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Analytical Study of River Bed Morphological Change at the El-Menia Bridge

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Abstract : In today's world, river transportation is one of the most significant tasks. Due to physical changes, navigation bottlenecks arise along the river. Furthermore, any building erected on the river, such as bridges, might alter the river regime, potentially causing local navigation bottlenecks. The goal of this study was to look into the morphological changes caused by the El-Menia Bridge. The current paper examines the Nile River's grain size distribution pattern. The goal of this research is to look at the suspended load and bed load of the study region before figuring out the best way to solve this navigational issue. The purpose of this investigation, however, was to highlight the existing sediment quantity. According to the study, the velocity and total suspended load on the west side are higher than on the east side. Dredging is the best solution for the El-Menia Bridge's navigation problems since it raises the bed level on the east side of the river channel, where the bridge's major navigation vent is located. Bottlenecks in the navigation system have appeared, and a traditional approach has been implemented to fix the problem.

KEYWORDS: Sediment transport, Suspended sediment concentration, Grain size, River navigation, Aswan Dam (AD.)

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1. INTRODUCTION

Natural rivers and alluvial canals are sensitive to human interference, which might change the sediment transport and flow rates. Human interference might take several forms (i.e. bank protection, dredging for navigation, bridge crossings, and barrages). Sediment transport degrades soil productivity as well as water quality, causing worldwide problems with river sedimentation and river morphology. Navigation bottlenecks appear due to the deposition process in the navigational path, and the movement of navigation is negatively affected. Dredging is carried out as a solution, but most bottlenecks are repeated again. A study area was chosen where data was available and impacts were found.

Several studies have been conducted to detect navigational bottlenecks, investigate the influence of dredging on river performance, and investigate the effects of morphological changes and human interventions on the navigation path. Gaber, M et al. (2021) used the Delft 3D model to simulate the third reach from kilometre 462 to 498 of the U.S. Roda gauge and show each zone of a bottleneck. They also determined the human interventions in the study and studied their impacts on the navigational path. It was concluded that nine zones of navigational bottlenecks appeared in 1982 in the minimum discharge case, but eight zones appeared in 2010 in this study's reach. Four zones appeared after using the dredging process and prediction by the Delft 3D model, and three of them were determined in the last report 2017-2018[4]. Darwish, K et al. (2016)

described geomorphologic changes along the Nile Delta coastline between 1945 and 2015. The study found that the coastline's geomorphology greatly changed during this time period, especially at the Damietta and Rosetta promontories, which were highly eroded after the construction of the Aswan High Dam. The trend has been the erosion of the beaches along the Nile promontories and accretion within the embayments between the promontories, resulting in an overall smoothing of the coastline [3]. Moussa, A. et al. (2017) used a 1-D model (GSTAR) to estimate the morphological changes before and after encroachment in various flood scenarios. It was concluded that the impact of encroachment on the fourth reach was found in Beni-Suef Governorate that was the most affected by the encroachment, which was located from km 102 to 164. At minimum discharge, they found that most locations were affected by the encroachment, which appeared from km 60.5 to334.5. The locations from km 334.506 to km 268.513 were deposition, and other locations were scoured from km 168.513 to 266.305. At maximum discharge, the area from km 286.512 to km 129.503 would be flooded, and the area from km 133.517 to km 73.503 would be sedimented [1]. Fahmy, W et al. (2010) identified the variations in bed and water surface levels through the first reach, which was located from downstream of "OAD" to upstream of the new Isna barrages. Comparison of the deduced water surface levels for various periods and locations along the reach - at passing 200million m^3/day – revealed that El-Gaafra and Kom - Ombo gauge stations were the only sites subjected to degradation since "HAD" construction. This degradation turned over and recovered sedimentation from the years 2002 and 1991 at El-Gaafra and Kom–Ombo respectively, and reached a maximum value of 0.011 and 0.315 m at El-Gaafra and Kom–Ombo in the year 2010. Also, the downstream part of the study reach has not been subjected to any degradation since "HAD" construction until the year 2010[2]. Sallam, G., (2005) studied ships' berthing problems upstream of Qena Bridge along the east side of the River Nile and in front of Hathor Hotel. According to the study, the ships encountered difficulties, particularly during the minimum water level period, when berthing on the east side of the Nile, upstream of the Qena Bridge and in front of the Hathor hotel, with a total length of about 1150 m along the east side of the Nile [9]. Sallam, G., et al. (2010) investigated siltation problems in a 60-kilometre reach of the Ibrahymia Canal in Upper Egypt. They used the two-dimensional model to reduce siltation at the upstream end of Dirot Barrages and to improve the flow efficiency at its downstream end [10].

