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Research Article

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Evaluating the Morphological Changes and Navigation Bottlenecks for the Fourth Reach of the Nile River

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Abstract The Nile River is the main route for inland navigation in Egypt. Rivers are dynamic systems governed by hydraulic and sediment transport process. Over time, the river responds to changing conditions in its environment by modifying its cross-sectional shape, thus increasing or decreasing its local sediment carrying capacity, observed as patterns of erosion and deposition. The existence of morphological changes is a result of the variation of water levels and discharges. Sediment deposition and lowering of water surface elevations create shallow water depth, which cause navigation problems in some areas. The existence of some morphological changes in the river such as bank failure, bed degradation, island formation, etc.; increase the interest towards sediment transport. So, the study of morphological changes is considered very important issue to determine the sediment and erosion rate in study reach then determine the trend of Nile River. Three data sets were compiled to describe the hydraulic conditions. This was achieved in order to identify the locations of sedimentation and erosion at study reach. This data had been collected at period 2003, 2010 and 2016. In this paper, the two-dimensional SRH-2D (The Sedimentation and River Hydraulics) model has been applied to a river reach for different scenarios of flow and discharge and accordingly, determine the navigation bottlenecks for each scenario in the fourth reach of the Nile River.

Keywords Nile river, SRH-2D model, Morphological Change, Navigation Channel, Navigation Bottlenecks

1. Introduction

River transport through the River Nile has been recently considered as important as other transport means. Inland navigation through natural rivers is mostly preferred since it presents a good opportunity for fuel saving, enhancing the environment, and improving road safety. Therefore, navigation through the River Nile has been recently considered as important as other transport means [1]. The Nile has been considered as a navigable channel throughout Egypt history. Around 3 million tons of cargo is transported over the Nile River between Alexandria, Cairo, and Aswan yearly. This transport is expected to increase considerably when the planned container terminal projects and other infrastructure projects in the Nile Delta are completed [2]. In cooperation with the Egyptian General River Transport Authority (EGRTA), the Nile Research Institute (NRI), embarked on a hydrographic survey of the River Nile between Cairo and Aswan for a distance of about 953 km. The aim of this survey was to develop a suitable navigational path serving the navigation movement along the river. Using the collected hydrographic data, navigational contour maps have been developed with a proposed navigational path. This path is designed to be two-way and maneuverable and have a navigational draft of 2.30 m under the minimum water levels available along the river. Also, areas prone to navigational bottlenecks could be located. It has been proposed to dredge them to provide safe navigation through the river [3]. Finally, to facilitate the movement of vessel traffic in the Nile River, the navigation channel is maintained by River Transport Authority (RTA) and Nile Research Institute (NRI) at a minimum width of 100 meters (m), and a minimum depth of at least 2.30 m.

Raslan, Y., SadekN., and. Attia, k., (2009) studied the Impact of Navigation Development on Damietta Branch. [4]. Hossam El-Sersawy (2001) studied the better identification and prediction of the location of the bottlenecks that may affect navigation in the River Nile [5]. NahlaSadek (2001) studied the morphological changes impact on water surface profile predicted for the River Nile by using one dimensional mathematical model to analyze different hydraulic parameter [6]. NahlaSadek (2012) study the island development impacts on the River Nile morphology [7].

2. Materials and Methods

2.1. Study area

The Nile River is divided into four reaches segregated by four Barrages. The study reach is located in the fourth reach which extends from Assuit Barrage at Km 544.78 from High Aswan Dam (HAD) to Delta Barrage at Km 953.00. The study reach is with a total length of 100 km. It was selected because of their distinct characteristics, which is geometrically complicated and characterized by the morphological changes and navigation bottlenecks. The reach is extended from km 53.00 to km 153.00 downstream of El-Roda Gauge Station. The selected reach consists of many islands, meandering curves, and straight parts (figure 1).

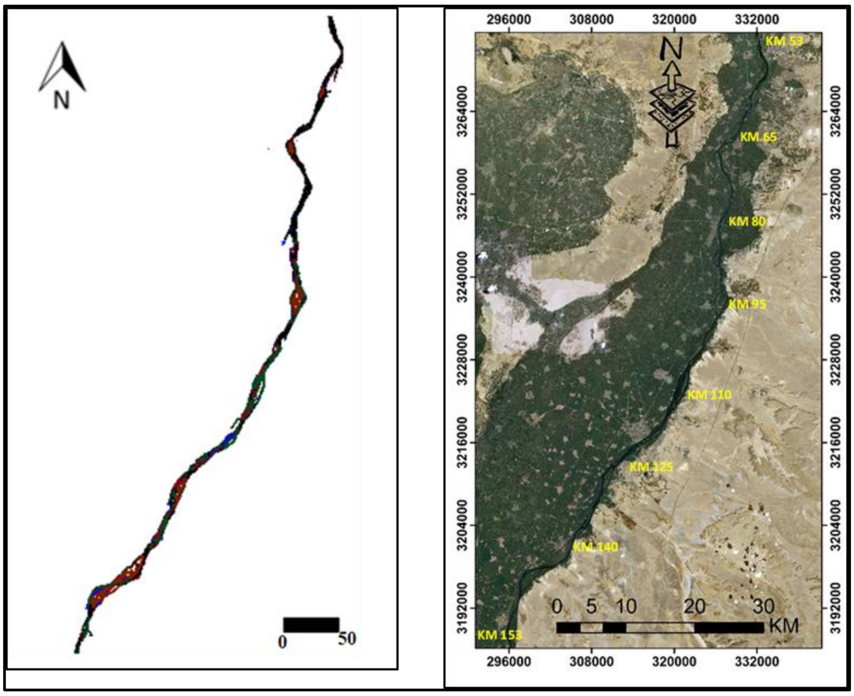


Figure 1: General plane of study reach

2.2. Methodology

To release the objectives, the following had done:

- Review the literature and collecting the available field data such as bed levels flow velocity, sediment transport, properties of the bed particles and the passing discharge at the selected study reach.
- Collecting the required (bathymetric, hydrological, and hydraulic) data.
- GIS and Civil 3D have been applied to evaluate the morphological changes, which occurred at the study region D.S. Assuit Barrage.
- Calibrating the numerical model to make sure it's ability to predict the morphological changed.

- The Sedimentation and River Hydraulics model (SRH-2D) has been applied to a river reach for different scenarios of flow and discharge and accordingly, determine the navigation bottlenecks for each scenario in the fourth reach of the Nile River.

2.3. Data collection

The bathymetric data, hydrologic and hydraulic data such as stage and flow hydrographs, water velocities, and rating curves are collected to establish the initial and boundary conditions of the numerical model. The bathymetric data were obtained from the contour maps, produced from the recent hydrographic survey of the river bed for the year 2003, 2010 and 2016 provided by the Nile Research Institute (NRI). The river channel geometry presented by Easting, Northing, and Elevation (E, N, and Z) points were used for the mesh generation. The coordinates of the mesh were referenced to the WGS84 ellipsoid (World Geodetic System, 1984) with Universal Transverse Mercator (UTM) Projection. The river bed levels were clarified with an accuracy of ± 5 cm by using echosounder flow depth measurements. A hydrological study was carried to analyze the flow discharges and the corresponding water levels daily of a study reach. The river discharges from Assiut Barrage was analyzed as the upstream boundary condition. The study river reach is located between two water level gauge stations; the first is the El-Kraimat gauge station which located at km 87.90, and the second is Bani Sweif gauge station km 118.40 as seen in table (1).

