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Environmental impacts assessment of the River Nile navigational projects

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ABSTRACT

Transport is a crucial sector in the socio-economic development in Egypt. Transport is inextricably linked to, and exerts a strong influence on, other sectors of the country's economy. Cheap, efficient, adequate, safe, and environmentally friendly transport services provide effective support to agricultural and industrial production, tourism, and to social and administrative services that are key to national development. Thus, transportation is essential to achieving the goals of poverty reduction and sustainable development. The Egyptian Government has paid a lot of attention to the preparation of the Nile River as a navigation channel. Such preparation includes surveying, dredging, and installation of aids to navigation. All such efforts aim to increase the safety of navigation in the Nile River. Dredging is done to enlarge or deepen a navigation channel or for the purposes of waterfront construction, utilities placement and environmental remediation.

Two dimensional mathematical model was used in this study. The model was calibrated and verified using field measurements. The calibration process showed an agreement between the predicted and measured parameters. The model was applied to evaluate the situation before and after dredging.

In this paper another aspect of safety is being addressed, namely the environmental impact of channel dredging which is a temporary solution where the dredged material is added to the agriculture soil. The grain size distribution of the bed sediments upstream Assuit Barrage was analyzed and the environmental impact assessment was conducted by comparing the average total heavy metals concentration with the permissible values of different sediment quality. The samples were within the permissible standard limits. Also, water quality parameters were measured before and through dredging. Twenty one surface water samples were collected (middle of main channel). The physical and chemical properties of the surface water samples for the first trip (Before dredging) and the second trip (during dredging), are discussed.

Moreover, it was concluded that the environmental impact of navigation development resulted in a drop of 1.2 cm in the water level in the navigational channel and a decrease in the velocity magnitude within the study area. The increased turbidity might be detrimental to benthic species particularly sedentary species such as tube worms. and Prolonged reduced water column clarity might also lead to a reduction in the photosynthetic productivity of the water column.

This study recommended that studies should consider the positive and negative impacts of the channel design. It was further suggested that a quantitative biological impact assessment of the aquatic life should be executed to propose mitigation measures. Developing guidelines for EIA to be conducted dredging projects.

Key words: Nile River, navigation channel, mathematical modeling, water quality, dredging disposal, environmental assessment.

INTRODUCTION

The construction of Aswan High Dam has caused significant changes in morphological parameters in the River Nile and these changes resulted in deposition and erosion along the river channel (Abdelbary, 1992). As a result, many navigation bottlenecks along the river appeared especially during winter season. Inland waterway transport has become a significant element in the development of Egypt's transport and tourism infrastructure. A large project for the Nile River rehabilitation was started since 1999. The objective of this project was to conduct a hydrographic survey for the purpose of designing the waterway started from Aswan Dam to Mediterranean Sea. The daily water levels on Nile River are dependent on the actual discharges released downstream the Aswan High Dam (HAD) to satisfy the basic requirements of irrigations and water intake structures as well as the municipal and industrial needs (Attia and El- Sersawy, 2005). One of the problems that threaten the navigation is the lack of enough water depth for navigation. Since most of Nile water is used for irrigation (about 85%), the water level in the Nile is affected by the irrigation requirements throughout the year. During July and August, the irrigation water requirements are high. While in December and January, the water requirements are low. As a result, water level in the Nile during December and January is the lowest throughout the year and navigation faces real problems during this period unless additional water is released from Aswan High Dam (Raslan and Abdelbary, 2001) .

Routine dredging activities are carried out to maintain a depth of 2.3 m at low water stage. The navigation channel has a minimum average channel width of 100 m. This study intends to use the modern techniques and latest technologies of mathematical models to evaluate and simulate the occurred changes in hydraulically parameters . Based on the actual and basic interaction between the hydraulics, morphological and environmental parameters, main tools can be utilized to illustrate and explain these relations. Dredging is essential to maintain inland waterways; for the development of river facilities; for flood mitigation; and for removal of sediments from structures, basins and water intakes. Much of the material removed during these necessary activities may require disposal from the site. The greater proportion of the total amount of material dredged worldwide is, by nature, similar to undisturbed sediments in inland and coastal waters. A smaller proportion of dredged material, however, is contaminated by human activity to an extent that major environmental constraints need to be applied when considering disposal or use of these sediments (Smith *et al.,* 1996) **.**
This study aims to evaluate and to assess the environmental impacts for the navigational problems taking into consideration the river's morphological status and the water levels corresponding to the minimum discharges

MATERIALS AND METHODS

A Brief description of the study area

The Nile River in Egypt is divided into four main reaches. The first reach is from the downstream of the Aswan High Dam to the upstream of Isna barrage. The second is from the downstream of Isna barrage to the upstream of Nag Hammadi barrage. The third reach is from the downstream of Nag Hammadi barrage to the upstream of Asyut barrage and the fourth reach is from the downstream of Asyut barrage to the upstream of delta barrage.

A study reach was chosen to be investigated. Third reach is the main target of the study. This reach was chosen as it has available data that could describe it and could satisfy the present investigation requirements.

The chosen reach is located between Sohag at the upstream, and El-Maragha at the downstream. It is between km 480.0 and km 463.0 from El-Roda gauge as shown in Figure (1). The river width varies between 470.0 m (at the downstream end) and 845.0 m (at the upstream end).

In addition to the bathymetric data, the model requires hydrologic and hydraulic data such as stage and flow hydrographs, river velocities, and rating curves to establish the initial and boundary conditions.

