EVALUATING EFFICIENCY OF THE RIVER NILE NAVIGATIONAL PATH

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ABSTRACT

Dredging is currently used as a temporary work to keep the River Nile navigable. Also, it is used to maintain the intakes of water plants and power. Due to the lack of an integrated manage most of the ongoing dredging, lack of the studies of the impact of dredging on the River morphology and forecasting variables incident dredging. Accordingly, this research aims to analyze and evaluate the effect of re-dredging on the River morphology. In addition, it will be predicted the rate of these changes (general degradation and aggradation) expected along the River Nile by applying a 2-D mathematical model (Delft 3D) which is considered the most suitable model to simulate the water surface profile and the sediment transport was used in this research. Korimat region was selected, which lies between km 85 to km 99 U/S Roda gauge station. The study reach had been subjected to continuous dredging work at several navigational bottlenecks and also around the intakes of Korimat water and power stations. A comprehensive field survey for data collection was conducted at 2016. Different scenarios were applied to select the optimum navigational path which could support decision-makers to plan integration measures to limit the complications of re-dredging on the river stability.

Key-words: River Nile, Numerical Modeling, Navigational Path, Degradation, Aggradation.

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1 INTRODUCTION

Dredging is undertaken mainly to remove the silt levels building up on the river bed due to sediment transport processes. Although it is deemed a good way to solve the problem of navigational bottlenecks and to keep the working efficiency at the intakes of water plants and power but it has been found that it causes significant changes in river morphological parameters, which result in deposition and scour along the river channel bed. Also, it has been proven to have other negative effects on the water flow and aquatic life. It usually changes and disrupts the natural flow of a body of water. Changing the water flow patterns, often many navigation bottlenecks emerge, especially during the winter season when the discharge releases are minimal. These bottlenecks always hinder and hamper the navigational traffic movement and cause the watercraft to get aground in most cases.

2 LITERATURE REVIEW

Several studies were carried out on the local and international levels based on field investigations at rivers rehabilitations to accommodate navigating vessels. These studies show the negative and the positive impacts of dredging. Liangwen et al. (2007) examined the sand dredging impacts on river bed evolution in the lower reaches and delta of Dongjiang River in China. It was found that dredging...
increases the channel capacity due to lower the river bed and decrease the longitudinal river bed gradient. Gob et al. (2005) found that dredging Semo River is created a channel (2 km long and 1 m deep). This channel acted as a sediment trap. On the other hand, Pinter et al. (2004) recommended implementing structures to limit the local shoaling problems. El-Sersawy (2001) studied the better identification and prediction of the location of the bottlenecks that may affect navigation in the Nile River using two-dimensional hydrodynamic flow and sediment transport model. Ismail et al. (2011) studied the impact of dredging on the River Nile water levels they concluded that no significant changes occurred on the longitudinal water surface. Based on the conclusions of Attia and Ahmed (2006) a simulation was conducted by Attia et al (2010) using one dimensional model (SOBEK) for Damietta branch downstream Zefat Barrage. Raslan et al. (2015) the analysis in this paper showed the implications of dredging in Damietta Branch on river regime and flow water level. Comparing river water level after dredging with that before dredging downstream Delta and Zefat Barrage indicated significant drop in the water level. Heider et al. (2013) proposed that it may increase water level during low flow season using groynes (Spur Dikes) in Damietta branch downstream Zefat Barrage to overcome the navigational bottlenecks, a simulation using one dimensional model (SOBEK) for reach under investigation. The simulated scenarios were justified several results, which represent the effect of length and spacing distance of Groynes (spur dikes) on enhancing the raise of the water level. This leads to the decrease in navigation bottlenecks. Sadek et al. (2015) examined the effect of bank erosion and bend types on the efficiency of Damietta branch on the navigational path.

3  OBJECTIVES

This research aims to study and to evaluate the side effects of the repeated dredging of navigational bottlenecks and around the intakes of water and power stations on the River Nile morphology. Also, the river bed areas subject to continuous dredging are monitored, analyzed and evaluated to find the time frequency between successive dredging processes. In addition, two alternatives of navigational path will be examined to be able to select the optimum path, which mitigates the impacts of dredging on the river stability and to achieve many purposes. Statistical analysis is used to select the two critical consecutive discharge (Maximum and Minimum Mm³/d) hydrograph which released downstream High Aswan Dam using over twenty years from the historical data. Two dimensional mathematical Model (Delft 3D) is used to simulate and predict the future rate of sedimentation and erosion along the study area.