Table 1: Data Collection for the Study Area

Data	Location	Period	Source	Usage
Bathymetry Survey	River reach length of 100 Km	2003,2010,2016	NRI	Grid Development
Discharge	Downstream Assuit barrage	2003,2010,2016	NRI	Downstream Boundary condition (BC)
Water Level	El-Kraimatand Bani Sweifgauges.	2003,2010,2016	NRI	Upstream Boundary condition (BC)
Velocity measurement	Three cross sections for years 2003, 2010 and 2016	2003,2010,2016	NRI	Calibration-Verification
Bed Samples	Eight bed samples at different location of 100 km	2003,2010,2016	NRI	Roughness Coefficient

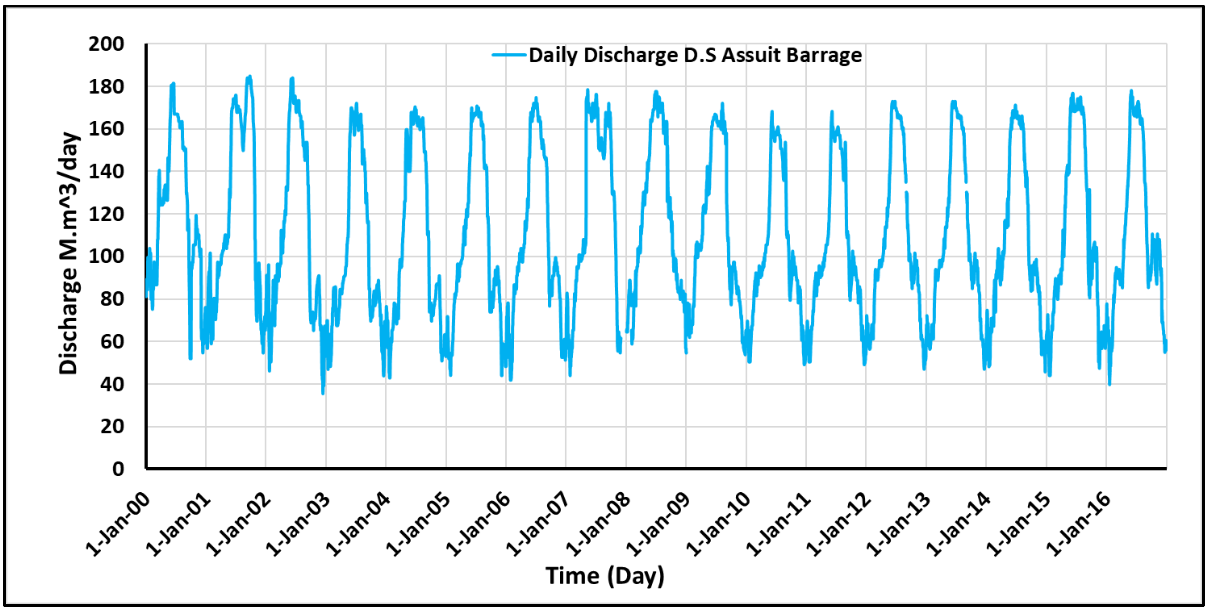


Figure 2: Daily Discharge Hydrograph D.S. Assuit Barragefromyear 2000 to 2016

Figure 2 shows the daily discharges passing D.S. Assiut Barrage during the period from 2000 to 2016, This Figure shows that the maximum discharge is about 182 Mm3/day during the year 2001, while the minimum discharge is 38Mm3/day during year 2003.

3. Numerical Model

3.1. 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, 2008, 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.

$$\frac{\partial hU}{\partial t}+\frac{\partial hUU}{\partial x}+\frac{\partial hUV}{\partial y}= \frac{\partial hTxx}{\partial x}+\frac{\partial hTxy}{\partial y}-gh\frac{\partial z}{\partial y}-\frac{Tbx}{\rho}+Dxx+Dxy \quad (4.1)$$

$$\frac{\partial hV}{\partial t}+\frac{\partial hUV}{\partial x}+\frac{\partial hVV}{\partial y}= \frac{\partial hTxY}{\partial x}+\frac{\partial hTYy}{\partial y}-gh\frac{\partial z}{\partial y}-\frac{Tby}{\rho}+Dyx+Dyy \quad (4.2)$$

$$\frac{\partial h}{\partial t}+\frac{\partial (hU)}{\partial x}+\frac{\partial (hV)}{\partial y}=0 \quad (4.3)$$

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. The depth averaged turbulent stresses, Txx, Tyy, and Txy, utilize the Boussinesq approach as:

$$Txx = 2(\upsilon+\upsilon t)\frac{\partial U}{\partial x}-\frac{2}{3}k \quad (4.4)$$

$$Txy = (\upsilon+\upsilon t)(\frac{\partial U}{\partial y}+\frac{\partial v}{\partial x}) \quad (4.5)$$

$$Tyy = 2(\upsilon+\upsilon t)\frac{\partial v}{\partial y}-\frac{2}{3}k \quad (4.6)$$

Where ν is kinematic viscosity and νt is eddy viscosity and k is the turbulent kinetic energy. The eddy viscosity is calculated using a turbulence model. Two turbulence models, discussed by Rodi (1993), are utilized in SRH-2D: The k-ε model and the parabolic model. Choosing the parabolic model as the sole turbulence model for this project, the eddy viscosity is calculated as:

$$\upsilon t = Ct\, U^{*} h \quad (4.7)$$

3.2. Mesh Generation

The model has been used to generate the mesh which represents the study area from KM 53 to KM 153 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 25 m. The number of all elements was 130908 and the number of all nodes was 67472.

