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Enhancing navigation safety through the Nile River to avoid bottlenecks using a quasi-real-time approach and Google Maps

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Abstract: The significant importance of the Nile River emerges not only from the fact that it represents the main water source for Egypt but also from its being an important water path for sailing to transport goods or for Nile tourism cruises. Because of climate change and the construction of the Ethiopian Renaissance Dam, Egypt may have to reduce the discharges from the High Aswan Dam (HAD), which may cause a reduction in water depth below a safe level for navigation. Consequently, this study aims to present a quasi-real-time approach to detect the locations of bottlenecks that threat navigation path via mobile Google Maps. Accordingly, the topographic, hydraulic data, the alignment and geometry of the navigational channel, were collected from the Ministry of Water Resources and Irrigation of Egypt. AutoCAD Civil 3d is adopted in this study to determine navigational bottleneck locations of the Nile River's first reach. Two surface models were created: The Riverbed surface and the navigational path surface using a Triangular Irregular Network (TIN). As a result of the created TIN-Surface modelling via the current study; the amount of sediment, that should be dredged, was estimated (at about 2.1 million.m^3). In addition, the navigation path bottlenecks map for the studied reach was created based on minimum water levels at Aswan High Dam's winter closure and the navigational path's geometry. In conclusion, this study provides a simple solution for avoiding bottlenecks by presenting a user-friendly web Google Maps of these locations to represent the Nile River's current navigation condition in quasi-real-time and support the decision-maker on river navigation conditions.

1. Introduction

River navigation is considered one of the most essential means of transportation worldwide, whether for commercial or recreational purposes. It offers a cost-effective method for transporting heavy goods when compared to trains or trucks. In Egypt, inland waterway

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transport between Aswan and Luxor is one of the most important tourist activities, especially during the winter season when tourist numbers are at their peak. On the other side, minimum discharge release coincides with this season.

Where the minimum flow discharge is released downstream (D.S) of the Aswan High Dam (AHD) from November to January at a minimum of 60 (MCM/D; 694 m^3/s), whereas the maximum discharge is about 250(MCM/D; 2,893 m^3/s) from June to August [1]. The variation of the released discharges and the corresponding different water levels lead to sedimentation and erosion processes. That, in turn, affects river navigation and major downstream hydraulic structures due to Riverbed morphological changes and flow-sediment interactions [2]. In addition, the Nile River is the longest alluvial river in the world and is exposed to permanent sedimentation and erosion processes. Ahmed et al. [3] concluded that, after the construction of the AHD, the first Nile River reach experienced an increase in bed sedimentation rates from year 1962 to 2010. Which in turn affects badly the navigation path and causes navigational bottlenecks. ArcGIS and HEC-RAS were used to analyze morphological changes in the Nile River's first reach between 2011 and 2014. The Toffaleti transport sediment equation and fall velocity method were found to be most consistent with natural conditions, allowing for the prediction of riverbed elevation. It was found the highest sedimentation would occur in some areas on the first reach of the Nile River by the year 2020 and 2030[4] . Additionally, Abdel-Aziz [5] evaluated the navigation condition under all flow conditions D.S. of the AHD through the Nile River for 1 year. He found that the number of navigation bottlenecks increased at discharges ranging from 60 to 75 MCM/Day. Therefore, the minimum water levels correspond to the minimum water discharge from November to January and decreased required navigation water depth, coinciding with the peak tourism in the winter season.

Several studies were conducted to investigate the river navigation conditions, according to morphological changes and dynamic hydraulic conditions. Karmaker and Dutta [6] evaluated the morphological changes that might have happened in the Brahmaputra River, based on a 2D hydrodynamic and morphological model. According to the GSTARS 2.0 model by Sadek and Hekal [7] predicted the Riverbed morphological changes at the cross sections of the bottleneck areas on the fourth reach from Assiut to Cairo through the period (2006 – 2017). El-Manadely, et al [8] predicted the sedimentation deposition volume along Lake Nasser/Nubia and evaluated the navigation waterway, based on a hydrographic survey of the reservoir and a numerical model (Delft-3D). Moreover, Calibration and verification were performed between 2009-2012, and the model was useful for monitoring future waterway designs. The real-time and detailed knowledge regarding navigational flow conditions and waterway conditions represented one of the most important factors impacting navigation safety[9] . Helal, et al. [10] developed a hydro morph dynamical map of the Nile River navigation according to different discharge flow conditions and minimum water levels using the Delft3D and GIS approach. According to the water level data from hydrological stations along the Danube waterway, real-time flow conditions are obtained by the Application of GIS and Web technologies [11]. Elsersawy and Kamal [12] adopted an application linkage between Inland Electronic Navigational Charts (IENCS) and (GIS) to monitor and analyze the navigation path by computing the volume of deposition and erosion and predicting the locations of navigation bottlenecks.