It was decided to research the morphological changes in the study region further based on the above-mentioned characteristics that were gathered from the literature. The need to analyze Nile navigation numerically was realized.

2. THE STUDY AREA

The El-Menia Bridge is 684.95 kilometres from AD. It was built in the year 1987. Except for the navigation vent, which is 62.00 m wide, it has 15 vents that are each 40.00 m wide [7]. The navigation vent is situated between two vents, each of which is 50 metres wide. Near the Nile River's east bank, the navigation vent was located. The information shown here solely pertained to the survey of five cross-sections. Upstream of the bridge, cross-section 1 was surveyed at kilometre 684.33 from AD, cross-section 2 at km 684.88 from AD, and cross-section 3 at km 684.93 from AD. While downstream the bridge, cross-section 4 is located at kilometre 684.98 from AD and cross-section 5 is located at kilometre 685.415 from AD. Figure 1 shows the bridge's location as well as the measured cross-sections.

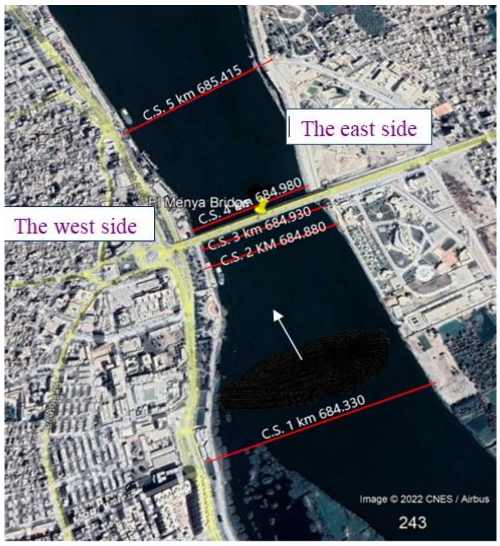

FIG 1. The location of the bridge and the surveyed cross-sections

3. MATERIALS AND METHODS

3.1. Data Collection

Data on morphological changes are collected and analyzed to determine the relationship and its impact on the creation of navigation bottlenecks. Three cross-sections upstream the bridge and two cross-sections downstream the bridge were surveyed at the research area by NRI in 1982 and 2002[5][6]. Streamflow velocities were measured at fife vertical portions from west to east at each one. The velocity was measured at five depths in each vertical portion. They are 0.50 m below the surface of the water, 0.75 m above the riverbed, and at 25%, 50%, and 75% of the total depth. Figures 2 to 6 show the variance of velocities for the selected cross-sections.

NRI measured suspended sediment-load transfer at the same five cross-sections: 1, 2, 3, 4, and 5. From west to east, the cross-section profile was divided into five measurement locations. The suspended load was measured at five depths in each vertical section. In addition to the surface water and the riverbed, they are 0.50 m below the surface of the water, 0.75 m above the riverbed, and at 25%, 50%, and 75% of the total depth. The average suspended sediment load can be calculated by analysing collected water samples at the NRI laboratory, as indicated in Table 1. A total of 125 samples were collected.