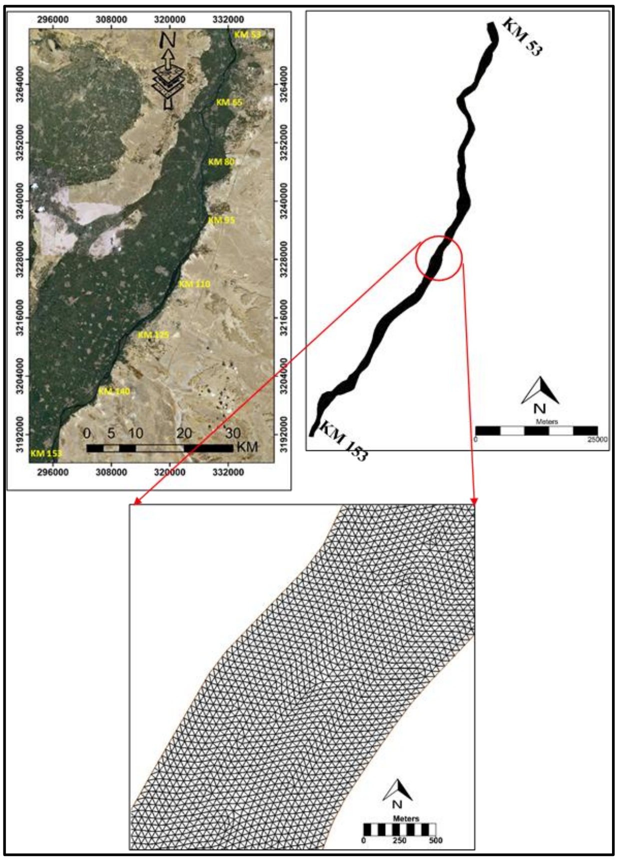


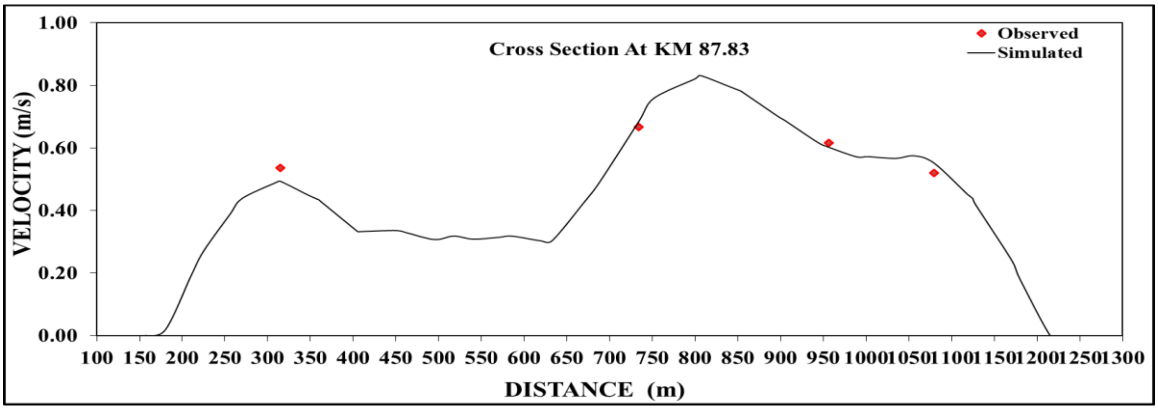
Figure 3: Study Reach Mesh Element Composition

3.2. Model calibration

The model was calibrated using the surveyed data at 2003 and the inflow discharges and water levels at different flows as shown in table 2. Comparison of the measured field velocities and obtained velocity profiles at the three cross sections located as shown in figure 4, it showed that there is a good agreement for the calibration.

Table 2: Boundary Condition of the calibration

Calibration Time	Q(Mm³/day)	WL (m)
Jun-2003	169.805	20.45



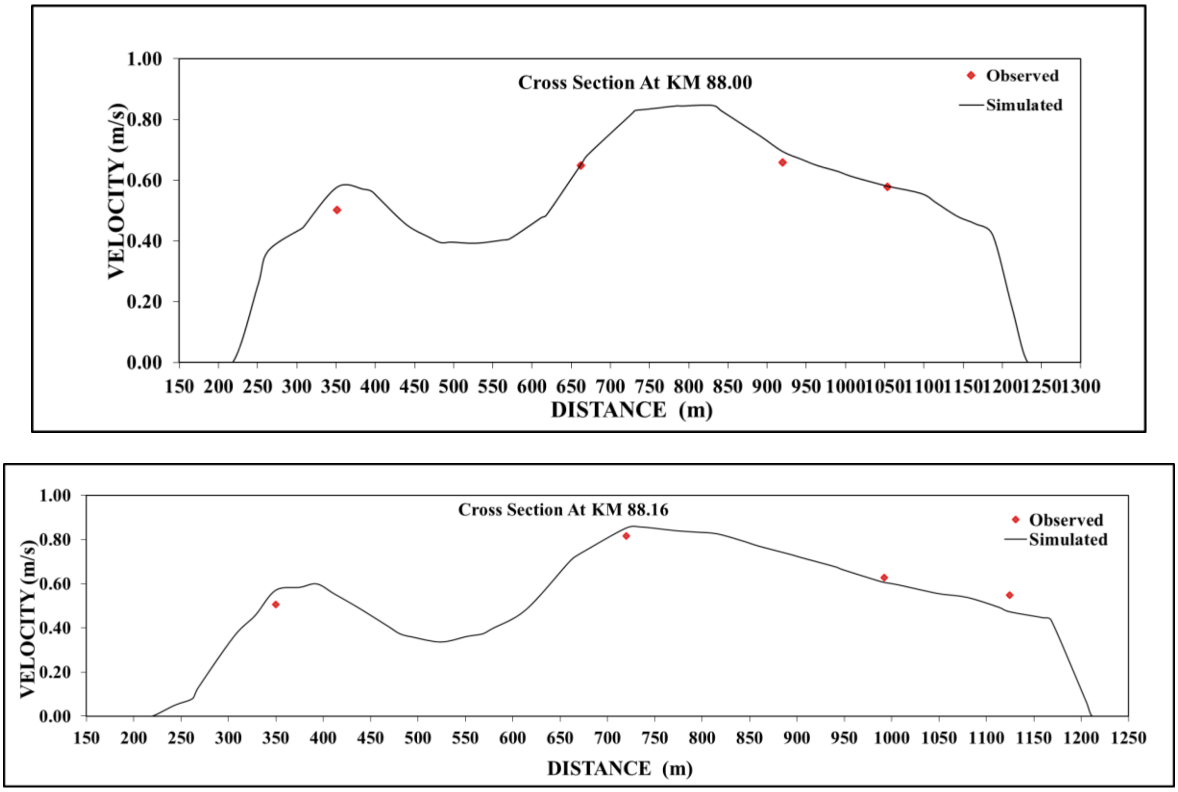
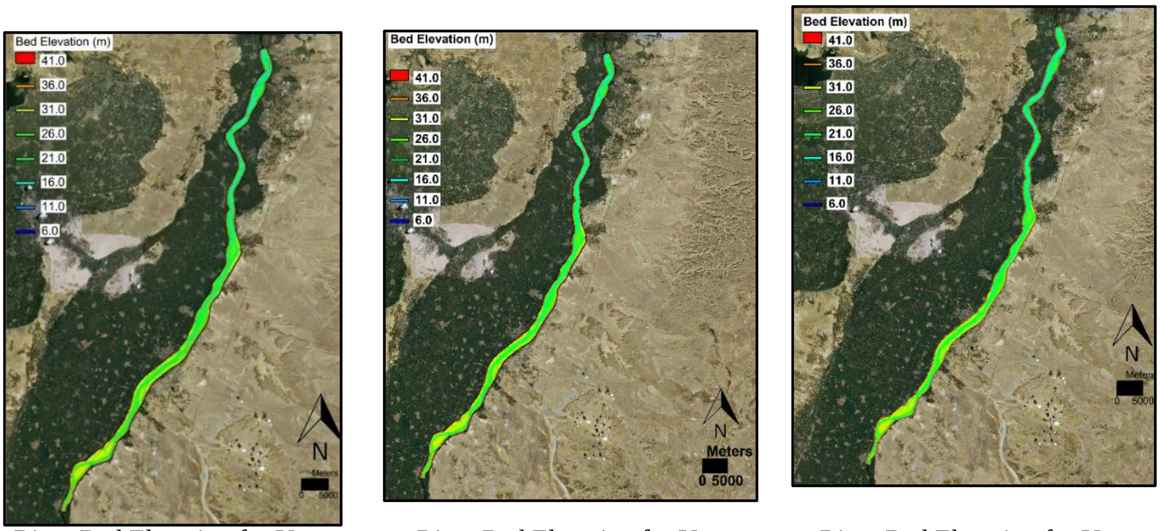


Figure 4: Depth average velocities calibration and the cross sections location

4. Results and Analysis

4.1. Morphology Comparison of Years 2003, 2010 and 2016 by applied GIS

A morphological comparison for the different years 2003, 2010, and 2016 has been satisfied by applying GIS and Civil 3D. Accordingly, the annual rates of sediment and erosion are determined at the different kilometers of the study area. The annual rates of sedimentation and erosion are obtained using GIS, while the quantity of sedimentation and erosion are obtained employing Civil 3D for each section of the study reach.