The lack of real-time information regarding navigational flow conditions and waterway conditions prevents proactive measures to avoid bottlenecks and ensure safe navigation. In addition, current navigational tools and systems lack user-friendly interfaces to visualize current navigation conditions, limiting the accessibility of critical information for decision-makers in navigation safety. To address these challenges, this study develops an approach that combines real-time data collection, analysis, and visualization techniques to enhance navigation safety and avoid bottlenecks along the Nile River. Google Maps is a widely used mapping platform that offers a user-friendly interface and facilitates quasi-real-time data integration for efficient decision-making.

2. Materials and methods

This section introduces the different details for achieving the research starting from the data collection and preparation. Also, the data processing by AutoCAD Civil 3d is explained through the different sections.

2.1. Data collection

In the current study, the hydraulic and bathymetric (topographic maps and hydrographic survey data) data were collected from the Ministry of Water Resources and Irrigation of Egypt[13]. The collected data was prepared and processed by AutoCAD software.

a) Hydraulic Data

The hydraulic data was collected from the four-gauge stations located along the study reach, as shown in Table1.

Table 1: Gauge stations along the Nile River first reach

No	Gauge station	Location/ Km/D. S OAD	Minimum water level/(m)
1	Downstream (Old Aswan Dam) Station	6.300	81.00
2	El Biara Station	49.500	79.69
3	El Kelh Station	127.69	77.35
4	Upstream Esna Barrage Station	166.64	76.20

b) Topographic contours map

The current study used topographic survey contour maps for the first reach of the Nile River (from km 0 to km 167 downstream OAD) which was prepared by the Nile Research Institute (NRI) (2005). The collected topographic maps were prepared to coordinate a unified framework for the terrain data. The current study uses a geographic calculator desktop as a platform for coordinate system transformation for the topographic contour maps of the first reach from the local coordinate system Egyptian Transverse Mercator (ETM) to Universal Transverse Mercator (UTM) reference basis ZONE 36 WGS 84.

c) Hydrographic Navigation Path Survey Data

A cooperation between the Egyptian General River Transport Authority (EGRTA) and the Nile Research Institute (NRI) to design a navigational path along the Nile River. The proposed navigation path was designed for two-way traffic and is a maneuverable navigation path with a depth of 2.30 m under minimum river water levels. The hydrographic survey data was presented by Easting, Northing, and Elevation (E, N, and E) to describe the geometry of the navigation path per 1 km., as shown in Figure 1.

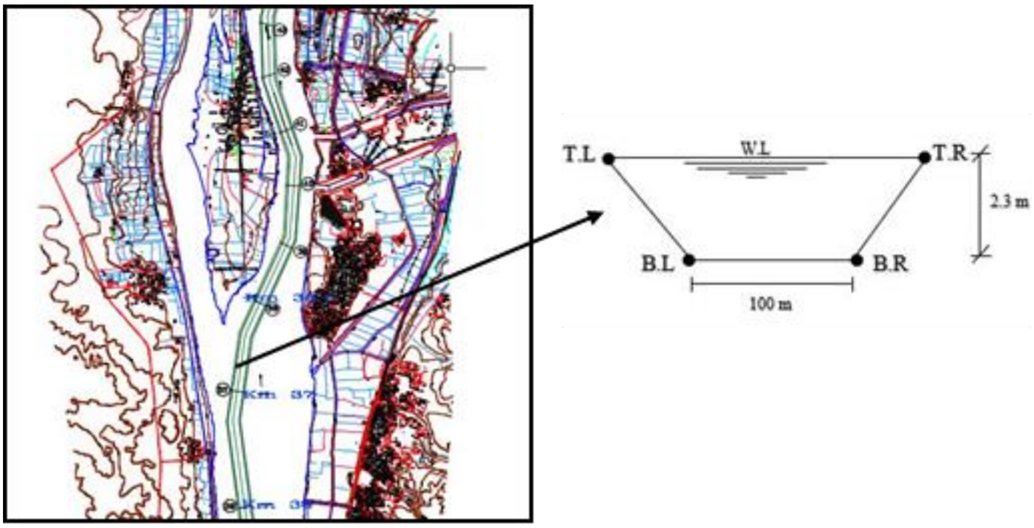

Fig.1: Typical sketch of navigation path cross-section.