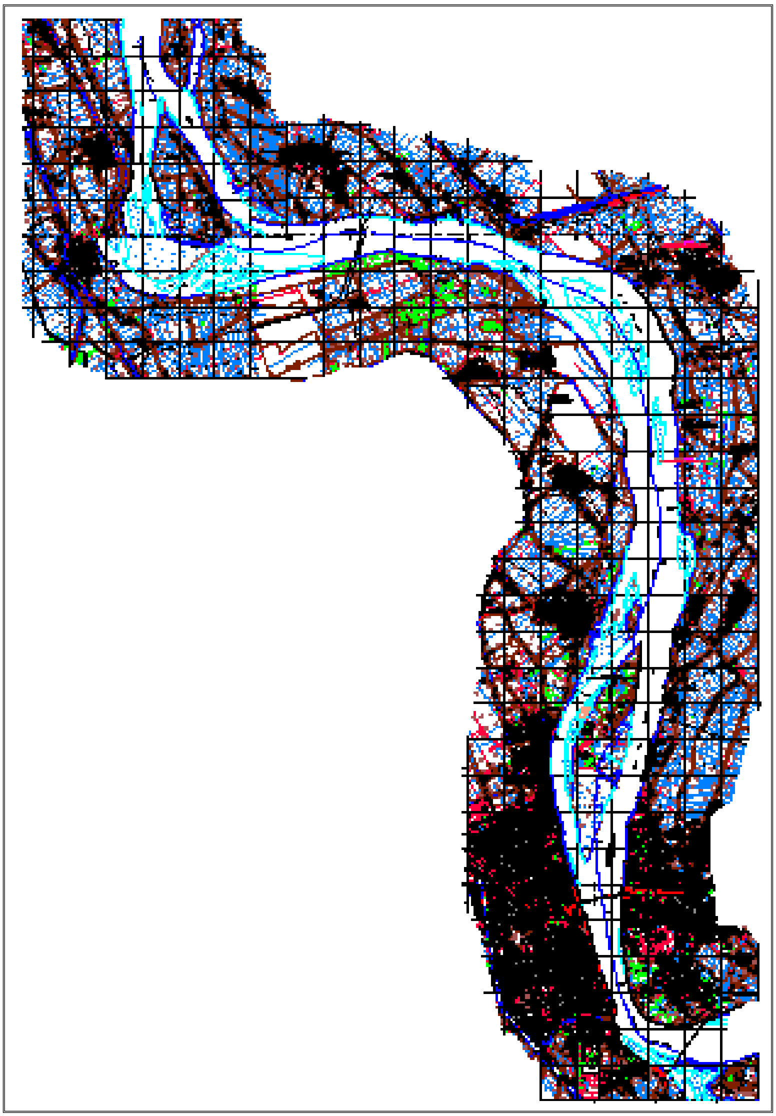

Fig. (1): Layout of the studying area [7]

Data collection

Hydrographic (bathymetric), hydrologic, hydraulic, and sediment data were collected as inputs for the water and sediments flow model. Also, water quality data, dredging materials were collected and analyzed.

Bathymetric data

The bathymetric data describe the geometry of river beds in the study area, were based on data obtained from contour maps, produced from the recent hydrographic survey of year 2005 provided by the "Nile Research institute" NRI. The channel geometry presented by Easting, Northing, and Elevation (E, N, and Z) was used for the mesh generation. The coordinates of the mesh were referenced to the WGS84 ellipsoid with Egyptian Transverse Mercator (ETM) projection.

Hydrological and Hydraulics data

In addition to the bathymetric data, the model requires hydrologic and hydraulic data such as stage and flow hydrographs, stream velocities, and rating curves to establish the initial and boundary conditions. The hydrological records for the study reach including maximum and minimum flow discharges and the corresponding minimum water levels (EI-Moattassem and Hassan, 1990) .

The minimum inflow through the reach ranges between 36 and 76 mm^3/day, while the maximum inflow ranges between 186 and 222 mm^3/day (NRI , 1992).

The Mathematical Model

Numerical models could be considered as the most widely technique to solve mathematical expressions that describe any physical phenomena. A two dimension numerical model, the Surface Water Modeling System (SMS) was used to simulate the impacts of the proposed river regulation works. The model was developed by Brigham Young University in cooperation with the U.S. Army Corps of Engineers. The SMS software provides valuable tools for mesh generation, data interpolation, and graphical visualization. The model can calculate water surface elevation and flow velocities, and any other functional data can be calculated at each node of the designed mesh for shallow water flow problems and support both steady and dynamic model simulation. The model solves the depth-integrated equations of mass and momentum conservation in two horizontal directions. The depth-averaged surface water flow equations are derived by integrating the three-dimensional mass and momentum transport equations with respect to vertical coordinate from the bed to the water surface, assuming that vertical velocities and accelerations are negligible (El Sersawy, 2001; SMS , 2002)**.** A finite element mesh was created within SMS (Fig. 2) for mesh generation. The resulting solutions which contain water surface elevation, flow velocities, sediment concentrations, and any other functional data were calculated at each node of the designed mesh. There are some limitations when using the SMS model for long reach and long time especially in the number of the cross section which can be simulated.

