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Study of Sediment Transportation at River Nile berths areas

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الملخص العربي:-

نتيجة للتدخلات البشرية في مجرى نهر النيل فقد تأتى بنتائج غير مرغوب فيها متمثلة في نحر أو إطماء قد يؤثر سلباً في كفاءة المجرى المائي ويؤدي إنشاء المراسي النيلية في مواقع عشوائية يتم اختيارها دون النظر إلي تأثيرها علي مورفولوجية نهر النيل إلي اضطراب كبير في التوازن الديناميكي للأنهار مما يؤدي إلي نتائج غير مرغوب فيها ولذلك تعتبر المواقع التي تتعرض للتعرية المستمرة أفضل المواقع لبناء الأرصفة.

Abstract:

Constructing berths at random sites picked without consideration of their impact on river morphology significantly disturbs the dynamic equilibrium of river systems, which has several undesirable consequences. This research attempts to address the issue of impact of berths on dynamic equilibrium of river systems by providing a means through which berths could be located without affecting river morphology significantly. The study focuses on identification of potential sites suitable for constructing berths along a 97 Km long river stretch within the fourth reach of the Nile River in Egypt. The berthing locations are chosen using surveyed river cross sectional data and HEC-RAS software and include consideration of the geomorphological process that occurred at the sites (whether the sites are experiencing degradation or aggradation). The water surface profile and the sediment transport of the study river stretch were simulated in HEC-RAS. The water surface profile model was used to identify manning's roughness coefficient that represents the roughness of the river stretch under study through model calibration and validation. The selected manning's roughness coefficient was used in the sediment transport model which was run with different sediment transport capacity equations. The output of each sediment transport capacity equation was compared to the measured river geometry to select the equation that works best for the study area. Using the chosen sediment transport equation, the future river channel geometry was predicted. Comparison of predicted geometry with measured river cross sections in the past was carried out to identify the geomorphological process that occurred at all cross sections. Sites with continuing erosion are preferable locations for

the construction of berths. Cross sections in the study area that are found to experience erosion during the study period were chosen as suitable location for berth construction.

KEY WORDS: Berths, River Morphology, Aggradation, Degradation, Sediment Transport Capacity Equation

1. Introduction

1.1 Background

Rivers are conduits through which water and sediment are carried to the oceans of the world. Factors that affect the shape of the cross section of any river channel includes flow, quantity and characteristics of sediments moving through the section and the character or composition of the material from which the bed and banks of the channel are made of. The stable form that a river channel assumes is one in which an equilibrium exists between the shear stress applied by the flow and the resisting stress of the bed and bank materials. (Luna B., 1994)

Characteristics of river channel such as bed and bank materials, flow and sediment carried by the river water vary with distance in the longitudinal the direction. A river can be divided into reaches, which are river segments with uniform characteristics such as channel materials, flow characteristics, water surface slope, size and shape. (Dingman, 2009)

Rivers serve numerous uses for humankind including water supply for domestic, industrial and agricultural uses, hydropower, waste disposal, recreation and navigation. (J. David & Maria M., 2007). The main Nile River in Egypt is no different. It has been providing all the benefits mentioned above to the people of Egypt since ancient times.

Nile River is one of the rivers in the world that have been used for navigation since ancient times. ‘In Egypt, the Nile is navigable by sailing vessels and shallow-draft river steamers as far south as Aswan.’ (Karyabwite, 2000). Structures such as barrages, navigation locks and berths are built across the Nile River to make navigation possible. The first structure built across the Nile North of Cairo is delta barrage. It was completed in 1861. The purpose of the barrage is to raise water for irrigation and navigation. Assuit, Esna and Nag-Hamady Barrages were constructed in 1902, 1908 and 1930 respectively. Although the main use of the barrages is for irrigation, they also serve the purpose of making Nile River navigable. (Conniff, Molden, Peden, & Awulachew)

Structures constructed to make rivers navigable disturbs its dynamic equilibrium and affect its morphology. Several studies have investigated the morphological changes of the main Nile River in Egypt. However, none of them relates the morphology of the river with berth sites. To fill this gap the current study is undertaken and investigates the impact of berths on the morphology of the Nile River.