2.2. Methodology

Shading light on the main research objectives, this study is performed to detect the navigational bottlenecks along the Nile River from the Old Aswan to Esna Barrage. The study takes minimum water levels in the Nile River during winter closure as a critical condition to obtain the lowest position of the navigational channel path. AutoCAD Civil 3d Software was adopted to find the bottlenecks between the Nile Riverbed surface and the navigational channel bed surface. Finally, we export the navigational path with bottlenecks locations to Google Maps to obtain a quasi-real time model. Fig. 2 shows the research methodology flow chart.

a) TIN-Surface creation

AutoCAD Civil 3D software was used to model the topographic survey data for the riverbed and the hydrographic survey data for the proposed navigation path. To construct surface models, the triangulated irregular network (TIN) method was employed. The TIN method is a widely used technique for representing irregularly spaced data points and generating continuous surface models. It effectively captures the complex geometry of waterway surfaces by connecting surveyed points with non-overlapping triangles [14] . Then, the volume of the sedimentation was obtained, based on the comparison between the previous two surfaces (Riverbed and Navigation path) using Tin- Volume Surface Technique.

b) Creating the River Profile

By analyzing the river's longitudinal section and creating a profile view, the difference in height between the existing river bed and the designed navigation path can be assessed, allowing to identify and address potential bottlenecks in the navigation channel[15] .

