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ROSETTA BRANCH Water Way Dredging for Navigation Sustainability

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Abstract: Rivers act as highways for trade and transport before the existence of cars and railroads. The construction of Aswan High Dam in Upper Egypt controlled the flow passing through the Nile River providing consistent flow discharge and making river navigation possible. The main objective is to develop a first-class two-way navigation channel in Rosetta Branch according to the Egyptian River Transport Authority (RTA) recommendations. A 2D numerical model was adopted to study the branch's current condition by analyzing the morphological changes that occurred in the branch during a period of 17 years from the year 2003 to 2020. The results show that Rosetta branch of the Nile River suffers from a severe deposition, which affects river navigation in the current state as the most affected reach suffering from severe deposition appears in the first 80 km of the branch. Dredging operations are required to construct a navigation channel where two navigation channel scenarios were proposed with dredging depths of 2.3m and 3.5m respectively below the minimum water level. It can be concluded that the second scenario managed to provide a safe navigable water depth through the branch despite the dredging cost and the decrease in water levels. It's recommended to study the morphological and environmental impact of dredging operations on Rosetta branch in future research.

Keywords: Rosetta branch; inland river navigation; river modeling; 2D numerical model; dredging operations

1. INTRODUCTION

River channels were used long ago for trade and transportation before the introduction of modern roads and railroads [1]. However, ancient written sources provided little information about how transportation was carried out in fluvial systems focusing instead on famous major rivers [2]. River navigation plays a vital role in any country's economy as it is considered the most economical means of transport [3].

Many recommendations were set by international authorities for navigation channel design criteria to maintain inland river navigation. Among those are the US Army Corps of Engineers, the Permanent International Association of Navigation Congresses (PIANC), and the International Association of Ports and Harbors (IAPH) [4].

Any navigation channel design criteria depend mainly on three main factors: channel width, depth, and alignment. The width is affected by vessel size, maneuverability, bank clearance, alignment, weather, visibility, and one-way or two-way channel [5]. The depth is a top priority for safe navigation and is affected by: vessel draft, minimum clearance, soil type, flow discharge variation; and waves caused by the vertical motion of the vessel [5]. The channel alignment is affected by: vessel dimensions, vessel velocity, channel bends and obstructions. The channel alignment should be as straight as possible to provide safe maneuverability and visibility for the drivers; the alignment path is preferred to follow the thalweg line to reduce the amount of dredging volume as possible. Bends along the channel alignment should be minimized as the frequent change in sailing direction and the wider lane of the vessel in a bend compared with the same path in a straight line leads to stiffer navigation [5].

The River Transport Authority (RTA) of the Egyptian Transport Ministry is the authority responsible for setting and regulating inland river navigation in Egypt. (RTA) classified inland river navigation in Egypt into three different classes each class having its unique characteristics [6].

The Nile is the longest river in the world and the main source of water in Egypt. Nile River is famous for its frequent morphological changes as a result of its alluvial nature [7]. The Nile River is heavily used for inland navigation. However, its current navigation capacity is lower than its potential one [8]. The Nile River travels 927 km from upper Egypt to the Nile Delta afterward it diverges into two branches; the Damietta branch towards the east and the Rosetta branch towards the west. Rosetta branch is approximately 240 km in length from its starting point from Delta Barrage to its promontory on the Mediterranean Sea. Rosetta branch is well known as a meandering channel with a sinuosity index of 1.5 containing 17 river bends in addition to the increasing number of large and under-forming islands making planning a navigation channel pretty challenging [9].

The construction of Aswan High Dam in Upper Egypt controlled the flow discharge passing through the Nile River enabling inland river navigation by constantly providing navigable flow conditions suitable for safe navigation throughout the year [10]. Navigation bottlenecks appear as a result of the reduction in clearance between bed level and vessel keel due to the lack of sufficient flow or deposition trend along the waterway caused by frequent morphological changes. Navigation bottlenecks can be eliminated either by dredging operations, river training structures, or providing extra flow discharges to compensate for the reduction in water depth [11].