1.2 Statement of the Problem

Berths are commonly constructed close to tourist sites along the Nile River without investigating the effect that the berths will have on morphology of the river. This has resulted in problems such as rapid silting up of berth sites that necessitates frequent dredging. Besides being costly, extensive dredging at berths sites could result in reduction of sediment carried to and deposited at the Nile Delta by the river. This is problematic because the Nile delta is very essential for the development of Egypt. The other consequence of excessive sedimentation at berthing sites is bank failure and flooding downstream of the berthing sites due to the deposition of sediments by the river at the berthing sites and the tendency to erode the downstream area. In order to avoid such problems berth sites should be selected following a river morphological study.

Additional berths are planned to be constructed along the Nile as part of a project that aims to making the Nile River navigable from Lake Victoria to Mediterranean Sea. Careful study is important when identifying berthing locations for the project in order to minimize their impact on the morphology of the Nile River and the undesirable consequences.

1.3 Research Objectives

This research is carried out with the following objectives.

I. Investigating the impact of berths on the morphology of the Nile River
II. Identifying suitable locations for current and proposed berths that would result in as minimum impact as possible on the morphology of the Nile River
III. Analyze whether the existing berths are located at sites suitable for constructing of berths

2. Literature Review

2.1 Impact of Navigation on Dynamic Equilibrium of Rivers

Worldwide, more than 500,000 Km of waterways have been altered for navigation (Tockner & Stanford, 2002). Several measures are taken along a river to make it navigable that includes construction of dams, locks, channelization (channel widening, straightening or deepening), contraction using spurs or jetties, bank stabilization, dredging and releasing additional water during low flows. These changes make the river unstable by disturbing its dynamic equilibrium. (Garde, 2006)

2.2 Navigation along the Nile River

The Nile River has played an important role throughout history as transportation links for both people and freight. Due to lack of reliable technical means for safe navigation, river transportation along the Nile is facing several problems. In order to improve navigational efficiency and to ensure safety of cruise vessels it is recommended to design a suitable navigational path with sufficient depth, execute a regular hydrographic survey along the whole river and maintain the hydrographic survey equipment. Additional measures such as producing navigational charts and updating them regularly, installation of navigational aids such as buoys and beacons that allow safe navigation 24 hours a day, vessel traffic management involving provision of planning data to the lock and berths manager and information on position of vessels were also recommended (Abdel-Aziz, 2004).

Inland navigation, which is a safe and environmentally friendly means of transport in natural streams, is one of the main tourist-attracting sectors in Egypt. Navigation channels must be properly dimensioned in order for the inland navigation to be safe. Several factors are taken into account during the design of waterway channels. Some of these are; channel dimensions at different seasons, bank and bed erosion, flood magnitudes, size of locks, berths, ship dimensions etc. (Hossam & Ahmed, 2005)

Water level of the Nile River is high during summer and low during winter season due to high discharge release during the summer to meet the high irrigation water requirements and low discharge release during winter season corresponding to low irrigation water requirements. The water depth in winter may be insufficient for navigation which is a treat to tourism. Berth sites are at risk of insufficient water depth especially during winter season and a further decrease in water depth due to deposition. Thus, they are navigational bottlenecks at which hydraulic and morphological studies are necessary. (Elsersawy & Kamal, 2017)

Tourism is a very important contributor to the economy of Egypt. Cruise tour on the Nile River and part of Lake Nasser is one of the most tourist attraction activities. A large number of tourists enjoy cruise tour at the heart of world civilization along the Nile River and visit of world heritage sites. Function and attractiveness of the Nile cruise tourism is highly affected by performance of existing berth facilities. ((JICA), 2000)

2.3 Berth Site Selection Criteria

Berthing sits are exposed to sedimentation and subsequent shoaling of water. Berths should be located in such a way that sedimentation is kept as minimum as possible. Locations that are considered as suitable for the construction of berths should not have submerged islands because the islands may restrict movement of vessels. Another factor that is taken into account when identifying berthing sites is maximum and minimum water level which is used to fix level of berths and to determine the level of dredging required. (Dr. Hossam & Dr. Magdy, 2004)

