EVALUATION AND ANALYSIS OF THE MORPHOLOGICAL CHANGES AND DREDGING ON THE EFFICIENCY OF DAMIETTA NAVIGATIONAL BRANCH , EGYPT FROM 2009-2020

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ABSTRACT

The Damietta branch is considered one of the first-class waterways in Egypt. It is also a vital part of the VICMED project, which connects Lake Victoria to the Mediterranean Sea, achieving the shortest linking paths between the Nile Basin countries and Europe. Damietta branch exposed to many morphological changes since Aswan High Dam construction and human interventions such as river rehabilitation, water station intakes, and frequent dredging operations. All of that are affecting the branch behavior and stability. The current research is evaluating the morphological changes of Damietta branch over the years, and their effect on the waterway in reach bounded by Delta Barrage and Zefta Barrage to identify the locations of erosion and sedimentation, consequently navigational bottlenecks locations. Data were collected in the period 1982, 2009, 2014, and 2020. SMS and Civil 3D were used in the process of evaluating morphological changes. Then a two-dimensional (SRH-2D) model has been applied to determine the navigational bottlenecks that might occur in the lower flow conditions and their frequency in different years. It concluded that the sedimentation rate from 1982 to 2009 was around 0.2 m/year, while the years 2009 to 2014 was

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about 0.25 m/year and during the period 2014 to 2020 it was 0.5 m/year. These results showed that the stream has become more reactive and less stable with the continuous maintenance of navigation, and the sediments represented in the increase in the size of the islands. Therefore, the study accordingly recommended eluding wide-ranging dredging for its adverse implications.

Keywords: waterways, dredging, Morphological Change, Navigation Bottlenecks, SRH-2D model.

INTRODUCTION

The Nile River, as an alluvial river, is subjected to change its morphological characteristics due to changes in the flow regime, and bed and bank characteristics. The human interventions such as river training, dredging, water stations, bank protection, bridges, and other structures is affecting the river morphology as well. River tends to restore its equilibrium state by changing its morphological characteristics such as cross-sectional shape, slope, roughness, bed material size, and patterns, which consequently affects the navigation channel depth, width, and alignment and leads to create a navigational bottleneck along the river reach. Therefore, a morphological study using mathematical models is needed to predict the river response to any human interventions, as its effect can be resulted in changes along the river not only local effect (Telvary 2004).

(Sadek, et al., 2004), stated that the encroachment on the floodplain during the last three decades reduced the river capacity, which can help appearing new navigation bottlenecks. (Moustafa, 2005), discussed the Nile

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River morphology expected changes for the reach of Damietta Branch. He studied the difference between the meander morphologies at 1982 and 2001 such as: channel width, channel depth, meander wavelength because this reach is meandering and contains many bends and islands. He developed (GSTARS 2.0) model to predict the morphological changes. Then, he found that due to the increase of flow the average amount of degradation is 14.91m/km, and the amount of aggradations is 10.62 m/km. (Sadek, et al., 2015), examined the effect of bank erosion and bend types on the efficiency for Damietta branch. They estimated that the relations between different bend parameters which may be used to predict the length of navigational path and the bank erosion to mitigate occurrence navigation bottlenecks. (Elsersawy, & Kamal, 2017), studied and evaluated the existing berths in secondary reach. This research is concluded that the percentage 26% of the existing berths are satisfied the navigation depths conditions, the percentage of 58% require maintained dredging and the percentage of 16% of the existing berths does not satisfy the navigation depths conditions.

The continuous cycles of deposition and scouring due to natural cases and human interventions can negatively affect the riverbed elevation and in turn can affect the need for changing the alignment of the navigation path along the study reach.

The data of human actions and morphological changes were collected, studied and analyzed during a period including river navigation development project, to know their relationships and its effects on the formation of the navigation bottlenecks. Mathematical model (SRH-2D) has used to simulate the hydrodynamic and sediment transport movements in the study reach. The results of research could be supported decision makers to take the measures in avoiding or mitigating the extensive dredging.

The objectives the study are to:

- Evaluate the morphological changes of the Damietta branch of the Nile River.
- Determine the trend of erosion and sedimentation in the study reach of Nile River.
- Investigate the navigation bottleneck in different years (2009, 2014, and 2020) to identify the location, which consider as permanent bottlenecks.

STUDY AREA

Damietta branch has chosen as a study area. As it is considered one of the first-class waterways, it is also a vital part of the VICMED project, which connects Lake Victoria to the Mediterranean Sea. Damietta branch is about 227.45 km. starting from D.S.Delta Barrage at kilometer 26.5 from El Roda gauge station to the New Damietta Barrage at kilometer 253.95.

The reach bounded by Delta Barrage and Zefta Barrage was selected as a study area as it has many navigational bottlenecks and complex morphological characteristics due to meandering. This part is covers approximately 93 km in Damietta branch from Delta barrages at km 26.5 to Zefta barrages at km 119.5 downstream of El Roda Gauge Station. As indicated in Figure (1).

The navigation channel was designed in the Damietta branch, with a minimum width of 40 m and Depth 2.3 m under minim water level. The River Transport Authority (RTA) and the Nile Research Institute (NRI) maintain the navigation channel.

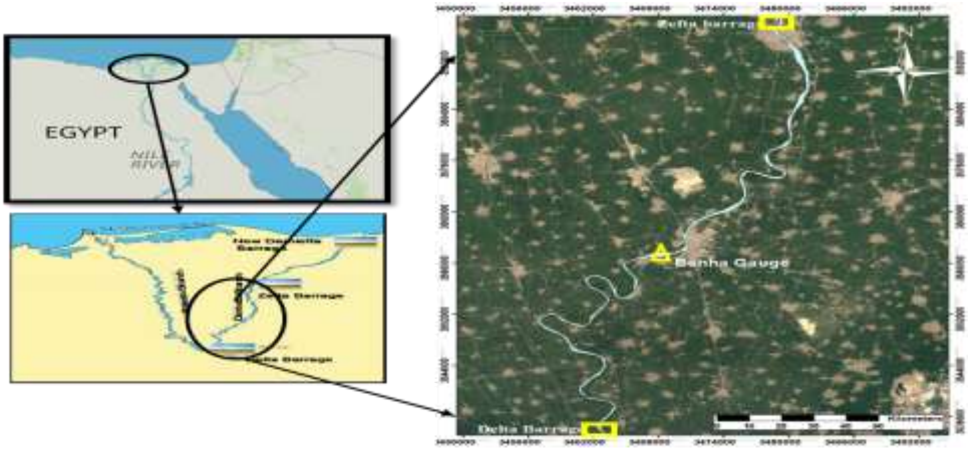
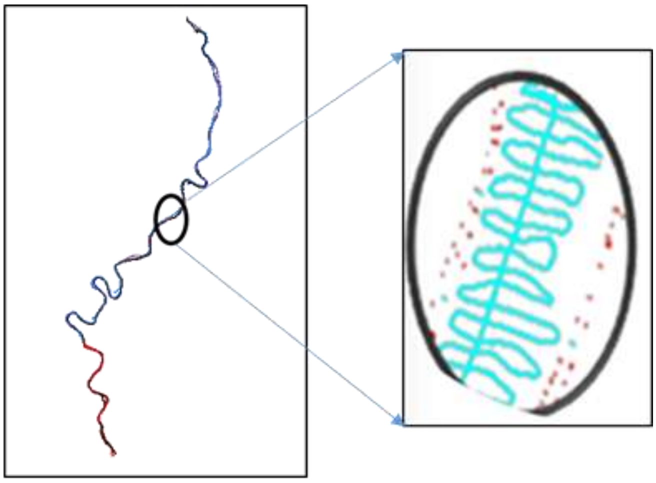