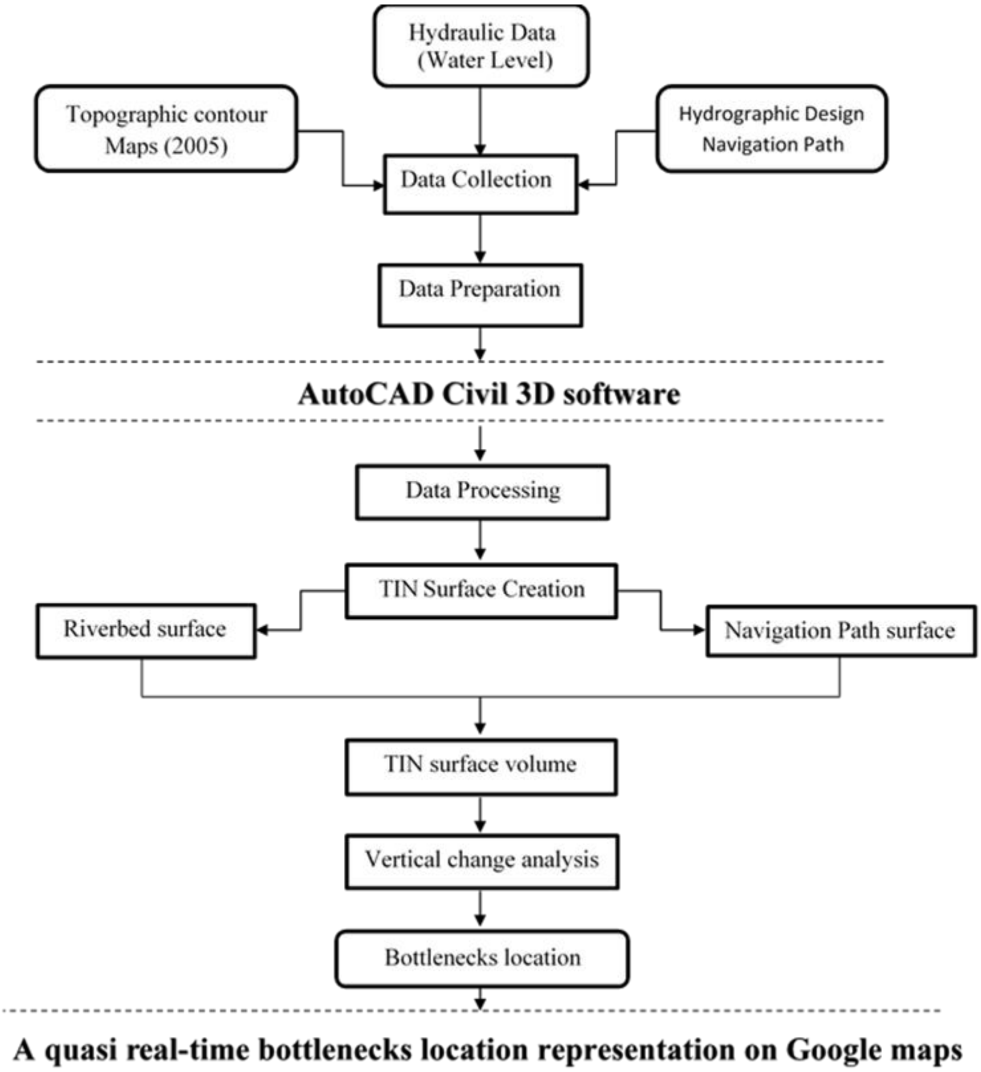

Fig. 2: The framework methodology of mapping the bottlenecks' locations on the navigation path along the study area

- *Vertical Alignment creation*

The vertical alignment represents the longitudinal section of the river path, and "the profile view" is the result. In the current study, the profile view defines the surface elevation of the riverbed morphology and the designed navigation path along the Nile River.

- *Assembly*

Assemblies represent the cross-sectional composition of the channel ways. The current study applies a trapezoidal shape of designed navigation to cross-sections with an allowable side slope. The trapezoidal shape provides a specific profile to the cross-sections of the navigation design.

- *Corridor modelling*

The corridor modelling for the navigation path was done based on vertical alignment and the cross-sectional assembly components of the designed navigation.

c) View current navigation status on Google Maps

According to the global coordinate system (UTM), the AutoCAD civil 3d drawing coordinate system was set on projection "WGS84/UTM zone 36 N, “. After that, the current river navigation condition was mapped and presented quasi-real time via Google Maps mobile.

3. Results and Discussion

3.1. Vertical Change Analysis

Vertical alignment represents the longitudinal section of the river and the “profile view” [16]. Based on vertical alignment and the cross-sectional assembly components of the designed navigation, the corridor modelling, the profile view of the surface elevation of the riverbed morphology and the designed navigation path along the Nile River were created. Fig. 3 and Fig. 4 illustrate samples of the longitudinal section model of riverbed morphological conditions downstream of Fares bridge region from Km 72.00 to Km 74.00 and Edfu bridge region from Km 113.00 to Km 115.00. The longitudinal section (view of the profile) shows the difference in height between the existing riverbed and the designed navigation path and identifies the areas of bottlenecks.