The vertically integrated momentum equations are written as: For flow in the x direction, and for flow in the y direction, the vertically integrated mass transport equation (continuity equation) is:

$$\frac{\partial(HV)}{\partial t} + \frac{\partial}{\partial y}\left\{\beta_{vv} HVV + (\cos\alpha_y \cos\alpha_z)^2 \frac{1}{2} gH^2\right\} + \frac{\partial}{\partial x}(\beta_{uv} \mathrm{HVU}) + \cos\alpha_y \mathrm{gH} \frac{\partial \mathrm{z_b}}{\partial y}$$

$$+\Omega \mathrm{HV} + \frac{1}{\rho}\left[\tau_{by} - \tau_{sy} - \frac{\partial(\mathrm{H}\tau_{yx})}{\partial x} - \frac{\partial(\mathrm{H}\tau_{yy})}{\partial y}\right] = 0$$

$$\frac{\partial(HU)}{\partial t} + \frac{\partial}{\partial x}\left\{\beta_{uu} HUU + (\cos\alpha_x \cos\alpha_z)^2 \frac{1}{2} gH^2\right\} + \frac{\partial}{\partial y}(\beta_{uv} \mathrm{HUV}) + \cos\alpha_x \mathrm{gH} \frac{\partial \mathrm{z_b}}{\partial x}$$

$$-\Omega \mathrm{HV} + \frac{1}{\rho}\left[\tau_{bx} - \tau_{sx} - \frac{\partial(\mathrm{H}\tau_{xx})}{\partial x} - \frac{\partial(\mathrm{H}\tau_{xy})}{\partial y}\right] = 0$$

$$\frac{\partial H}{\partial t} + \frac{\partial(\mathrm{HU})}{\partial x} + \frac{\partial(\mathrm{HV})}{\partial y} = q$$

Where H = water depth;
z = vertical direction;
zb is the bed elevation;
zs = zb + H = water surface elevation;
u = horizontal velocity in the x direction;
v = horizontal velocity in the y direction;
βuu, βuv, βvu, and βvv = momentum flux correction coefficients that account for the variation of velocity in the vertical direction;
αx = arctan ($\partial z_b / \partial x$),
αy = arctan ($\partial z_b / \partial y$),
αz = arccos (1-cos2 αx –cos2 αy);
g = gravitational acceleration;
Ω = Coriolis parameters;
ρ = water mass density, which is considered constant;
τbx and τby = bed shear stresses acting in the x and y directions, respectively;
τsx and τsy = surface shear stresses acting in the x and y directions, respectively;
τxx , τxy , τyx , and τyy = shear stresses caused by turbulence;
q = unit source (inflow) or a unit sink (outflow) term.

The SED2D model calculates the suspended sediment concentration using the basic convection- diffusion equation, which it is presented in Ariathurai, MacAthur, and Krone as follows:

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = \frac{\partial}{\partial x}\left(D_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(D_y \frac{\partial C}{\partial y}\right) + \alpha_1 C + \alpha$$

Where C = concentration;
t = time;
u = flow velocity in x direction;
x = primary flow direction;
v = flow velocity in y direction;
y = direction perpendicular to x;
Dx = effective diffusion coefficient in x- direction;

Dy = effective diffusion coefficient in y- direction;
α1 = a coefficient for the source term;
α2 = the equilibrium concentration portion of the source term.

Several options are available in the SED2D model for computing bed shear stresses using τb = ρ(u*)2 , where; ρ = water density and u* = shear velocity which can be calculated by using smooth wall log velocity profile, and the Manning shear stress equation.

The sediment load transport was determined by using Ackers-White (SMS , 2002) formula which was adopted for this model because it is performed satisfactorily in tests, seems to be complete, and because it is reasonably simple. It is based on analysis of 925 sets of laboratory and field data. The following empirical formula was proposed:

In which:

$$S_t = Kb\bar{u}\,d_{35}\left[\frac{\bar{u}}{u_{*,b}}\right]^n \left[\frac{Y - Y_{cr}}{Y_{cr}}\right]^m$$

Where St = total sediment load transport,
u- = mean flow velocity,
Δ = relative water density (1.65),
b = flow width,
υ = kinematic viscosity,
u*,b = bed shear velocity,
Rb = hydraulic radius,
d_{35} = particle diameter of bed material.

The numerical technique used to solve the governing equations is based on the Galerkin finite element method. Then, SMS Model automatically generated a mesh or grid network from the map module and then interpolated the bathymetric data into the mesh. The mesh contains 624 elements and 2153 nodes. The element width ranges between 34 m and 54 m and its length ranges between 50 m to 200 m with concentrating the number of elements in important areas along the study area as shown in Figure (2).