In addition to engineering and environmental criteria, selection of a site for new berthing facilities should take into account distance of berth location from antiquity sites, accessibility to monument sites in terms of adequate distance from the river bank, and nearness to historical sites, etc…. ((JICA), 2000)

3. Description of Study Area

The Nile River Basin with an area of 3.18 million Km^2 and annual discharge of 84 BCM is shared by 11 countries one of which is Egypt. The river is the longest in the world with a length of 6695 Km. (Mohamed, 2016)

Aswan High Dam at the south of Egypt controls the Nile River in Egypt. The Aswan High Dam and other four barrages constructed along the river divide it into four reaches. The first reach extends between Aswan High Dam and Esna Barrage. The second reach extends between Esna Barrage and Nagga Hammady Barrage. The third reach extends between Naga Hammady Barrage and Assuit Barrage. The fourth reach, which is the last reach, starts from downstream of Assuit Barrage and ends upstream of Delta Barrage. (Hekal, 2018)

Reach four is the longest of all the reaches (around 408 Km) representing 44% of the total river length. It is subjected to heavy services such as inland navigation, water extraction and many other activities because it extends through the busiest and most densely populated governorates of the country (Hekal, 2018).

The current study is undertaken on a river segment within reach four that begins at a distance of 97 Km upstream of Roda station and ends at Roda station Figure 1. This river segment was selected for the study because of the availability of recent surveyed cross sectional data. For the rest of the river section the available contour map is from year 2003-2008 but for this stretch, cross sectional data for year 2016 and 2017 is available.

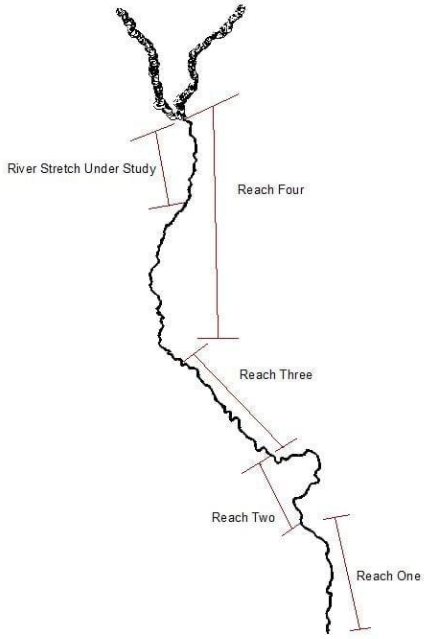

Figure 1: Location of Study Area

Within the river stretch under study there are fifteen berths located at a distance of 1.21, 1.43, 2, 4.4, 4.88, 5.54, 7.725, 8, 8.135, 8.645, 9.16, 10, 26.3, 26.6, 76.9 Km upstream of Roda Station (Figure 2). This represents 21% of the total berths in reach four that has 45% of the total berths along the Nile River.

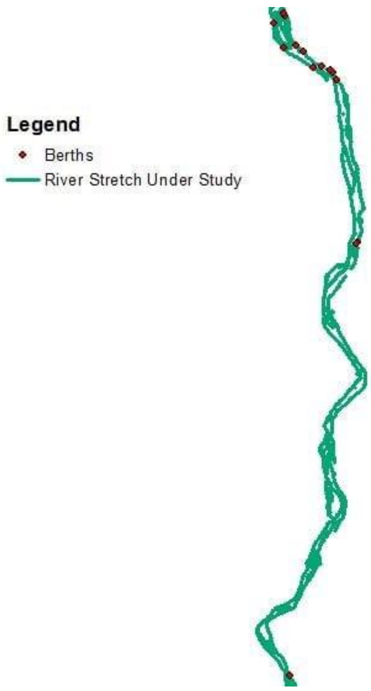

Figure 2: Concentration of berths in the river stretch under study

4. Data Acquisition and Processing

Geometric data, hydrologic data and sediment data that were used to carry out the study were collected from Nile River Institute (NRI).

4.1 Geometric Data

Geometric data of the study river stretch were prepared from contour maps of 1982, 2003 and 2016 that were collected from Nile Research Institute (NRI). Raster design toolset in AutoCAD was used to digitize the contour map of 1982. Digitization was not required for contour maps of year 2003 and 2016 as they were available in AutoCAD file. Cross sectional data (station and elevation) for 1982, 2003 and 2016 were extracted from the contour maps using Civil 3D software at a spacing of 500 meters. The cross sectional data of 2017 that was obtained from a survey was directly collected from NRI.