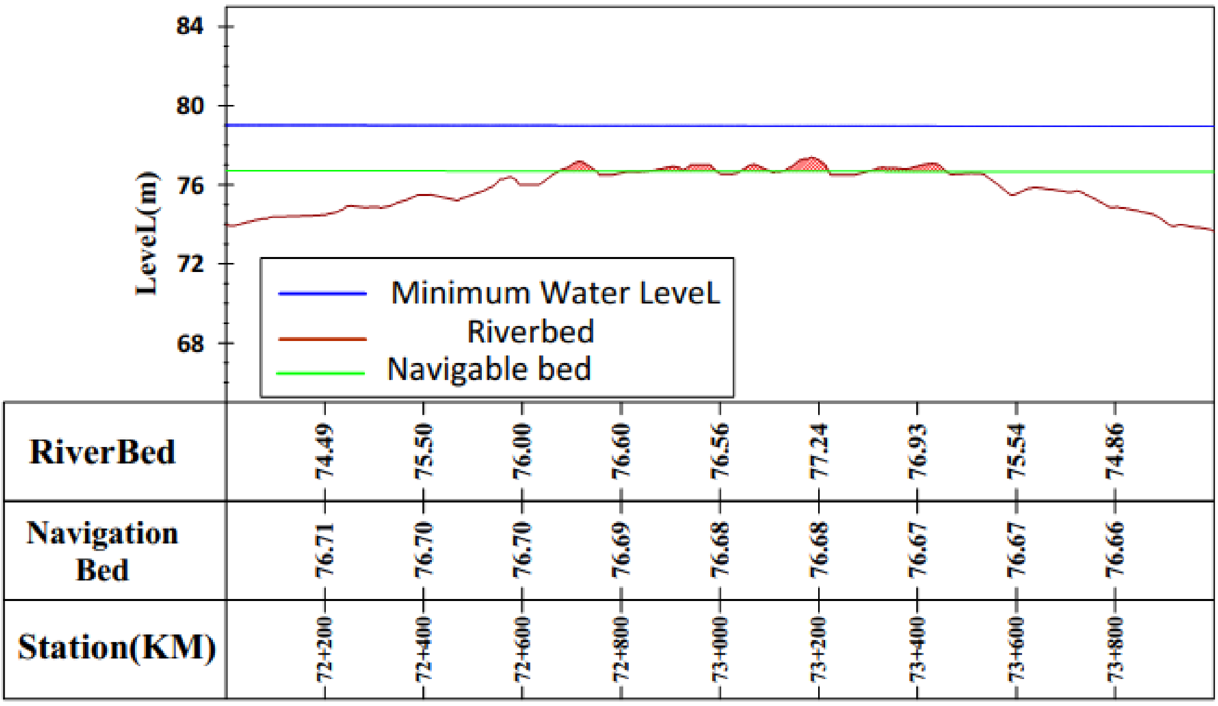

Fig. 3: The longitudinal section downstream of Fares Bridge.

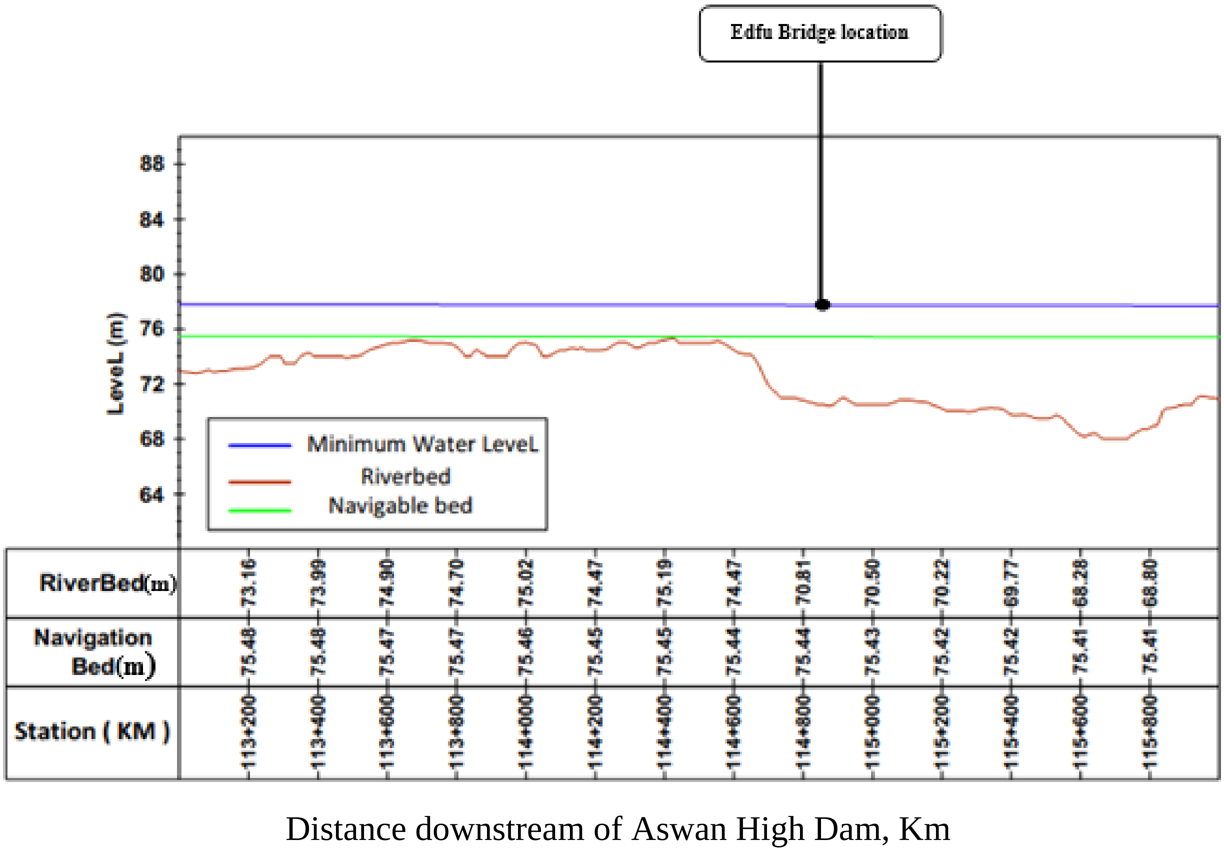

Fig. 4: The longitudinal section at the Edfu Bridge.

