The Impact of Spur Dikes on the Dynamics of Erosion and Deposition Processes in the Nile River in Abnub Area: A Study in Engineering Geomorphology Using Artificial Intelligence

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Abstract

Spur dikes are one the most important factors affecting the degree of activity of the erosion and deposition processes, particularly the vertical at the Nile streambed. In order to study the mutual relations between them, the study relies on the environmental systems approach using artificial intelligence techniques to produce 1D, 2D, 3D maps. The study's inputs are classified into main ones such as characteristics of spur dikes, DEM, topographic maps, and satellite images; and secondary ones such as hydrological and mechanical characteristics of the Nile streambed sediments, through which it is possible to understand many of the ambiguities in the occurrence of geomorphological changes and try to reach the best suitable spur dikes to protect the banks from the erosion process.This is conducted by application to the Nile stream in the Abnub area, due to the spread of many spur dikes in their various shapes. In addition, they play a major role in the occurrence of vertical and horizontal geomorphological changes, and result in the spread of many phenomena including scour holes, sandbars, and swamps. Above all, spur dikes have proven effective in protecting the banks from the erosion process, and thus have achieved their intended aim.

Keywords: Spur dikes, erosion, deposition, scour holes, sandbars.

تأثير الرؤوس الحجرية علي ديناميكية عمليتي النحت والارساب بمجري النيل بمنطقة أبنوب: دراسة في الجيومورفولوجيا الهندسية باستخدام الذكاء الاصطناعي

أ.د. أحمد إبراهيم محمد صابر(1)، د. هويدا توفيق أحمد حسن(2)

مستخلص

تعد الرؤوس الحجرية من أهم العوامل المؤثرة في درجة نشاط عمليتي النحت والإرساب وخاصةً الرأسي بقاع مجرى النيل. ولدراسة العلاقات المتبادلة بينهما اعتمدت الدراسة على منهج النظم البيئية باستخدام تقنيات الذكاء الاصطناعي في إنتاج خرائط أحادية وثنائية وثلاثية الأبعاد، وقد تم تصنيف مدخلات الدراسة إلى رئيسية، مثل: خصائص الرؤوس الحجرية وDEM وخرائط طبوغرافية ومرئيات فضائية، ومدخلات ثانوية، مثل: الخصائص الهيدرولوجية والميكانيكية لرواسب قاع مجرى النيل، والتي يمكن عن طريقها تفهم الكثير من الغموض في حدوث التغيرات الجيومورفولوجية ومحاولة الوصول إلى أفضل الرؤوس الحجرية ملائمة لحماية الضفاف من عملية النحت. وذلك بالتطبيق على مجرى النيل بمنطقة أبنوب، وذلك لانتشار العديد من الرؤوس الحجرية بأشكالها المختلفة، كما أن لها دورًا كبيرًا في حدوث التغيرات الجيومورفولوجية الرأسية والأفقية وانتشار العديد من الظاهرات الناتجة عنها، مثل: حفر انجراف، وحواجز رملية، ومستنقعات، كما أثبتت الرؤوس الحجرية فاعليتها في حماية الضفاف من عملية النحت، وبذلك فقد حققت الهدف المنوط بها.

الكلمات المفتاحية: الرؤوس الحجرية، النحت، الإرساب، حفر انجراف، حواجز رملية.

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1. Introduction

Spur dikes (also known as groins) are considered a means of protection that are widely used in controlling local erosion in rivers, as they help protect the banks due to reducing the flow velocity near them (Yang et al., 2022). In contrast, the flow is strong and turbulent around the spur dikes, causing a change in the direction and pattern of flow. That is, the velocity increases, producing large vortices, which in turn leads to the occurrence of local erosion around them as well as the emergence of the most important erosion phenomenon, which is scour holes (Han et al., 2022). However, the flow velocity after collision with the spur dike converts kinetic energy into potential energy. In addition, the pressure difference resulting from this sudden change leads to creation of a low-velocity flow current in the opposite direction to the main flow behind the spur dike, which increases local deposition and creates the most important deposition phenomenon, which is sandbars (Giglou et al., 2018).

Moreover, the spur dikes are built separately or in groups according to the requirements and characteristics of each site. They are widely used in meandering channels in order to control the erosion of concave banks, as flow characteristics change in direction and velocity. Therefore, when designing spur dikes, it should be taken into account in choosing their angles, morphomteric characteristics and the distances between them that they are consistent with the hydrological and morphological conditions of the bank to be protected from ersosion, in order for them to perform their intended role.

2. Sources and Methodology of the Study

2.1. Previous Studies

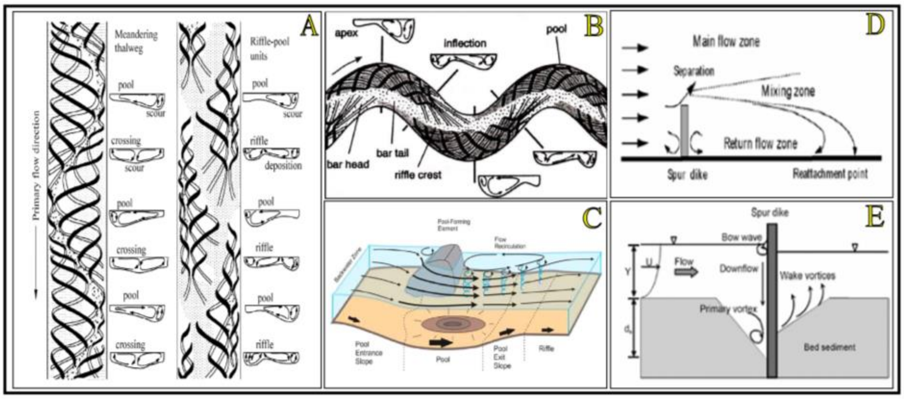
The Arab Geographical Library lacks a detailed study of this topic, so the current study is the first geographical study to address spur dikes as a means of protection and as a factor affecting the dynamics of the erosion and deposition processes in detail. Nevertheless, there have been many engineering studies that have dealt with this relation, some of which have used mathematical models or laboratory experiments. Instances of these studies include the studies of Kadota and Suzuki (2010), Alauddin et al. (2011), Zhang et al. (2012),),Masjedi and Foroushani, (2012). Kuhnle and Alonso (2013), Ibrahim (2014), Basser et al. (2015), Elsaeed et al. (2015), Giglou et al. (2018), Inamdeen et al. (2021), Atarodi et al. (2021), Esmaeli et al. (2022), Han et al. (2022), Saber (2023), and Saber and Hassan (2023).

These studies have reached many results that illustrate the interaction relations between the spur dikes and the erosion and deposition processes so as to understand the occurrence of geomorphological changes in the stream. This is mainly in order to apply their results and methodology, or compare them with the study area. The following are the most significant results:

- The flow characteristics change significantly, as secondary currents are formed as a result of the flow disturbances that occur at the bends of the river. In addition, vortices (helical currents) are formed, and water accumulates on the concave side of the bend, resulting in complex currents that carry sediments and move them towards the convex side of the bend. These Secondary currents cause high velocity and shear stress on the concave side of the banks, which in turn enhances the erosion (Figure1/A-B).
- Local erosion is a type of erosion that is commonly observed around hydraulic blockage, particularly spur dikes and bridges.
- Local scour results directly from the impact of the spur dike on the local flow pattern. The flow past the spur dike may be divided into three zones: a main flow zone from the head of the spur dike to the opposite side of the channel, a wake zone behind the spur dike and a mixing zone in-between them (Figure1/C-D).
- Constructing spur dikes against approaching flow stream results in hydrostatic pressure's change upstream and

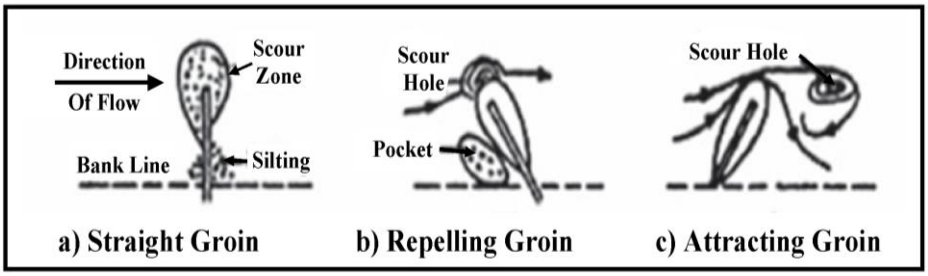
downstream of the structure, and this causes a complicated vortex area. These complicated vortex areas, which produce large vortices at the head of the spur dikes, provide the principle local scour mechanism. The mentioned local scour may jeopardize the safety of the structure and eventually lead structural failure (Figure1/E).

- The locations of the scour holes vary depending on the shape of the spur dike. It is found that the straight groin results in a scour hole directly in front of it, the attracting groin results in a scour hole located to its right, and the repelling groin results in a scour hole located to its left (Figure 2).



Source: Masjedi and Foroushani (2012), Basser et al. (2015), Wang et al. (2015), Haniffa M. (2019), and Rhoads B. (2020).

Figure 1: The Impact of Spur dikes and Meanders on the Characteristics of Water Currents in Rivers



Source: Ibrahim, 2014.

Figure 2: The Impact of the Angles of Spur Dikes on the Places of Scour Holes

- The impact of isolated spur dikes differs from the grouped ones on vertical erosion, as compound, complex and highly complex holes are associated with the grouped dikes. This is natural due to the fact that creating a group of spur dikes at different angles in a certain location makes the movement of flow and sediments more complex owing to the interaction between the different types of these dikes (Han et al., 2022). This, in turn, makes their impact higher in the vertical erosion process. As for the isolated dikes, if they are associated with a bending area in the bend, their impact is no less important than the grouped ones; in many cases, it even exceeds them in the severity of the occurrence of water vortices and vertical erosion.

2.2. Methodology of the Study

The study relies on the environmental systems approach in studying the mutual relations between the characteristics of spur dikes and the characteristics of erosion and deposition, as well as the extent of their impact on the geomorphological changes and phenomena of the stream. In order to achieve this, variables had to be adopted at different time periods using artificial intelligence techniques so as to reach rules and results that explain the relation between them. Variables are classified into the following:

2.2.1. Main Inputs

- A map of the locations of spur dikes is used to derive the morphometric and morphological database for them. It was issued by the Nile Research Institute in 1982, and its characteristics did not change in the 2007 maps.
- A DEM map is derived from maps of the Nile River bed levels issued by the Nile Research Institute in 1982 and 2007 at an appropriate drawing scale of 1:5000 with a contour interval of 0.5 m. It is used in order to know the direct impact

of the relation between the spur dikes and the dynamics of erosion and vertical deposition of the streambed.

- Topographic maps and satellite images, issued at different time periods, are used in order to know the horizontal changes, which are a reflection or result of vertical changes. This is mainly in order to know the indirect impact of the relation between the spur dikes and the dynamics of the horizontal erosion and deposition of the stream.