4.2 Hydrologic Data

Daily discharges measured at Assuit Barrage from 1982 to 2018 and the corresponding water level readings at Korimat station (located at 87.9 Km), Leethy station (located at 53.3 Km) and Roda station (0 Km) were collected from Nile Research Institute (NRI).

4.3 Sediment Data

Grain size distribution of sediment at five points within the study river stretch were obtained from reports collected from Nile Research Institute (NRI) for years 2004 to 2018.

5. Hydraulic Modelling

5.1 Water Surface Profile Modelling

The water surface profile of the study river stretch was simulated in HEC-RAS using geometric data and flow data as an input and water level as a downstream boundary condition. The water surface profile model was calibrated using manning's roughness coefficient as a calibration parameter and data of 1982 while validation was carried out using data of 2003 and 2016. Model calibration and validation were carried out by comparing simulated water level with water level readings at Koraimat and Leethy stations. The water level readings at Roda station, which is located at the downstream end of the study river stretch, were used as downstream boundary conditions. Model calibration and validation to select manning's roughness coefficient for the main channel were done using discharge with low magnitude (Q5%) and that for the floodplain was done using discharge with high magnitude (Q50% and Q90%) (Table 3).

Table 3: Discharges used for model calibration and validation

Year	Q5% (cumec)	Q50% (cumec)	Q90% (cumec)
1982	717.6	1064.8	1331.02
2003	594.71	989.13	1906.17
2016	658.8	1087.74	

5.2 Sediment Transport Modeling

The sediment transport of the study river segment was modeled in HEC-RAS using data of 2016. The model was run for one year using three different sediment transport capacity equations (Engelund-Hansen, Mayer-Peter Muller and Ackers-White) to obtain the river geometry for year 2017. The model output was compared with the river cross section surveyed in 2017. Among the three sediment transport capacity equations, the one that results in the best match with the measured cross section was taken as a suitable equation for the river stretch under study.

5.3 Prediction of Future Channel Geometry

The channel geometries expected in 2025 and 2040 were predicted by running the sediment transport model using the selected sediment transport capacity equation for 8 and 14 years respectively. The predicted channel geometries of 2025 and 2040 were compared to that of 2016 to identify the geomorphological process that has occurred at each cross section.

5.4 Selection of Berth Sites

Sites that are suitable for the construction of berths were selected based on the geometry predicted for 2025 and 2040. The geometry of the two years were compared to the geometry of 2016 at every cross section to classify cross sections as degrading sites or aggrading sites. Cross sections that exhibits continuing degradation or channel bed level drop due to erosion were chosen as good berthing sites.

6. Results and Discussions

6.1 Selected Manning's Roughness Coefficient

From the calibration done using HEC-RAS, it is found that a manning's roughness coefficient of 0.027 and 0.035 represent the roughness of the main channel and the floodplain of the study river stretch respectively. The water level obtained from the model matches the measured one when the manning's roughness coefficient of the floodplain is 0.035 while making the roughness of the main channel 0.027 (Figure 3).