A two-dimensional numerical model was adopted to study the impact of dredging operations on solving navigation bottlenecks in the fourth reach of the Nile River in Egypt where the results revealed that dredging operations cannot be adopted as a permanent solution as the riverbed returns to its original state within 10 years [8].

A two-dimensional numerical model was used to investigate river training structures and dredging operations as a solution for river navigation bottlenecks in the second reach of the Nile River where results proved that both are considered suitable solutions [12].

The main objective of this study is to develop a first-class two-way navigation channel along the Rosetta branch of the Nile River in Egypt by studying the morphological changes that occurred in the branch during a period of 17 years starting from the year 2003 to the year 2020; analyzing navigation bottlenecks along the branch; propose two different scenarios to develop a navigation channel; assessing each proposed scenario and determine the best suitable one.

2. MATERIALS AND METHODS

The methodology applied in this study consists of five stages; the first stage includes data collection of hydrological records, hydrographic data, water velocity measurements, and bed material samples. The second stage is conducting a topographic and bathymetric survey for the study reach, The third stage is using the acquired data to prepare the numerical model by generating the mesh, model calibration, and verification using assigned boundary conditions of hydrological records. The fourth stage is model application as the numerical model is executed to evaluate morphological changes that occurred in the Rosetta branch, evaluate the Rosetta branch's ability to host a navigation channel in the current state, and determine the locations of bottlenecks. The fifth stage is proposing different scenarios to develop a navigation channel, assessing each proposed scenario, and determining the most suitable one using (RTA) recommendations regarding the channel design elements and criteria as shown in Fig. 1.

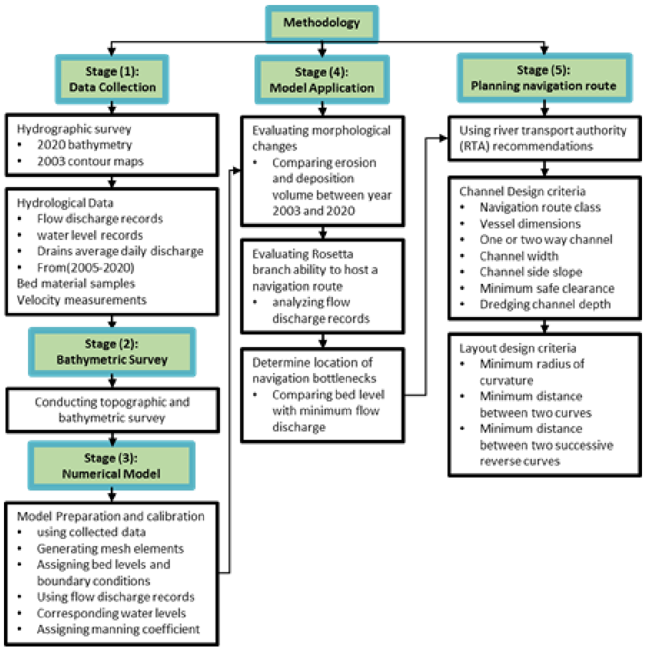

Fig 1. Methodology flow chart.

2.1Study Area

The study area extends over 155km along the Rosetta branch of the Nile River in Egypt. Starting from Delta Barrage at (30°11'36"N, 31°6'15"E) Km 26 downstream of Elroda water gauge station and heading north upstream towards Shabrakhet water gauge station at (31°0'50"N, 30°43'34"E) Km 181 downstream of Elroda gauge. Rosetta branch is considered a meandering channel whose average channel width is 122m and sinuosity index of 1.5 containing 15 islands, and an average bed slop of 8cm/km [9]. There are five water gauge stations to monitor water levels. Moreover, five drains are discharging their effluent directly into the branch as shown in Fig. 2.