2.2.2. Secondary Inputs

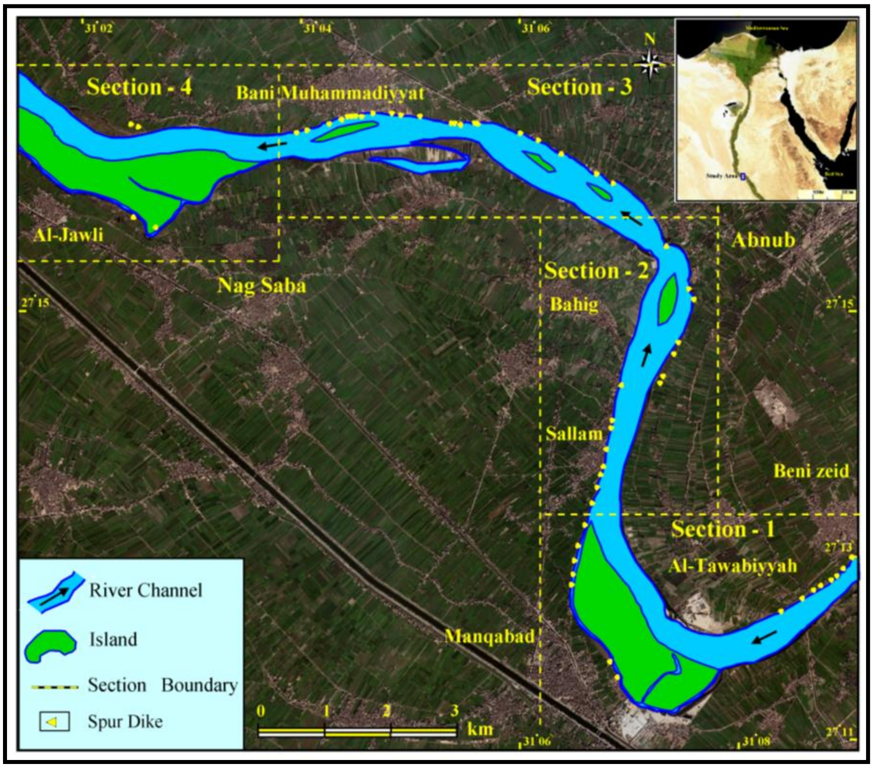
The factors affecting the geomorphology of water stream are numerous and intertwined to a degree that it is not possible to separate the impact of they have on each other. To understand the nature of the processes of erosion and deposition, particularly the vertical and its reflection on the horizontal with high accuracy, a number of secondary variables are identified. The most important of which are the hydrological and mechanical characteristics of the sediments of the Nile stream bed.

3. Objective of the Study

The research aims to conduct a detailed study that is useful in analyzing the relation between the spur dikes with their different morphometric and morphological characteristics, and the dynamics of the vertical and horizontal erosion and deposition processes. Through it, it is possible to understand much of the ambiguity in the occurrence of geomorphological changes and the appearance or disappearance of many phenomena in the water stream. In addition, the study attempts to reach the best suitable spur dikes to protect the banks from the erosion process.

4. Area of the Study

To achieve the objectives of the study, the Nile stream in the Abnub area is chosen. The reason for this is the spread of many spur dikes in different shapes, which also play a major role in the occurrence of vertical and horizontal geomorphological changes resulting from the processes of erosion and deposition. Moreover, the study area is divided into four sections; each section is characterized by morphological characteristics that differ from others in terms of the number, density and angles of the spur dikes and their impact on the processes of vertical erosion and deposition. The length of the Nile stream in 2022 in the study area reached 21 km, namely in the area extending from kilometer 549 to kilometer 570 of the Aswan scale. It extends between latitudes 27° 11´ 45" and 27° 17´ 00" north, and longitudes 31° 01´ 24" and 31° 09´ 05" east (Figure 3).



Source: SAS. Planet.

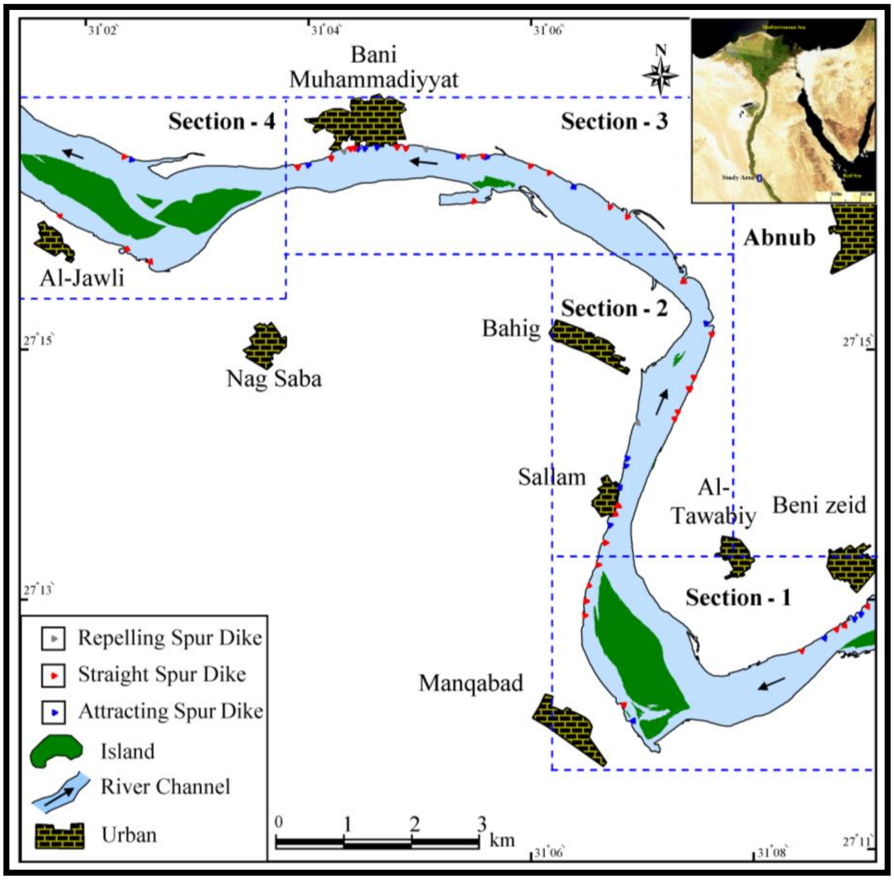
Figure 3: The General Features and Locations of the Study Area

5. Inputs

5.1. Main Inputs

5.1.1. Spur Dikes

The morphometric and morphological characteristics of the spur dikes in the Nile stream in the study area are numerous and varied (Figure 4 and Table 1). In this regard, they have been classified into three shapes: straight, repelling, and attracting. This is mainly for the sake of comparing the impact of each shape on the processes of erosion and deposition, and finding the relations between them and their impact in the geomorphology of the study area.



Source: Hydrotopographic maps, scale 1:5000, 1982.

Figure 4: The Spur Dikes in the Nile River in the Abnub Area

The following facts can be concluded from the analysis of Figure 4 and Table 1:

- The total number of spur dikes in the study area is 56. The third section accounts for the largest number, which is 23 spur dikes representing 41.1% of the total dikes in the study area. It is followed by the first and second sections, with 13 and 15 spur dikes, representing 23.2% and 26.8% respectively. The fourth section came in last place with 5 spur dikes representing 8.9%.
- The East Bank of the stream accounts for the highest percentage of spur dikes, as their number reached 38 spur dikes, representing 67.9%. The third section accounts for the largest number, which is 22 spur dikes representing 57.9% of the total number of spur dikes in the East Bank. Both the first and second sections are equal in terms of the number of dikes on the East Bank, which is 7 spur dikes. The fourth section came in last place with only two dikes.
- The number of dikes on the West Bank reaches 18 dikes, representing 32.1% of the total dikes in the study area. The second section accounts for 8 dikes, representing 44.4% of the total number of dikes created on the West Bank. It is followed by the first section with 6 dikes representing 33.3%, and the third section with one dike. The fourth section has three spur dikes.
- The straight shape (90°) is the dominant shape in all sections (Figure 5/A), as it accounts for 34 spur dikes, representing 60.7% of the total number of dikes in the study area. The third section accounts for 13 dikes of this shape, followed by the second section with 9 dikes, then the first section with 8 dikes, and finally the fourth section with 4 dikes.
- The attracting shape (105° and 150°), (Figure 5/B) comes in second place with 18 spur dikes, representing 32.1% of the total number of dikes in the study area. The third section, once more, accounts for the largest number with 7 dikes, followed by the first and second sections with 5 dikes each, and then the fourth section with one dike.

Table 1: The Morphometric Characteristics of the Spur Dikes in the Nile Stream in the Abnub Area

Spur Dike No.	The Angle Relative to the Direction of the Water Current	Distance from the Previous Dike	Bank	Section No.	Density Spur Dike/m
1	90	0	The East Bank	The First Section	1:927
2	130	164			
3	125	114			
4	90	168			
5	115	144			
6	90	238			
7	105	402			
8	90	6500	The East Bank	The Second Section	1:840
9	90	120			
10	90	380			
11	90	200			
12	90	630			
13	125	130			
14	90	65			
15	90	1200	The East Bank	The Third Section	1:404
16	90	300			
17	130	630			
18	90	400			
19	90	270			
20	125	630			
21	90	50			
22	75	200			
23	90	100			
24	105	50			
25	80	440			
26	90	300			
27	90	140			
28	105	260			
29	105	180			
30	105	100			
31	90	50			
32	90	50			
33	75	100			
34	90	200			
35	115	350			
36	90	150			
37	105	2700	The East Bank	The Fourth Section	1:3078
38	90	100			
39	115	0	The West Bank	The First Section	1:1702
40	90	180			
41	90	1000			
42	90	180			
43	90	170			
44	90	330			
45	90	310	The West Bank	The Second Section	1:781
46	120	260			
47	90	170			
48	90	110			
49	150	315			
50	120	300			
51	120	100			
52	60	200			
53	90	6000	The West Bank	The Third Section	1:8280
54	90	90	The West Bank	The Fourth Section	1:1846
55	90	90			
56	90	90			

Source: It is based on on Figure 4

Density = number of dikes / bank length (m), (water arms are excluded from the length).

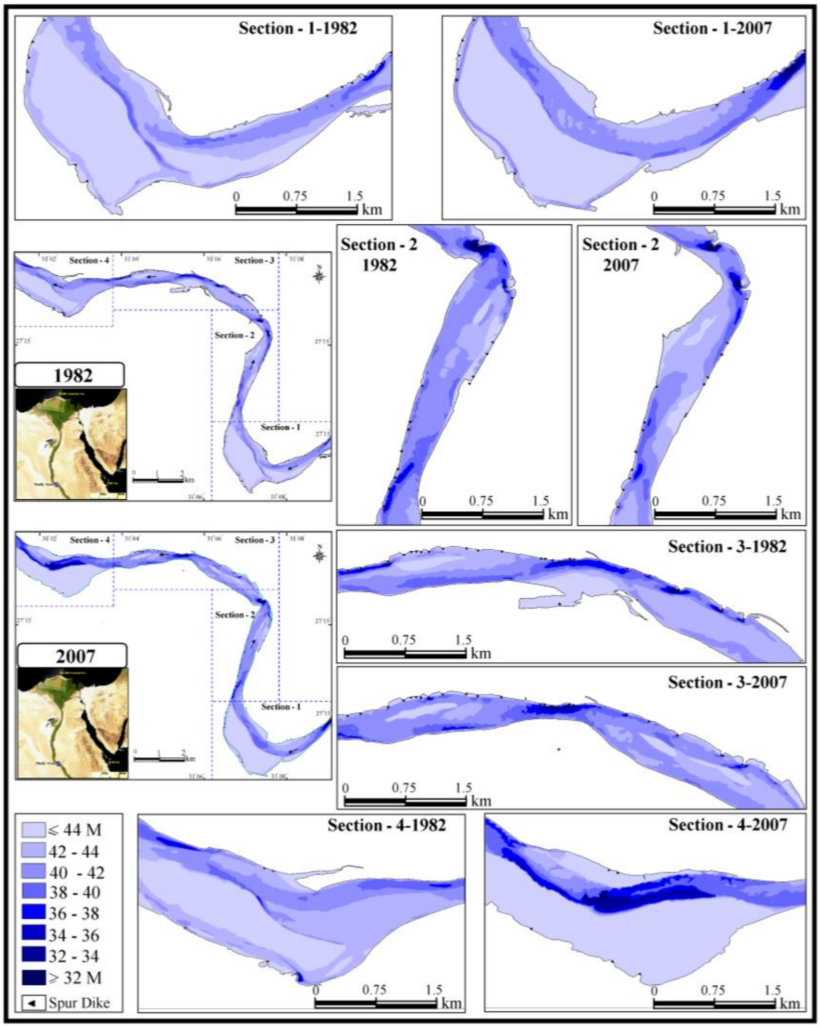
- The repelling shape (60° and 80°) comes in last place with a percentage of 7.2%, accounting for three dikes in the third section, and only one in the second section.
- The third section on the East Bank records the highest density of one spur dike per 404 metres, followed by the second section on the West Bank of one spur dike per 781 metres. The lowest density, on the other hand, is one spur dike per 8280 metres, which is recorded in the third section on the West Bank. It is worth noting that there is a concentration of a group of dikes in certain sites on the same bank, with a distance between them not exceeding 50 meters, and in other sites the difference in distances between them exceeds 4500 meters.