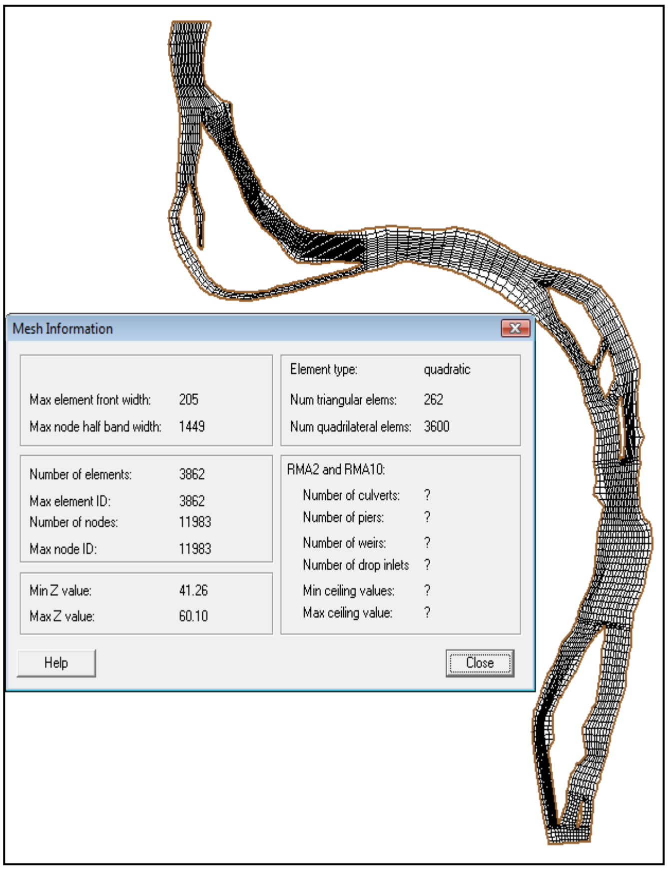

Fig. (2): Finite element mesh generation

Calibration and verification of the model

Several model runs are made to achieve the best agreement between measured and resulted values from the model for water velocity and cross section at study area. This was carried out by adjusting roughness coefficients at various locations along the modeled study area till the best results are achieved. The initial boundary condition is defined as the initial water levels as well as the bed elevation in terms of xyz data points. The initial water levels were used to simulate the flow characteristics. The boundary conditions consist of three conditions, inflow, outflow, and side boundary conditions. The inflow boundary was defined as the inflow discharge to the study area which is defined as the discharge downstream Nag Hammadi Barrage (35.8 m m3/day (414.35m^3/sec) at 1998.

The outflow boundary condition was used as water level at the end of the study reach. The simulation carried out using the field observation water level of 45 m for calibration, verification runs between minimum water level of 50.0 m and maximum water level of 52.0 m (NRI , 1990) **).**

The next step in the modeling process was the verification of model results in order to ensure that the model accurately reproduce conditions similar to the observed values in the prototype. The model was verified using the inflow discharges from D.S Nag Hammadi Barrage and water levels from Sohag station. The verification was tested by data of hydrographic survey at year 2007. It also uses the original bed elevations for the area of study, which were used exactly as calibrated period.

RESULTS AND DISCUSSION

Calibration and Verification Results

Calibration was performed to ensure the model adequately in predicting hydrodynamic conditions using a certain data for a certain period. Verification is performed to make sure that the model could produce reasonable results using a different set of data in a different periods.

Comparison of the field velocities and obtained velocity profiles at the cross sections by the model is shown in Figure (3). This figure indicates good agreement, where there were the same trend and distributions between the measured and simulated velocity profile for the section which located at 395.0 km upstream Roda gauge station. This figure shows that the simulated velocity ranges between 0.1 to 0.77 m/ sec. From this figure it can be concluded that the velocity magnitude in the east side was higher than the velocity magnitude in west side. The next step in the modeling process was the verification of model results in order to ensure that the model accurately reproduce conditions similar to the observed values in the prototype. The model was verified using the inflow discharges from D.S Nag Hammadi Barrage and water levels from Sohag gauge station. The verification was tested by data of hydrographic survey at year 2007. It also uses the original bed elevations for the area of study, which were used exactly as calibrated period. Figure (4) describes the results of numerical model simulated and observed cross section for verification.

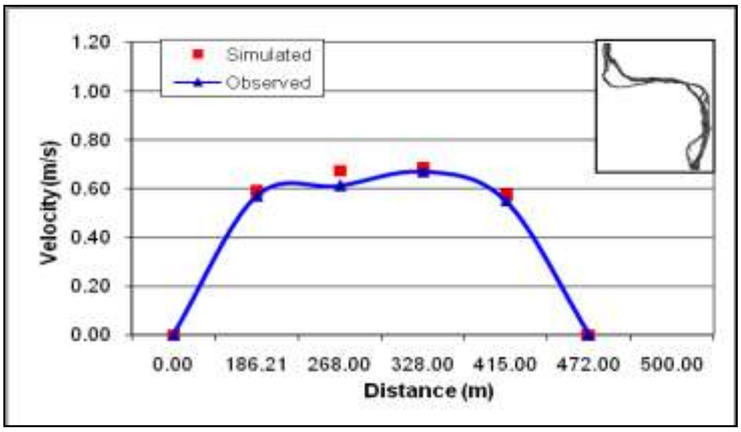

Fig. (3): Simulated and observed velocity for calibration.