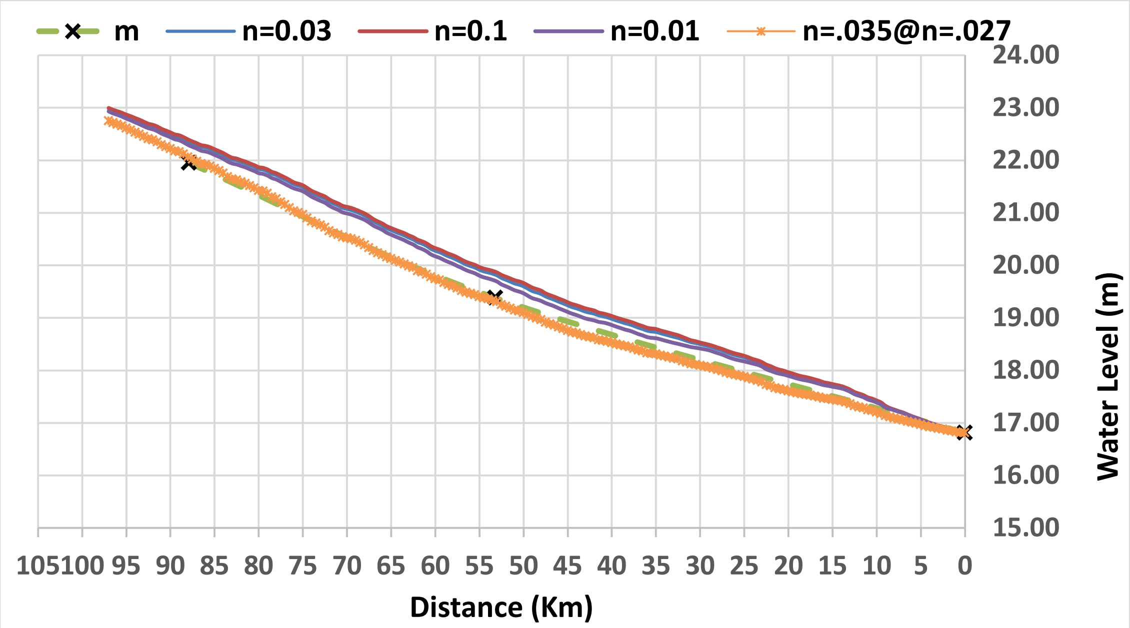

Figure 3: Measured Water Level and Model Output with Q90% of 1982

The water level profile obtained during model validation using Q50% from discharge readings of 2016 and the corresponding recorded water level is given in Figure 4. It can be seen that the manning's roughness coefficient selected during model calibration results in water level that is very close to the measured water level at both Leethy (53.3 Km) and Koraimat Stations (87.9 Km).

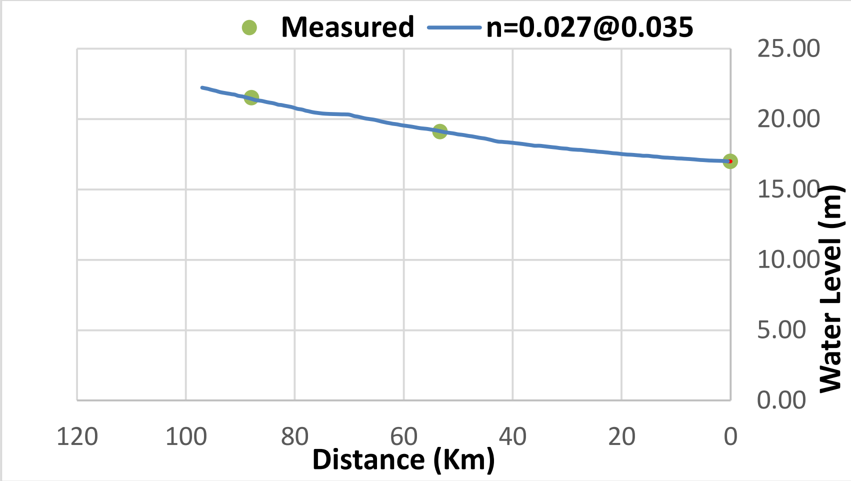

Figure 4: Measured Water Level and Model Output at Q50% of 2016

6.2 Selected Sediment Transport Capacity Equation

Comparison of river cross section obtained by running the model with the three different sediment transport capacity equations (Engelund-Hansen, Mayer-Peter Muller and Ackers White) to that of the river cross section available from survey of 2017 shows that the Mayer-Peter Muller equation results in the best match with the actual river cross section. This can be seen from the cross section of the river at station 90 is given in Figure 5 below.