Based on the abovementioned analysis, it is found that there is a large variation in the characteristics of the spur dikes established on the Nile stream in the study area. This variation has a direct impact on the activity and variation in the dynamics of the erosion and deposition processes in sections of the study area.

Figure 5: Types of Spur Dikes in the Abnub Area

5.1.2. Elevations (DEM)

The objective of studying the elevations of the Nile stream is to detect changes in the levels of the Nile streambed, and then determine the locations and characteristics of erosion and deposition and link them to the characteristics of the spur dikes in the study area (Figure 6 and Table 2).



Source: It is based on hydrotopographic maps, scale 1:5000, 1982 and 2007.

Figure 6: Elevation Categories of the Nile Stream in the Abnub Area in 1982 and 2007

Table 2: Elevation Characteristics of the Nile Stream in the Abnub Area

Categories (m)	Area of Elevation Categories in the First Section (%)		Area of Elevation Categories in the Second Section (%)		Area of Elevation Categories in the Third Section (%)		Area of Elevation Categories in the Fourth Section (%)	
	1982	2007	1982	2007	1982	2007	1982	2007
Less than 32	0.00	0.57	0.34	1.95	0.21	0.62	0.02	0.10
34 – 32	0.01	0.74	0.40	1.34	0.28	0.93	0.03	0.61
34-36	0.05	0.36	0.68	0.78	0.91	0.94	0.16	3.66
36-38	0.27	0.56	2.07	2.81	3.65	2.27	0.91	5.47
38-40	2.75	4.65	12.62	13.60	11.45	13.07	6.13	16.95
40-42	16.52	23.32	29.02	49.71	24.62	48.06	19.02	9.97
42-44	23.61	11.77	39.90	19.99	40.36	21.31	38.21	7.57
44 or more	56.79	58.03	14.97	9.82	18.52	12.80	35.52	55.67
Total	100	100	100	100	100	100	100	100

Source: It is based on Figure 6.

The analysis of Figure 6 and Table 2 indicates the following:

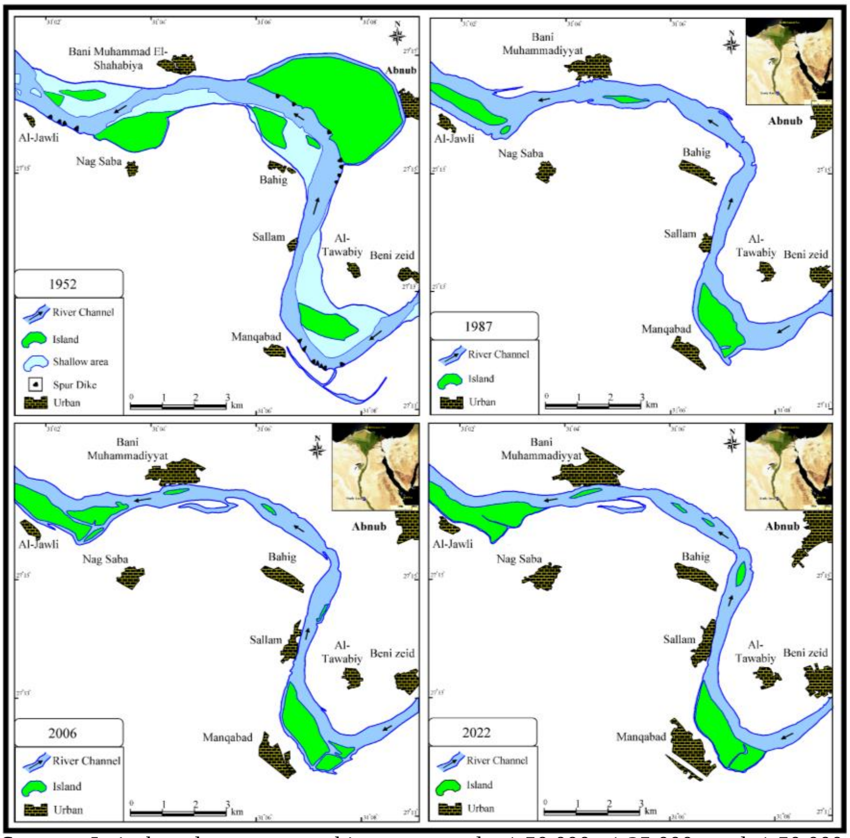
- There is an increase in the first and second categories (less than 34m above sea level) in all sections of the study area from 1982 to 2007. This increase indicates the activity of the vertical erosion process and the reduction of bed levels, particularly in the second and third sections. These sections record the highest percentages, 3.29% and 1.55% respectively, due to the activity of the processes of local and natural scour around spur dikes at the same time.
- The category of 34-38m is the beginning of the elevation in bed levels, and all sections of the study area witness an elevation in this category from 1982 to 2007. The largest percentage is concentrated in the fourth section, east of the island, with a percentage of 9.13%.
- The elevation category (38-40m) is the first nucleus for the formation of sandbars and swamps in the study area. All sections record an increase in the percentage of this category from 1982 to 2007, except for the fourth section, which records a higher percentage in 1982 than in 2007. This is owing to the increase in activity of the deposition process in that section, which results in an elevation in its levels,

entering the last category (44m and above), and coalescing into islands. Accordingly, this results in a decrease in the percentage of that category during the comparison period.

- There is a decrease in the elevation category (42-44m) in all sections of the study area from 1982 to 2007. The reason is attributed to the convert of sandbars and large parts of the swamps into islands, and the coalescence of some of them with the floodplain, which clearly appear in the first section as a result of increased deposition activity.
- The category of 44m or more above sea level witnesses a variation between sections of the study area. On the one hand, its percentage increases in the first and fourth sections to the highest percentage, particularly in 2007. This is due to the increase in deposition activity in them and the convert of sandbars and swamps into islands during the comparison period. On the other hand, its percentage decreases clearly in the second and third sections, particularly in 2007. This is because an island coalesced into the third section of the West Bank, a sandbar coalesced into the East Bank, and swamps on the convex side of the West Bank coalesced into the second section. Accordingly, it becomes outside the boundaries of the stream, so the percentage of this category decreases.

5.1.3. Horizontal Morphological Changes of the Nile River Stream in the Abnub Area

The period from 1952 to 2022 witnesses changes in the horizontal morphological characteristics of the Nile stream in the study area (Figure 7 and Table 3).



Source: It is based on topographic maps, scale 1:50,000, 1:25,000, and 1:50,000, General Authority for Survey, and Satellite Images, 2022.

Figure 7: The Morphological Changes of the Nile Stream in the Abnub Area (1952-2022)

Table 3: The Morphological Changes of the Nile Stream in the Abnub Area (1952-2022)

Year / Characteristics	1952	1987	2006	2022	Change (1952-1987)	Change (1987-2006)	Change (2006-2006)	Change (1952-2020)
Stream Area (km^2)	33.7	15.0	14.1	13.7	-18.7	-0.9	-0.4	-20.0
Water Surface Area (km^2)	20.8	12.2	9.7	8.8	-8.6	-2.5	-0.9	-12.0
Length of the East Bank (km)	24.4	24.4	21.0	20.9	0.0	-3.4	-0.1	-3.5
Length of the West Bank (km)	31.7	23.9	28.7	27.6	-7.8	4.8	-1.1	-4.1
Islands Number	7.0	5.0	10.0	6.0	-2.0	5.0	-4.0	-0.1
Islands Area (km^2)	12.9	2.9	4.4	4.9	-10.0	1.5	0.5	-8.0

Source: It is based on Figure 7.

The analysis of Figure 7 and Table 3 indicates the following:

- The area of the stream decreases in 1987 to less than half compared to the year 1952, as the amount of decrease reaches 18.7 km^2. This decrease continues in subsequent periods until it reaches 20.0 km^2 as a difference in change from the year 1952 to 2022, and consequently the water surface decreases from 20.8 to 8.8 km^2 during the study period. The reason for this is the decrease in water levels as a result of the decrease in the amount of drainage after the construction of the High Dam. As a result, there are an exposure of shallow lands on the surface, and siltation and coalescence of the secondary channels that separated the islands from the floodplain.
- The study period witnesses an increase in the length of the West Bank over the East Bank, with the rate of increase reaching 7.3 km in 1952 and 6.7 km in 2022. The main reason for this is attributed to the increased curvature towards the west resulting from the emergence of a number of river islands. It is also noted that there is a decrease in the length of both the West Bank from 1952 to 2022 with a difference of 4.1 km, and the East Bank with a difference of 3.5 km during that period.
- The number of islands varied during the study period, reaching 7 islands in 1952, decreasing to 5 islands in 1987, then increasing to 10 islands in 2006, and finally decreasing again to 6 islands in 2022. The reason for this variation is attributed to the coalescence of the river islands during the study period to each other and not to the flood plain as a result of the secondary channels between them being exposed to siltation because of the high level of their beds, which appeared particularly in the fourth section. In addition, the area of the islands varied as well, as it decreased from 12.9 km^2 in 1952 to 4.9 km^2 in 2022 with a difference of 8.0 km^2. In spite of this decrease, the area of the islands increased slightly from 4.4 km^2 to 4.9 km^2 from 2006 to 2022.