4  STUDY AREA

A sub-reach of about 11 km of River Nile Reach 4 at Korimat area, which is, located about 86 km upstream (U/S) Roda gauge is selected to be the study area since it is subjected to much re-dredging. It has many navigation bottlenecks that hinder the passage of the navigational traffic. Also, it has the intakes of Korimat water plant at km 87.85, the intake and outlet of the power plant at km 91.5 and the recent power plant at km 97. They are located on the east side while the alignment of navigational path locates on the west side. They need repeated dredging processes to keep their operation efficiency, which they may affect the river morphology and stability. This sub-reach extends from km 86 to km 97 U/S Roda as shown in Figure (1).
5 DATA COLLECTION

The data required to simulate the study area and predict the side effects of dredging include the followings:

5.1 Hydrographic Data

The data of the study area bathymetry were taken out of the most recent hydrographic contour maps produced by the Nile Research Institute (NRI) in 2003 and new hydrographic survey in 2016. These data were in the form of vector points along the entire area. The points are made of coordinates (x,y,z) that help for creating the 3-D elements that are necessary for simulating the study reach inside the selected model. Also, two datasets of two hydrographic surveys performed in 2004 and 2005 for the study area were collected for calibration and verification purposes from the historical data records available at NRI. The evaluation of the dredging processes at different locations along the study area was surveyed in field reconnaissance at the year 2015. The integrated hydrographic survey system has been used to conduct field measurements required for the study.

5.2 Flow Velocity Distribution Measurements

The velocity distribution measurements were collected at the same time of the survey in 2003, 2004 and 2005. Cross sections were selected carefully to cover the entire length of the area. At each section, three vertical positions (East, Middle, and West) were chosen to measure the flow velocity from top to bottom (surface to bed). The measurements were taken first at 0.50 cm under the water surface. Then, they were taken at 25%, 50%, and 75% of the total water depth, and at 0.75 cm above the bed. All the measurements were taken by a flow current meter of Brand "Valeport". The mean velocity was computed at each vertical and then, the 3 mean velocities at the 3 verticals were averaged to give the final average flow velocity of the entire cross section.

5.3 Water and Bed Material Sample Measurements

Measurements for water and bed material samples were done in-site during the surveys of 2003, 2004 and 2005. Three water samples and 3 bed material samples were collected at the 3 vertical positions of each cross section mentioned above. These samples were taken by special devices and kept in bottles and plastic bags till they were sent to the soil lab at NRI for analysis. They were analyzed to get the grain size distributions of the suspended and bed material load sediments such as $D_{50}$, as shown in Figure (2).
5.4 Hydrological Data

It is known that the variation of discharges released through rivers and the corresponding fluctuations in water stages result in a sediment transport process, which, in turn, causes river bed morphological changes. Also, flow discharges and the corresponding water stages are essential data to simulate the hydrological characteristics of the study reach. Therefore, the monthly average discharges of two years that were released D/S Assuit Barrages were collected from the historical records from 1982 to 2009 at NRI. These two years were specifically chosen as they were characterized by maximum and minimum discharge releases respectively as shown in Figure (3) to represent the most critical situation that can effect of the river morphology.

Figure 3. History of max and min released discharges D/S Assuit Barrages from the year 1982 to the year 2009