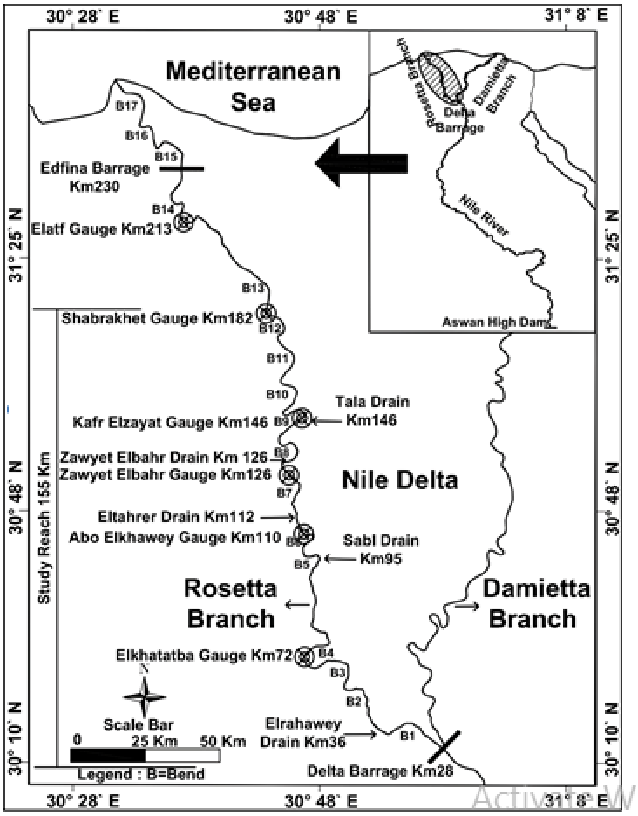

Fig 2. Study area layout and characteristics.

2.2Data Collection

The collected data to achieve the purpose of the study include the following; daily hydrological records of water levels at five water gauge stations (Elkhatatba, Abo Elkhawey, Zaywet Elbahr, Kafr Elzayat, and Shabrakhet); daily hydrological records of flow discharge at Delta barrage were used as an upstream boundary condition as shown in Fig. 3. Hydrographic survey was implemented for the bed level of the study area of the year 2003 and 2020, four velocities cross-sections were used for numerical model calibration and verification, and five-bed material samples along the study area at km (57, 64, 94, 120, and 150) respectively were used for calibrating manning's roughness coefficient value as the D50 was 0.35 mm and soil classification was fine to medium sand. The velocities and bed samples were implemented during the hydrographic survey of the year 2020. The collected data indicate that the maximum recorded discharge was 90 (million m^3/day) during the year 2007, and the minimum discharge record was 5 (million.m^3/day) during the year 2005. and the dominant flow discharge passing through the branch was 12.5 (million m^3/day) as shown in Fig. 3(c) and Table 1.

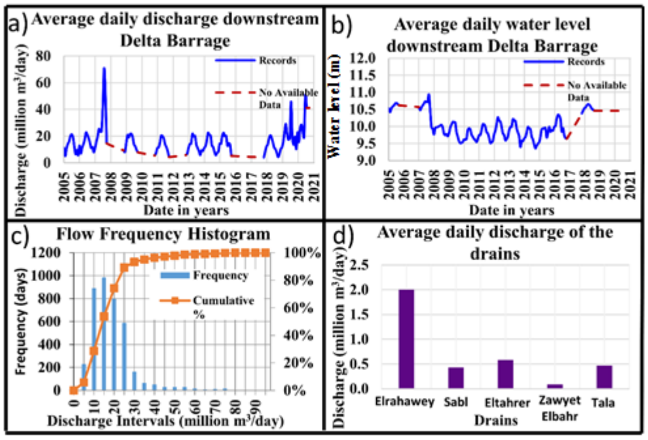

Fig 3. Data collection

TABLE 1. Data collection of the study area

Data type	location	Period	usage
Bathymetry	Extending over 155km	The year 2003 and 2020	Mesh generation
Water level records	five water gauge stations	From the year 2005 to 2020	Model calibration and verification
Flow discharge records	Delta barrage	From the year 2005 to 2020	Model calibration and verification
Velocity measurements	Four cross-sections	The year 2018 and 2021	Model calibration and verification
Bed material samples	5 locations	From the year 2005 to 2020	Estimating Manning's roughness coefficient