5.2. Secondary Inputs

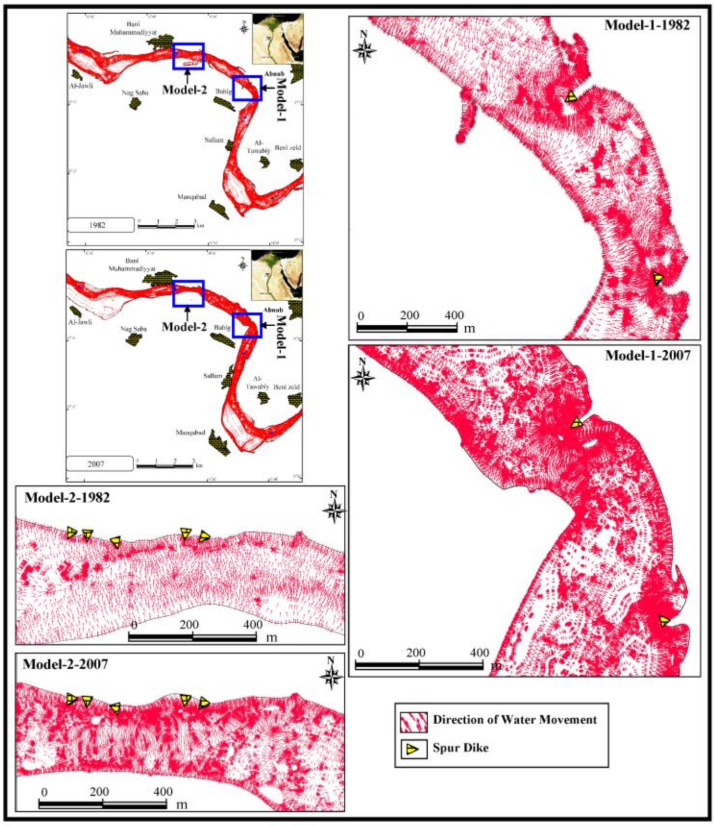
5.2.1. Hydrological Characteristics

- **Drainage amount:** The annual average amount of water drainaged behind the Assiut Barrage is 66.6 billion m^3 before the construction of the High Dam, while it reaches its lowest rate after the construction of the dam at a rate of 35.6 billion m^3, a decrease of 46%. On the one hand, the difference between the lowest and maximum drainage before the construction of the dam reaches 16. 5 billion m^3. On the other hand, the monthly rates converge after the construction of the dam, ranging between 2.2 and 4.4 billion m^3 throughout the year (Hassan, 2023). This decrease results in the shrinkage of the water body, the exposure of shallow areas, and the appearance of sandbars that soon turn into islands. Accordingly, this indicates an increase in deposition rates over erosion rates, whether on the vertical or horizontal levels.
- **Water level:** The lowest water level in the Abnub area ranges between 43.17m and 43.64m in 1993 and 1997 respectively with a difference of 2.98m and 2.83m from the maximum water level for the same two years, reaching 46.15m and 46.47m respectively. The Abnub area witnesses the highest values of water levels at the beginning of 1995 until it reaches its maximum in 1997 (Nile Research Institute, 2010). This is due to the fact that it is the period when the total storage capacity of Lake Nasser was completed (Kamal and Sadek, 2017). Moreover, the variation in water levels on the Nile stream in the Abnub area is reflected in the following: the exposure of the beds of the shallow areas, the siltation of the secondary channels to become part of the adjacent floodplain during the lowest water levels, and the increase in rates of erosion, particularly in the concave parts of the study area during the maximum water levels as a result of the increased velocity of water currents.

- **Water Currents:** The average velocity of water currents in the middle of the study area is 0.84 m/s. The velocity of the water current is measured at the middle of the curvature of the bend, which leads to an increase in its velocity, and thus an increase in the natural scour activity resulting from the bend of the study area and the local scour resulting from the construction of spur dikes. In contrast, the average velocity of water currents in the south of the study area is 0.36 m/s. The velocity of the water current is measured in the islands area, which leads to an increase in friction as a result of the bifurcation, so the velocity of the water current decreases. Above all, the Abnub site represents the highest velocity of the water current, reaching 0.91 m/s on its eastern side, 0.87 m/s on its western side, and 0.89 m/s in its middle (Nile Research Institute, 2018). It is worth noting that the water velocity is not constant; it may change from one section to another within the study area, from one period to another, and from one place to another, due to the variety in relief characteristics as the analysis of the aforementioned elevation characteristics indicate an increase in the relief of the Nile streambed, particularly in the spur dikes area. Accordingly, there is a great variation in the water direction on the streambed during the period from 1982-2007 (Figure 8). This variation, in turn, leads to overlapping and intertwining between the different directions, particularly in the scour holes area. As a result, there are disturbances in water movement, which help create numerous water vortices, increasing the force of water currents on vertical erosion during the comparison period.
- **Froude number[(3)]**: The lowest value is recorded in the first section, reaching 0.06, which indicates a low velocity of

(3) It determines the degree of flow. If the number is less than one, the flow velocity is low; if the number is greater than one, the flow velocity is high and has a high ability of erosion and transport. However, in the case of critical flow, the Froude number is equal to one, and it is calculated from the following equation: $Fr = V/gy^{1/2}$, as Fr = state of flow, (V) = average velocity of water, (g) = gravitational acceleration, and (y) = average depth of the water section (Kasper, 2005).

water currents and that it is of the subcritical type. On the contrary, a higher value is recorded in the second section, reaching 0.13. Although this value is higher compared to the previous section, it is still low, and it is also considered of the subcritical type. Despite this fact, the section has witnessed significant rates of erosion. This does not mean that there is a contradiction, but rather indicates the presence of other factors whose impact cannot be separated, namely human interventions represented by the spur dikes as well as their impact, whether on the erosion or deposition process, particularly if their locations are associated with the center of curvature in river bends.



Source: It is based on hydrotopographic maps, scale 1:5000, 1982 and 2007.

Figure 8: The Direction of the Water Currents Movement on the Nile Streambed in the Abnub Area (1982-2007)

5.2.2. Mechanical Characteristics of the Nile Streambed Sediments

Erosion of sediments and highly cohesive formations requires greater flow energy, because it is not easy to erode them from the bed or transport their grains (Zhang, et al., 2012). Unlike these, fine grains are easy to erode. This is reflected in the variation in the river's energy consumption in both cases. Table 4 indicates the mechanical characteristics of the Nile streambed sediments in the study area.

Table 4: The Mechanical Characteristics of the Nile Streambed Sediments in the Abnub Area

Section Location	Location from the Stream	Gravel (%)	Sand (%)			Classification
			Coarse	Medium	Fine	
South of the Study Area	East	0.00	30.16	59.29	10.55	Medium to Coarse Sand
	Middle	1.68	29.58	58.79	9.95	Medium to Coarse Sand
	West	0.00	28.53	63.50	7.97	Medium sand
Mean		0.56	29.42	60.53	9.49	Medium to Coarse Sand
Middle of the Study Area	East	3.93	41.17	63.45	1.45	Medium to Coarse Sand
	Middle	3.02	27.31	65.85	3.82	Medium sand
	West	2.32	30.82	63.28	3.57	Medium to Coarse Sand
Mean		3.09	33.10	60.86	2.95	Medium to Coarse Sand

Source: The Nile Research Institute, 2009.

The analysis of Table 4 indicates the following:

There is a dominance of the percentage of sand in the study section over the percentage of gravel, noting a high percentage of gravel in the middle of the study area. It reaches 3.93% east of the stream (concave part) and decreases to 2.32% west of the stream (convex part). section one, however, witnesses a noticeable decrease in the percentage of gravel, which only appears in the middle of the stream.

Medium to coarse sand prevails in the two sections of the study area in all parts of the stream except the west of the first section and the middle of the second section, which are dominated by medium sand with a percentage of 63.5% and 65.85% respectively. Futhermore, there is a high percentage of coarse sand in the bed sediments of the second section east of the stream (41.17%) compared to its counterpart in the first section (30.16%).

It is evident from the previous analysis that the Nile streambed consists of medium to coarse sand that is easy to erode, particularly with the increase in the strength of hydraulic erosion resulting from the spread of water vortices around the spur dikes spread across the Nile stream in the study area along with the bending areas. As a result, there is availability of many sediments that led to creating a new force increasing the river's energy, which is the force of mechanical erosion, one of the most effective types of erosion on the geomorphology of the water stream, particularly the vertical one in the study area.

6. Discussion

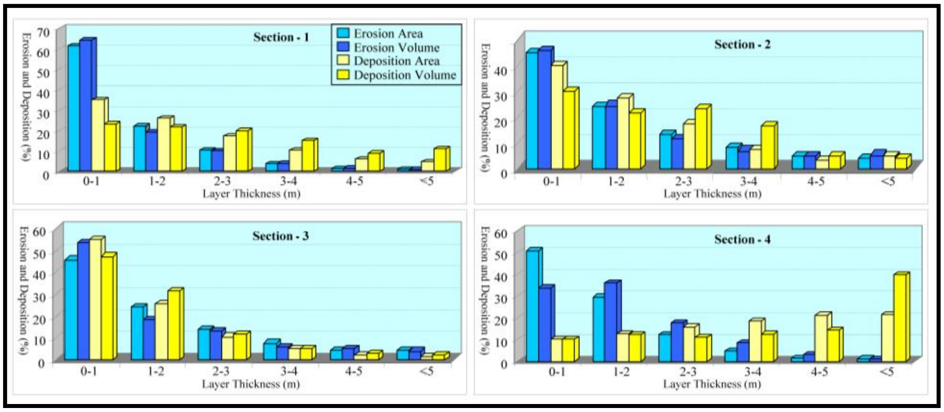
6.1. The Impact of Spur Dikes on the Dynamics of Vertical Erosion and Deposition at the Nile Streambed

The study relied on artificial intelligence techniques so as to produce maps that illustrate the dynamics of the vertical erosion and deposition processes, whether they are one-dimensional (thickness/m), two-dimensional (area/m^2), or three-dimensional (volume/m^3). This is conducted based on DEM maps during the period from 1982 to 2007, as shown in Figures from 9 to 14 and Tables 5 and 6:

Table 5: The Characteristics of Erosion and Deposition in the Nile Streambed during the period from 1982-2007

Section No.	Thickness (m)	Erosion Area (%)	Erosion Volume (%)	Deposition Area (%)	Deposition Volume (%)
The First Section	0-1	23.26	35.12	64.48	61.51
	1-2	21.87	26.23	19.26	22.28
	2-3	19.92	17.48	10.02	10.36
	3-4	15.04	10.44	3.86	3.63
	4-5	8.88	5.97	1.52	1.31
	5 or more	11.03	4.73	0.86	0.91
Total		100	100	100	100
The Second Section	0-1	29.75	39.75	46.19	45.47
	1-2	21.56	27.61	24.60	24.42
	2-3	23.18	17.79	11.79	13.26
	3-4	16.30	7.15	6.94	8.37
	4-5	5.04	2.94	5.21	4.59
	5 or more	4.17	4.76	5.27	3.89
Total		100	100	100	100
The Third Section	0-1	47.22	54.91	53.53	45.63
	1-2	31.38	25.67	18.44	24.33
	2-3	11.68	10.55	13.18	13.77
	3-4	4.95	5.13	5.78	7.62
	4-5	2.72	2.39	4.95	4.23
	5 or more	2.05	1.35	4.12	4.42
Total		100	100	100	100
The Fourth Section	0-1	10.25	10.16	33.80	50.89
	1-2	12.33	12.81	35.92	29.54
	2-3	10.91	15.82	17.56	12.17
	3-4	12.43	18.39	8.63	4.87
	4-5	14.28	21.28	3.21	1.33
	5 or more	39.80	21.54	0.88	1.20
Total		100	100	100	100

Source: It is based on Figures 10,11 and 12.