Figure (1): Study area location on map

MATERIAL AND METHODS

Data Collection: Required Data were collected to enable the simulation of the study reach such as bathymetry data, Hydrological data, Velocity, Bed material samples, Navigational path. Nile Research Institute (NRI) provided data used throughout this research. Four datasets of bed bathymetry are available; the first dataset is a collection of maps was created for the Nile River during 1982 by the Kenting Earth Science Ltd. Company. The other three datasets were carried out by NRI during 2009, 2014 and 2020. The by means of hydrographic survey and land survey of riverbanks with 50 interval, as shown in figure (2).



Figure(2): Sample of the Bed Survey Data in the Study Reach, (NRI map 2020). River discharges and the corresponding water levels are essential data for simulating the hydrological parameters of a study area. The periodic monitoring of discharges at the Delta barrages was perform. The corresponding upstream and downstream water levels at those barrages and different gauge stations were essential for the next analysis.

The analysis of the recorded hydrological data for five years (from 2014 to 2018) has revealed that the high flow discharge values have mainly

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recorded from June to September, while the minimum values are from November to March. The maximum daily flow discharge value is 63 million m3/day Downstream Delta Barrage, which has recorded in June 2014. The minimum daily flow discharge value is 10 million m3/day, which has recorded in January 2017, and the dominant flow discharge value based on analysis range from 20 to 25 M.m3/day as shown in Figure (3).

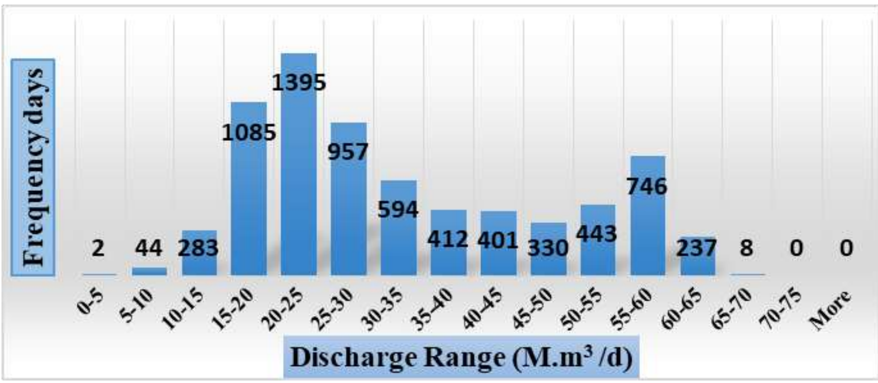
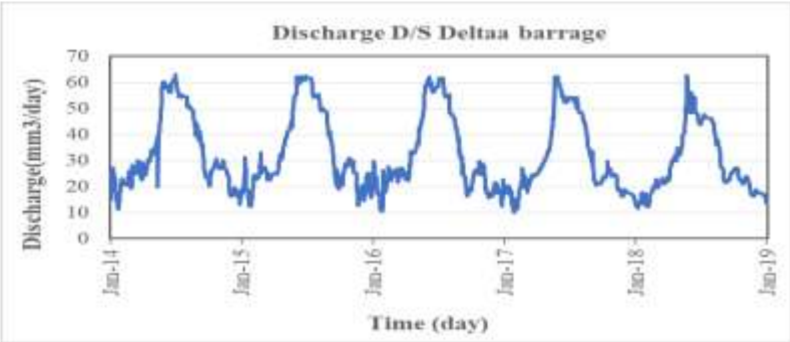
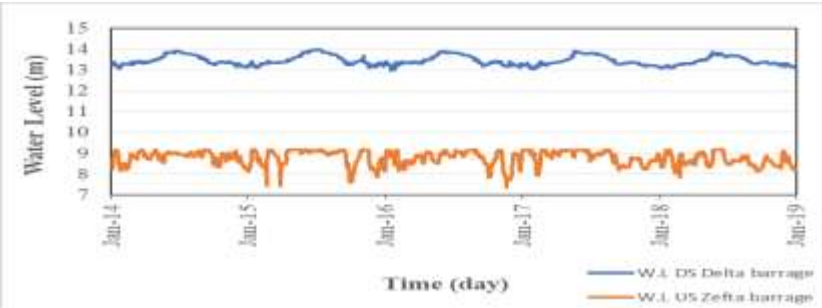


Figure (3): Analysis of discharge flow from 2014 to 2018.

The hydrological records flow discharges were collected downstream of Delta barrages for the past five years as shown in Figure (4). Also, the hydrological records (water levels) were collected at downstream of Delta barrages, upstream of Zefta barrages and Benha gauge for the past five years as shown in Figures (5&6).



Figure(4): Discharges for the Delta barrage from 2014 to 2018



Figure(5): Water levels D.S Delta barrage gauge and U.S Zefta barrage gauge from 2014 to 2018

Figure (6): Water levels at Benha gauge from 2014 to 2018

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The velocity measurements have performed by using bray stoke current-meter type. The velocity profiles have measured in each profile at (0.5 m from water surface, at 25%, 50%, 75% of water depth and 0.75m from bed) at three location at the same cross section. This process repeated in three locations at west, middle and east of each cross section and have the average velocity in each point. Grab Sediment Sampler was used to collect sample of bed level for six of cross sections were collected and analyzed to know bed material data (D 50% = 0.025 mm).