2.3Bathymetric survey

A hydrographic survey of the study area of the year 2020 was used in this study which was carried out by the Nile Research Institute "NRI" of the National Water Research Center of Egypt. Implementing a HYPACK system by integrating an echo-sounder and a GPS device, the system is used to combine the data received from both echo-sounder and GPS, providing the bathymetry data as (x, y, z). X and Y characterize easting and northing coordinates respectively, while Z represents bed elevation taken from the echo-sounder. The bathymetric survey was carried out for the branch along a pathway of cross sections spaced at intervals of 50 m and a differential GPS system was employed to deliver a global accuracy of nearly 1 m.

3.NUMERICAL MODEL

3.1SRH-2D Numerical Model

This study implemented the Sedimentation and River Hydraulics-Two-Dimensional numerical model (SRH-2D). The SRH-2D is a hydraulic module integrated within the surface water modeling system package (SMS-2D) which is a comprehensive package of tools for 2D hydraulic model development. (SRH-2D) is a 2D hydraulic numerical model aiming at 2D hydraulic principles of river hydraulics and sediment transport developed at the U.S. Bureau of Reclamation (USBR) [13]. (SRH-2D) solves the depth-averaged and time Navier Stokes equations (known as the depth-averaged St.Venant Equations) to govern the flow regime [14] as follows:

$$\frac{\partial H}{\partial t}+\frac{\partial HU}{\partial x}+\frac{\partial hV}{\partial y}=0 \qquad (1)$$

$$\frac{\partial HU}{\partial t}+\frac{\partial HUU}{\partial x}+\frac{\partial HVU}{\partial y}=\frac{\partial HT_{xx}}{\partial x}+\frac{\partial HT_{xy}}{\partial y}-gH\frac{\partial z}{\partial x}-\frac{\tau_{bx}}{\rho} \qquad (2)$$

$$\frac{\partial HV}{\partial t}+\frac{\partial HUV}{\partial x}+\frac{\partial HVV}{\partial y}=\frac{\partial HT_{xy}}{\partial x}+\frac{\partial HT_{yy}}{\partial y}-gH\frac{\partial z}{\partial y}-\frac{\tau_{by}}{\rho} \qquad (3)$$

where x and y: horizontal cartesian coordinates, U, V: depth-averaged velocity in x and y directions respectively, t: time, H: water depth g: gravitational acceleration, T_{xx}, T_{xy}, T_{yy}: depth-averaged stresses due to turbulence, τ_{bx}, τ_{by}: bed shear stresses, $Z=Z_b + h$, Z: water surface elevation, Z_b: bed elevation, ρ: water density.

3.2Mesh Generation and Boundary Conditions

To represent the study area with suitable high accuracy, the SRH-2D numerical model was used to generate a mesh consisting of 180,000 triangular elements. The average mesh element width is 30 m at the floodplains and areas outside the navigation channel route, whereas the width was reduced to 5 m at both the bottleneck's areas and inside the navigation channel route to better represent the bed level and to maintain the stability of the model by not increasing mesh elements. The bed level was assigned to the elements of the mesh at each node. The upstream flow boundary conditions are the flow discharge from five drains and Delta barrage while the downstream boundary condition is the water level at the shabrakhet water gauge station as shown in Fig. 4.

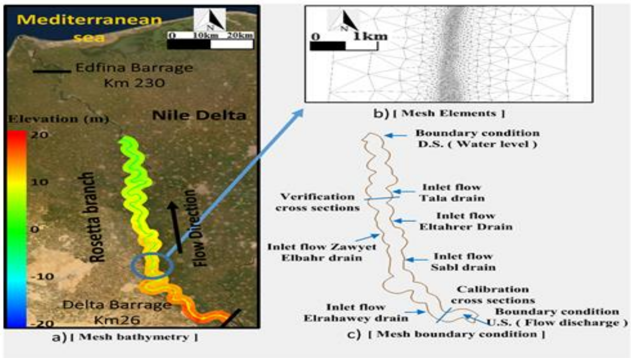

Fig 4. Numerical model mesh generation and boundary conditions.