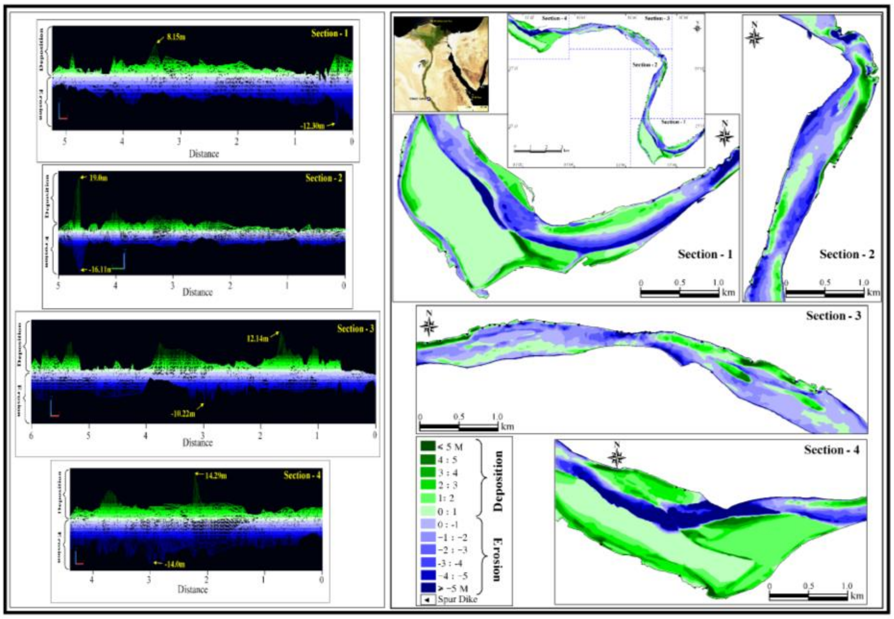


Source: It is based on Table 5.

Figure 9: Characteristics of Erosion and Deposition in the Nile Streambed (1982-2007)

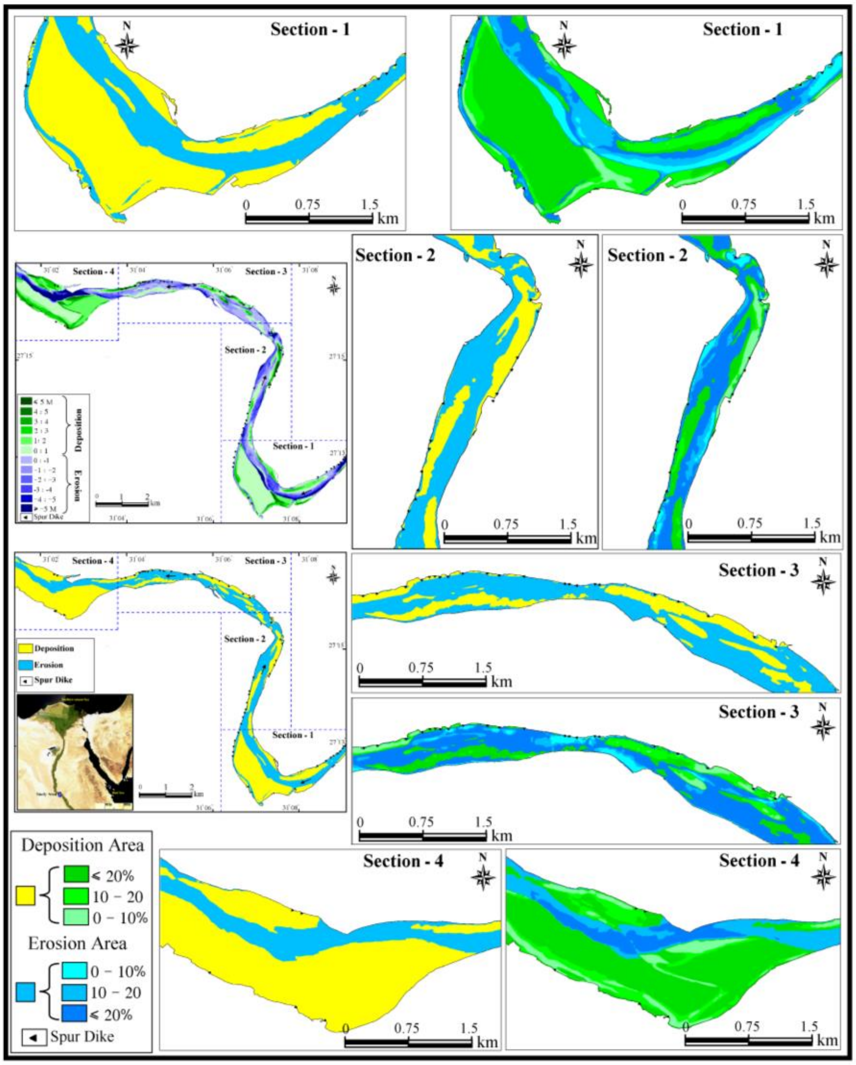
6.1.1. One-dimensional and Two-dimensional Erosion and Deposition Layers:

The thickness and area of the layers of erosion and deposition vary between sections of the study area (Figures 9,10 and 11, and Table 5) as follows:



Source: It is based on hydrotopographic maps, scale 1:5000, 1982 and 2007.

Figure 10: The Thickness of (One-dimensional) Erosion and Deposition Layers in the Nile Streambed in the Abnub Area



Source: It is based on hydrotopographic maps, scale 1:5000, 1982 and 2007.

Figure 11: The Area of the (Two-dimensional) Erosion and Deposition Volume Layers in the Nile Stream in the Abnub Area

6.1.1.1. One-dimensional and Two-dimensional Erosion Layers:

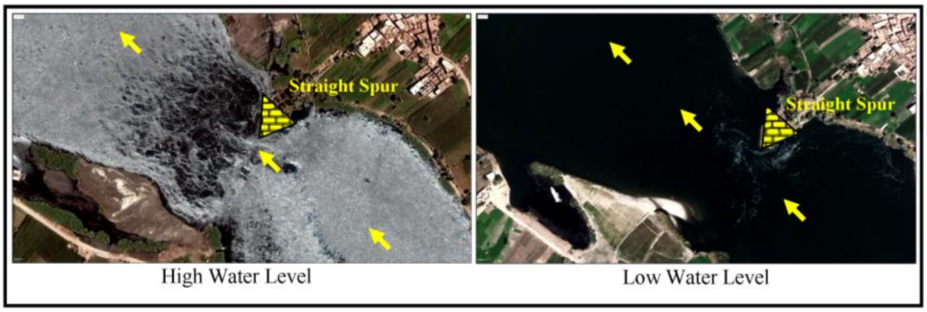
- The first category (0-1 m) represents the minimum thickness of the erosion layer of the streambed. Above all, this category is the most widespread category in the first three sections. This is mainly because it records the highest area percentages of 47.22%, 29.75%, and 23.26% of the total area of sections three, two, and one respectively, and it is located somewhat far from the sites of the spur dikes. On that account, its origin is primarily due to total scour rather than local scour.

- The second category, in which the thickness of the eroded layer from the streambed ranges from 1 to 2m, comes in second place in terms of area percentages in the first three sections, even though its percentage also increases in the fourth section compared to the first category of the same section. It spreads in the areas adjacent to the first category.
- The percentage of the area of the erosion layers whose thickness is more than 5m or more varies between the sections of the study area. On the one hand, it decreases in the first three sections so that it does not exceed 17.25% of the total area of the sections. On the other hand, it reaches its maximum in the fourth section with an area of 39.8%, noting that the maximum thickness of the eroded layer from the streambed in the study area ranges between 10.22 and 16.11 m, covers very limited locations in all sections. This is mainly because it is associated with the occurrence of severe water vortices in the sites of the spur dikes, particularly the second section.

It is evident from the previous analysis that total scour(4) has an effective role in the presence of large areas represented by the weak thickness of the erosion layers in the first and second categories. However, approaching the areas of local scour resulting from spur dikes and bends increases the thickness of the eroded layers from the streambed, until it reaches its maximum thickness in the places where the spur dikes and concave sides participate together in the creation of severe water vortices such as the end of the second section (Figure 12). Nevertheless, these areas cover limited areas of the sections, and accordingly the increase in depth is not often

(4) The river erodes the bed and banks instead of the sediment load after the construction of the High Dam (Hassan, 2014). In essence, total scour is the sum of the processes of long-term degradation, general scour and local scour.

followed by an increase in area. In the first categories, which represent the minimum thickness of the eroded layer, the highest area is recorded due to the increase in the dimensions of length and width, particularly in the first three sections.



Source: Google Earth Pro.

Figure 12: The Impact of Spur Dikes in Creating Extreme Water Vortices as a Result of Their Location at the Curvature Center

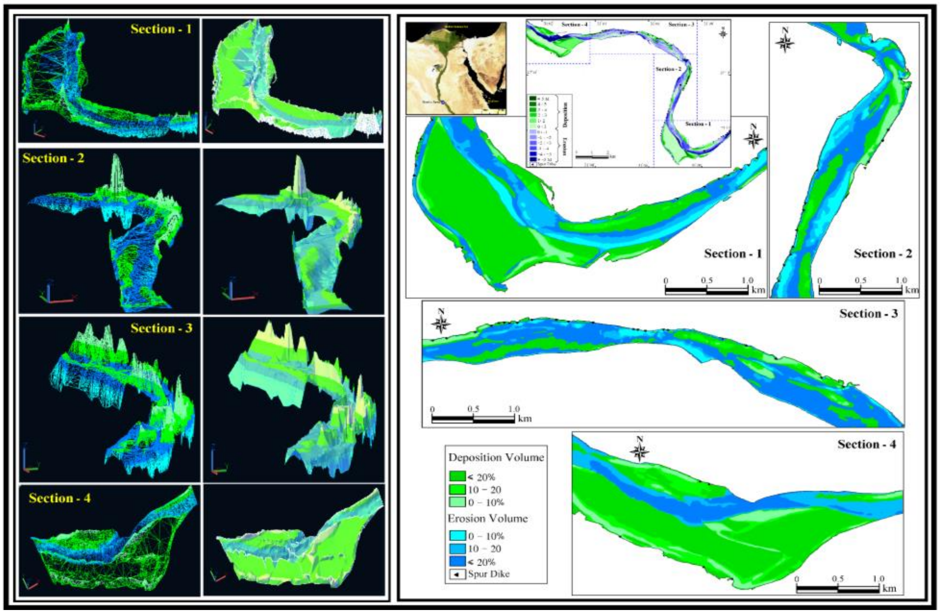
6.1.1.1. One-dimensional and Two-dimensional Deposition Layers

- The first category (0-1m) represents the minimum thickness of the deposition layer in the Nile streambed in the study area. It is a thin layer that covers the islands and deposition sites near the spur dikes and the convex sides of some sections. This category occupies the largest categories in terms of area percentages in the first three sections, due to its spread over wide areas, which compensate for the decrease in deposition thickness, particularly in the first section with a percentage of 64.48% of the deposition area in the same section.
- The second category, which represents the thickness of the deposition layer on the Nile streambed between 1 and 2m, comes in second place in terms of area percentages in all sections of the study area, except for the fourth section. It records the highest area percentage for this category, reaching 35.92% of the area of the section. In addition, this category is associated with swamps in its distribution.

- The moderate deposition is associated with thicknesses ranging between 2 and 4m, which are distributed in places of sandbars. Moreover, all sections witness an increase in the percentages of the area covered by this category, particularly the thickness from 2 to 3m, as the fourth section records a percentage of 17.56% of the total area percentages of the categories.
- A decrease in the area percentage of the deposition layers whose thickness is 5m or more in all sections of the study area, particularly in the first and fourth sections, as their area do not exceed 11.13% of the total area of the sections, and in the first section in particular reaching 0.86%. The distribution of their locations is linked to the modern islands and secondary channels between islands and in some locations of spur dikes as a result of the increase in deposition rates in front of them, which has led to the end of its intended role. It is worth noting that the maximum thickness of deposition in the study area ranges between 8.15 and 19.0m, and it covers very limited areas in all sections. The main reason for this is that it is linked to human interventions through the backfilling process, whether for secondary channels or part of the Nile stream adjacent to the floodplain to be exploited as agricultural land.