- **MORPHOLOGY CHANGE COMPARISON OF YEARS 1982, 2009, 2014 AND 2020 BY SMS & CIVIL 3D:** The morphological changes were evaluated and analyzed for the different years, 1982, 2009, 2014 and 2020 by applying SMS and Civil 3D. Accordingly, the annual rates of sediment and erosion were determined at the different significantly locations of the study reach. SMS was used to determine the annual rates of sedimentation and erosion, while the quantity of sedimentation and erosion are obtained employing Civil3D for each section of the study reach. The following Figures (7) to (9) illustrate annual sedimentation and erosion rates, elevations, and quantities of sediment and erosion for the studied cross-sections for the years 1982, 2009, 2014 and 2020. From the analysis results, it is monitored that the effect of navigation development at km 35 and 41 where the navigational path empty from the deposition during the period from 2009 to 2014 because of dredging works. Intensive dredging is also observed around their sites. While during the period from 2014 to 2020, some deposition appeared because of these areas becoming sediment traps. Therefore, it is expected the aggradation will take place ultimately as a result of narrow channel or new under forming island with the limited flow. While the sites at km 58 and 80 always are suffered from deposition.

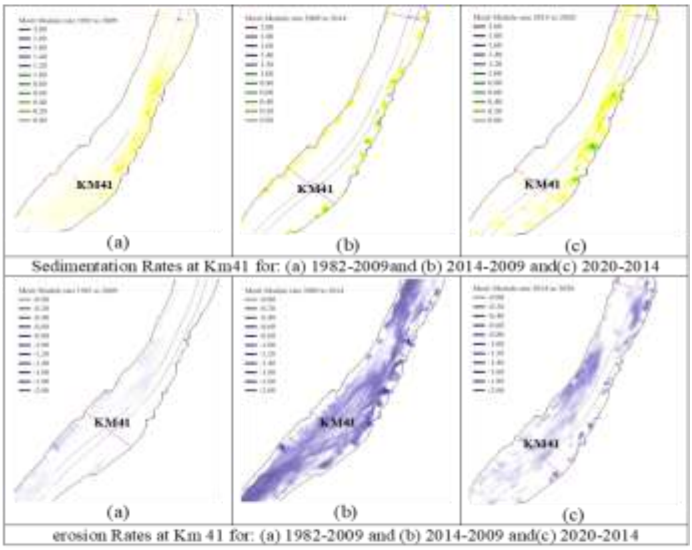


Figure (7): Annual sedimentation and erosion rates for cross sections at km41

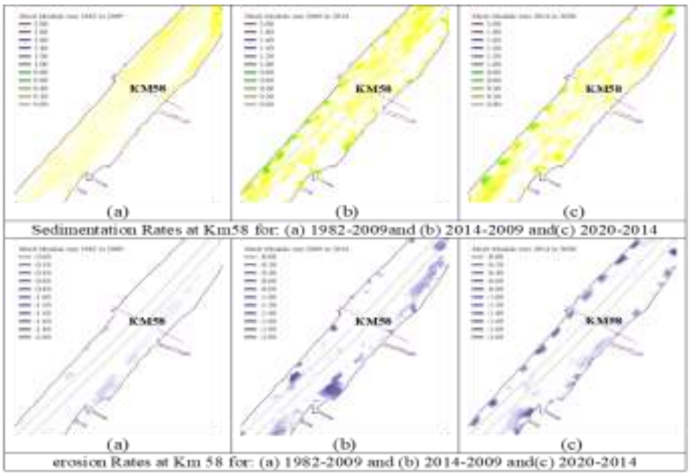


Figure (8): Annual sedimentation and erosion rates for cross sections at km58

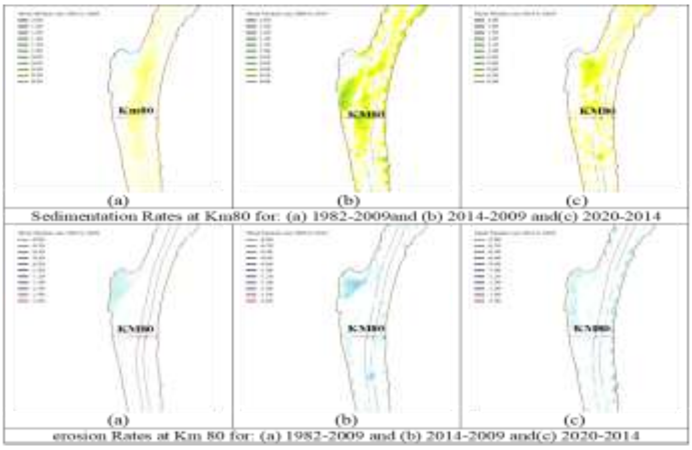
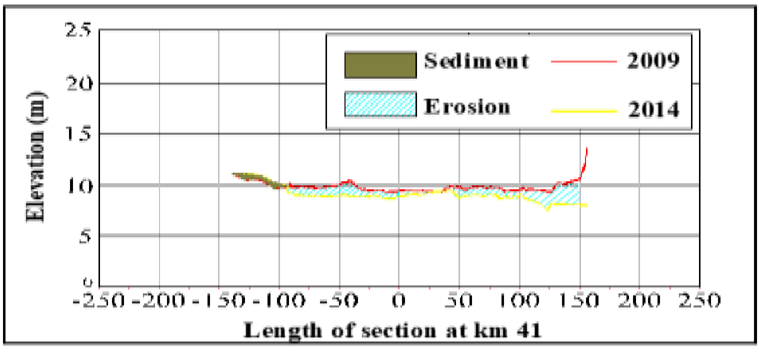


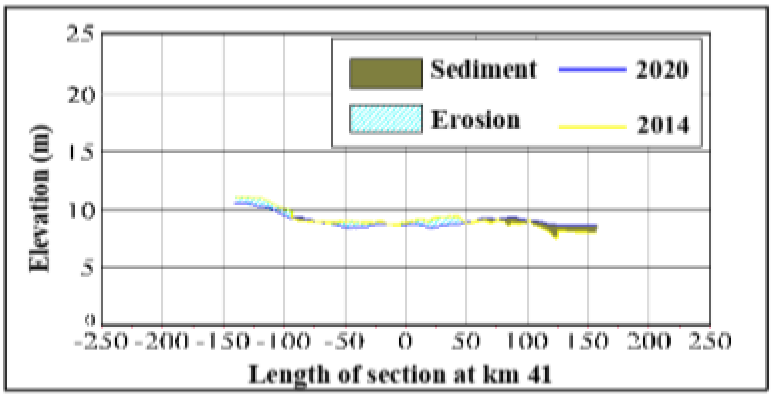
Figure (9): Annual sedimentation and erosion rates for cross sections at km80

For the study area, the sedimentation rate from 1982 to 2009 was around 0.2 m/year, from the years 2009 to 2014 was around 0.25 m/year and the years 2020 to 2014 was around 0.5 m/year. In addition, the erosion rate from 1982 to 2009 was around 0.13 m/year. However, from the years 2009 to 2014 was around 0.6 m/year and the years 2020 to 2014 was around 0.4 m/year. It can be concluded from the previous analysis that the erosion/sedimentation rate is increased especially in the late periods because of the human intervention represented in the continuous dredging of the navigation path. Hence, the human intervention contributes to increasing the rate of morphological changes compared with the natural changes.