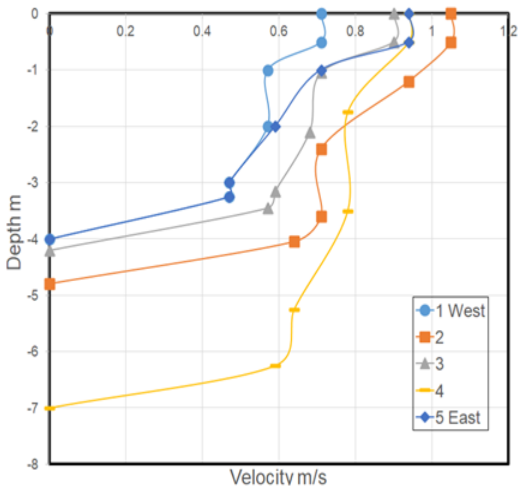

FIG 2. Velocities at cross-section 1

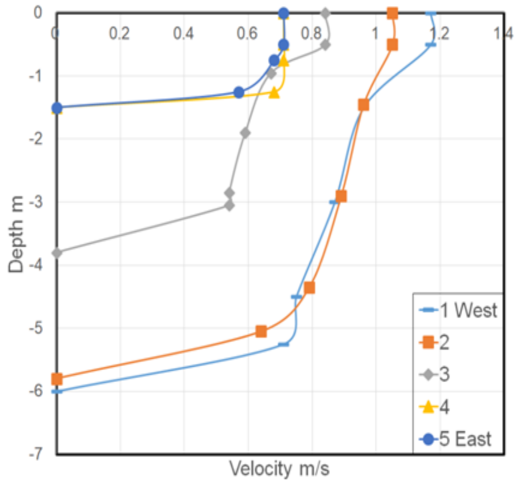

FIG 3. Velocities at cross-section 2

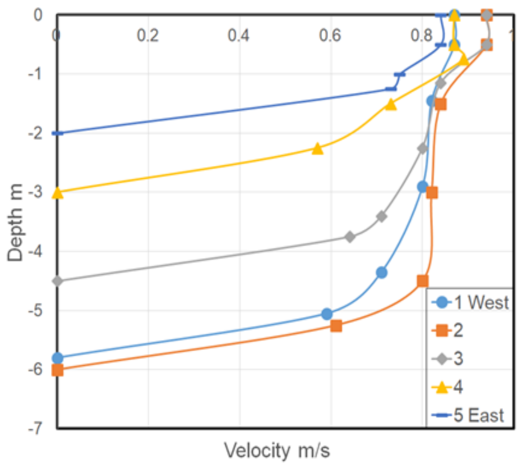

FIG 4. Velocities at cross-section 3

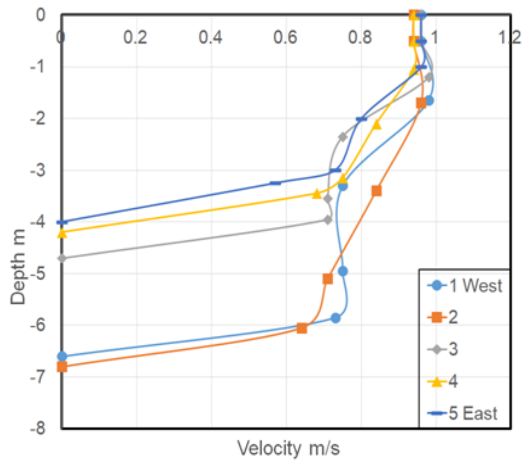

FIG 5. Velocities at cross-section 4

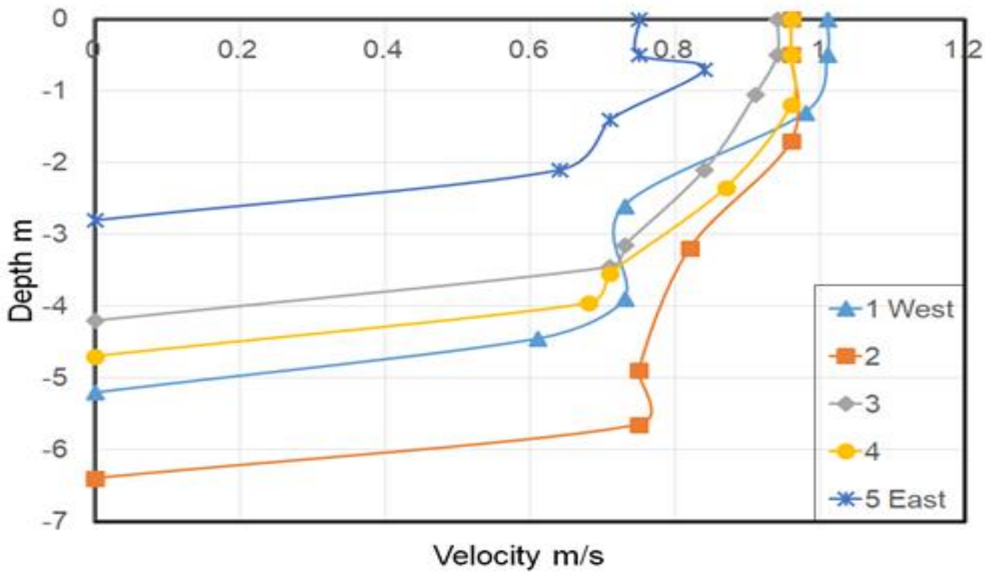

FIG 6. Velocities at cross-section 5

TABLE 1. Average suspended sediment-load concentration(c)

Location	Suspended Sediment Concentration P/M				
	Cross-section 1 at km 684.330	Cross-section 2 at km 684.880	Cross-section 3 at km 684.930	Cross-section 4 at km 684.980	Cross-section 5 at km 684.415
West	135	137	139	142	135
2	133	127	135	137	133
3	129	132	142	138	134
4	121	115	146	140	136
East	116	131	151	112	130

The purpose of studying the changes in the river bed is to investigate sediment movement in the river. The components of sediment load as well as prospective local sources of sediment were investigated. The two components of sediment, bed-load and suspended load, must be measured to determine the overall load of sediment. In rivers, bed sediment is the primary source of carried sediment. Scooping can be used to sample bed material.

The gadget, which was operated from a moored boat, was used to measure the bed-load conveyance. This mechanical sampler was created to take measurements as it came into contact with the bed. The research area's bed-load and suspended-load transportation rates were satisfactorily measured. The same areas where the velocities were observed were used to gather bed material samples. The cross-section was divided into five stations, and 25 samples from the study region were taken. The particle size characteristics of the bed-load sediment samples were studied and tabulated in table 2. The grain size distribution is shown in Figures 7 to 11 for each cross-section. It may be stated that the majority of the bed material in this study is fine, coarse, and medium sand.