3.3Model Calibration and Verification

The model calibration process used a flow discharge of 5 million m^3/day at The Delta Barrage as the upstream boundary condition with the corresponding water level at Shabrakhet gauge station as a downstream boundary condition. Two stream velocity cross-sections were used for velocity calibration where the velocity was measured at a flow discharge of 5 million m^3/day at km 37.5 and 37.6 respectively as shown in Fig. 5. The best suitable value for the Manning roughness coefficient (n) was found to be 0.015 after several model simulations. The numerical model was also verified as the verification process used a flow discharge of 12.5 million m^3/day at The Delta Barrage as the upstream boundary condition with the corresponding water level at Shabrakhet gauge station as a downstream boundary condition as shown in Fig. 5. Two stream velocity cross-sections were used for velocity verification where the velocity was measured at a flow discharge of 12.5 million m^3/day at km 146.4 and 146.5 respectively as shown in Fig. 5. The Model performance was verified by computing mean absolute deviation (MAD), mean square error (MSE), and root mean square error (RMSE). The computed values were 0.02, 0.01, 0.02, and 0.97.

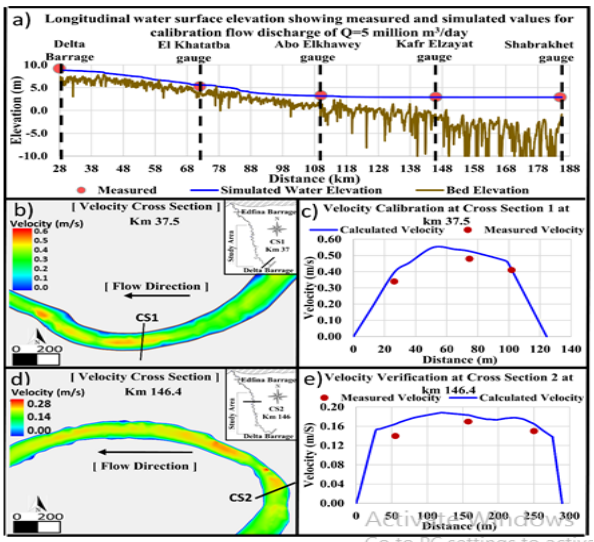

Fig 5. The numerical model calibration and verification Process

4.DEVELOPING A NAVIGATION CHANNEL IN ROSETTA BRANCH

4.1Navigation Channel Criteria

The used criteria for developing a navigation channel in the Rosetta branch follow the recommendations mentioned by the River Transport Authority (RTA) of Egypt and consist of the following:

First-degree two-way navigation channel.

The navigation channel width of 40 m.

Navigation channel minimum clearness of 0.5 m.

Navigation channel side slope of 1:5.

The navigation channel is used for freight transport.

Vessel length and width are 100 m and 7.5 m respectively.

The maximum ship draft is 1.8 m.

The navigation channel's minimum radius of curvature is 500 m.

The minimum distance between successive reverse curves is 500 m.

4.2Proposed Navigation Channel Scenarios

Dredging channel operations will be required to satisfy the minimum clearance of 2.3 m between the minimum water level resulting from the minimum flow discharge of 5 (million m^3/day) and the bed level of the navigation channel to provide safe river navigation in the branch. Two dredging scenarios were proposed in this study; the first scenario relies on dredging a channel with a width of 40 m and depth of 2.3m below minimum water surface elevation, while the second scenario requires dredging a channel of depth 3.5 m as shown in Fig. 6. and Table 2.