- **The quantities of both sedimentation and erosion have been investigated by Civil 3D as shown in the following figures:**

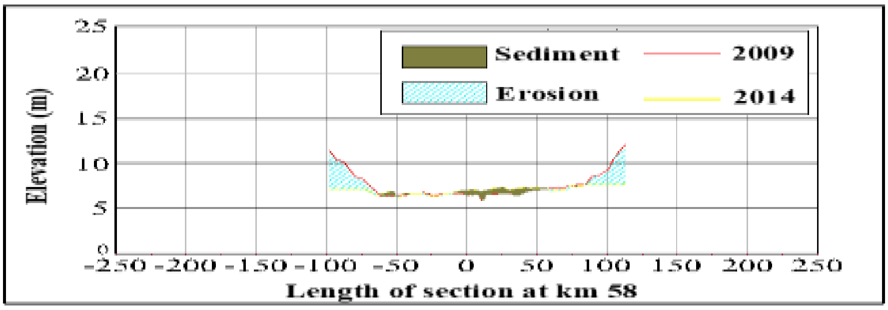


(a)

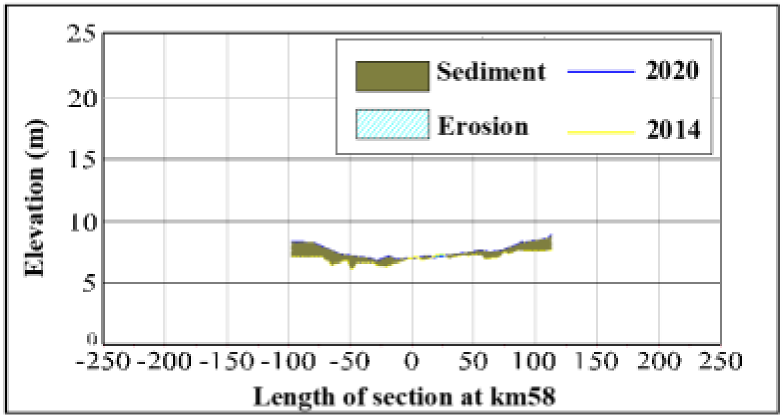


(b)

Figure (10): Comparison of Bed Profiles in at Km 41 for: (a) 2009-2014 and (b) 2014-2020

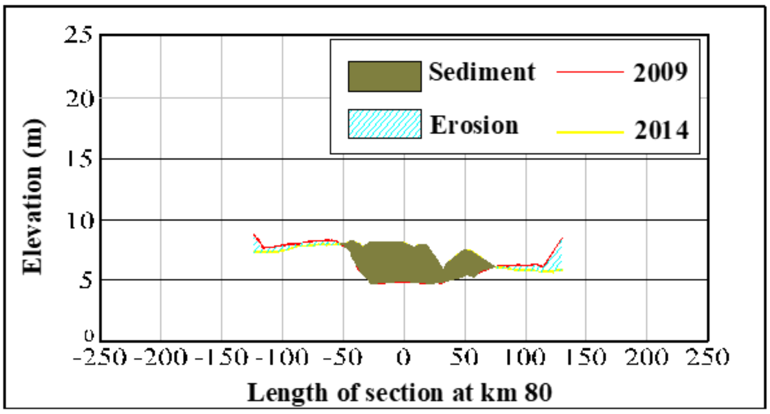


(a)



(b)

Figure (11): Comparison of Bed Profiles in at Km 58 for: (a) 2009-2014 and (b) 2014-2020



(a)

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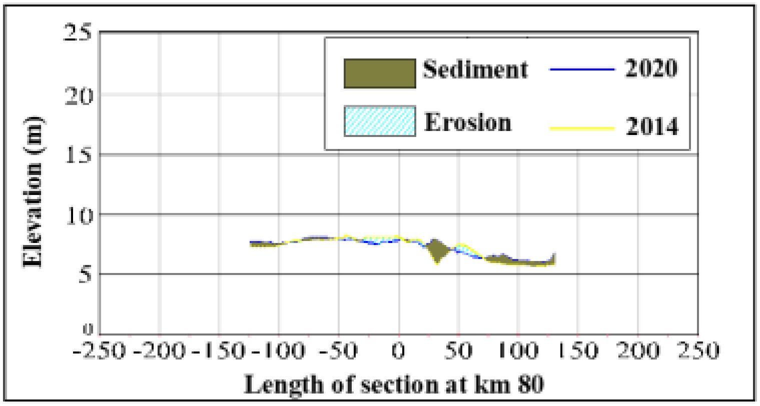

(b)

Figure (12): Comparison of Bed Profiles in at Km 80 for: (a) 2009-2014 and (b) 2014-2020

The quantities of both sedimentation and erosion were computed and recorded along the study reach and during the study period after the navigation, development project and continues maintenance of the navigational channel. Figure (13, 15) other hand, Figure (14, 16) represents as a result of the net of sedimentation or erosion along the study reach. It is clear from the figure that the erosion is predominant especially D.S. Delta Barrage at km29 until to km 62.

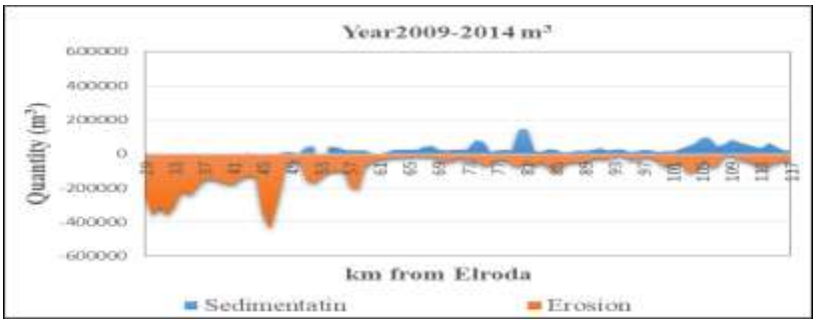

Figure (13): Sedimentation and Erosion Quantities for the Years 2009-2014

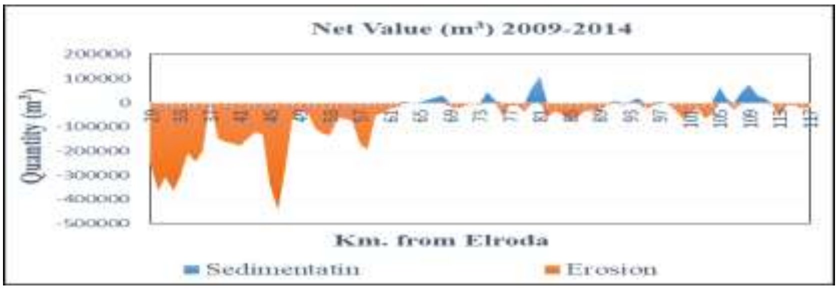

Figure (14): Net Value of Sedimentation and Erosion Quantities for the Years 2009-2014