The suspended load of a flow of a river is the portion of its sediment uplifted by the fluid's flow in the process of sediment transportation. It is kept suspended by the fluid's turbulence. The suspended load generally consists of smaller particles like clay, silt, and fine sand.

TABLE 2. Grain size distribution in the study area

C.S. no.	Location	D 50 mm	D-Mean mm	% Gravel	% Sand				% Silt	Classification
					Coarse	Medium	Fine	Total		
C.S. 1	West	0.28	0.29	-	4.09	83.59	12.31	99.99	-	Medium sand
	2	0.42	0.5	1.22	30.63	62.33	5.83	98.79	-	Medium to coarse sand
	3	0.24	0.27	-	7.60	55.57	36.83	100	-	Medium to fine sand
	4	0.42	0.5	4.54	23.35	63.27	8.84	95.46	-	Medium sand
	East	0.49	0.54	-	38.42	59.89	1.69	100	-	Medium to coarse sand
C.S. 2	West	0.73	0.89	9.27	61.44	28.09	1.21	90.74	-	Coarse to Medium sand
	2	0.96	1.09	18.37	41.02	39.55	1.06	81.63	-	Coarse to Medium sand
	3	1.10	N.A	33.60	33.32	30.32	2.69	66.33	0.07	Gravely coarse to medium sand
	4	0.42	0.50	1.95	28	65.97	4.08	98.05	-	Medium sand
	East	0.27	0.26	-	1.05	81.81	17.15	100	-	Medium sand
C.S. 3	West	0.4	0.43	-	17.07	80.96	1.97	100	-	Medium sand
	2	0.42	0.47	-	23.22	74.95	1.82	99.99	-	Medium sand
	3	0.29	0.31	0.23	5.65	81.85	12.28	99.78	-	Medium sand
	4	0.25	0.28	-	3.82	69.49	26.69	100	-	Medium sand
	East	0.4	0.44	-	17.54	79.81	2.64	99.99	-	Medium sand
C.S. 4	West	0.25	0.24	-	4.51	60.40	35.09	100	-	Medium to fine sand
	2	0.42	0.5	1.22	30.60	62.28	5.84	98.72	0.07	Medium to coarse sand
	3	0.24	0.27	-	7.60	55.59	36.81	100	-	Medium to fine sand
	4	0.42	0.47	-	22.90	73.62	3.47	99.99	-	Medium sand
	East	0.5	0.55	-	39.85	57.79	2.29	99.93	0.07	Medium to coarse sand
C.S. 5	West	0.46	0.56	4.67	32.70	59.32	3.31	95.33	-	Medium to coarse sand
	2	0.46	0.56	3.24	34.36	59.84	2.56	96.76	-	Medium to coarse sand
	3	0.37	0.43	1.53	17.30	77.40	3.78	98.48	-	Medium sand
	4	0.36	0.39	0.92	14.06	81.61	3.41	99.08	-	Medium sand
	East	0.37	0.41	0.43	15.53	80.95	3.08	99.56	-	Medium sand