6.1.2. Three-dimensional Vertical Erosion and Deposition Layers in the Nile Stream

This method is considered the most accurate one when calculating the rates of erosion and deposition, and comparing them to reach accurate results about the impact of spur dikes (Saber and Shalapy, 2021). This is owing to the fact that it depends primarily on the three dimensions of the area (length, width, and thickness). The analysis of Figures 13 and 14 and Tables 5 and 6 indicates the following:



Source: It is based on hydrotopographic maps, scale 1:5000, 1982 and 2007.

Figure 13: The Volume of (Three-dimensional) Erosion and Deposition in the Nile Stream in the Abnub Area

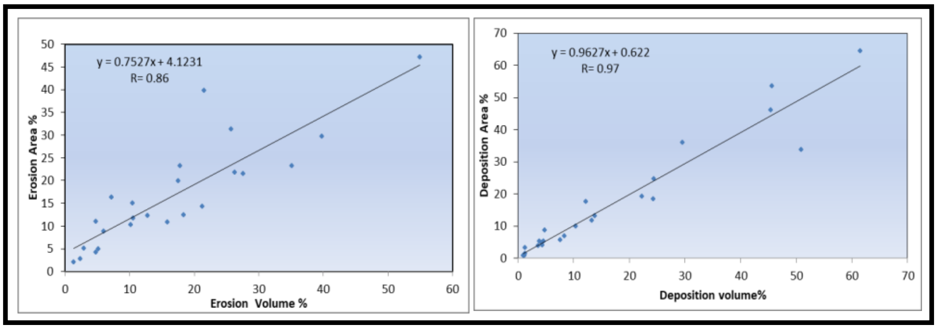
Table 6: Characteristics of the Volume of Erosion and Deposition in the Nile Streambed during the Period from 1982-2007

Section No.	Annual Rate of Erosion m^3/year	Annual Rate of Deposition m^3/year	Difference between the Annual Rates of Erosion and Deposition
1	5029.16	3613.32	1415.84
2	3275.96	1451.24	1824.72
3	2854.16	1529.32	1324.84
4	5715.20	6288.28	-573.08
Total	16874.48	12882.16	3992.32

Source: It is based on Figure 13.

- In general, there is a dominance of the volume of erosion over the volume of deposition during the period from 1982 to 2007, as the annual rate of erosion reaches 16874.48 m^3/year, and deposition 12882.16 m^3/year, with a difference of 3992.32 m^3/year. This is a logical result because of the spread of many spur dikes in the study area, in addition to the total scour that characterizes the study area as a bend area, appearing clearly in the first and fourth sections in particular.

- During the comparison period, the volume of deposition exceedes the volume of erosion in the fourth section, reaching 6288.28 m^3/year and 5715.2 m^3/year respectively, with a small difference that does not exceed -573.08 m^3/year.
- There is a decrease in the percentages of the volume of erosion and deposition which are less than 10% of the total volume of sediments in the first three sections. They are spread in the deepest places represented by the scour holes, and the highest places represented by the secondary channels and islands. The reason is attributed to their association with limited positions or areas, and this confirms the strong direct relation between area and volume that reach 0.86 for erosion and 0.97 for deposition (Figure 14). In this regard, this means that thickness, which is the third dimension, has less impact than length and width (area) when calculating the volume of sediments.



Source: It is based on Table 5.

Figure 14: The Correlation between Area and Volume of Erosion and Deposition in the Study Area

- The percentages of the volume of erosion and deposition increase to more than 20% of the total volume of sediments in the sections, in places of erosion and deposition with weak thickness of less than 2m. They occupy most sections of the study area, and the reason is mainly due to total scour rather than local scour.

The following is evident from the aforementioned:

- The vertical erosion is most intense in the sites of the grouped spur dikes, as the maximum thickness of the erosion is reached in these sites. It is also associated with all types and shapes of compound, complex and highly complex scour holes, which are characterized by increased dimensions and depths. As for the isolated spur dikes, they are less than the grouped spur dikes in terms of the intensity of the vertical erosion unless their presence is associated with concave sides, their impact increases and even surpasses them in vertical erosion.
- Increasing the distances between the spur dikes increases the length of the return flow zone. By increasing it, a low-velocity zone is formed, which contributes to increasing the deposition rate along this distance. This appears clearly in the second section, south of the center of the curvature of the bend, and in the third section at its beginning and end. Besides, this is consistent with the findings of the study of Giglou et al. (2018) that explains that the greater the inter-space distances between the spur dikes, the more that creates bigger vortices, and hence the biggest field with low velocity and high level of sedimentation occur. On the other hand, it is observed that the convergence of the distance between the spur dikes results in an increase in the process of vertical erosion. This case appears clearly in the third section at the center of the curvature of the bend, in the second section on the West Bank at the beginning of the section (bend area), and at the beginning of the first section on the East Bank (bend area), which has been associated with the formation of compound, complex and highly complex holes.
- Local deposition arises as a result of the occurrence of local scour, as it is located at a distance from the spur dike in the direction of the downstream, is formed on the opposite side, or both together (Figure15). It appears in the first section on the East Bank and the second section on the West Bank due

to the presence of a group of Spur dikes, resulting in the formation of many sandbars, and this is consistent with the studies of Kadota and Suzuki (2010) and Fang et al. (2006).

- Human intervention in the first section contributes to an increase in erosion rates over deposition rates. That is, the cleansing processes of the secondary channel for use as fish farms, as well as the scour holes caused by spur dikes in 1982 and which continued until 2007, have helped in the formation of deep areas suitable for fish farming. Besides, the presence of the grouped dikes at the beginning of the section in the bend area had the impact of increasing erosion rates as well.

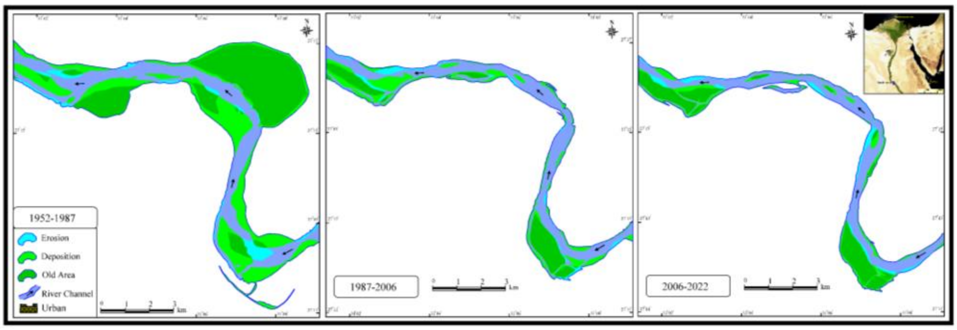
Figure 15: The Association of Local Deposition with Local Scour Sites in the Spur Dikes Area

- The cessation of spur dike activity in the fourth section has led to the dominance of deposition rates over erosion rates. This increase appears in the rise in the level of secondary channels and the creation of bars and swamps that cover most of the section. As a result, the spur dike areas turn into swamps and become part of the floodplain on the East Bank. The rates of erosion in the concave side of this section, the cleansing processes in the secondary channel located to the west of the island to ensure that water reaches the fish farms, and cutting off parts of the island and combining them with the fish farms have reflected on the increase in erosion rates in the section, but deposition rates have prevailed.

- Local scour resulting from spur dikes, which are characterized by their high numbers in the second and third sections, and the natural scour in the concave sides as well as the small area of the islands in them play a major role in the dominance of the volume of erosion over deposition.

6.2. Horizontal Changes Resulting from the Erosion and Deposisition Processes in the Nile River in the Abnub Area

Horizontal Changes are mere reflection of vertical changes resulting from the processes of erosion and deposition and the impact of the spur dikes. The horizontal changes (horizontal erosion and deposition) are to be tackled as follows(Figure 16) and (Table 7):



Source: It is based on topographic maps, scale 1:50000, 1:25000 and 1:50000, General Authority for Survey and satellite Images, 2022.

Figure16: Horizontal Geomorphological Changes of the Nile Stream in the Abnub Area from 1952 to 2022

Table 7: The Horizontal Changes Resulting from the Erosion and Deposition Processes during the period from 1952-2022

Period	Section No.	Erosion Area (km²)				Deposition Area (km²)				Difference between the Total of Erosion & Deposition (km²)
		The East Bank	The West Bank	River Islands	Total	The East Bank	The West Bank	River Islands	Total	
1952-1987	1	0.10	0.12	0.57	0.79	0.98	1.29	1.1	3.40	-2.61
	2	0.01	0.03	0.04	0.08	0.95	1.8	0.0	2.75	-2.67
	3	0.10	0.17	0.0	0.27	1.03	0.88	0.27	2.2	-1.93
	4	0.04	0.24	0.36	0.64	0.68	0.36	0.97	2.0	-1.36
	Total	0.25	0.56	0.97	1.78	3.64	4.3	2.34	10.28	-8.5
1987-2006	1	0.01	0.16	0.10	0.27	0.24	0.41	0.33	0.98	-.71
	2	0.09	0.02	0.0	0.11	0.11	0.14	0.0	0.25	-.14
	3	0.07	0.06	0.06	0.19	0.11	0.44	0.02	0.57	-.38
	4	0.33	0.01	0.14	0.48	0.08	0.26	1.2	1.54	-1.06
	Total	0.50	0.25	0.30	1.05	0.54	1.25	1.55	3.34	-2.29
2006-2022	1	0.2	0.09	0.14	0.43	0.19	0.01	0.31	0.5	-0.07
	2	0.003	0.37	0.0	0.37	0.28	0.02	0.09	0.4	-.03
	3	0.04	0.15	0.04	0.23	0.10	0.21	0.09	0.4	-.17
	4	0.20	0.0	0.17	0.37	0.19	0.36	0.48	1.03	-.66
	Total	0.443	0.61	0.35	1.40	0.76	0.60	0.976	2.30	-.90

Source: Source: It is based on Figure 16.

The analysis of Figure 16 And Table 7 indicates the following:

- **The period (1952-1987):** It is considered one of the periods that witnessed the most changes in the hydrological characteristics of the Nile stream as a result of the decrease in the amount of water drainaged after the total control of the river's water after the construction of the High Dam. This, in turn, resulted in a decrease in the river's energy, which activated the deposition process. This period records the highest area of deposition compared to the area of erosion, reaching 10.28 km^2 and 1.78 km^2 respectively. However, this increase does not represent the result of the deposition process only, but it is due to the receding of water from the shallow areas, its appearance on the surface, and its coalescence into the banks of the stream. In addition, these areas spread in the convex areas of the stream, and the source of their sediments is due to the activity of the process of erosion in the concave sides and the presence of spur dikes before the construction of the High Dam (Figure 16). They are also spread in the secondary channels, particularly those that separate Bahij Island from the East Bank. On the other hand, the erosion process is concentrated on some islands and separate areas of the West Bank.