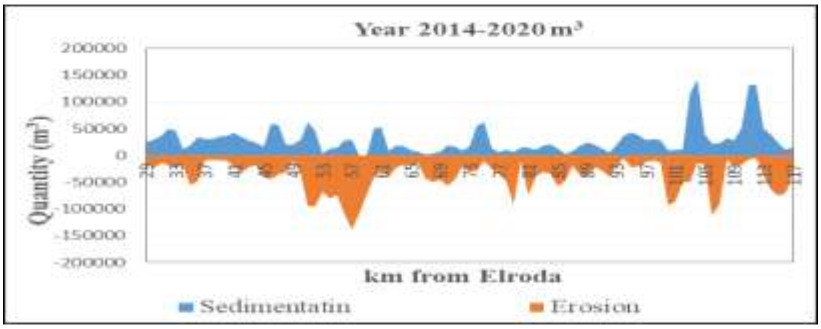

Figure (15): Sedimentation and Erosion Quantities for the Years 2014-2020

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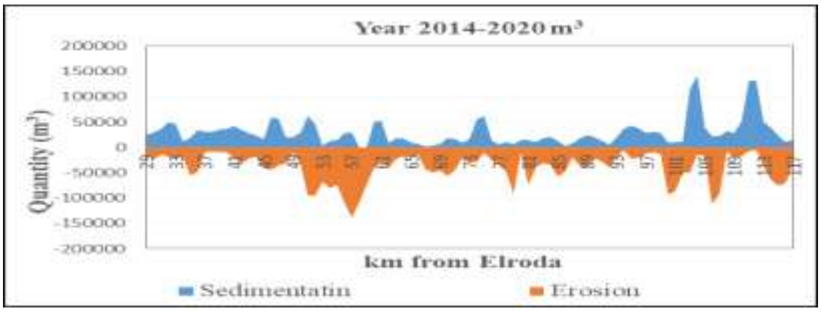

Figure (16): Net Value of Sedimentation and Erosion Quantities for the Years 2014-2020

NUMERICAL MODEL

Model Description: The Sedimentation and River Hydraulics-Two-Dimensional model (SRH-2D) is a 2D hydraulic numerical model based on 2D hydraulic principles and considerations for sediment transport, temperature and vegetation. It has been in development since 2004 by Dr. Yong Lai at the US Bureau of Reclamation. SRH-2D solves the St Venant equations (2D depth averaged) using a finite-volume method. From the time of its creation, it has been successfully used and tested for a number of scenarios (e.g. Lai, and Greimann, 2008 & Lai, 2010). SRH-2D developed by Aquaveo, the Surface water Modeling System (SMS) fulfills this role as the graphical user interface for this work. SMS streamlines the model efficiency reducing the amount of commands needed for the creation of a model.

Hydrodynamic Equations for SRH-2D

$$\frac{\partial h}{\partial t} + \frac{\partial (hU)}{\partial x} + \frac{\partial (hV)}{\partial y} = 0$$

$$\frac{\partial hU}{\partial t} + \frac{\partial hUU}{\partial x} + \frac{\partial hUV}{\partial y} = \frac{\partial hTxx}{\partial x} + \frac{\partial hTxy}{\partial y} - gh\frac{\partial z}{\partial y} - \frac{Tbx}{\rho} + Dxx + Dxy$$

$$\frac{\partial hV}{\partial t} + \frac{\partial hUV}{\partial x} + \frac{\partial hVV}{\partial y} = \frac{\partial hTxY}{\partial x} + \frac{\partial hTYy}{\partial y} - gh\frac{\partial z}{\partial y} - \frac{Tby}{\rho} + Dyx + Dyy$$

Where: t is time, x and y are horizontal Cartesian coordinates, h is water depth, U and V are depth-averaged velocity components in the x and y respectively, e is excess rainfall rate, and g is the force of gravity.

Model Construction: Before carrying out any sediment transport simulations, a series of hydraulic simulations were run to ensure model stability and accuracy.

The model has been used to generate the mesh, which represents the study area from km 26.5 to Zefta barrages at km 119.5 downstream of El Roda Gauge Station, by providing element and node information in the appropriate format. The mesh file defines the finite element by assigning coordinates and elevations to nodes located at the Vertices of the elements. The element width in the mesh was 15 m. The number of all elements was 231,341 and the number of all nodes was 476,206. Figure (17) presents the final iteration that is wrapped around the provided digital elevation model.

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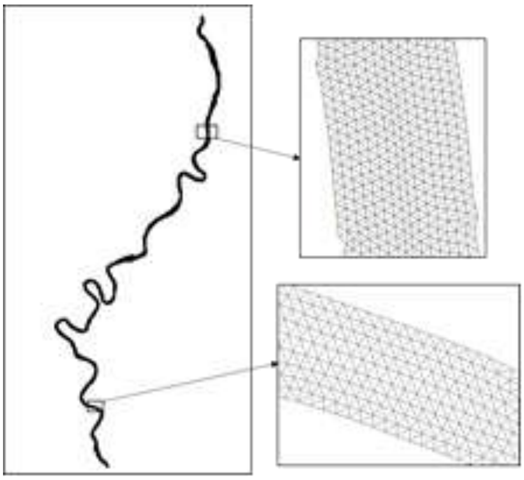

Figure (17): Study Reach Mesh Element Composition

Model Calibration: The model was calibrated using the surveyed data at 2020 and the inflow discharges and water levels as shown in table (1). The location of the cross section shown at Figure (18). Comparison of the measured field velocities and obtained velocity profiles at the cross sections located as shown in Figure (19). The water level was verified at the stations' Delta, Banha and zefta Barrage show in figure (20).