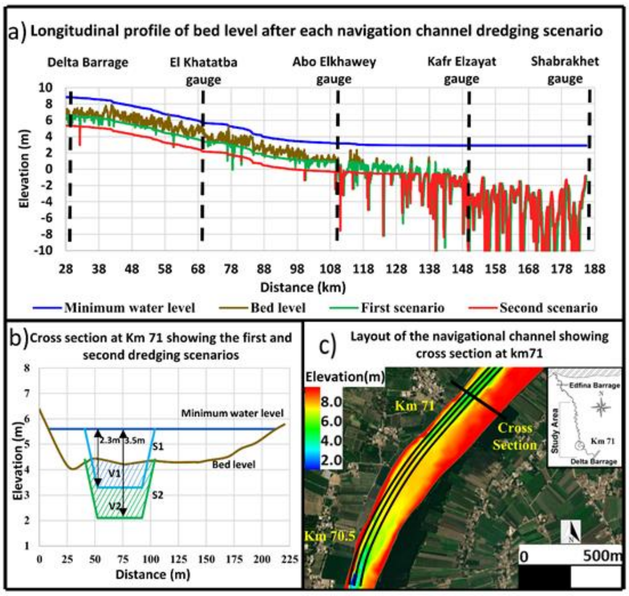

Fig 6. The proposed navigation channel scenarios and characteristics.

TABLE 2. Different navigation channel dredging scenarios

Scenario	Length (Km)	Width (m)	Dredging depth (m)	Dredging volume (million.m^3)	Cost (Million L.E)	Flow (million m^3/day)	class	Minimum clearance (m)
S1	155	40	2.3	5	800	5	1st	0.5
S2	155	40	3.5	18	2000	5	1st	0.5

4.3Model Application

The numerical model will be applied to achieve the following:

Evaluate the morphological changes that occurred in the Rosetta branch during a period of 17 years from the year 2003 to 2020

Determine navigation bottlenecks.

Evaluate the ability to develop a navigation route in the current state.

Proposing two navigation channel dredging scenarios

Analyze the impact of each scenario on water level and river navigability

Determine the best suitable navigation channel scenario that provides a safe clearance related to the minimum flow discharge of 5 (million m^3/day).

5.RESULTS AND ANALYSIS

5.1Morphological Analysis.

The results of implementing the two-dimensional numerical model in the current state show the following; (1) The morphological analysis of comparing Rosetta branch bed level between the years 2003 and 2020 using Civil 3D software shows a prevailing deposition trend [9] as shown in Fig. 7. (2) The calculated deposition volume is double the erosion amount as shown in Table 3. (3) The deposition trend results into the formation of several navigation bottlenecks, especially in the first 80 km of the branch corresponding to the minimum flow discharge of 5 (million m^3/day). Inland river navigation in the Rosetta branch can’t be achieved due to the lack of sufficient water depth during the minimum flow discharge periods resulting from the deposition trend and bottleneck creation.