River Bed Elevation for Year 2003 | River Bed Elevation for Year 2010 | River Bed Elevation for Year 2016

Figure 5: Illustrate annual sedimentation and erosion rates, elevations, and quantities of sediment and erosion for the studied cross-sections at Km 64, 80, 87, 106for the years 2003, 2010, and 2016

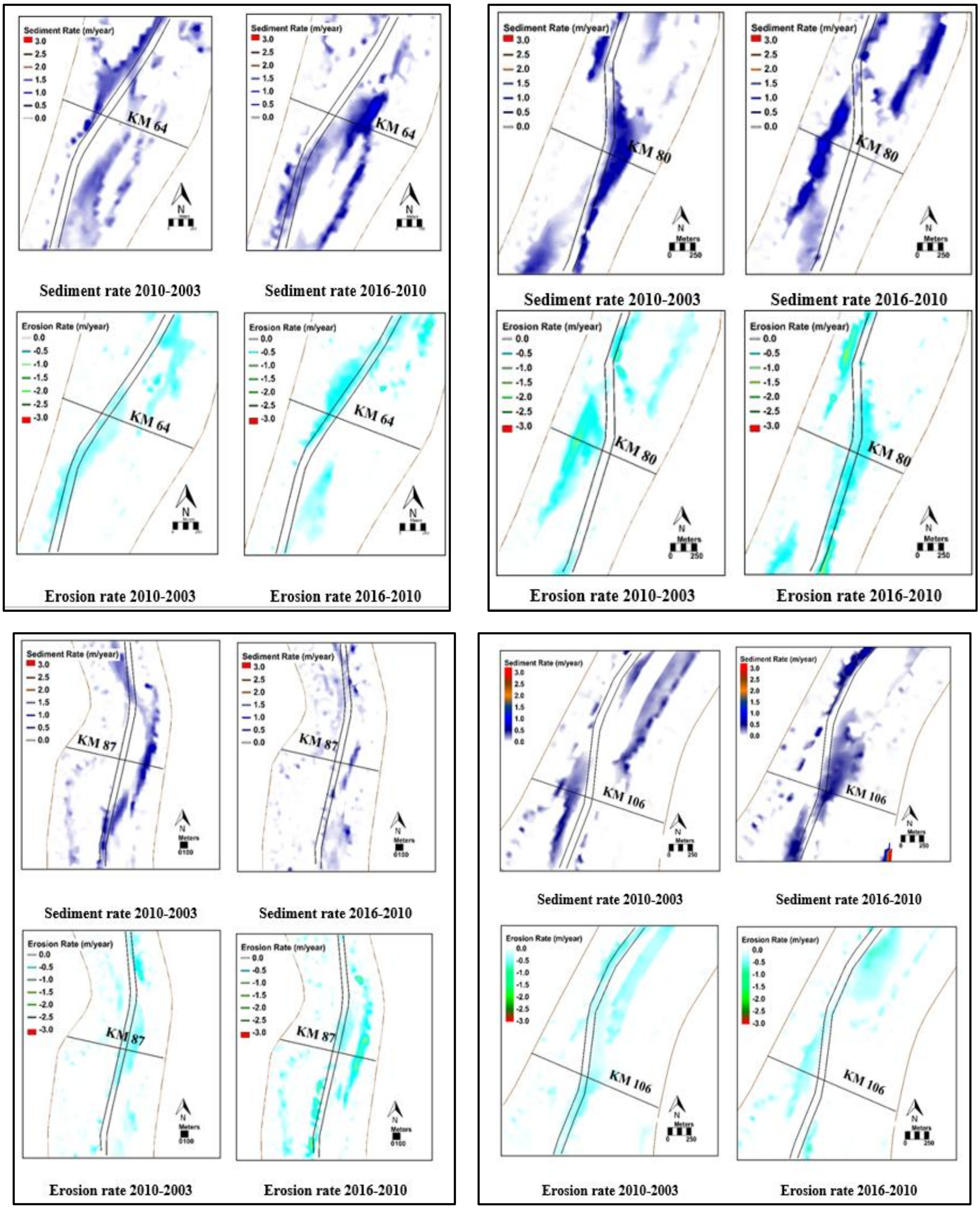


Figure 5: Annual sedimentation and erosion rates for cross sections at km 64, 80, 87 and 106

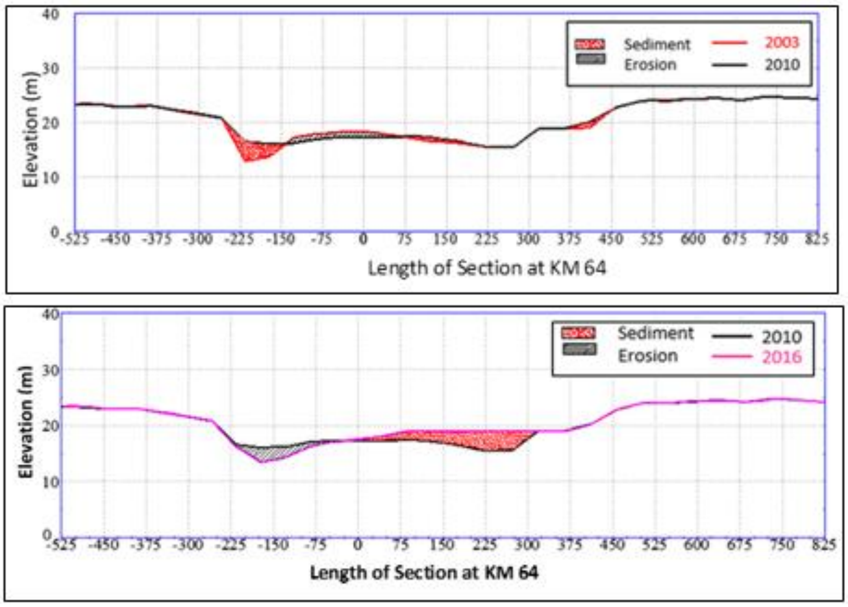


Figure 6: Quantities of Sediment and Erosion at Km 64 for: (a) 2010-2003and (b) 2016-2010 by Civil-3D