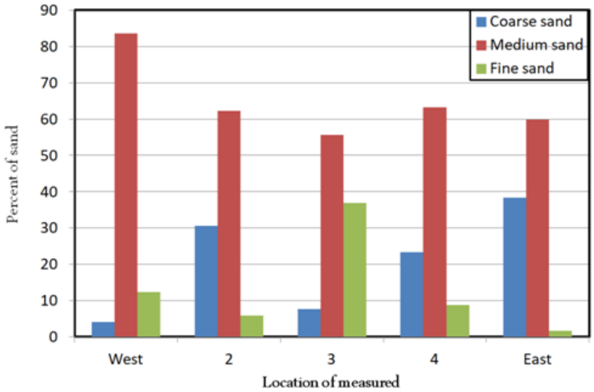

FIG 7. Grain size distribution at c.s 1

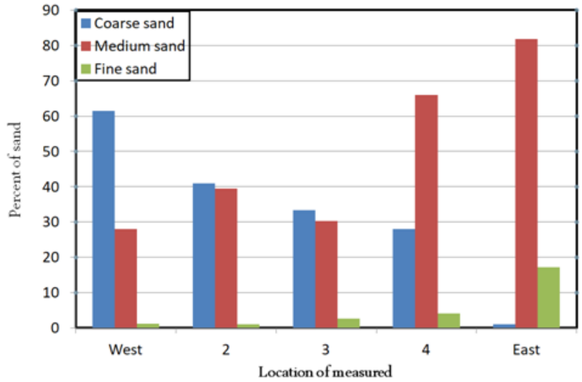

FIG 8. Grain size distribution at c.s 2

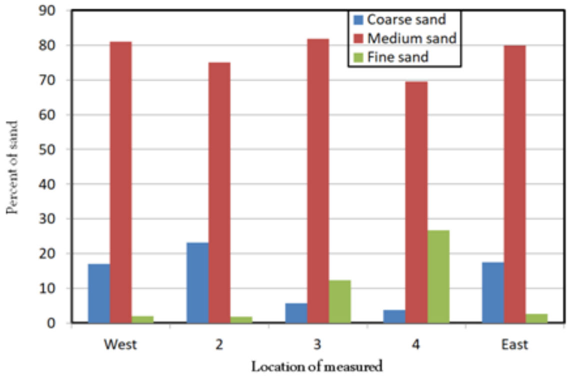

FIG 9. Grain size distribution at c.s 3

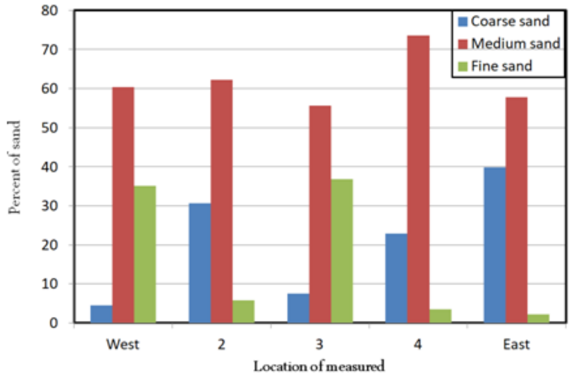

FIG 10. Grain size distribution at c.s 4

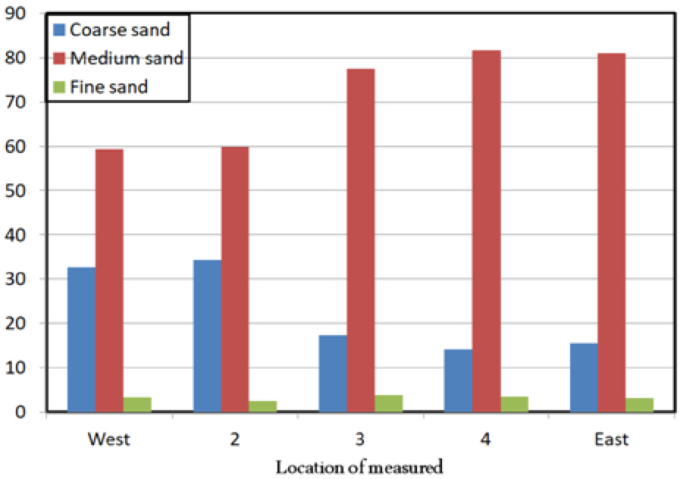

FIG 11. Grain size distribution at c.s 5

4. DISCUSSION OF RESULTS

4.1 Analyses of Suspended Load Transport and Bed-Sediment Load Data

Table 1 shows the suspended sediment concentration at different cross-sections in the area of study. The bed-load budget and the formation of the river bed are closely interrelated. The best way to gain an insight into these natural formative processes is to gather some impression of at least the bedload yield. In larger rivers, direct measuring of the natural bed-load transport is especially suitable for this purpose. From this, a so-called bed-load function can be developed in relation to discharge or water level. When measuring the bed-load transport, a number of limiting factors have to be taken into account, in contrast to suspended load measuring. This has led to different methods of determination. Amongst these factors are the grain sizes transported, the formation of bedforms, and the observation that bed-load transport mostly sets in only at higher discharges.

The bed-load transport rates, including variation ranges, measured in the Nile River are shown in Figures 7 to 11. As can be observed, the bed river material in the study area consisted of medium sand in the range of (28.9%: 83.59%), coarse sand in the range of (1.05%: 61.44%), fine sand in the range of (1.06%: 36.38%) and gravel in the range of (0%: 33.6%). Also, cross-sections 1, 3, 4, and 5 