Table (1): Boundary Condition of the calibration

Module	Item	Value
Hydrodynamics	bathymetric survey	2020
	Discharge D.S Delta Barrage	58.15 M.m3/day
	Water level at U/S of Zefta barrage	(8.94) m
	Manning’s roughness n value	0.023

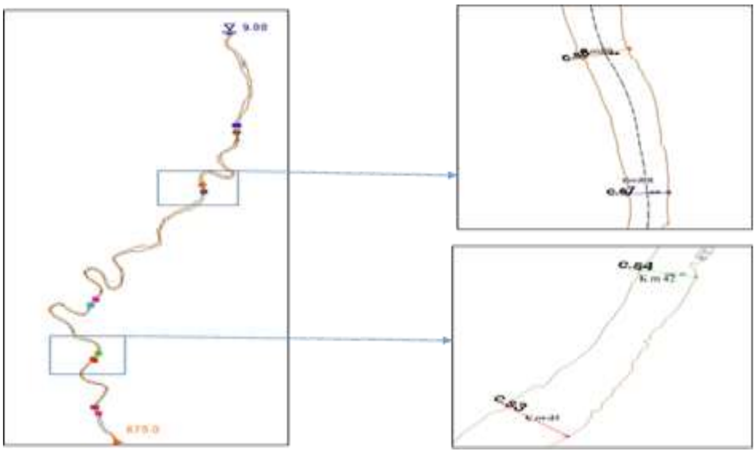

Figure (18): The location of the cross section

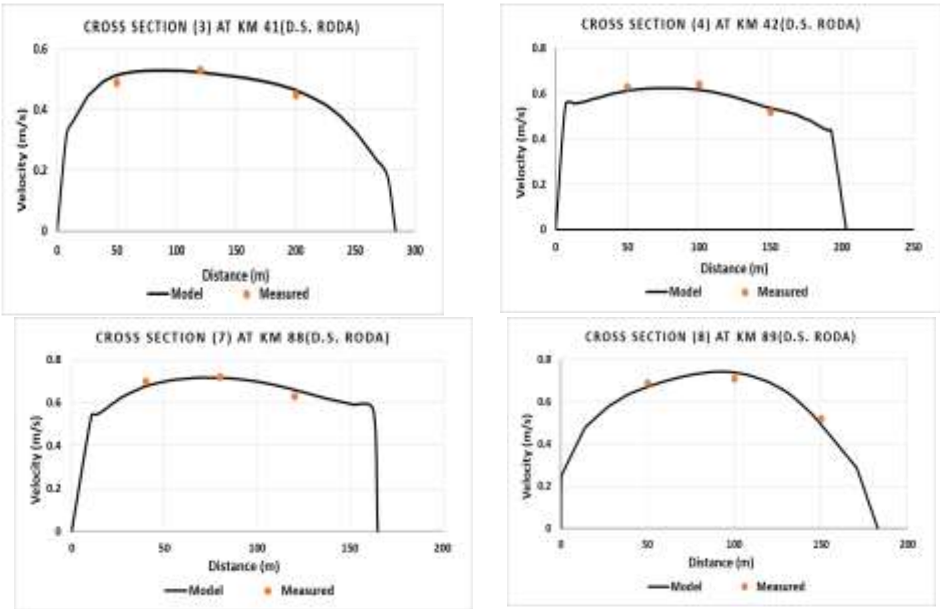

Figure (19): Velocity Calibration

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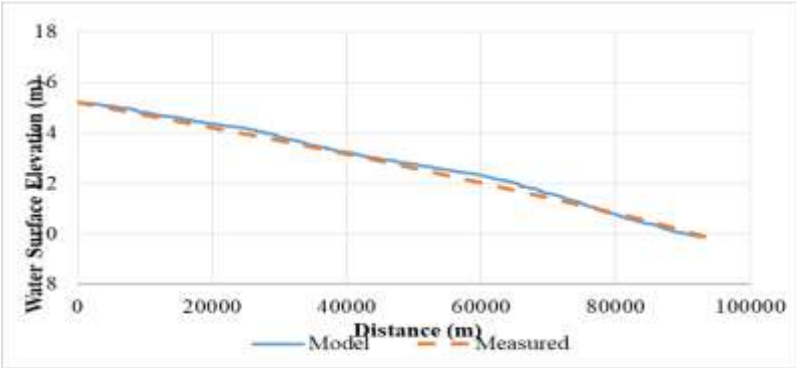

Figure (20): Water Level Calibration

Model Application: The scenario was simulated in this study according to minimum discharge path along the study reach and the corresponding water levels for the years 2009, 2014 and 2020. From the simulation results, the locations of the navigational bottlenecks were determined for these years.

Minimum Discharge Scenario

The minimum flow condition was determined during period from 2009 to 2020. Table (2) shows the minimum discharge and the corresponding water surface elevation at upstream Zeft Barrage. A steady state simulation as performed using SRH-2D model to determine the navigational bottlenecks. The number, characteristics, and locations of the navigational bottlenecks is determined in the study area.

Table (2): Minimum Discharge and Corresponding Water Levels

Boundary Condition / Year	**Years 2009, 2014 and 2020**
Minimum Discharge	10 Mm3/day
Corresponding Water Level	9.15 (m)

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RESULTS AND ANALYSIS

After applying the model to the worst case of the flow, it was possible to evaluate all the characteristics of the study area such as the bed elevation, velocities, water levels, and depths, and then determine the navigational bottlenecks for the different three years. The bottleneck is determined by knowing whether the depths exceeded 2.30 m or not and if the depths in the navigation channel were less than a value the navigation bottleneck will occur and must be considered.

Navigation Bottlenecks Assessment for the Year 2009: As shown in Figure (21), there are 18 navigational bottlenecks in year 2009, and they are concentrated in the area from km 30 to km 60.