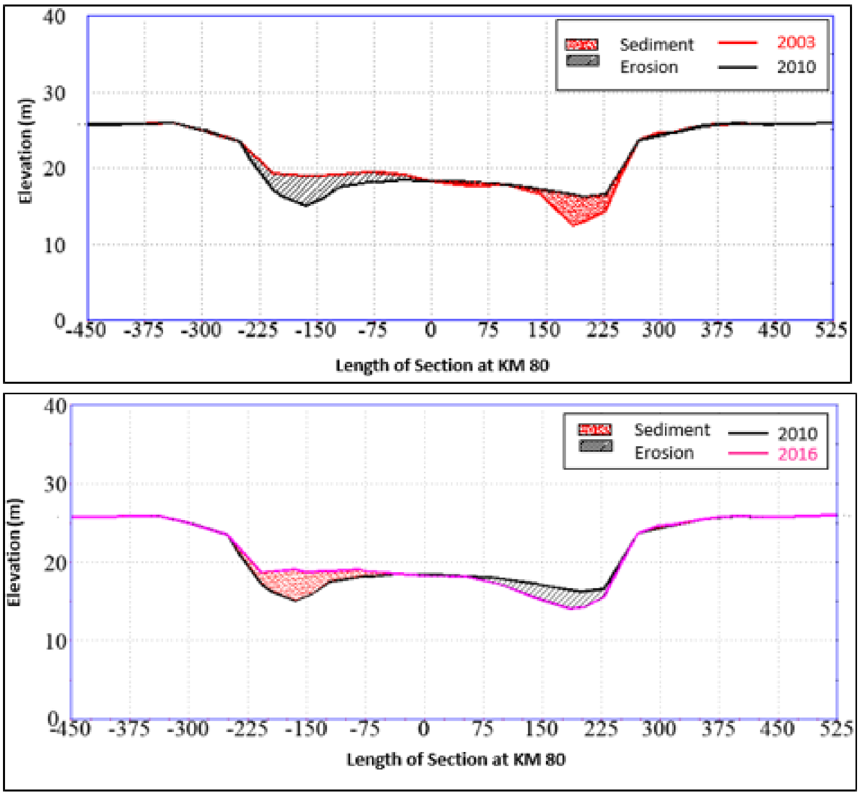


Figure 7: Quantities of Sediment and Erosion at Km 80 for: (a) 2010-2003and (b) 2016-2010 by Civil-3D

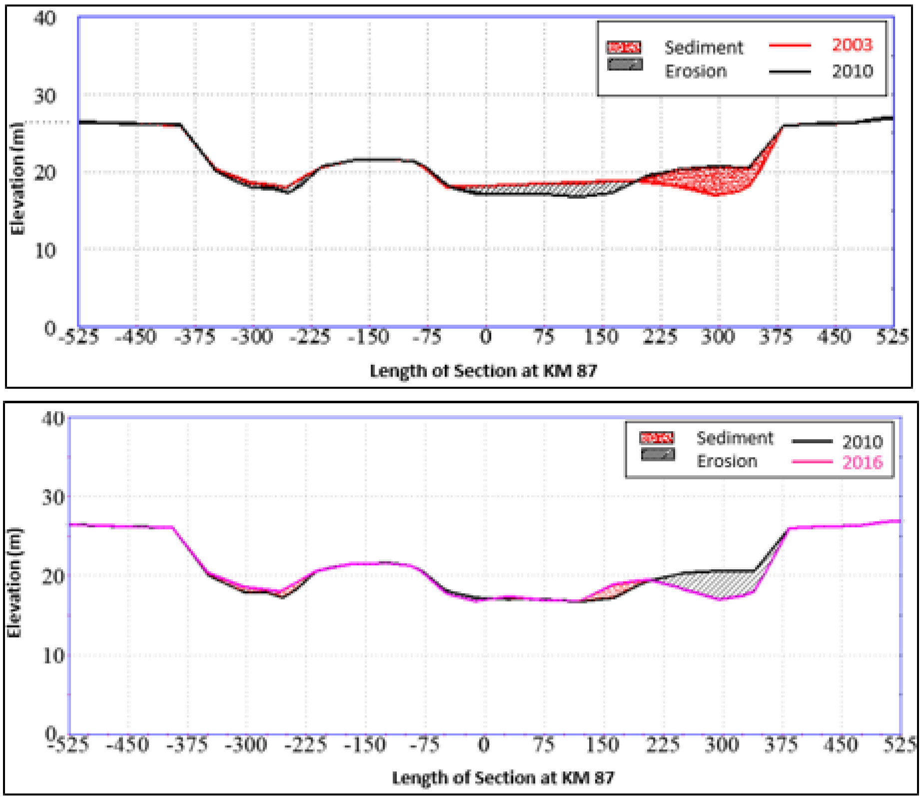


Figure 8: Quantities of Sediment and Erosion at Km 87 for: (a) 2010-2003and (b) 2016-2010 by Civil-3D

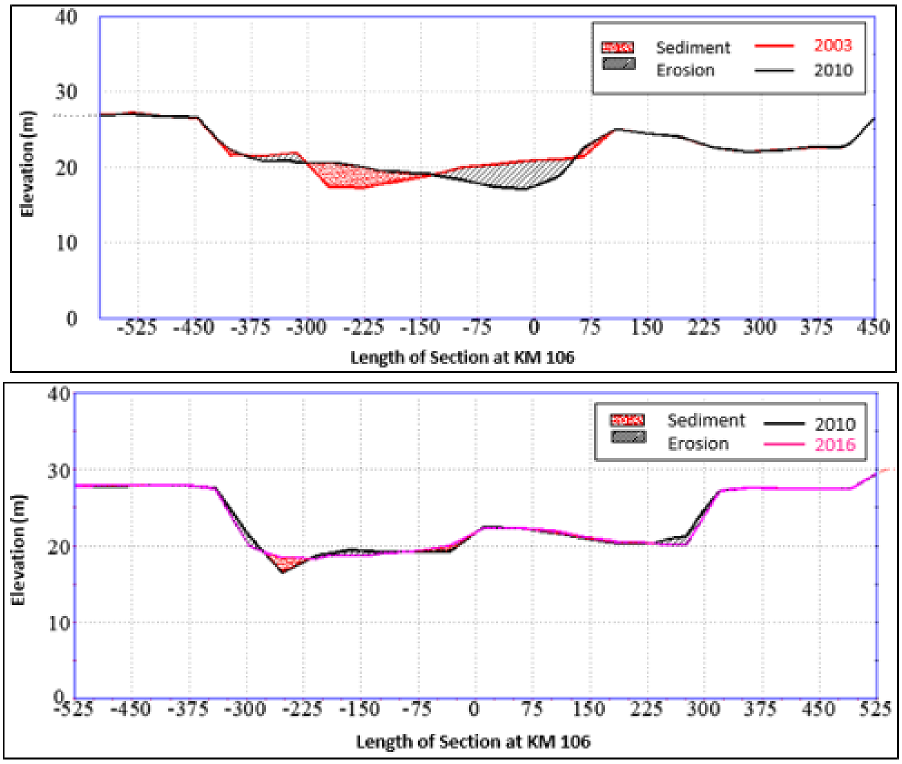


Figure 9: Quantities of Sediment and Erosion at Km 106 for: (a) 2010-2003and (b) 2016-2010 by Civil-3D

Table 3: Sedimentation and Erosion Quantities at the Years 2010-2003

C.S. No	**Location, Km**	**2010-2003**	
		Sedimentation (m^3)	**Erosion (m^3)**
1	Km 64	14027.90	9101.24
2	Km 80	16927.25	20389.82
3	Km 87	82063.95	55752.84
4	Km 106	14684.23	31706.31