3.2. Volumes of Required Dredging and Locations of Bottlenecks

The volumetric calculations of dredging were computed over the study's reach according to the TIN-Surface volume modelling by using AutoCAD Civil 3D. Fig.5 represents the obtained locations of bottlenecks along the study reach.

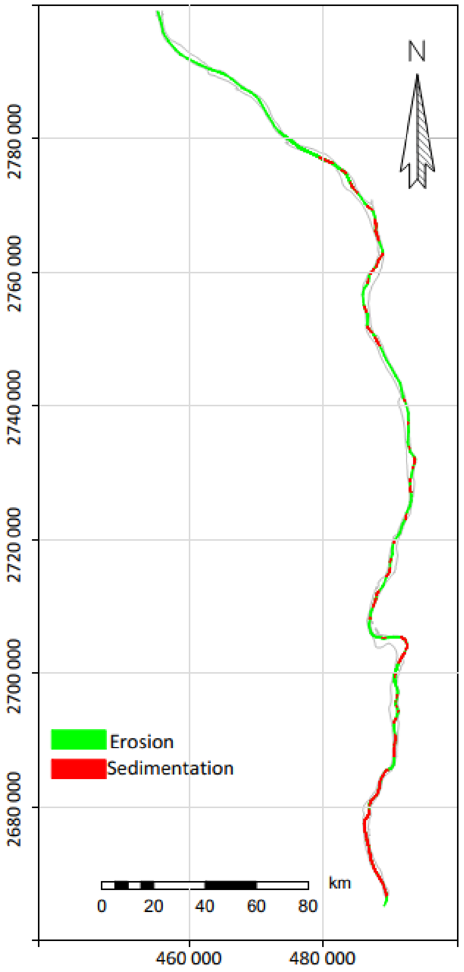

Fig. 5: The first reach navigation path condition

Table 2 shows the locations and volume of the navigation path bottlenecks which were obtained, according to the volumetric approach that was used by AutoCAD Civil 3D to compute the total volume of sedimentation over the study reach. It was found that about 34 locations from (OAD) to Esna Barrage need urgent dredging. The total volume of sedimentation to be dredged is about 2.1 million.m^3 of sediment.

Table 2: locations and volume of sedimentation along the first reach (from km 9.850 to km 122.450 downstream OAD)

Region	**Kilometer**		**Cut Volume/m^3**	**Average depth of sedimentation (m)**
	From	**To**		
Downstream AHD to Elbiara gauge station	9+850	9+950	309.8	0.031
	11+350	11+500	11.64	0.001
	11+650	17+050	406,555	0.75
	17+700	23+050	341974	0.64
	24+050	26+600	243027	0.95
	26+950	28+350	64259	0.46
	28+850	30+000	9436	0.08
Elbiara gauge station to el kelkh gauge station	35+200	35+400	1080	0.054
	35+700	37+000	175444	1.350
	38+700	38+950	1736	0.069
	42+900	43+150	417	0.017
	45+800	48+000	190096	0.864
	48+650	50+200	16962	0.109
	56+950	57+000	830	0.166
	57+750	57+800	864	0.173
	58+850	59+600	32975	0.440
	60+300	61+000	61382	0.877
	63+500	64+950	17246	0.119
	65+750	66+250	12029	0.241
	68+700	69+150	2072	0.046
	72+650	73+550	14799	0.164
	76+950	77+850	188943	2.099
	78+400	78+950	204085	3.711
	80+550	80+750	97	0.005
	81+250	81+800	6400	0.116
	83+750	84+000	340	0.014
	87+200	87+500	2266	0.076
	90+600	90+950	287	0.008
	99+850	101+300	71958	0.496
	102+150	103+300	140 237	1.220
	105+450	106+500	16708	0.159
	110+100	110+900	3676	0.046
	114+100	115+000	9384	0.104
	122+200	122+450	2641	0.106