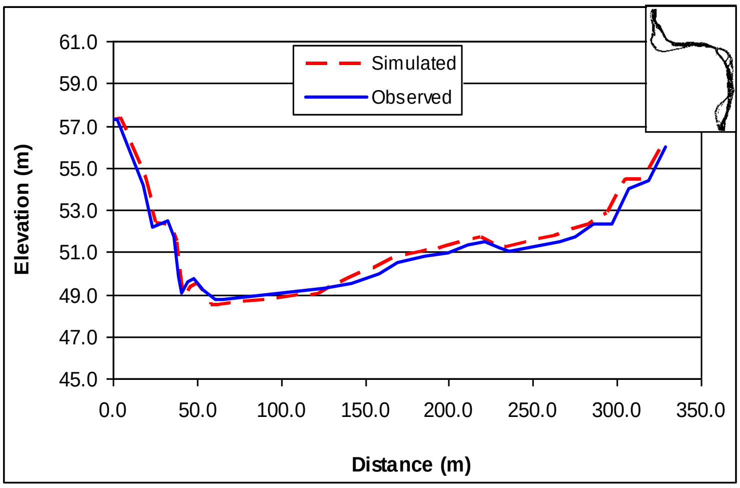

Fig. (4): Simulated and observed x.sec. for verification

Model application results

1- Simulation of the Flow before dredging in minimum water level

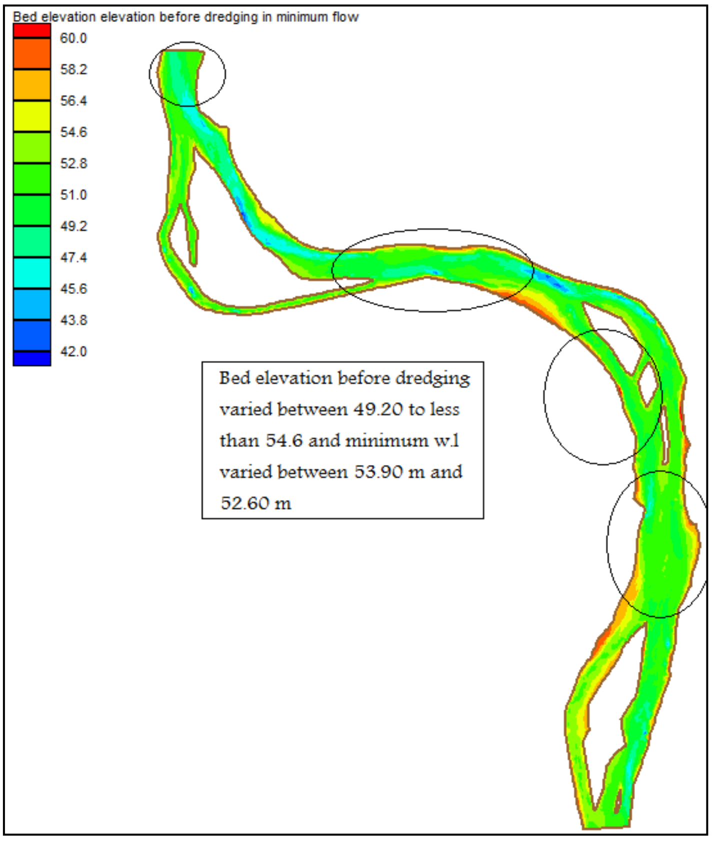

Fig. (5): Bed elevations before dredging

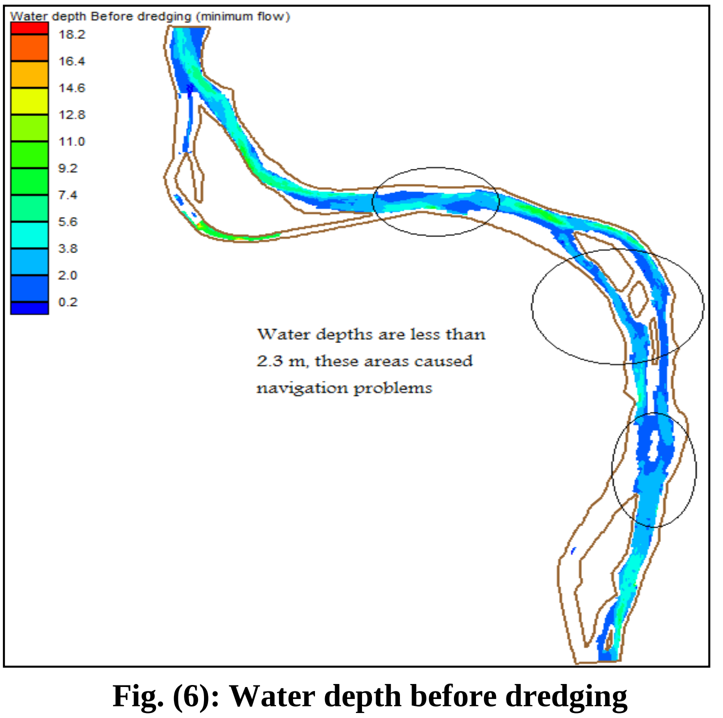

Fig. (6): Water depth before dredging

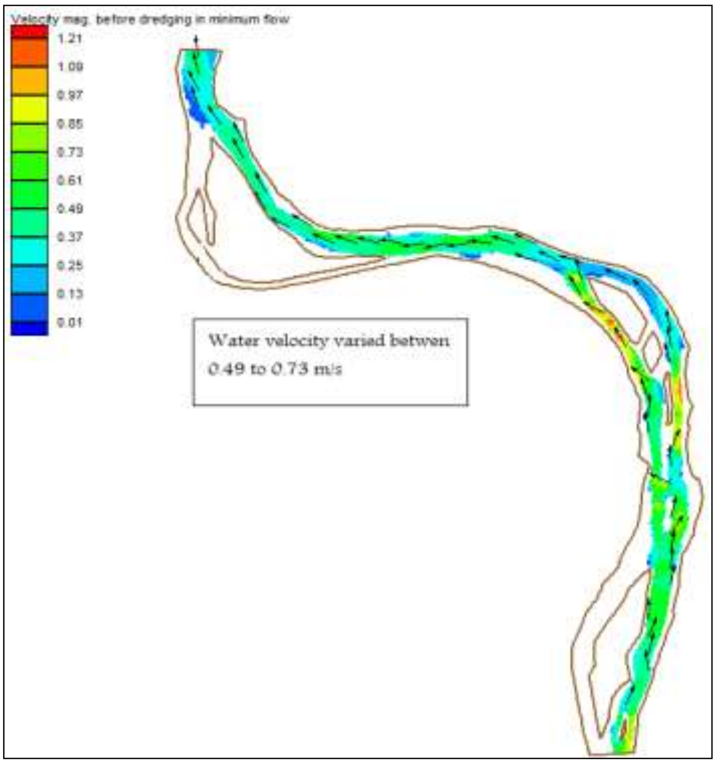

Fig. (7): Water velocities before dredging

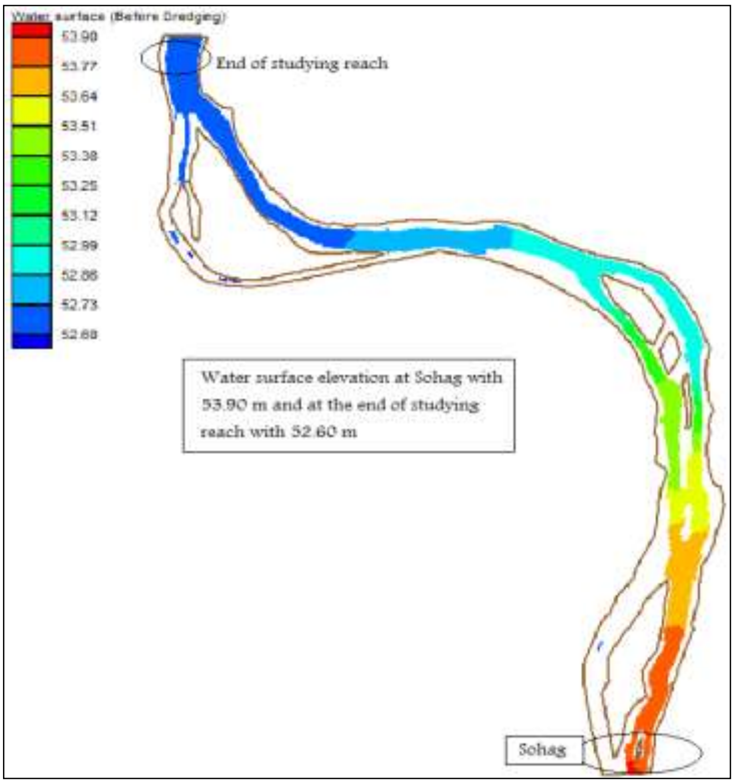

Fig. (8): Water surface before dredging

2- Simulation of the Flow after dredging in minimum water level

After simulating the flow before implementing the dredging project, the model was used to simulate the flow after the realization of the project. Consequently, the mesh of the study area was modified to simulate the new dredged bed. It was developed from the base mesh where the bathymetry was modified and the resolution was kept consistent with the base mesh. At the locations where dredging was proposed, the node density in the base mesh was higher than the surrounding areas.

The model was run to simulate 2009 in order to produce the consequences of dredging on the hydraulic parameters of the river reach under investigation. The effects of the dredging process on the study area were thus determined. Moreover, the changes in the deposition rates, and other hydraulic parameters were identified. The bed elevations were improved within the reach km 468.0 to km 469.0 from El-Roda gauge and from km 475.0 to km 477.0 from El-Roda gauge. The bed elevation changed from 49.2 m to 52.8 m. The simulated bed elevations within the study reach was given in Figure (9).

Figure (10) illustrates the water depth after dredging where the depths are ranged from1.20 m to 7.8 m. The values of water velocities were reduced due to the dredging process. The velocities varied in values from 0.12 m/s to 0.72 m/s as shows in Figure (11). The water surface elevation at the studying reach, after dredging are varied between (52.56) m to (53.90) m. Figure (12) shows the water surface after dredging.