Figure 16: The Impact of Erosion Process on the Banks of the Nile Stream in the Abnub Area

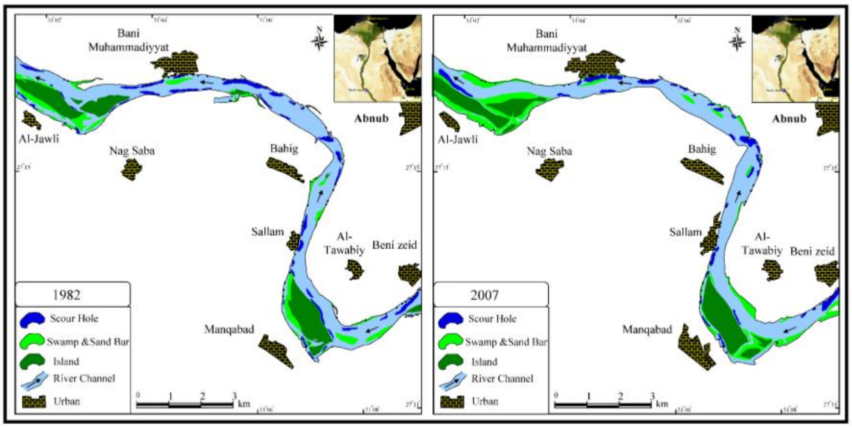
- **The period (1987-2006):** Deposition rates continue to exceed erosion rates during this period, but with a smaller difference of 2.29 km^2, noting that a balance has occurred between erosion and deposition rates on the East Bank, reaching 0.50 km^2 and 0.54 km^2 respectively. However, they vary at the level of each section; for instance, the second and third sections record low rates of erosion on the East Bank to the advantage of deposition. The reason for this is attributed to the density and spread of spur dikes along the two sections, which reduce the horizontal rates of erosion. Besides, the highest rate of erosion is recorded on the West Bank in the second section, as it reached 0.16 km^2, and it witnesses the highest rates of deposition on the same bank. An exception to this is the fourth section, which records the highest rate of erosion on the East Bank at 0.33 km^2, due to the cessation of the activity of the spur dikes and being part of the floodplain. It also witnesses an increase in deposition rates on the West Bank with a percentage of 20.8%, and on the islands with a percentage of 77.4% of the total deposition area in the sections. Accordingly, this period witnesses the emergence of the role of spur dikes and their impact on the processes of erosion and deposition in the study area. It is noted that all the positions of the spur dikes become in a state of stability or sites of deposition, and that most of the areas that are subjected to the process of erosion, whether the banks or the islands, are located far from the positions of the spur dikes, and their origin is mainly due to being on the concave sides of bends.

- **The period (2006-2022):** It is a period of stability and regularity in the amount of water drainage, during which the erosion rates in sections of the study area increase from the previous period, reaching 0.35 km^2. This increase varies between the banks and the islands, as the West Bank and the islands are affected by an increase in the erosion process with a percentage of 68.4% of the total erosion in the sections, while the rates of erosion on the East Bank decrease to the advantage of deposition at a decreasing rate of 0.06 km^2 from the previous period. The reason for this is attributed to the spread of spur dikes in the East Bank in all sections of the study area. As a result of the intense vertical erosion, the local deposition behind the dikes increases and sandbars and swamps appear in front of the scour holes, which causes the levels of the holes to rise. In addition, they are exposed to backfilling, so the erosion activity decreases, and deposition increases. This case appears clearly in the second section, in which the rates of erosion decrease to the advantage of deposition. Above all, the deposition process also decreases in this period compared to the previous period, at a decreasing rate of 1.04 km^2, and the higgest percentage is recorded in river islands with a percentage of 42.4% of the total deposition.

The study of the horizontal changes indicates the dominance of the deposition process over the the erosion process in all periods of the study. However, it decreases with the recent periods from 8.50 km^2 to 2.29 km^2 and then to 0.90 km^2. Despite the dominance of deposition, it records the lowest rates in the first three sections, which is normal as the volume of vertical erosion is dominant in these sections. Unlike these three sections, the rate difference is for deposition in the fourth section; its rate increases due to the fact that the volume of vertical erosion is less. Furthermore, the study pinpoints that the increase in the rates of deposition on the East Bank in the second section resulting from the spur dikes is followed by an increase in the erosion rates on the West Bank. This is mainly for the sake of achieving hydraulic balance in the stream. Accordingly, the spur dikes prove their effectiveness in protecting the banks, particularly the East Bank, from the erosion process and they achieve their intended aim.

6.3. The Geomorphological Phenomena Resulting from the Spur Dikes

The variation in the morphometric and morphological characteristics of the spur dikes in the Nile stream in the study area has led to the emergence of many geomorphological phenomena associated with them. Instances of these phenomena are scour holes, sandbars, and swamps (Figure 17), which can be explained as follows:



Source: It is based on hydrotopographic maps, scale 1:5000, 1982 and 2007.

Figure 17: The Geomorphological Phenomena in the Nile Stream in the Abnub Area

- The sections of the study area witness a numerical increase in all types of scour holes[5] from 1982 to 2007, but this increase is concentrated in single and compound holes, with an increase of 5 to 10 holes respectively. They have increased in the first three sections as a result of the activity of the vertical erosion process. However, they have disappeared from the fourth section, whether due to increased deposition or as a ressult of the coalescence into each other, as the number decreases from 10 holes in 1982 to only one hole formed as a result of the coalescence of three holes in 2007. Moreover, all morphometric dimensions decrease except for the length of single and compound holes at the level of all sections. On the contrary, the dimensions have increased in complex and highly complex holes, particularly in area and depth, and this is normal as a result of the continued vertical erosion activity in them.
- There is an increase in the area of sandbars (Figure 18) and swamps (Figure 19) in all sections except the second section, as the percentage of their areas increased from 9.6% in 1982 to 23.7% in 2007 of the total area of the study area. This is mainly due to the availability of sediments resulting from the increase in the depths of scour holes due to water vortices resulting from the spur dikes, and then the emergence of a low-velocity flow stream in the opposite direction to the main stream behind the spur dike. This, in turn, results in increased local deposition. Accordingly, the phenomenon of sandbars and swamps is closely related to the positions of the spur dikes and scour holes (Figure 20). In addition, the area of sandbars and swamps reach its maximum in the fourth section in 2007, with a percentage of 52% of the total area of the section. This leads to a decrease in the activity of the spur dikes and the end of their role to become part of the swamps

[5] Scour Holes in the study area are divided into four types: single holes, compound holes (consisting of single holes), complex holes (consisting of compound holes), and highly complex holes (consisting of complex holes). They represent stages of the development of scour holes, as a result of deepening activity and the intensity of the vertical scour due to the spur dikes.

or the floodplain, for there is a mutual and intertwined relation between them. On the other hand, the second section records the lowest percentage in the area of sandbars and swamps, because some of them have coalesced into the floodplain and became part of it, going outside the boundaries of the stream during the study period.

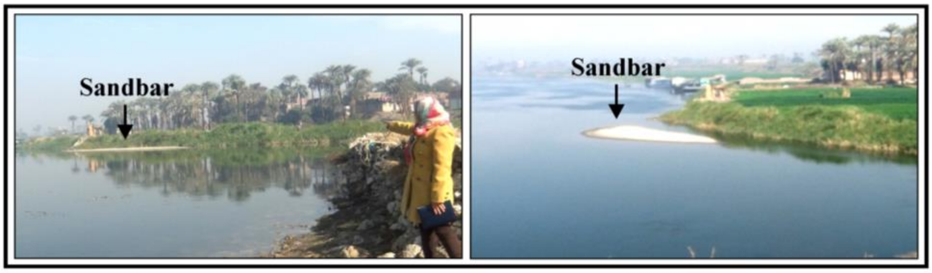


Figure 18: Sandbars in the Nile Stream in the Abnub Area

Figure 19: Swamps in the Nile Stream in the Abnub Area

Source: Google Earth Pro.

Figure 20: Development of Sandbars near Spur Dikes in the Nile Stream in the Abnub Area

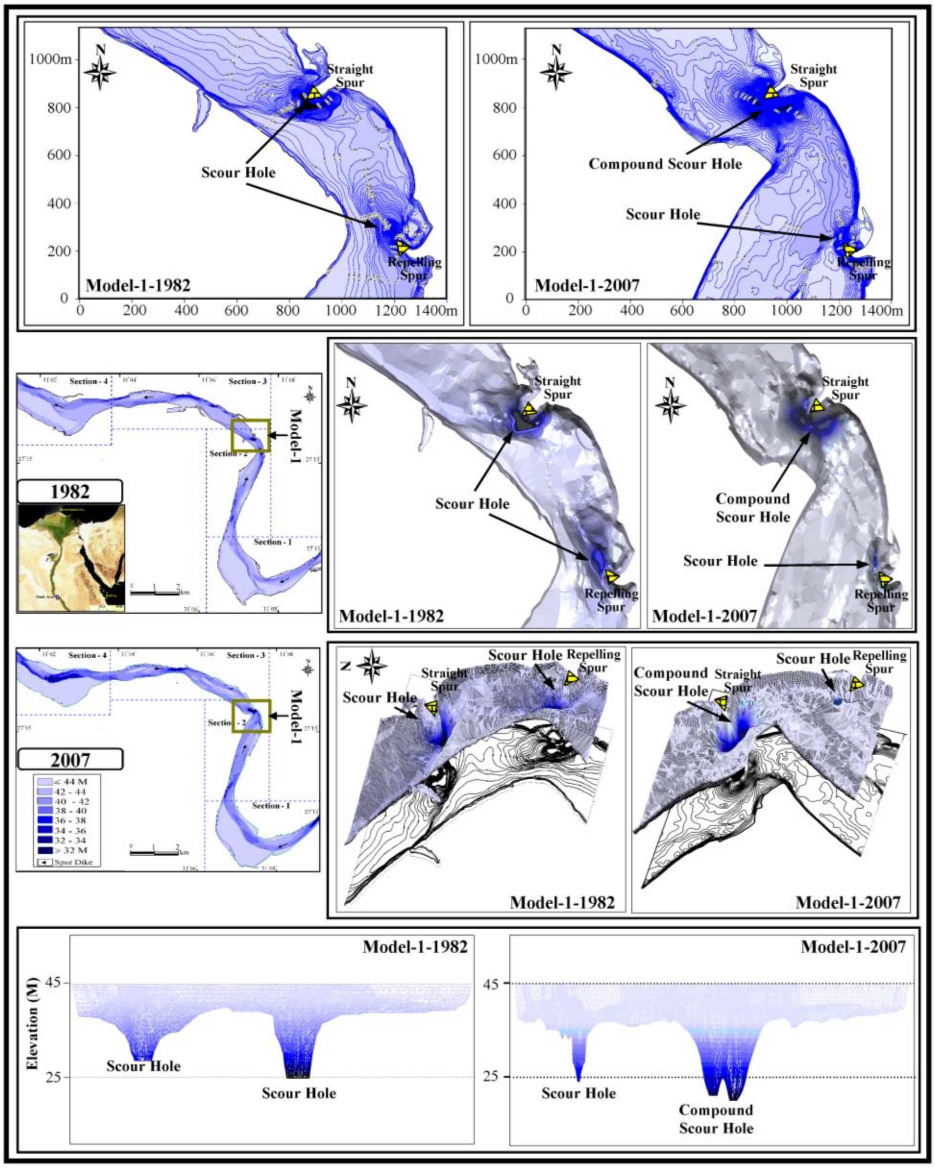
What follows is a study of the most important geomorphological phenomena resulting from constructing spur dikes as well as the most clear and accurate phenomenon in reaching results clarifying the relation between them. This phenomenon is scour holes.

In essence, scour holes are hollows whose level is lower than the streambed level, and are created by water vortices that result from human interventions such as spur dikes and engineering structures and in the concave sides of bends (Linda, 1993). Figures 17, 21 and 22 and Table 8 show the morphometric and morphological characteristics of the scour holes in the Nile stream in the study area.