3.3. Real-time bottleneck's location representation on Google Maps

The main target of this work is to present a quasi-real-time Nile River navigation condition to detect the located bottlenecks via a user-friendly web Google Maps illustrating the Nile River's current navigation condition. The map of the Nile River's navigation condition (KML map) that includes the river channel boundary, the navigation path, and the bottleneck areas was created. The created map can be easily uploaded to the Internet and displayed by other software or web services that can be easily used. Fig. 6 illustrates the created maps of the Nile channel boundary and the real-time location on the created map of the Nile River's current navigation condition of the Edfu Bridge region and the locations of the bottlenecks via Google Maps and as shown satisfactory results were obtained.

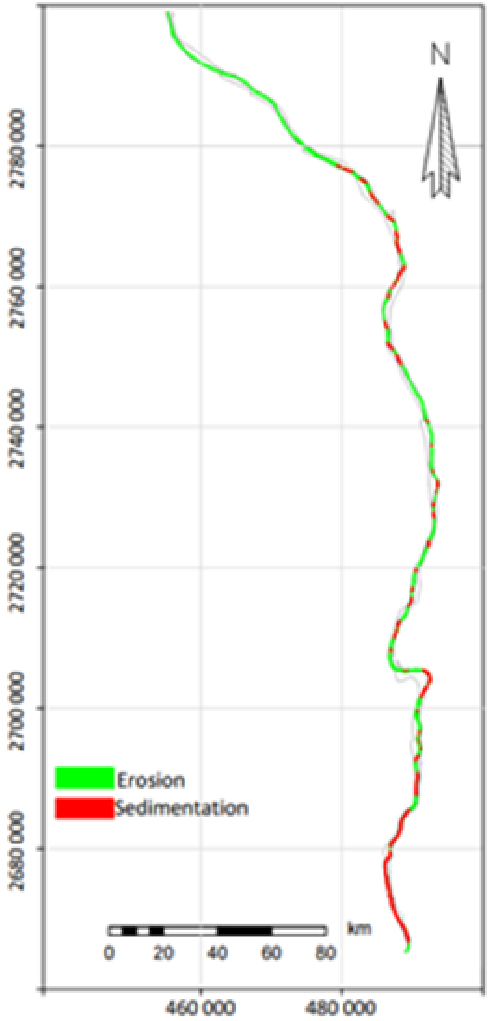

Fig.6: The maps of real-time bottlenecks location at the Edfu bridge region

Moreover, Fig. 7 presented a quasi-real-time approach to the move from location (a) at Km 67.00 downstream of OAD to location (b) at Km 67.30 downstream of OAD before the Fares bridge and from location (c) at Km 69.15 downstream of OAD to location (d) at Km 70.41 downstream of OAD after Fares bridge to detect the validity of the river channel boundary, the navigation path, and the bottleneck areas.

Fig.7: Representation of real-time location at fares bridge: (a)&(b) location before fares bridge (from Km 67.00 to Km 67.30), (c)&(d) location after fares bridge (from Km 69.10 to Km 70.41)

Fig. 8 presents a quasi-real-time approach to the move of the location from the old Esna Barrage at Km 167.00 D.S OAD to the new Esna Barrage at Km 168.00 D. S OAD to detect the validity of the river channel boundary, the navigation path, and the bottleneck areas.