consisted of mostly medium sand, while cross-section 2 consisted of mostly coarse in the west and medium sand in the east. The bed-load transfer rates of sediment were in the range of D_{50} of 0.24:1.1 mm upstream of the bridge and the range of 0.24: 0.50 downstream of the bridge as can be seen in Table 2.

$$Q_{ss} = \sum q_{ss} * A_{effec.} \quad \text{Equation 1}$$

$$Q_{ss} = \sum V_{average} * C_{average} * A_{effec.} \quad \text{Equation 2}$$

$$Q_{w} = \sum V_{average} * A_{effec.} \quad \text{Equation 3}$$

Where, Q_{ss} = total suspended load m^3/s; q_{ss} = suspended load/m^2; $A_{effective}$ = the effective area at every vertical section in m^2; $V_{average}$ = Average velocities at each vertical section in m/s; $C_{average}$ = Average suspended sediment concentration at every vertical section. As a result, equations 1, 2 and 3 were used to compute Qss, Qw, and qss. Using the above formulae, Table (3) shows the quantity of suspended load (Qss and qss):

TABLE 3. The calculated Qss, average velocities, average area effective, and average suspended sediment concentration

Location	Cross-section 1 at km 684.330				Cross-section 2 at km 684.880				Cross-section 3 at km 684.930			
	$V_{average}$	C	$A_{effec.}$	Q_{ss}	$V_{average}$	C	A_{effec}	Q_{ss}	$V_{average}$	C	A_{effec}	Q_{ss}
West	0.65	135	335.3	29422.6	0.84	137	435.9	50163.4	0.72	139	434.7	43504.8
2	0.75	133	413.8	41276.6	0.82	127	430.7	44853.1	0.76	135	413.2	42394.3
3	0.64	129	292.1	24115.8	0.58	132	301.3	23067.5	0.73	142	325.6	33751.7
4	0.71	121	230.1	19767.9	0.64	115	146.5	10782.4	0.65	146	242.9	23051.2
East	0.60	116	222.3	15472.1	0.61	131	77.7	6209	0.64	151	197.2	19057.4
q_{ss}	425.57		-	-	449.29		-	-	497.88		-	-
Q_{ss}				130055				135075.4				161759.4
Q_w	1011.99			-	1035.241				1148.797			