6 MODEL DESCRIPTION

Delft-3D is a world leading 3D modeling suite to investigate hydrodynamics, sediment transport and morphology and water quality for fluvial, estuarine and coastal environments. The Delft-3D program suite is composed of a set of modules (components) each of which covers a certain range of aspects of a research or engineering problem. The FLOW module is the heart of Delft3D and is a multi-dimensional (2D or 3D) hydrodynamic (and transport) simulation program which calculates non-steady flow and transport phenomena resulting from tidal and meteorological forcing on a
curvilinear, boundary fitted grid or spherical coordinates. The MOR module computes sediment transport (both suspended and bed total load) and morphological changes for an arbitrary number of cohesive and non-cohesive fractions. Both currents and waves act as driving forces and a wide variety of transport formulae have been incorporated. For the suspended load this module connects to the 2D or 3D advection-diffusion solver of the FLOW module; density effects may be taken into account. The MOR module may be extended to include extensive features to simulate dredging and dumping scenarios. Numerical models could be considered as the most widely applied technique to solve mathematical expressions that describe any physical phenomena. Those models are mainly classified by some spatial dimensions over which variables are permitted to provide much more detailed results than others. However, a collection of adequate and reliable field data is highly required to fulfill suitable model calibration and verification leading to a successful application. For this respect, in case of large width to depth ratio of the water body, the horizontal distribution of flow quantities might be the main interest and two-dimensional solutions based on the depth averaged flow approximations will provide an acceptable description of flow motion. For this purpose, the Delft3D Model 2-D or 3-D hydro-dynamic (and transport) simulation module would be used to simulate the water flow along the study reach. For sediment transport computations, several sediment transport formulae are included in the model. For example 1) Van Rijn (1993), 2) Meyer-Peter -Muller (1948), 3) General formula and 4) Van Rijn (1984).

7 MODEL PREPARATION

The steps taken to simulate surface-water flow using Delft3D are as follows: Data assessment, network design, model calibration and testing finally model application. These five steps are common to the operation of almost any type of numerical model. The Delft3D modeling suite contains the grid generator program RGFGRID that allows generating a curvilinear grid. RGFGRID provides all kind of features to develop a grid, such as refine or de-refine the grid globally or locally for the reservoir grid the distance between nodes is 50 m this resolution is suitable relative to the study area as shown in Figure (4).

Figure 4. Study Reach Grid Elements and Bathymetry Data

7.1 Model calibration and verification

The model was calibrated for both flow velocity distribution and sediment transport but before calibration, the following data were entered into the model as inputs:
7.2 Bathymetry

The geometry of the study area was simulated and conceptualized in the model by creating a 3-D grid using the vector points that had been taken out from the survey maps of years 2004 and 2005 as mentioned before.

7.3 Boundary Conditions

For calibration, a discharge of 1965 m$^3$/sec (corresponding to the time of study area survey in 2004) was given to the model as a boundary condition just U/S the study area. Also, the corresponding water stage of 23.1 m amsl was given as a downstream boundary condition.

As for verification, another discharge value of 1980 m$^3$/sec (corresponding to the time of study area survey in 2005) and its corresponding water stage 23.50 m amsl used as an input data to the model as upstream and downstream boundary conditions respectively.

7.4 Roughness Coefficients

An initial trial value of Manning coefficient (n) of 0.025 (based on the grain size distribution analysis results). The second trial of 0.030 to represent the bed roughness of the study area ways given to the model. Feeding the model with the data required, it was run several times with modifying and adjusting Manning's Coefficient to predict flow velocity distributions and cross sections closest to those of the year 2004 and 2005, which were measured during the two field surveys of the study area. Figure (5) shows the locations of the calibration & verification cross sections, while figure (6) gives the velocity calibration and verification. The sediment calibration and modification are shown in figure (7). From the figures, it is found that there is a reasonable agreement between the computed and measured values of the flow velocity distributions and morphological change at the chosen cross sections. Finally, it is found from calibration runs that the best sediment transport equation that can be used to predict the morphological changes within the study area is Van Rijn (1993). Accordingly, the model is reliable to give acceptable predictions.

![Figure 5. Locations of the Calibration & Verification Cross Sections](image_url)
Calibration Results - Flow Velocity Distribution Section (1)

Verification Results - Flow Velocity Distribution Section (4)

Calibration Results - Flow Velocity Distribution Section (2)

Verification Results - Flow Velocity Distribution Section (5)

Figure 6. Flow Velocity Calibration and Verification

Calibration Results - Sediment Transport

Verification Results - Sediment Transport

Figure 7. Flow sediment transport calibration and verification using Meyer-Peter-Muller (1948).