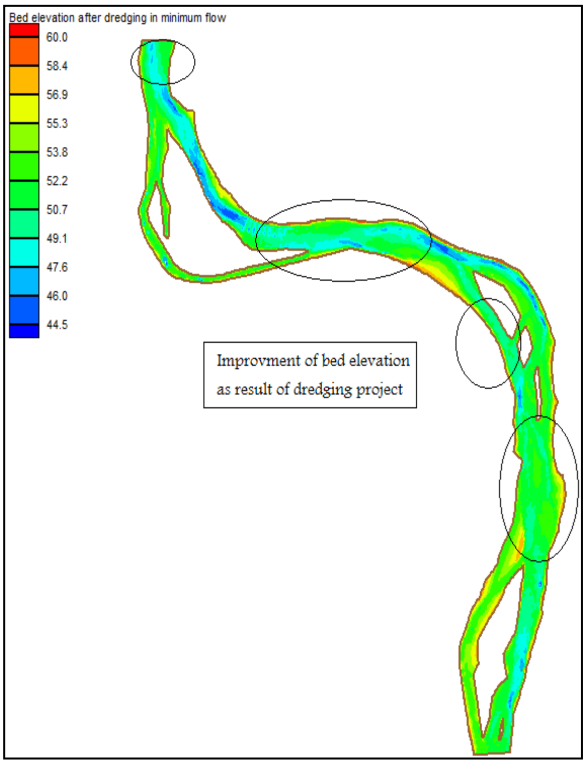

Fig. (9): Bed elevations after dredging

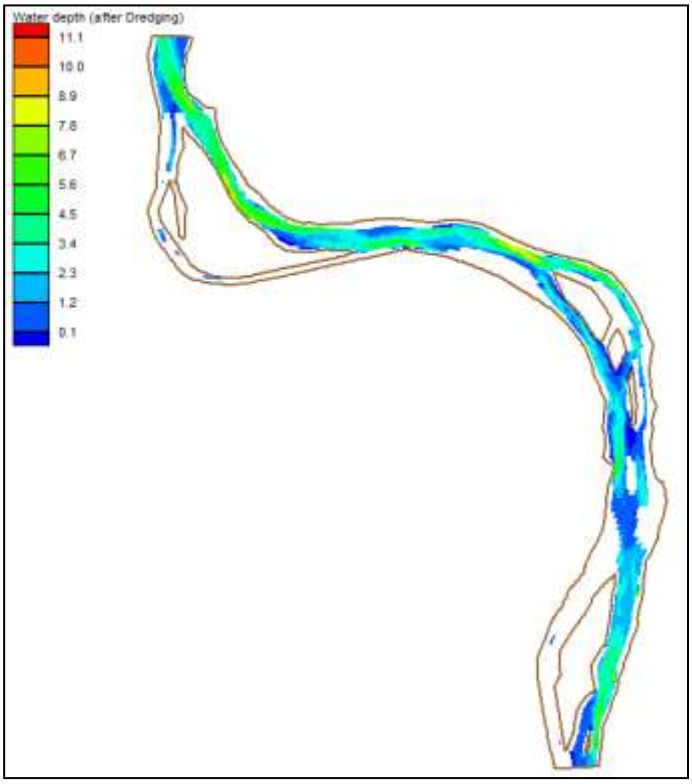

Fig. (10). Water depths after dredging

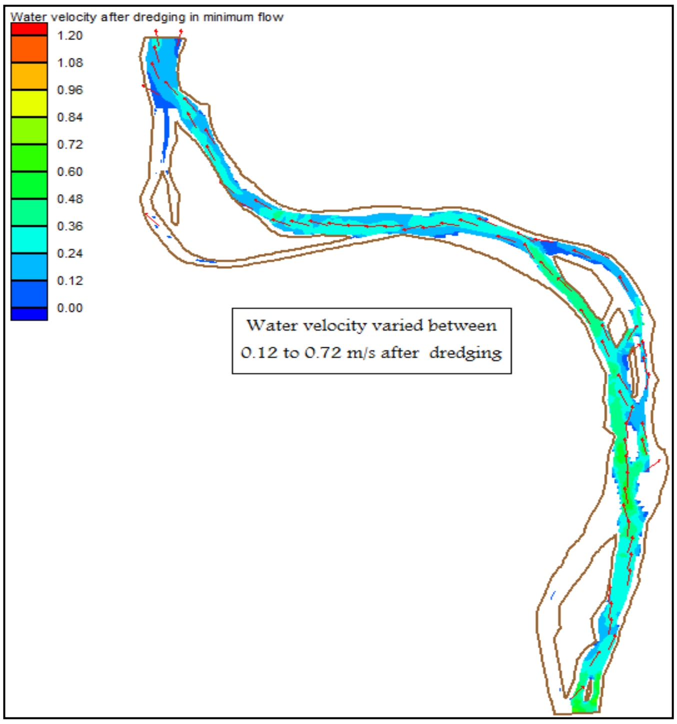

Fig. (11). Water velocities after dredging

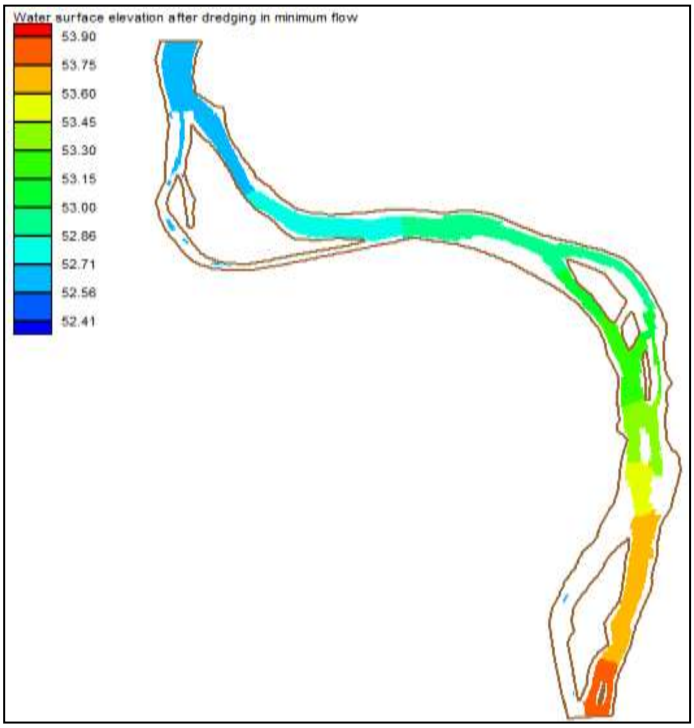

Fig. (12). Surface water elevations after dredging

Assessment of water quality before and after dredging

1- Surface Water Quality

To study the physical, chemical, microbiological and biological properties of the study area through the dredging project. Two field trips were planned, the first trip (Before dredging) and the second trip (during dredging). Twenty one surface water samples were collected (middle of main channel).

2- Turbidity and Total Suspended Solids (TSS)

The turbidity concentration in the first trip (before dredging) ranged between 4.4 NTU to 10.1NTU due to deposition of most of the salts in the study area. While TSS ranged between (6-15) mg/l. In the second trip (during dredging), Turbidity ranged from 7.9 to 19 NTU while in other sites turbidity ranged between (4.4 – 10.6) NTU. TSS results ranged between (16 – 38) mg/l. Figure (13) illustrated the difference between before and during dredging in total suspended solids and Figure (14) illustrated the difference between before and during dredging in turbidity.