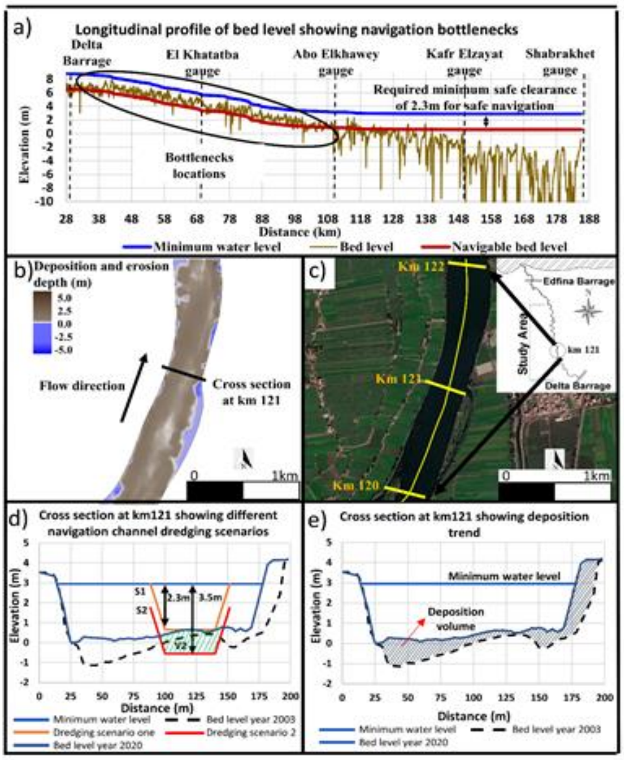

Fig 7. The morphological analysis of the study area.

TABLE 3. Deposition and erosion volume output from the morphological analysis of the Rosetta Branch.

Year	Erosion volume (million m^3)	Deposition volume (million m^3)
(2003-2020)	5.8	12.6
	Erosion rate (m/year)	Deposition rate (m/year)
Avergae rate	0.02	0.03
Maximum rate	0.12	0.22

5.2 The Proposed Navigation Channel Scenarios Analysis

Two navigation channel dredging scenarios were proposed in this study. The first proposed navigation channel scenario required a total dredging volume of 5 (million m^3) and led to a decrease in surface water level by an average of 15 cm causing a failure in providing a safe water depth for navigation as shown in Fig. 8(a,c). The second scenario required a total dredging volume of 18 (million m^3) and caused a decrease in surface water level by an average of 90 cm but managed to provide a safe water depth for navigation as shown in Fig. 8(b,d). The best suitable scenario is the second one as it successfully managed to provide the required water depth for navigation despite the huge cost of the dredging volume and the decrease in surface water elevation.

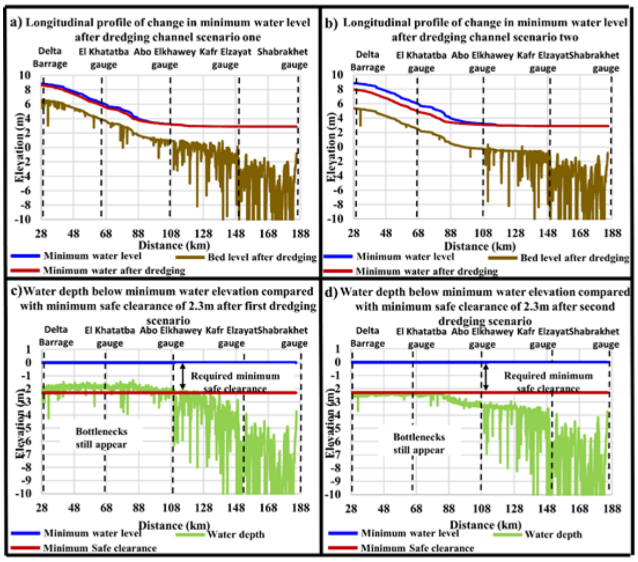

Fig 8: The proposed navigation channel scenarios and their impact on water levels and the required minimum safe clearance.

6.CONCLUSION

The conclusion of this study can be summarized as follows:

The established numerical model was successfully implemented showing its capability of demonstrating the study area's morphodynamic and geometric characteristics to achieve the study objectives.

The morphological analysis run by the numerical model shows a prevailing trend of deposition in the Rosetta branch.

The amount of deposition and erosion along the study reach during a period of 17 years from the year of 2003 to 2020 was calculated using Civil 3D software where the total volume of deposition and erosion is 12.6 and 5.8 million m^3 respectively.

Rosetta branch doesn’t provide suitable safe conditions for a first-class two-way navigation channel in the current state as the current minimum water flow discharge doesn’t provide safe navigable water depth conditions along the branch.

The second navigation channel dredging scenario is better than the first where the dredging depth of 3.5 m managed to provide a safe navigable water depth for the vessels to navigate through the branch despite the dredging cost and the decrease in water levels

It’s recommended to study the economic and environmental impact of constructing a navigation channel using dredging operations on Rosetta branch in future research.

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