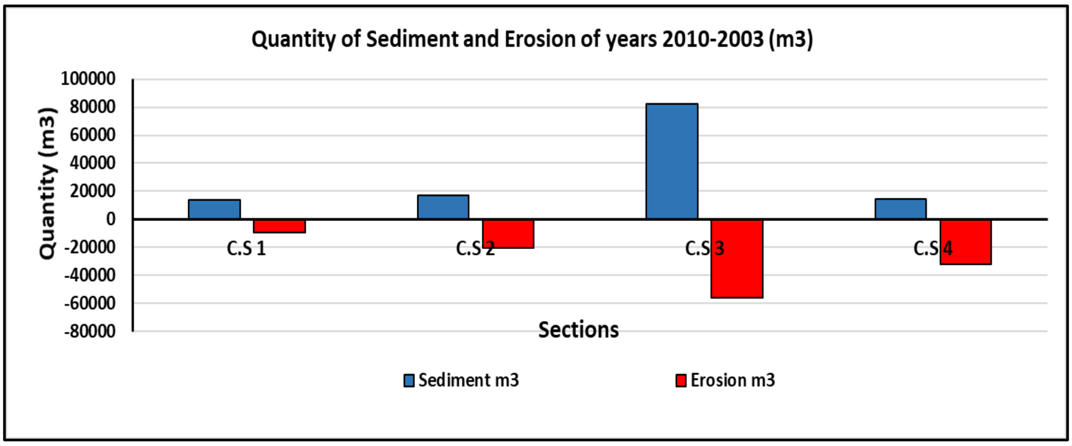


Figure 10: Sedimentation and Erosion Quantities for the Years 2003-2010

Table 4: Sedimentation and Erosion Quantities at the Years 2016-2010

C.S. No	**Location, Km**	**2016-2010**	
		Sedimentation (m^3)	**Erosion (m^3)**
1	Km 64	31764.02	11211.37
2	Km 80	18862.39	12985.47
3	Km 87	24567.61	86439.52
4	Km 106	13432.71	7968.58

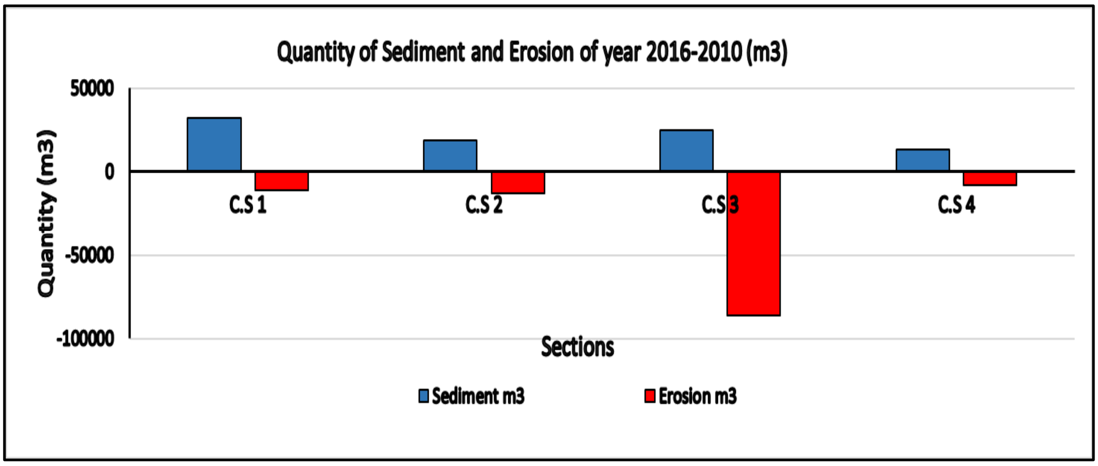


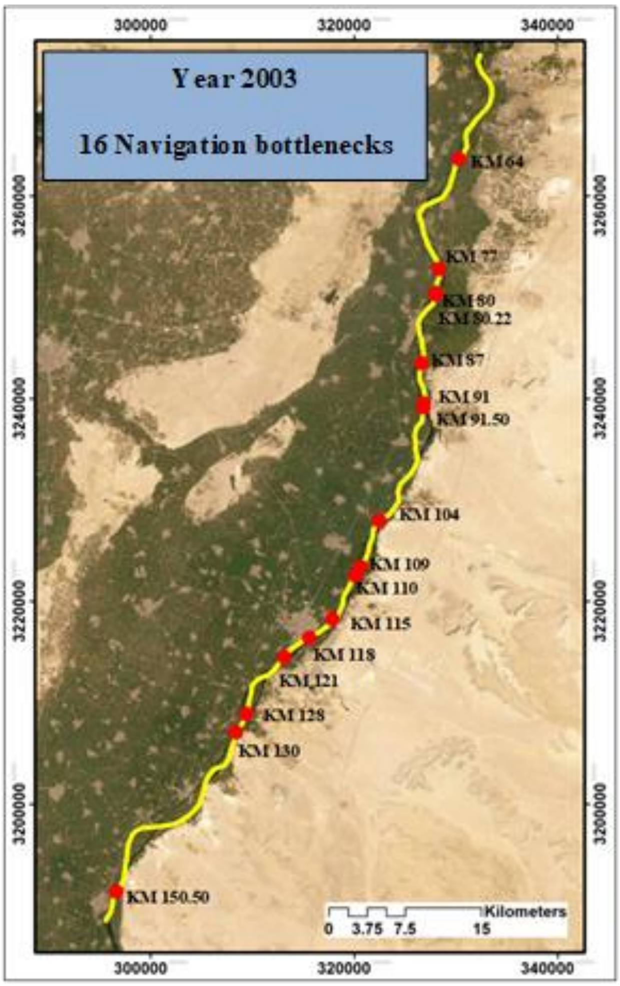
Figure 11: Sedimentation and Erosion Quantities for the Years 2010-2003

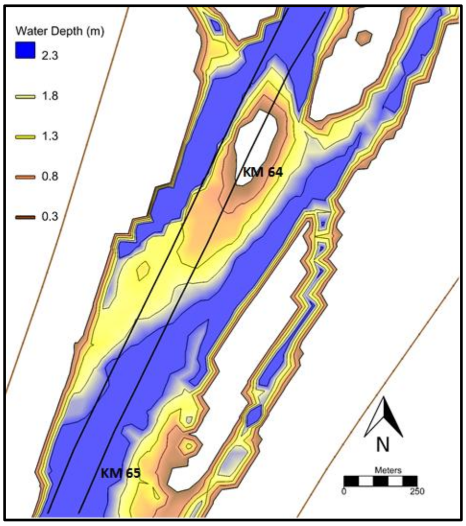
The sediment rate of cross-sections for 100 km of study area of the Nile River was around 0.4 m/year. The erosion rate was around 0.5 m/year.section No. 3 is the largest section in which a change in erosion and sedimentation occurred, this section is located at km 87, and this region has frequent navigation problems as it has some hydraulic structure that affect the morphology of the Nile River.