TABLE 3. Continued

Location	Cross-section 1 at km 684.330				Cross-section 2 at km 684.880				Cross-section 3 at km 684.930			
	$V_{average}$	C	$A_{effec.}$	Q_{ss}	$V_{average}$	C	A_{effec}	Q_{ss}	$V_{average}$	C	A_{effec}	Q_{ss}
West	0.65	135	335.3	29422.6	0.84	137	435.9	50163.4	0.72	139	434.7	43504.8
2	0.75	133	413.8	41276.6	0.82	127	430.7	44853.1	0.76	135	413.2	42394.3
3	0.64	129	292.1	24115.8	0.58	132	301.3	23067.5	0.73	142	325.6	33751.7
4	0.71	121	230.1	19767.9	0.64	115	146.5	10782.4	0.65	146	242.9	23051.2
East	0.60	116	222.3	15472.1	0.61	131	77.7	6209	0.64	151	197.2	19057.4
q_{ss}	425.57		-	-	449.29		-	-	497.88		-	-
Q_{ss}				130055				135075.4				161759.4
Q_w	1011.99			-	1035.241				1148.797			

The analyses of suspended sediment samples showed that the average velocities, the areas effective and the average suspended sediment concentration in the west were higher than in the east in c.s 2, 3 and 4. So, the total suspended load transport rates were the biggest on the west side. These lead to having a lateral migration of bed material, where there was degradation. The deposit occurred on the east side where the navigation vent was located. Figures 12 and 13 show that suspended load increased from c.s 2 to c.s 4 and reduced at the other cross-sections

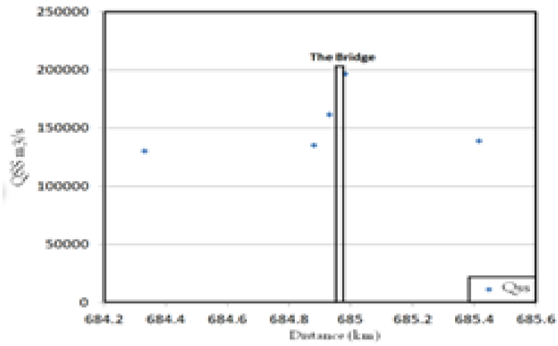

FIG 12. Total suspended sediment at each cross

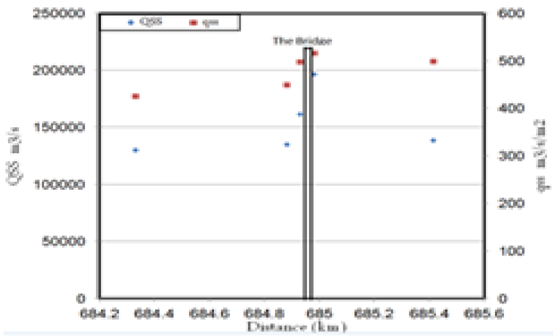

FIG 13.Total suspended sediment and suspended sediment concentration/m^2 at each cross-section

From the above, Three formulas were employed to account for suspended-load transport rates. Suspended-loads required the velocity to keep the sediment transported above the bed. With low velocity, the sediment will deposit. According to the figures, it was clear the suspended-load increased around El-Menia Bridge.

4.2 Deposition and Scour Values during the Period from 1982 to 2002

Sediment transport in rivers is a critical and vital parameter to monitor at a hydrometric station. Measurements of suspended and bed-load discharge in rivers with natural regimes as well as human management operations must be carried out. The lowering of the bed elevation owing to erosion is referred to as "general channel degradation". The bed material is fine in some circumstances, but degradation will result in channel incision. In some circumstances, the material is coarse enough to cause aggradations. Soil erosion and sediment transport processes have had a negative influence on the research area. From 1982 to 2002, the deposition and scour values for each cross-section were calculated and displayed in Table 4. Figures 14 and 15 show the average water level at each cross-section, which was used in the calculation. The depths of these cross-sections were compared to ascertain the variation that occurred (morphological changes).