Table 8: The Morphometric Characteristics of Scour Holes in the Nile Stream in the Abnub Area (1982-2007)

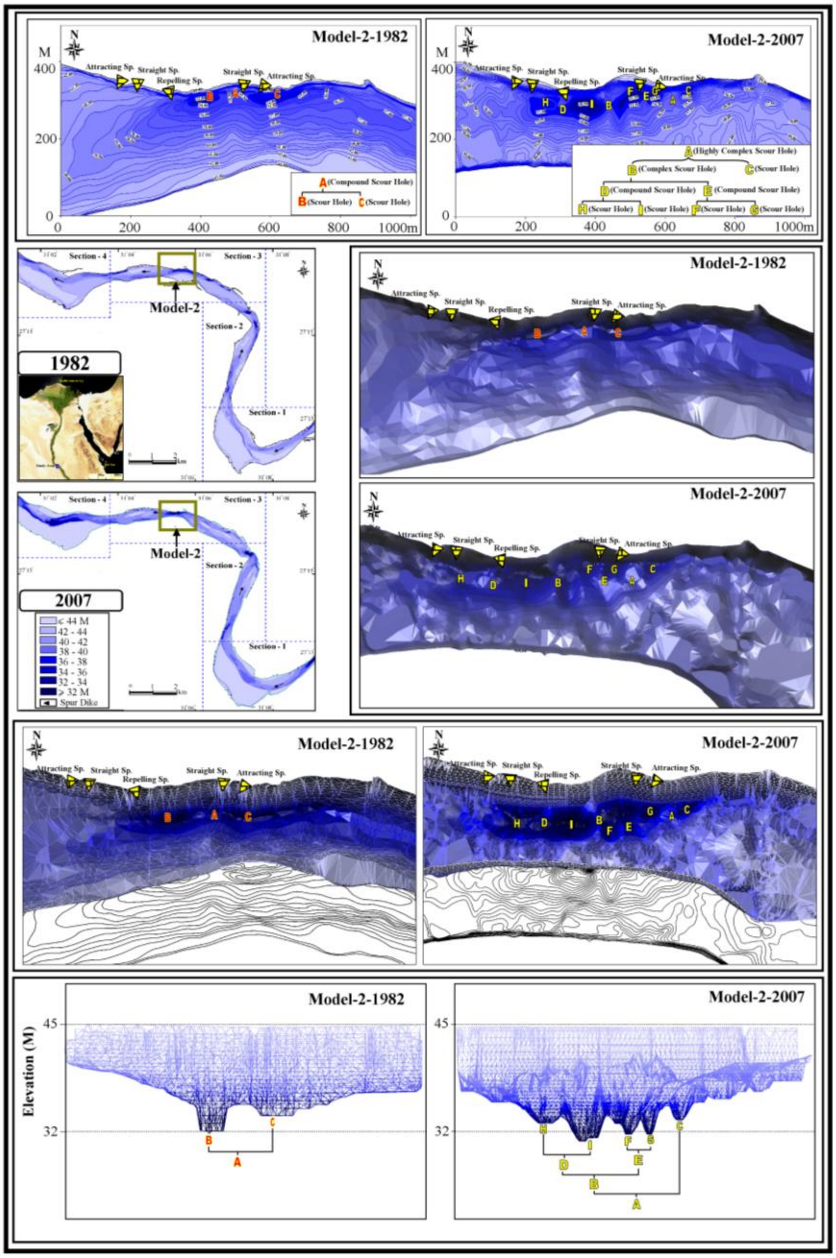
Hole Type	Section	Area (%)		Mean Length (m)		Mean Width (m)		Mean Depth (m)		Density (hole/km^2)		Shape	
		1982	2007	1982	2007	1982	2007	1982	2007	1982	2007	1982	2007
Single	1	3.3	1.0	308.7	197	39.8	21.3	1.6	2.0	2.6	2.0	elongated	elongated
	2	8.7	3.2	464.8	173.7	68.5	37.8	5.4	4.5	2.7	5.4	elongated	less elongated
	3	7.7	3.5	170	133.8	40.4	30.1	3.3	3.0	4.5	7.4	less elongated	less elongated
	4	3.2	0.7	363.3	1336	35.8	85.0	2.3	0.2	4.5	0.06	elongated	elongated
Mean		5.7	2.1	326.7	460.1	46.1	43.6	3.2	2.4	3.6	3.7	elongated	elongated
Compound	1	1.8	0.3	1030	305	84.4	52.9	6.7	3.1	4.7	0.2	elongated	less elongated
	2	--	4.5	--	414	--	78.8	--	8.4	--	1.3	--	less elongated
	3	6.1	3.3	1169.5	321	74.3	48.3	7.3	4.6	0.6	1.9	elongated	less elongated
Mean		2.6	2.7	733.2	346.7	52.9	60.0	4.7	5.4	1.8	1.1	elongated	less elongated
Complex	1	--	2.2	--	892	--	133.0	--	9.6	--	0.2	--	elongated
	3	--	2.6	--	584.5	--	65.0	--	5.3	--	0.6	--	elongated
Mean		--	2.4	--	738.3	--	99.0	--	7.5	--	0.4	--	elongated
Highly Complex	3	--	1.7	--	671	--	76.9	--	6.4	--	0.3	--	elongated

Source: It is based on hydrotopographic maps, scale 1:5000, 1982 and 2007 and Figure 17.



Source: It is based on hydrotopographic maps, scale 1:5000, 1982 and 2007.

Figure 21: A Model of the Impact of Single Spur Dikes on Scour Holes in the Second Section of the Nile Stream in the Abnub Area in 1987 and 2007



Source: It is based on hydrotopographic maps, scale 1:5000, 1982 and 2007.

Figure 22: A Model of the Impact of Grouped Spur Dikes on Scour Holes in the Third Section of the Nile Stream in the Abnub Area in 1987 and 2007

The analysis of Figure 17 and Table 8 indicates the following:

- The third and second sections record the highest density of scour holes in the study sections from 1982 to 2007, as it increases from 4.5 holes/km^2 and 2.7 holes/km^2 in 1982 to 7.4 holes/km^2 and 5.4 holes/km^2 in 2007 respectively. This is related to the number of holes, which reach their maximum in the two sections, reaching 32 and 16 holes respectively in 2007.
- The distribution and density of scour holes are linked to two main locations: the first is the places of the spur dikes, as they were concentrated in front of and behind them according to the type of each dike, and the second is the concave sides of each section. The density of the holes and the extent of their concentration increase if the construction of the spur dike is associated with places of bending. Moreover, it is observed that most of the compound, complex and highly complex holes are associated with the grouped spur dikes at the level of all sections, particularly the third section (Figure 22). However, there is an exception for individual cases in some sections. One instance is in the second section, in which a hole turns from a single hole in the position of a straight spur dike(6) in 1982 to a compound one in 2007 (Figure 21). Another instance is in the third section, in which two isolated dikes are linked to the formation of the compound holes. It should be noted that the complex and highly complex holes did not appear or be formed until 2007, which shows the impact of the time factor in the development of scour holes and their deepening.
- All sections witness a noticeable decrease in the percentage of areas of single scour holes, as it decreases from 5.7% in 1982 to 2.1% in 2007, with a decrease rate of 3.6%. The percentages of areas of scour holes also vary between the different sections. Above all, the second section records the

(6) It is the deepest hole in all sections of the study area, as its depth increases from 14.9m in 1982 to 17.3 m in 2007.

highest percentage of decrease in the area of scour holes from 8.7% in 1982 to 3.2% in 2007. It is also the section with the highest decrease in other dimensions of scour holes, which decrease by more than half in length and nearly half in width from 1982 to 2007. The main reason for this is attributed to the increase in the level of three single scour holes on the eastern bank of the section, which are on their way to being silted up and backfilled. However, they still take the same shape as the hole (Figure 21). In addition, it is observed that the level of the bottom of a hole in the first section of the secondary channel increases as a result of the presence of local deposition in front of it. On the contrary, the morphometric dimensions of complex holes decrease from 1972 to 2007 at the level of each section and not for the general mean because they do not appear in the second section in 1982.

- Some scour holes are characterized by excessive length at the expense of width, due to the complementary impact of both the spur dikes and the bending areas in their construction. In addition, the deepest holes are linked to them, and the best example of this is the holes in the second section.
- The shapes of the scour holes[7] vary in the study area, between elongated and less elongated, and most of the holes in the study area are located in the second shape (Table 8). Many of them turn from the elongated shape to the less elongated shape, particularly all the compound holes in addition to the single hole in the third section during the comparison period. It is also worth noting that there are some single holes taking a circular shape in the third and first sections in 2007.
- All sections of the study area except the fourth section witness an evident numerical increase in all types of scour holes. Single holes in the first three sections increase from 32

[7] The shape of the scour hole is determined by applying the roundness ratio equation: the ratio of the length of its transverse axis / the length of its longitudinal axis (Al-Husseini, 1988).

holes in 1982 to 47 holes in 2007, of which 23 holes are concentrated in the third section in 2007. Compound holes appeared in 1982 in the first and third sections only; the compound hole in the first section in 1982 turned into a complex one in 2007, and a single hole in the same section turned into a compound one. Above all, the third section is the one that witnesses the most increase in the appearance of compound holes in 2007 compared to the year 1982, which increase from two to six holes, and the compound holes turned into complex and highly complex holes (Figure 22). This is mainly due to the fact that it is the section in which groups of spur dikes, to which this type of holes is associated, are most widespread.

7. Results

The study indicates several results that can be summarized in the following points:

- Spur dikes play an effective role in the degree of activity of the erosion and deposition processes, particularly the vertical at the Nile streambed.
- The maximum thickness of the eroded layers of the streambed reaches the places where the spur dikes and concave sides are both present, particularly if the spur dikes are of the grouped type. However, if they are isolated and their presence is associated with the concave sides, their impact increases and surpasses that of the grouped ones in vertical erosion.
- Vertical erosion intensifies as the distances between the spur dikes become closer. However, when the distance increases, it provides a suitable condition for the deposition process. Accordingly, local deposition is associated with local scour, even if its places differ in relation to the spur dike.
- The increase in the density of spur dikes, particularly the ones spread on the concave sides, leads to the dominance of the volume of vertical erosion over deposition.
- Vertical deposition rates increase over erosion rates in places where the activity of spur dikes ceases.

- The horizontal changes are a reflection of the vertical ones resulting from the erosion and deposition processes as well as the impact of spur dikes. In spite of the dominance of horizontal deposition, it records the lowest rates in sections in which the volume of vertical erosion increases.
- Local deposition resulting from local scour is not a prerequisite in the increase of vertical deposition, for that requires large amounts of sediments.
- Some places witness a constancy or increase in deposition rates (horizontal changes) as a result of the presence of spur dikes. This is followed by an increase in erosion rates in the corresponding places, so as to create hydraulic balance in the stream.
- There are many geomorphological phenomena resulting from the variation in the characteristics of spur dikes, including scour holes, sandbars, and swamps.
- Scour holes witness several stages of development as a result of the intensity of the vertical erosion caused by the spur dikes. To illustrate, the single holes turn into compound ones, and then the compound holes turn into complex and highly complex ones, particularly in areas including a number of grouped spur dikes.
- Shapes of scour holes vary between elongated and less elongated, with many of them turning from elongated into less elongated, while some single holes take a circular shape.
- All the different angles of the spur dikes have proven effective in protecting the banks from the erosion process, and thus they have achieved their intended aim. It is worth noting, however, that there are certain angles of spur dikes, such as the straight angle, that have proven effective in protecting the banks in addition to deepening the navigational channel. Nevertheless, it is preferable to combine the straight and attracting spur dikes, particularly in bending areas.

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