4.2. Navigation Bottlenecks Determine by SRH-2D during different years

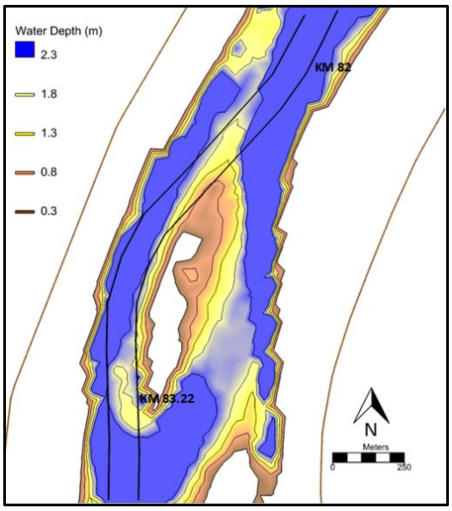
After applying the model to the worst case of the flow, it was became possible to assessment all the characteristics of the study area from the bed elevation, velocities, water levels and depths, and then determine the navigational bottlenecks for the different three years as the bottleneck is determined by knowing whether the depths exceeded 2.30 meters or not, and if the depths in the navigation channel were less than this value (2.30m) the navigation bottleneck will be occurred and must be taken into account.

(1) Navigation Bottlenecks Assessment for year (2003)





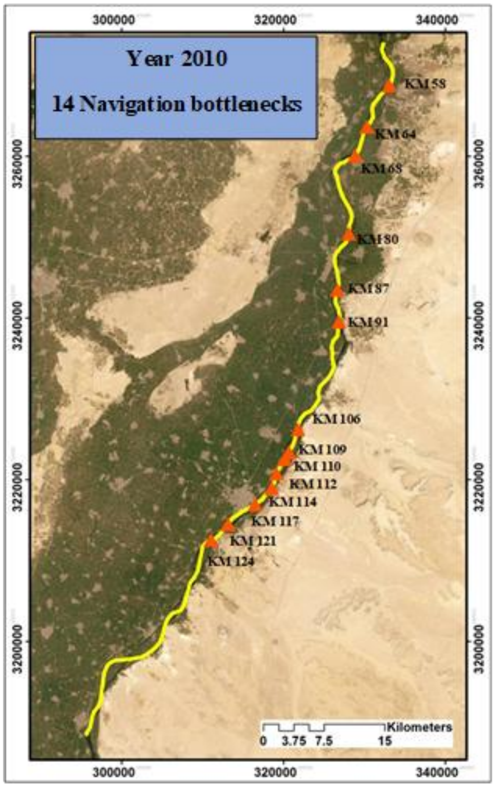
Navigation Bottleneck at km 64.00

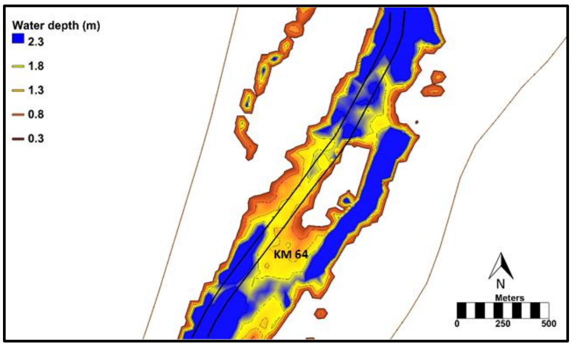


Navigation Bottleneck at km 80.22

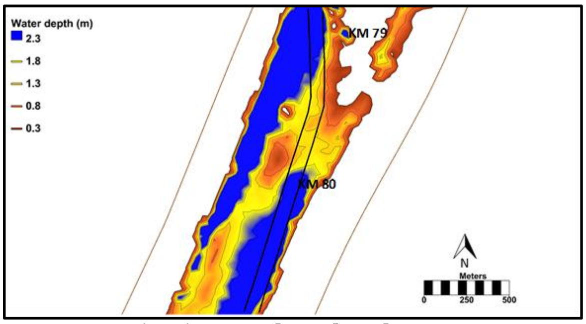
Figure 12: Numbers of navigation bottlenecks for year 2003 and some example for bottlenecks at km 64.00 and km 80.22

(2) Navigation Bottlenecks Assessment for year (2010)





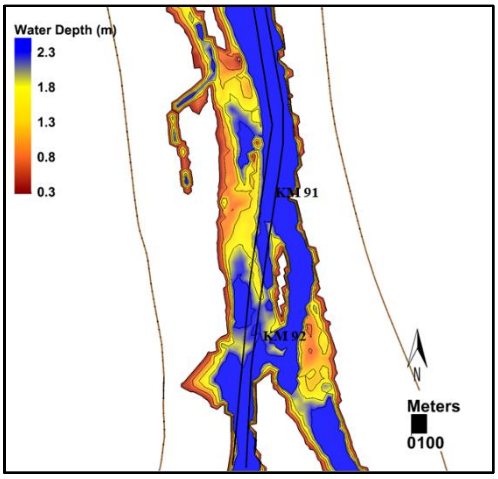
Navigation Bottleneck at km 64.00



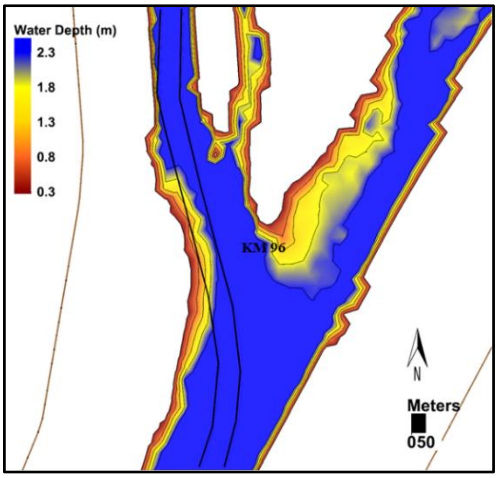
Navigation Bottleneck at km 80.00

Figure 13: Numbers of navigation bottlenecks for year 2010 and some example for bottlenecks at km 64.00 and km 80.00

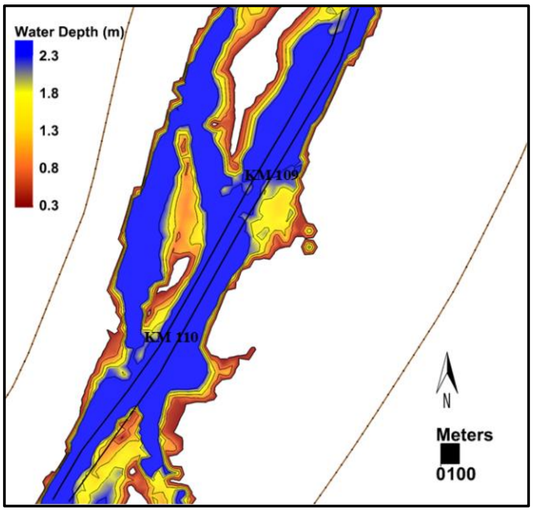
(3) Navigation Bottlenecks Assessment for year (2016)