8 MODEL SIMULATION

Confident with the calibration process, the model was further applied to simulate different scenarios of discharges to achieve the main objectives of this paper. In the model, the mesh is in the planer form. Therefore, the bed elevations should be assigned to each element composing nodal point at the same coordinates. Transforming coordinates of each scatter point and the Delft3D Quick in program automatically interpolates mesh node. Therefore, it can be able to use the recent hydrographic survey data at year 2016 to predict the probable river bed morphological changes for two alternatives of navigational paths. The optimum path, which mitigates the river disturbance, will be selected as shown.
in Figure(8). To estimate the flow discharge at each channel of study area after applying each scenario of the different scenarios by Delft3D. Two cross sections were selected in east and west channel at the same line of that cross lines which integrated the grid as shown in fig.8

![Cross section at each channel](image)

**Figure 8. The navigational paths alternatives for the study region & cross sections at each channel of island**

### 8.1 Prediction of Morphological Changes after applying the first scenario:

The first scenario was representing the model simulation before dredging along the west navigational path. It was selected to evaluate the morphological changes without any human intervention and to determine the natural river changes. The numerical simulation was carried out for 2 years using monthly maximum and minimum discharges at the upstream of the study area and water levels above MSL at the downstream boundary of the study area. This model was utilized to predict the hydrodynamic effects of the different flow cases on the river morphology. Consequently, it may help to take actions to improve the integrated dredging management system.

Figure(9) shows the longitudinal bed level profiles for both the initial river bed levels for the year 2016 and the predicted ones through the navigational path in case of releasing the proposed discharges for two years. From this figure, it could be noticed that the navigation bottlenecks only in the region between km 89 to 90.2 and between km 94.7 to 96. From figure (10), it is clear that the river bed levels will arise with a value ranging between 0.50 m and 3.8 m at some cross-sections as the results of velocities are low inside the inner bend of meander and the point bar are formed. In the meantime, other cross-sections are expected to drop in bed levels ranging between 1.00 m and 3.1 m due to much of the sediment eroded from the outside bank.
The navigation channel was designed and alignment to have dimensions of 75 m width and 2.3 m depth from the minimum water level that observed in the last 15 years and the side slope is 5:1. Scenario 2 was the river conditions after dredging which was carried out for two years with the same discharges proposed. The model was applied and the results were analyzed and plotted. The impacts of dredging for the navigation path in the west channel and the dredging process front of the water and power stations at the east channelon the river morphology will be analyzed in this section. Fig. 12 shows a comparison between the current lowest river bed levels after dredging at the west channel of the study reach and the predicted longitudinal thalweg path along the navigational path. It is exposed to erosion ranging between a value 0.20 m and 2.4 m at some of the cross-sections. At the meantime, other cross-sections will experience a rise in bed levels ranging between 0.50 m and 3.50 m as shown in Figure (13). Also, it is clear that the navigational path from km 85 to km 99 will be a safe area without any expected navigation bottlenecks. Finally there are some locations is very close to bed level for navigational path so it can expect that their locations expose
to deposition shortly causing obstructions for navigation, these locations are in different places between km 90 and km 99 from Roda gauge station. Figure 14 shows a comparison between the current lowest river bed levels and the predicted longitudinal path at the centerline of the assumed navigational path in east channel, thalweg path after dredging the navigation path at the west channel and dredging front of stations in the east channel. It is clear that the path from km 90 to km 95.5 will be unsafe area due to presence of Korimat power station at km (91.8), Dikes at km (92.3), Water pumping plant at km (93.7). In addition, the presence of Korimat water treatment plant that leads to disturbance in the bed level causing either sedimentation or erosion. On the other hand, the distance from km (99) to km (85) is more frequent to deposition more than erosion. It can be clear that it is exposed to erosion ranging between a value 0.20 m and 1.2 m at some of the cross-sections. At the meantime, other cross-sections will experience a rise in bed levels ranging between 0.50 m and 3.20 m as shown in Fig.15. Although some morphological changes were occurred but this scenario is considered better than the first scenario because it is noticed that the appearance of navigational bottlenecks at the west navigational path for the study area will be reduced.

**Figure 11.** Longitudinal section predicted at the center line of the west navigational path (scenario 2)

**Figure 12.** Sedimentation and erosion predicted for bed level at the west navigational path (scenario 2)

**Figure 13.** Longitudinal section at the center line of the east navigational path (scenario 2)
Figure 14. Sedimentation and erosion for bed level at the east navigational path (scenario 2)

For second scenario the values of discharge are presented in table.2. It is clear that the values of discharges in west channel increased in this scenario leading to creation of new navigable depths in west channel of Korimat Island.