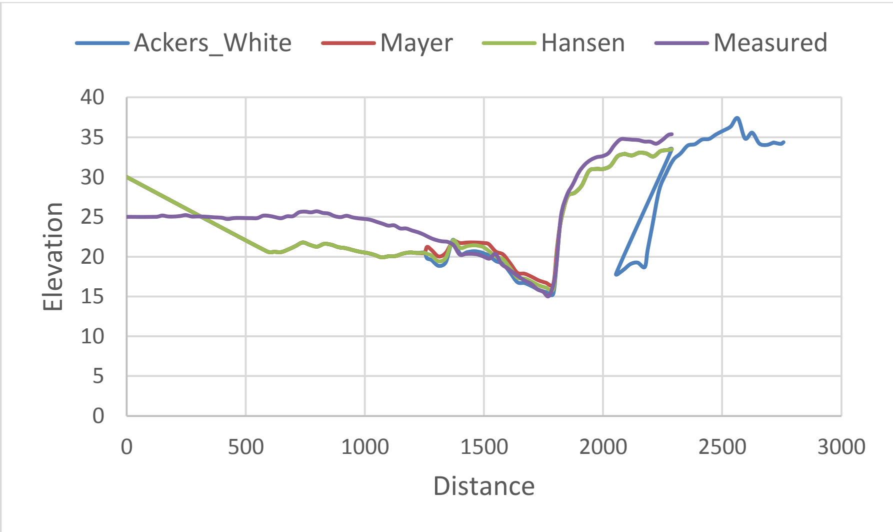

Figure 5: Section at Km 90 from Roda

6.3 Classification of Cross Sections in the Study Area

By observing the cross sections obtained from the model, they were classified into three main categories that are cross sections with one island, cross sections with two islands and cross sections no islands. Depending on the geomorphological process that occurred at each cross section, they were further categorized as given in Table 4.

Table 4: Classification of cross sections

Categories	Cross Sections(at km from Roda station)
1. Cross sections with one island	
1.1 Bed level drop in both 2025 and 2040	6, 13, 48,69,78,82,83,88,96, 65
1.2 Bed level drop in both 2025 and 2040 in the channels but level rise at the island	51, 94, 95
1.3 Bed level rise in both 2025 and 2040	21, 25,52,91
1.4 Bed level rise in 2025 but no change in 2040	92
1.5 No bed level change in 2025 but bed level drop in 2040	12,50, 54,93
1.6 No change in 2025 and bed level rise in 2040	4
1.7 Bed level rise in both 2025 and 2040 but level drop at the island	62
1.8 Bed level drop in 2025 but bed level rise in 2040	27
1.9 No bed level Change in both 2025 and 2040 but level rise at the island	44
1.10 Bed level drop in 2025 but no change in 2040	45
1.11 No change in bed level in both 2025 and 2040	84
1.12 Bed level rise in 2025 but drop in 2040 and level rise at the island	90
2. Cross sections with two islands	
2.1 Bed level rise in 2025 and no change in 2040 in the channels but level drop in 2025 and no change in 2040 at the islands	43
2.2 Bed level rise in both 2025 and 2040	3,5,11,79
2.3 Bed level drop in both 2025 and 2040	1,9
2.4 Bed level rise in 2025 and 2040 but level drop at the islands	63
2.5 No Change in bed level in both 2025 and 2040	2
3. **Cross sections with no island**	
3.1 Bed level drop in both 2025 and 2040	7,8,16,19,20,33,34,46, 47,53,55,58,66,67,68, 70,80,81,85,87,89
3.2 Bed level rise in both 2025 and 2040	28,35,37, 41, 42,49,56,74,75,86
3.3 Bed level drop in 2025 but bed level rise in 2040	39
3.4 Bed level rise in 2025 but bed level drop in 2040	24
3.5 No bed level change in 2025 but bed level rise in 2040	15,59,73
3.6 No bed level change in 2025 but bed level drop in 2040	17,29,31,32,36,64,76
3.7 Bed level drop in 2025 but no change in 2040	10,14,26,38,40, 57,60
3.8 Bed level rise in 2025 but no change in 2040	18,30,61,77
3.9 No change in bed level in both 2025 and 2040	22,23,71,72

6.4 Sites Suitable for Construction of Berths

Sedimentation is inevitable at locations where berths are constructed. Constructing berths at sites that are already experiencing sedimentation is not advisable because the amount of sedimentation will increase even more. Sites at which there is erosion or bed degradation are better suited for constructing berths.

The 96 cross sections in the study river stretch (excluding cross section at station 0 and 97) were divided into three main categories, which are cross sections with one island, cross sections with two islands and cross sections with no island. Out of the total 96 cross sections, 58 cross sections are found to have no islands, 29 cross sections have one island and 9 cross sections have two islands. Out of the 58 cross sections with no islands, 22 of them are in the category of cross sections that are subjected to bed level drop due to erosion.