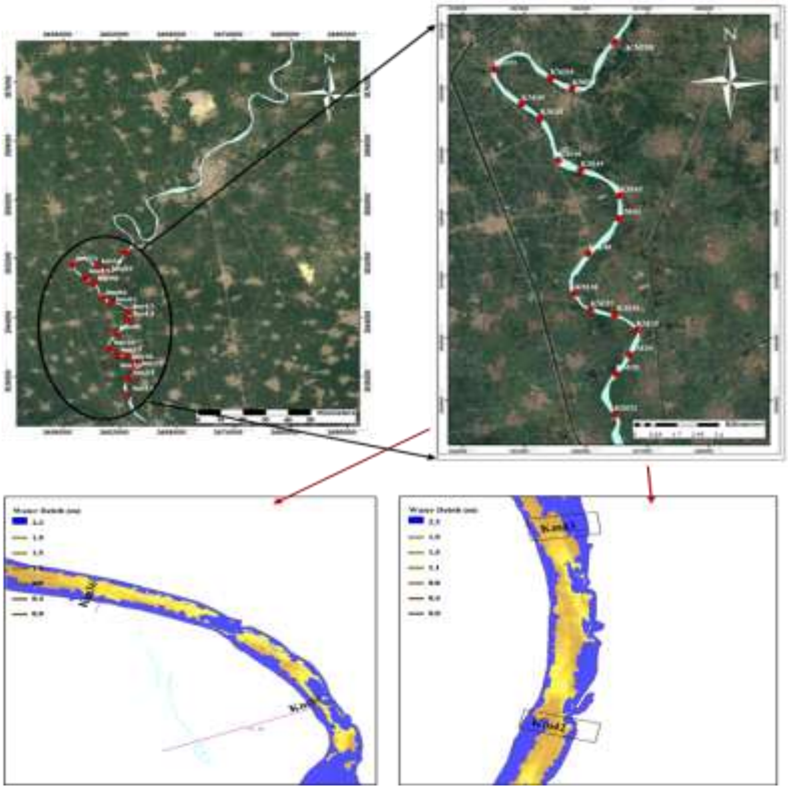

Figure (21): Navigation Bottlenecks for the Year 2009

Navigation Bottlenecks Assessment for the Year 2014: Figure (22), shows the locations of the navigational bottlenecks in year 2014. They are 13 navigational bottlenecks.

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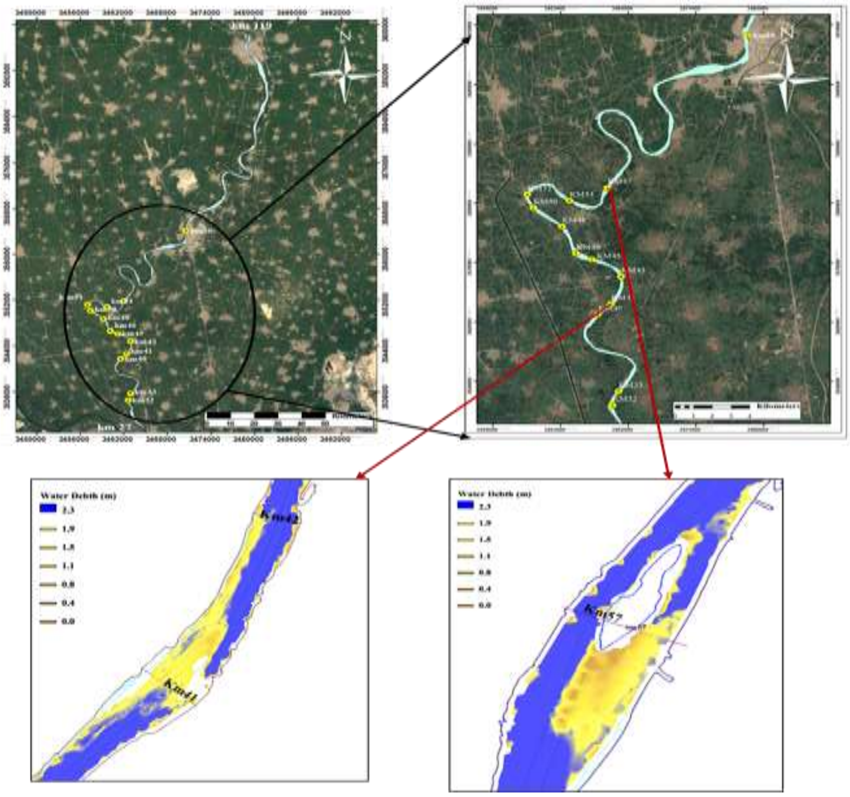

Figure (22): Navigation Bottlenecks for the Year 2014

Navigation Bottlenecks Assessment for the Year 2020: Figure (23) shows the places of navigational bottlenecks in year 2020, which are 16 areas of navigational bottleneck

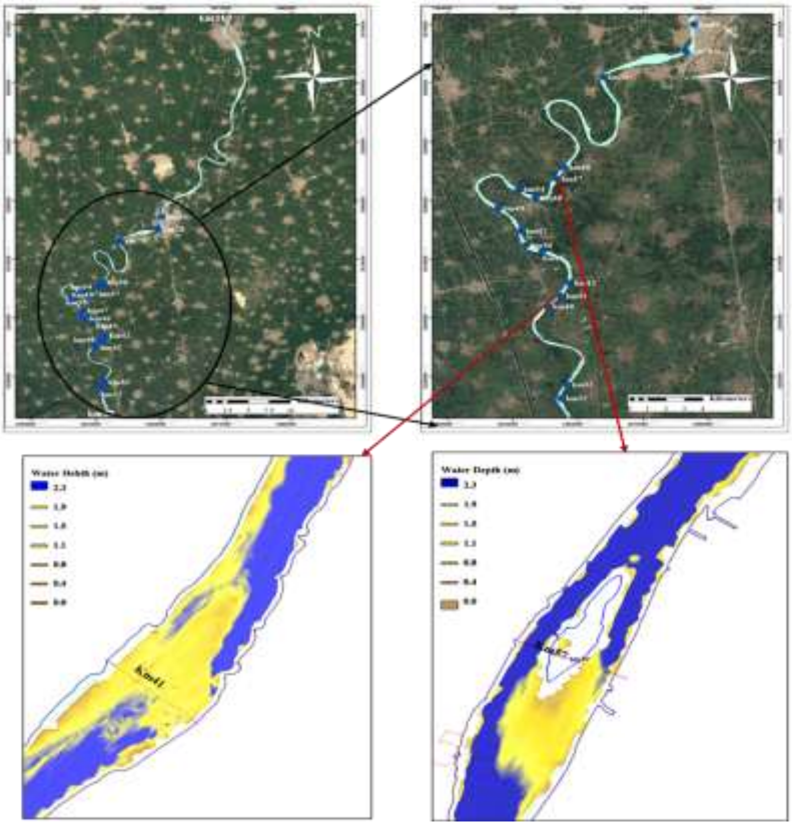

Figure (23): Navigation Bottlenecks for the Year 2020

From the previous figures, all the navigation bottlenecks for the three years 2009, 2014, and 2020 were determined coincident the Minimum Discharge scenario (worst case of the flow). Then it became possible to identify the locations and characteristics of the navigational bottlenecks for these years. Thus, it is easy to determine where the navigation bottleneck will have repeated during the three different years. This can be clarified via analysis for the results as shown in table (3).