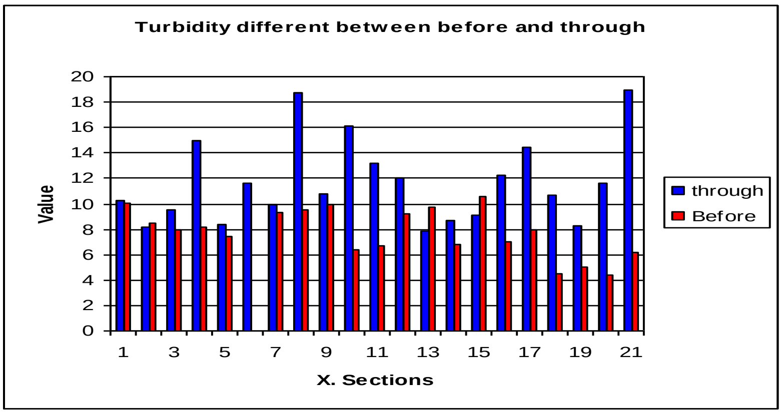

Fig. (13): Turbidity difference between before and through dredging

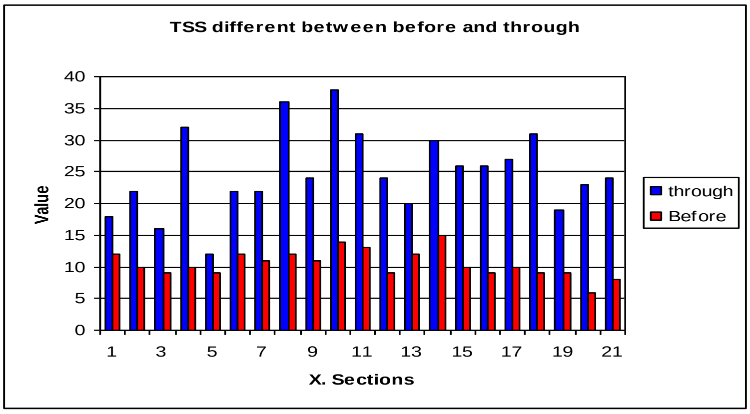

Fig. (14): TSS difference between before and through dredging

3- Heavy metals parameters

Many efforts have been undertaken to develop standard procedures and criteria for the assessment of environmental impacts on sediments; but until now, there was no universally accepted guidelines for sediment quality. In this study, the method for assessing the metals pollution in the bottom sediments at studying area was used. This assessment was conducted by comparing the average total heavy metals concentration with the permissible values of different sediment quality objectives (Table 1), (Liu *et al.*, 1999**)**. The results of this simple comparison revealed that the concentration of the investigated heavy metals in the studying area bottom sediments were found within the permissible limits of standards. However, this comparison with the sediments quality objectives might not be sufficient for assessment of pollution levels in bottom sediments of the area under study (Yousry, 2007) .

Table (1): Comparison between upstream Assuit Barrage and quality objectives

Quality Objective	Mn	Cd	Zn	Cr	Cu	Pb
Canidian target*		0.6	123	37	36	35
Agriculture land use*		1.4	200	64	63	70
Nile River (Upstrem Assuit Bar.)	79		34	7	31	20

*Liu *et al.*, 1999

3- Benefits and Risks of the use of bed sediments in agriculture soil amendment

Sediment of the river is added to agriculture soil both as means of disposal or as sources of fertilizer and conditioner for the agriculture soil, since they contain useful amounts of plant nutrients and organic matter. Sediment if reused in agriculture has a great potential to meet the needs of organic matter and nutrient in soil. The organic matter in the applied sediment enhances the soil's structure by reducing plasticity, bulk density, improving granulation, increasing porosity and water-holding capacity. In addition, sediment provides nutrient, increasing cation exchange capacity. Certain trace elements are essential in plant nutrition (micronutrients). Trace element uptake by roots depends on both soil and plant factors (e.g., source and chemical form of elements in soil, pH value, organic matter, plant species, and plant age). However, plants growing in a polluted environment can accumulate trace elements at high concentrations causing a serious risk to human health when plant base food-stuffs are consumed and have heightened public concern. Sediment dredging can create significant environmental impairments including aquatic habitat damage, bury spawning areas, degrade water quality, and disposal problems.

Conclusions

The results of applying model before and after dredging

- Successful applications of this model to simulating large scale river channel flows proved to be reliable and could be applied to similar cases to assist decision makers.
- The dredging process dropped the water surface, decreased the velocity and almost improved water depths for navigation channel.

The results of assessment water quality and dredging materials

- The increased turbidity might be detrimental to benthic species particularly sedentary species such as tube worms. The results of bed samples comparison revealed that the studying area bottom sediment concentrations were found within the permissible limits of standards.
- The organic matter in the applied sediment enhances the soil's structure by reducing plasticity, bulk density, improving granulation, increasing porosity and water-holding capacity Prolonged reduced water column clarity might also lead to a reduction in the photosynthetic productivity of the water column.

Recommendations

1. Studies must consider all positive and negative environmental effects of the alternative navigation channel designing. Some of the environmental effects may be changes in water levels, erosion, deposition, or distribution of wave energy along the shoreline.
2. The risk of using the dredging material where added to cultivation land at study area were

permissible.

3. In order to achieve environmentally sustainable development, it was recommended to prepare an EIA to cover the pre-construction, during-construction and operation phases.
4. Integration of new techniques modeling and GIS for impact assessment into the EIA study to help decision maker to select suitable actions and mitigation measures before the project implementation.

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