Islands are depositional features created as the river losses its transporting power and deposits the sediments that it carries. Thus cross sections with islands are not the best choice for the construction of berths since they indicate the occurrence of deposition at the site. The primary locations selected as the best sites are among cross sections with no islands, which were further scrutinized to rank them in terms of their suitability for the construction of berths

Cross sections with no islands that experience bed level drop or degradation are selected as the best sites for construction of berths. The class of cross sections that experience bed level drop includes those in which the river bed level in both 2025 and 2040 are less than that of 2016 irrespective of the relationship between the bed level in 2025 and 2040. Thus, they include cross sections whose bed level in 2040 is same as that of 2025, cross sections whose bed level in 2040 is higher than that of 2025 and cross sections whose bed level in 2040 is less than the bed level in 2025. Cross sections whose bed level in 2040 is the same as 2025 have experienced equal amount of erosion and deposition between 2025 and 2040. Cross sections whose bed level in 2040 is higher than that of 2025 have gone through deposition between 2025 and 2040 and cross sections whose bed level in 2040 is less than that of 2025 have experienced erosion. Based on the relationship between the river bed level in 2025 and 2040, the cross sections were termed as extremely suitable, highly suitable and moderately suitable for construction of berths.

Those cross sections whose bed level in 2040 is less than that of 2025 are best suited for construction of berths than the rest of the cross sections because in such cross sections erosion has outbalanced deposition during the study period. Out of the 22 cross sections with level drop, twelve cross sections have a lower bed level in 2040 than 2025 thus are found to show a decrease in bed level from 2016 to 2025 to 2040. These cross sections are chosen as extremely suitable for construction of berths. Cross sections with such characteristics are found at stations 7,8,19,55,65,66,67,68,70,80, 81,85. Table 5

Out of the 22 cross sections with level drop, four of them located at station 16, 20, 47 and 53 have the same river bed level in 2040 and 2025. Six cross sections at station 33,34,46,58,87 and 89 have a higher bed level in 2040 than that of 2025. The four cross sections whose river bed level in 2040 and 2025 are equal are given the second place and termed highly suitable for the construction of berths. The six cross sections with higher bed level in 2040 than 2025 are selected in third place and termed as moderately suitable sites for the construction of berths.

The terms extremely suitable, highly suitable and moderately suitable are used to indicate the degree of suitability of the sites for construction of berths relative to each other.

Out of the twenty-nine cross sections having one island, nine cross sections located at stations 6, 13, 48,69,78,82,83,88,96 are subjected to bed level drop. At these cross sections, the river bed in 2025 and 2040 are at lower level compared to that of 2016 but the bed level of 2040 could be less than, equal to or greater than that of 2025. Out of the nine cross sections, five of them located at stations 6, 13,69,78,82 have river bed level in 2040 lower than that of 2025 and are termed extremely suitable for the construction of berths. Two of the cross sections at stations 48 and 96 have equal bed level in 2040 and 2025 and are termed highly suitable for the construction of berths. At two of the cross sections at stations, 83 and 88 the bed level of the river in 2040 is higher than that of 2025 and are termed slightly suitable for the construction of berths.

Out of the nine cross sections having two islands two of them located at stations 1 and 9 are subjected to bed level drop. At the cross section located at station 1 the bed level in 2040 is less than that of 2025 and is termed as extremely suitable for the construction of berths. At the cross section located at station 9 the bed level in 2040 is higher than that of 2025 and is termed as moderately suitable for construction of berths.

A summary of cross sections in the study area that are selected as suitable sites for the construction of berths and the degree of their relative suitability is summarized in Table 5.