Table 2. Flow discharges at east and west channel (scenario 2)

<table>
<thead>
<tr>
<th>Time</th>
<th>West channel</th>
<th>East channel</th>
<th>Discharge ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current time (Q max)</td>
<td>634.38 m³/sec</td>
<td>441.42 m³/sec</td>
<td>1.53</td>
</tr>
<tr>
<td>After 2 years (Q min)</td>
<td>344.65 m³/sec</td>
<td>150.12 m³/sec</td>
<td>2.29</td>
</tr>
</tbody>
</table>

8.3 Prediction Of Morphological Changes after applying the third Scenario:

The navigation channel was suitable to be designed and alignment at the year 1982 at the east channel of Korimat island because of the presence of lower bed levels than the west channel. On the other hand, from the year 2003 the navigational path was designed at the west channel because it has navigable bed levels at most of the area, so the purpose of this scenario aims to evaluate the effect of the design of the navigational path at the east channel where many activities exist. Fig. 15 shows a comparison between the current longitudinal river bed levels and the predicted longitudinal river bed levels at the east channel of reach study after applying the third scenario. It is proved that the path exposed to sedimentation ranging between a value 0.50 m and 3.2 m at some of the cross-sections. At the meantime, other cross-sections exposed to erosion from 0.5m to 1.00m as shown in figure (18).

Figure 15. Longitudinal section predicted at the center line of the east navigational path (scenario 3)
It is clear that the values of discharges in east channel increased in this scenario as shown in table.3 leading to the creation of new navigable depths. Also, this scenario may decrease the rate of deposition in the front of the water and power intakes. Moreover the island will not attach to any side of banks, therefore it helps the islands keeps its characteristic.

Table 3: Flow discharges at east and west channel

<table>
<thead>
<tr>
<th>Time</th>
<th>West channel (m³/sec)</th>
<th>East channel (m³/sec)</th>
<th>Discharge ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current time (Q maximum)</td>
<td>580.77</td>
<td>492.36</td>
<td>1.17</td>
</tr>
<tr>
<td>After 2 years (Q minimum)</td>
<td>308.68</td>
<td>186.10</td>
<td>1.65</td>
</tr>
</tbody>
</table>

9 DETERMINATION OF THE OPTIMUM NAVIGATIONAL PATH

To determine the optimum navigational path, we need to evaluate the east and west channels of the study area. The west channel has almost narrow section but the discharge in it is higher than the discharge which passes in the east channel. In east channel many activities were found as Korimat water plant station, Korimat Power station, dike and many ferries which make annual maintenance doing in it almost. From the results the third scenario where the navigational path is in the east channel the rate of deposition in the front of the water and power intakes may decrease consequently the efficiency for their increase. Moreover the island will not attach with any side of banks therefore it helps the islands keeps its characteristic.

10 CONCLUSIONS AND RECOMMENDATION

- This study investigated the effect of the dredging works on the river morphology and river water levels. The numerical model Delft 3D was used to predict the morphological changes along the study reach according to different proposed scenarios of discharge. Two alternatives of navigational paths were proposed the first is in the east channel for Korimat Island where many activities as the intakes of water and power plant exist, while the second path is in the west channel where the channel is narrow and most the flow pass through its.
- The model was calibrated and verified using data measurements. It gives a reasonable agreement between the computed and measured values of the flow velocity distributions and morphological changes at the chosen cross sections.
- The model was applied to predict the probable river bed morphological changes for two alternatives of proposed navigational paths. It can be concluded that the east navigational path is considered the best scenario, where the rate of deposition in the front of the water and power
Intakes may be decreased consequently increase their efficiency for with decreasing the rate of maintenance of navigational path. Moreover, the island will not attach to any side of banks, therefore it helps the islands keeps it’s characteristic which mitigate the river disturbance.

- In case of scenario no.1 the result shows that the navigational path in this scenario is more stability than in other scenarios but the west channel becomes narrow so we should find an alternative.
- In case of an alternative solution the result shows that the flow ratio increased in the east channel which caused to increase the velocity, which makes the depth safe as possible.
- Dredging is not the negative solution, but the lack of study to organize which leads to appear some problems a long time.

The following are also recommendations for future researches:

- It is very important to study other dredging negative impacts such as environmental impacts as a result from the dredging disposal.
- It can recommend that inland water transport activity can be put off or decrease the load vessels to decrease the required depth during certain number of days each year where the required water depth is not available to reduce the maintenance works in the long run consequently avoid the river disturbance.
- It is very important to study negative impacts of the second alternative solution.

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