of the meander (Fig.15) Also, the western bank of the meander rises from its eastern bank about 1.25 m (Fig.16) and (Fig.17) , for all of the above, the river turned to erosion in the west bank, which led to the emergence of a meander that began to Lateral extension



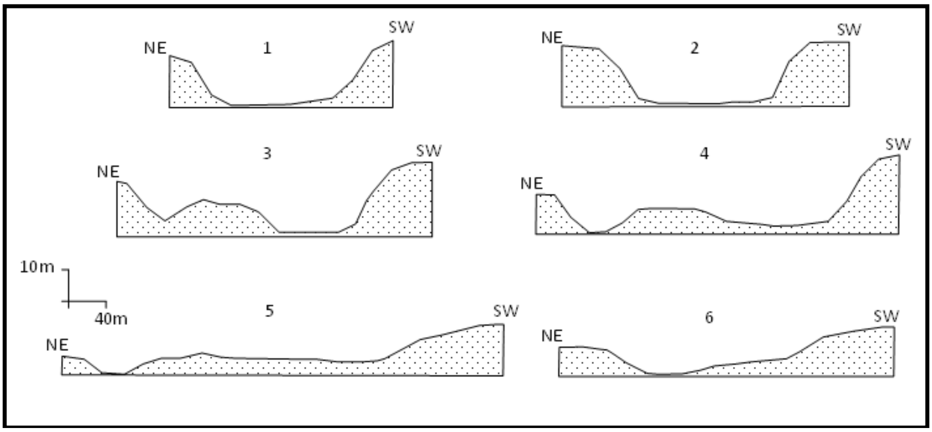
Source: French campaign maps of Egypt at a scale of 1:100,000 for the year 1798: 1801, and topographic maps ١٩٥٢ enhanced editions in ١:٢٥٠٠٠ scale.

Fig.15 The old island of Tant Al-Jazira



Source: Hydrotopographic maps scale1:5000, 2013, ١٩٥٢ enhanced editions in ١:٢٥٠٠٠topographic maps scale and Landsat images for 5 TM in 1984, 7 ETM in 2000 and 9 OLI/TIRS in 2022 .

Fig.16 the effect of local relief on the development of Meander No. 8



Source: Hydrotopographic maps scale1:5000, 2013

No. 8 Fig.17 Cross-sections on meander

Conclusion

outcomes of the current study indicate that The morphology of the meanders in the study area is primarily affected by the construction of the Aswan High Dam, which affected the hydrological and morphological characteristics of the Nile River in Egypt in general, the effectiveness of this effect increases as we head towards the estuary, where the volume of the river's discharge, its velocity and its ability to erosion decreases and tends to meander. Those hydrological and morphometric characteristics that the river acquired in the study area after the construction of the Aswan High Dam led to the dominance of the vertical and horizontal sedimentation process.

By using Multiple regression models (Backward), it is clear that the most influential variable on the morphology of the

meanders is the radius of curvature, there is a statistically significant relationship where the p-value of 0.008 is less than the acceptable alpha level of 0.05.

In general, these changes are reflected in the meanders migration, where two types of meanders migration can be distinguished in the study area are advanced rotation meanders and lateral extension meanders

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