Table 5: Suitable Sites for locating berths

Characteristics of Cross Sections	**Relationship between riverbed level in 2040 and 2025**	**Cross Sections**	**Terms indicating the relative suitability of the site for berthing**
No islands, bed level drop	Bed level in 2040 less than 2025	7,8,19,55,65,66,67,68,70,80, 81,85	Extremely suitable
	Bed level in 2040 same as 2025	16, 20, 47, 53	Highly suitable
	Bed level in 2040 higher than 2025	33,34,46,58,87,89	Moderately suitable
One island, bed level drop	Bed level in 2040 less than 2025	6,13,69,78,82	Extremely suitable
	Bed level in 2040 same as 2025	48,96	Highly suitable
	Bed level in 2040 higher than 2025	83, 88	Moderately suitable
Two islands, bed level drop	Bed level in 2040 less than 2025	1	Extremely suitable
	Bed level in 2040 same as 2025		
	Bed level in 2040 higher than 2025	9	Moderately suitable

Berths should not be located at sites where there are islands as much as possible. But if it is needed to select sites for the construction of berths in a river segment that contains islands, the choice can be made as discussed above and as given in Table 5.

As mentioned in the description of the study area, within the river segment under study there are fifteen berths located at a distance of 1.21, 1.43, 2, 4.4, 4.88, 5.54, 7.725, 8, 8.135, 8.645, 9.16, 10, 26.3, 26.6, 76.9 Km upstream of Roda Station. Among these berths, only the one located at 8 km from Roda station positioned a location selected as extremely suitable for the construction of berths by the study. Most of the existing berths are located as sights that not even selected as moderately suitable by the current study.

7. Summary, Conclusions and Recommendations

7.1 Summary

In this study the morphological changes of a 97 Km long river segment in the fourth reach of the Nile was investigated through sediment transport modelling in HEC-RAS. Based on the morphological changes that happened at each cross section during the study period (2016-2040) appropriate berthing sites were chosen. The best sites are those with no islands. Among sites with no islands those that are found to go through erosion throughout the study period (sites that exhibit bed level drop from 2016 to 2025 to 2040) are the best choice and were named extremely suitable for the construction of berths. Sites whose bed level in 2040 is same as 2025 are termed as highly suitable and those whose bed level in 2040 is higher than that of 2025 are termed a moderately suitable. Similarly, sites suitable for berthing were selected amongst cross sections with one island and with two islands depending on whether the main channel is subjected to aggradation or degradation. Sites with islands are not the first choice for locating berths but in river segments where island-free sites are not available suitable berthing location could be chosen following the methodology used in this study. Finally, the study assessed whether the berths that currently exist within the study river stretch are located at sites suitable for berthing.

7.2 Conclusions

Based on the findings of the research the following conclusions were made.

- The geomorphological process that occurs in the river at a given cross section could remain the same or change from one time period to another. (At most of the cross sections in the study area, the geomorphological process that occurs at a given cross section remains the same when considering different time periods. At some of the cross sections, the geomorphological process changes during different time periods). In other words in most of the cross sections only erosion or deposition occurs throughout the study period and at other cross sections erosion and deposition occurs alternatively.
- At the cross sections in the study area, which were spaced every one kilometer, the geomorphological process shows random variation.
- Among the fifteen already existing berths in the study river stretch, only one berth located at 8 Km from Roda station is found at one of the sites chosen as extremely

suitable for the construction of berths. This indicates that sediment transport modeling studies have not been done when selecting berth sites. This stresses the need for morphological studies preceding to construction of future berths along the Nile River.

- Analysis of river cross sectional data obtained from surveys should be integrated with sediment transport modelling to identify appropriate sites for positioning berths.
- The results from this research are significant due to the importance of assessment of geomorphological processes before construction of berths, which has been neglected so far when locating berths along the Nile River.

7.3 Recommendations

This research can be used as a stepping-stone for further studies on the morphology of the Nile at berth sites. The following recommendations are made for future studies.

- This study was done using a 1-D sediment transport model. Future studies should use a 2-D or 3-D model to simulate the river stretch in order to get results that are more realistic.
- The methodology used in this research can be applied to select appropriate sites for berths along the total stretch of the Nile.
- In this study, the berths that are already constructed were not included in the model. It is thus suggested to include the existing berths in the model of the river stretch in future studies to better investigate the impact of berths on the morphology of the river.
- Morphological studies should not only be done before constructing berths but also after the construction of berths to better analyze the change in river morphology due to the construction of berths.
- Morphological studies should not only be carried out for locating berths but also other structures such as intakes, bridges and pipelines.

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