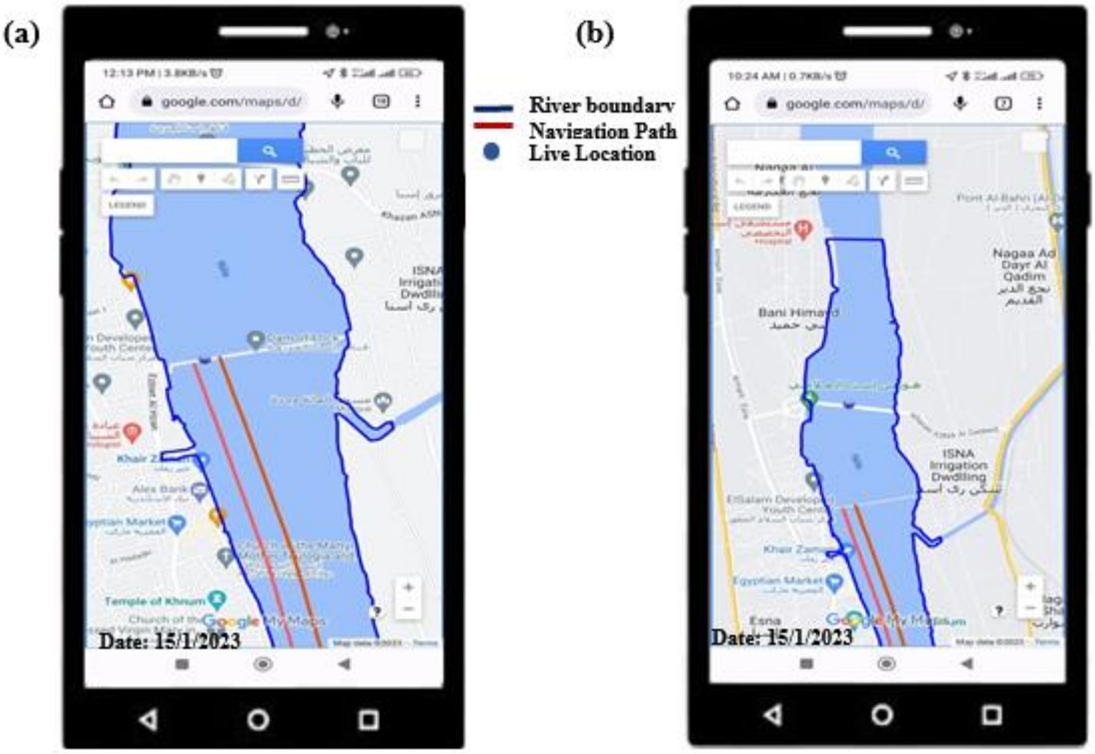

Fig.8: Representation of real-time location at Esna Barrage: (a) old Esna barrage (Km 167.00), (b) new Esna barrage (168.00)

3.4. Comparison Between the Current Study and Field Data by The Egyptian General River Transport Authority (ERTA)

Table 3 shows the computed amount of sediment that should be dredged downstream of Fares bridge location from 72.20 Km to 73.80 Km and at Edfu bridge location from 113.20 Km to 115.80 Km. The current study suggests dredging of 18062 m^3 and 9555 m^3, from the two locations respectively. On the other hand, the actual dredged sediment amount by (ERTA) (using field data) was equal to 23815 m^3 and 90756 m^3 in the same previous locations, respectively. The error value, as is clear from the data, is somewhat small in the first location, while in the second location is observed to be large. The authors attribute error emergence to the time difference between the surveying maps' date and the date of construction of the two bridges where the Edfu Bridge is older than the Fares bridge, which permits more and more accumulation of sediment as time progresses.

Table 3: Comparison of results between the computed sediment by using the present approach and the amount dredged of sediment by (RTA) using field measurements.

Region	**Amount of sediment by Study approach (m^3)**	**Amount of sediment by (RTA) Method (m^3)**	**Variation (%)**
Fares Bridge	18062	23815	24.20
Edfu Bridge	9555	90756	89.50

4. Conclusions

The present study was developed to present a quasi-real-time river navigation condition based on minimum water levels at Aswan High Dam's winter closure period and the navigational path's geometry. To achieve this goal two surfaces were created using AutoCAD Civil 3D. The first surface is the Nile Riverbed, while the second is the recommended navigation channel surface by (ERTA). The intersection between the previously mentioned surfaces represented the locations of the bottlenecks. It was found about 34 locations need dredging about 2.1 million—cubic meters. Determining the bottleneck locations is very important to decision makers to supply them with the hotspot locations that need urgent dredging to protect Nile cruises from running ground the Riverbed. The real-time locations were validated in the Fares Bridge region and the Edfu Bridge region. Furthermore, the study gives a clear image for sailors for quasi-real-time river navigation on their cruises through the Nile by using a user- mobile-friendly Google Maps web rather than depending on their experience. The authors recommend that the current work could be enhanced and strengthened by continuously updating the Nile morphology and the vertical location of the navigation channel based on the minimum water level. Also, sensors along the reach could be installed to help sailors and passengers with various facilities.

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