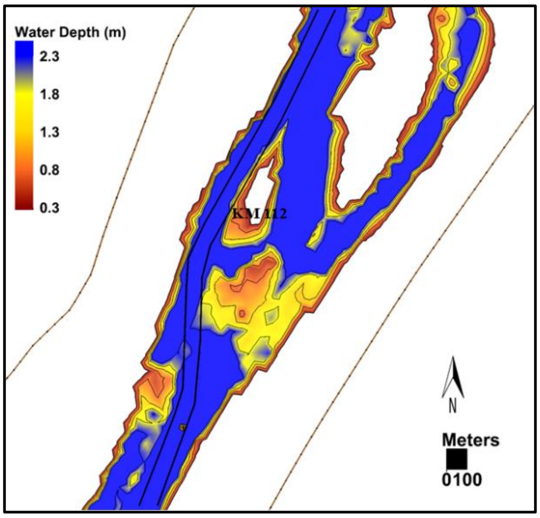


Navigation Bottleneck at km 91.00



Navigation Bottleneck at km 96.00





Navigation Bottleneck at km 110.00 **Navigation Bottleneck at km 112.00**

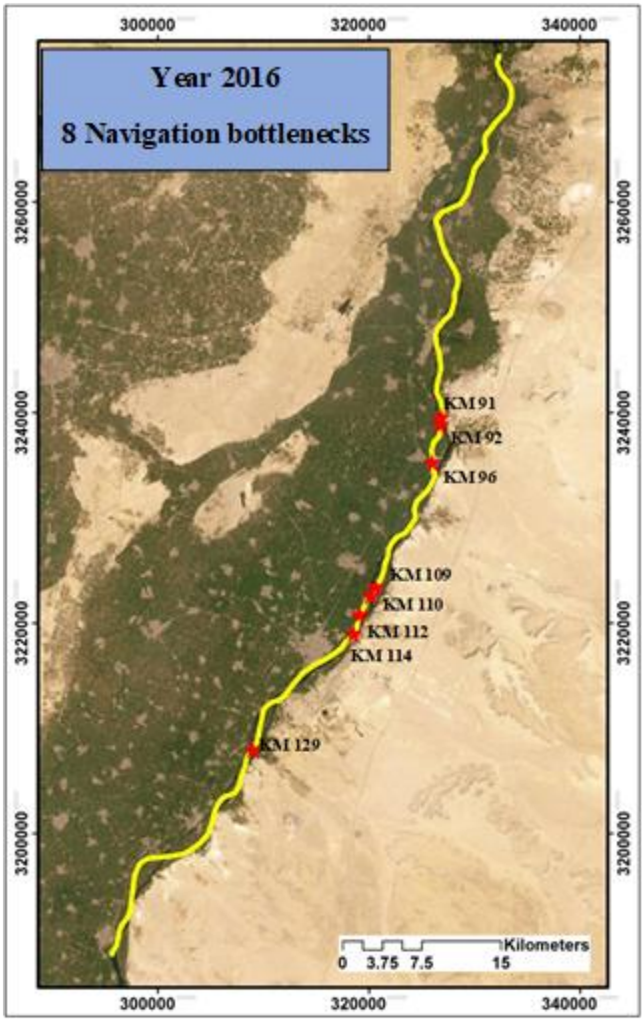


Figure 14: Numbers of navigation bottlenecks for year 2010 and some example for bottlenecks at km 91.00, km 96.00, km 110 and km 112

From all the above, all the numbers of navigation bottlenecks for the different three years 2003, 2010 and 2016 were determined for the first scenario (worst case of the flow), And then it became possible for us to determine the locations and characteristics of the navigational bottlenecks for the different years, Thus, we had the ability to determine where the navigation bottleneck will have repeated during the three different years. This can be clarified by making an analysis for these results as follows:

Table 5: The Bottlenecks During the Different Years 2003, 2010 and 2016

Locations (KM)	Bottleneck of year 2003	Bottleneck of year 2010	Bottleneck of year 2016
KM 58		✓✓✓	
Km 64	✓✓✓	✓✓✓	
KM 68		✓✓✓	
Km 77	✓✓✓		
Km 80	✓✓✓	✓✓✓	
Km 83.22	✓✓✓		
Km 87	✓✓✓	✓✓✓	
KM 91	✓✓✓	✓✓✓	✓✓✓
Km 91.5	✓✓✓		
KM 92			✓✓✓
KM 96			✓✓✓
KM 104	✓✓✓		
KM 106		✓✓✓	
KM 109	✓✓✓	✓✓✓	✓✓✓
KM 110	✓✓✓	✓✓✓	✓✓✓
KM 112		✓✓✓	✓✓✓
KM 114		✓✓✓	✓✓✓
KM 115	✓✓✓		
KM 117		✓✓✓	
KM 118	✓✓✓		
KM 121	✓✓✓	✓✓✓	
KM 124		✓✓✓	
KM 128	✓✓✓		
KM 129			✓✓✓
KM 130	✓✓✓		
KM 150.5	✓✓✓		
Total Bottlenecks Numbers	16 Bottlenecks	14 Bottlenecks	8 Bottlenecks

Table: 6 The Repeated Bottlenecks during the Different Years

Locations (KM)	Bottleneck of year 2003	Bottleneck of year 2010	Bottleneck of year 2016
Km 54	✓✓✓	✓✓✓	✓✓✓
Km 64	✓✓✓	✓✓✓	
Km 80	✓✓✓	✓✓✓	
Km 87	✓✓✓	✓✓✓	
KM 91	✓✓✓	✓✓✓	✓✓✓
KM 109	✓✓✓	✓✓✓	✓✓✓
KM 110	✓✓✓	✓✓✓	✓✓✓
KM 112		✓✓✓	✓✓✓
KM 121	✓✓✓	✓✓✓	

According to the analysis of results, the locations of erosion and sedimentation can be correlated to the locations of repeated navigation bottleneck during different periods years. The results revealed that there are kilometers showing repeated navigation bottleneck in two years and others showing repeated navigation bottleneck in three years. For the KM 64.00, KM 80.00, and KM 87.00, the navigation bottleneck appeared in 2003 and 2010, where the quantity of sedimentation for each kilometer in these years was 14027.90 m3, 16927.25 m3 and 82063.95 m3 respectively. For the navigation bottleneck that appeared in 2010 and 2016 at the KM 112.00, the quantity of sedimentation was 27588.27 m3. Moreover, for the KM 91.00, KM 109.00, and KM 110.00, the navigation bottleneck occurred repeatedly in three years, where the quantity of sedimentation for each one of these kilometers during the period (2003 to 2010) was 18419.03 m3, 27302.92 m3 and 19970.55 m3 respectively. But, quantity of sedimentation for each one of these kilometers during the period (2010 to 2016) was 20939.84 m3, 17214.27 m3 and 11043.61 m3 respectively.

5. Conclusions

In this study, the two-dimensional numerical models used to investigate the Nile River morphology, trend of the study reach, and determine the navigation bottlenecks at different scenarios. The model can be used to evaluate scenarios that are difficult to measure in the field or in a physical model It was concluded that the section No. 3 is the largest section in which a change in erosion and sedimentation occurred, this section is located at km 87, and this region has frequent navigation problems as it has some hydraulic structure that affect the morphology of the Nile River. After applying the minimum scenario of the flow for different years (2003, 2010 and 2016) it concluded that the total numbers of navigation bottlenecks in 2003 was 16 bottlenecks, in 2010 was 14 bottlenecks and in 2016 was 8 bottlenecks.There are kilometers showing repeated navigation bottleneck in two years and others showing repeated navigation bottleneck in three years. For the KM 64.00, KM 80.00, and KM 87.00, the navigation bottleneck appeared in 2003 and 2010.For the navigation bottleneck that appeared in 2010 and 2016 at the KM 112.00.Moreover, for the KM 91.00, KM 109.00, and KM 110.00, the navigation bottleneck occurred repeatedly in three years. Finally, the sections at KM 91.00, KM 109.00, and KM 110.00 are the worst sections where the navigation bottleneck repeated in this locations during three years (2003, 2010 and 2016).So they must be taken into account to solve this problem.

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