TABLE 4. Erosion and sedimentation quantity for cross sections

Cross-section no.	The location from AD. (km)	Deposition (m^2)	Scour (m^2)	Net Value		Material Volume (m^3)	Net Impact
				deposition (m^2)	Scour(m^2)		
1	684.330	323	-176.2	146.8			S
2	684.880	233.5	-709.3		-475.8	-90475	E
3	684.930	93.1	-867.2		-774.1	-31247.5	E
4	684.980	98.8	-1137.4		-1038.6	-45317.5	E
5	685.415	113.7	-314.7		-201	-269613	E

E=erosion & S=sedimentation

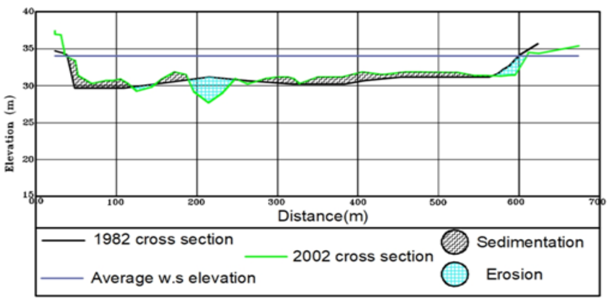

FIG 14. The deposition and scour at c.s.1

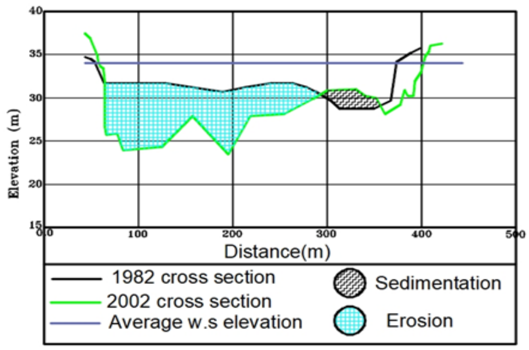

FIG 15. The deposition and scour at c.s.4

From the given statistics and tables, it can be deduced that erosion was more common than deposition on the bed. The erosion was concentrated on the west side of the river. Because of the presence of the El-Menia Bridge, the portion from km 684.880 to 685.415 from AD was scoured. The calculated volume of erosion materials in this area was about 436653 m^3. Sedimentation has occurred on the portion at km 684.330 from AD, which was 550 metres from the bridge. The east side, where the navigation vent is located, had clear shallow water depth, which could present navigational difficulties. Instead of being on the east side of the channel, the navigation path was switched to the west side. The Egyptian General Authority for River Transportation stipulates that a minimum water level of 2.3 metres and a navigation width of 100 metres are required for safe passage [8]. These objectives must be satisfied. To meet these objectives, 182398 m^3 of dredging must be carried out on the east side of the research area to limit silt deposition on the bed.

5. CONCLUSIONS

Based on the above findings, the most vulnerable areas to erosion and deposition were discovered to be the west and east of the river channel, respectively, including the bridge. It was significant that the west side's bed level has decreased while the east side has climbed. Variations in hydrological parameters such as water levels and discharges caused these modifications. In addition, any building placed on the river, such as bridges, might have an impact on the river's flow. This may cause local navigation bottlenecks.

The navigation path was changed from being on the east side of the channel to being on the west side. In this study, the total suspended load and bed-load (morphological modifications) of the study area were examined and compared. According to the studies, the west bank of the river had the highest overall suspended load conveyance rates. The water current velocity on the west side of the bridge was increasing faster than on the east side. Erosion was more common than deposition on the bed, and it was determined in the research area. The calculated volume of erosion materials in this area was about 436653 m^3. Sedimentation was more common than erosion upstream of the navigational vent site.

The best approach is to dredge the main channel on the east side of the study area to reduce silt deposition at the Nile River's bed, which requires a depth of 2.3 metres for safe sailing. In these portions, the estimated volume of dredged materials was around 182398 m^3. Dredging increases the velocity of water on the east side of the river channel (where the major navigation vent is located) and creates a uniform velocity distribution along the main channel, reducing sediment deposition.

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