Table (3): the Bottlenecks during the Years 2009, 2014, and 2020

Location (Km)	Bottleneck (2009)	Bottleneck (2014)	Bottleneck (2020)	Location (Km)	Bottleneck (2009)	Bottleneck (2014)	Bottleneck (2020)
Km31	□	---	---	Km45	□	□	□
Km32	---	□	□	Km46	□	□	□
Km33	□	□	□	Km48	□	□	□
Km34	□	---	---	Km49	□	□	□
Km35	□	---	---	Km51	□	□	---
Km36	□	---	---	Km54	□	□	□
Km37	□	---	---	Km55	□	---	□
Km38	□	---	---	Km57	---	□	□
Km40	□	□	□	Km58	□	---	□
Km41	---	□	□	Km73	---	---	□
Km42	□	---	□	Km78	---	---	□
Km43	□	□	---	Km80	---	□	□
Total Bottlenecks					18	13	16

According to the analysis of the results, the sites of sedimentation and erosion can be correlated with sites of frequent navigational bottlenecks during the different studied years. The results showed that some sites show frequent navigational bottlenecks in the two studied years, and others show frequent navigational bottlenecks in the three studied years. Which means that dredging for these sites is not appropriate.

For the locations at Km 43 and 51, the navigation bottleneck appeared in years 2009 and 2014. The sedimentation volumes for these sites were 47, 955.15 m3respectively. For the navigation bottleneck that appeared in the

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years 2014 and 2020 at the location at Km 32, 41, 57 and Km 80 the quantity of sedimentation was 135, 628, 98 m3 respectively. Moreover, for the locations at Km 33, 40, 45, 46, 48, 49, and 54, the navigation bottleneck occurred repeatedly in the three years. The quantity of sedimentation for these locations during the period 2009 - 2014 was 65,857.14 m3. While the quantity of sedimentation for these locations during the period 2014 - 2020 were 212432.32 m3. From these results, it is clear that according to the state of the navigational bottlenecks over the years (permanent or disappeared) and the behavior of the stream in the dredging area, it can be judged on the effectiveness of dredging operations. One of the main alternatives for mitigate dredging is the reduction of the draft navigation depth during the minimum discharge, change the direction of navigation path and finally it can be used submerged vanes after study the optimum shape and type.

CONCLUSIONS

This study studied the morphological changes in different years 1982, 2009, 2014, and 2020. Accordingly, the trend of the study reach of the Nile River was evaluated. This study evaluated also the navigation bottlenecks for different years. According to the results obtained from this study:

1- SMS and Civil 3D were applied to evaluate the morphological changes, which occurred in the study region D.S. Delta Barrage. Accordingly, evaluate the trend of the study reach of the Nile River.

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2- The numerical model (SRH-2D) was calibrated and verified using data measurements.

3- Minimum Discharge Scenario (The worst case of the discharge) and its corresponding water surface level was applied during the years from 2009 to 2020 to determine the number and locations of navigation bottlenecks.

4- The number of navigation bottlenecks was determined for different years 2009, 2014, and 2020 for the minimum case of the flow, where the number of navigation bottlenecks for 2009, 2014, and 2020 was 18, 13, and 16 respectively.

5- The navigation bottlenecks appeared in 2009 and 2014 at Km 43, and Km 51.00. While the navigation bottlenecks that appeared in 2014 and 2020 at Km 32, Km 41, Km 57, and Km 80. Moreover, the navigation bottleneck occurred repeatedly in the three studied years at Km 33, Km 40, Km 45, Km 46, Km 48, Km 49 and Km 54.

Finally, the sections at KM 33, KM 40, KM 45, KM 46, KM 48, KM 49 ,and KM 54 are the worst sections where the navigation bottleneck repeated in this locations during three years (2009, 2014 and 2020).So they must be taken into account to solve this problem.

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RECOMMENDATIONS

- Study the application of other alternatives for solving navigation problems other than dredging.
- Inland water transport activity can be put off during certain number of days each year when the required water depth is not available to reduce the maintenance works in the long run consequently avoid the river disturbance.
- Study other dredging negative impacts such as environmental impacts as a result from the dredging disposal.

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تقييم وتحليل التغيرات المورفولوجيا والتكريك على كفاءه الملاحة النهرية لفرع دمياط

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المستخلص

يعتبر فرع دمياط من الممرات المائية الهامة في مصر حيث انه جزءًا حيويًا من مشروع VICMED الذي يربط بين بحيرة فيكتوريا والبحر الأبيض المتوسط ، محققا أقصر طرق الربط بين دول حوض النيل وأوروبا. وحيث انه نظام ديناميكي تحكمه هيدروليكية وهيدرولوجية النهر من تنوع مقدار الفيضان السنوي والترسيبات ومشاريع أعالي النيل. تعرض فرع دمياط للعديد من التغيرات المرفولوجية منذ انشاء السد العالي ممثلة فيه تهذيب المجرى وعمليات التكريك المتكررة للملاحة واعمال مأخذ محطات المياه على مدار السنوات. خلال البحث سيتم دراسة ما تعرض له الفرع من التغيرات المورفولوجية والتدخلات البشرية على سلوك المجرى الواقع من خلف قناطر الدلتا حتى امام قناطر زفتي وعلى كفاءته كمجرى ملاحي من خلال تحديد مواقع الاختناقات الملاحية. تم تجميع البيانات في الفترة (١٩٨٢، ٢٠٠٩، ٢٠١٤، ٢٠٢٠). تم استخدام SMS وCivil3D في عملية تقييم التغيرات المورفولوجية التي تؤثر على سلوك المجرى. تم تطبيق نموذج ثنائي الأبعاد (SRH–2D) بعد معايرته لتحديد مواقع الاختناقات الملاحية التي قد تحدث مع التدفق المنخفض المتعاقب في سنوات مختلفة. وخلصت الدراسة إلى أن معدل الترسيب من عام ١٩٨٢ إلى عام ٢٠٠٩ كان حوالي ٠,٢ م / سنة، بينما بلغ معدل الترسيب في الأعوام من ٢٠٠٩ إلى ٢٠١٤ حوالي ٠,٢٥ م / سنة، وخلال الفترة من ٢٠١٤ إلى ٢٠٢٠ بلغ حوالي ٠,٥ م / سنة. أظهرت هذه النتائج أن التيار أصبح أكثر تفاعلًا وأقل استقرارًا مع التكريك المستمر، وقد تلاحظ ان حجم الجزر زادت مع تغير انماط النحر والترسيب. مما يؤدى الى أعاقة المسار الملاحي وزيادة مواقع الاختناقات الملاحية. لذلك أوصت الدراسة التخفيف من عمليات التكريك، مع دراسة بدائل أخرى.

الكلمات المفتاحية: الممرات المائية، التكريك، التغيير المورفولوجى، الاختناقات االملاحية، نموذج SRH–2D.