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Morphological Changes Analysis for Nile Bed at Aswan Bridge Area Using GIS

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ABSTRACT

This research presents Geographic Information Systems (GIS) spatial analyst application as a tool for morphological analysis and proposes an algorithm to use it for morphological changes studies. It also tests the new algorithm of this modern technique with the traditional cross sections approach. For this reason, a study area with a length of 4 km from 906 to 910 km, measured from El-Roda gauging station, was selected including Aswan Bridge at 907.93 km. The study shows there is a significant morphological change in this stretch due to the long study period and the construction of a hydraulic Structure (Aswan Bridge). Moreover, a comparison between the new GIS algorithm and traditional method was held, discussed and is presented for the bridge location and scour and deposition rates were compared with those of the whole study reach.

Keywords

Morphology; Nile River; Aswan Bridge; GIS; and Spatial Analysis.

1. INTRODUCTION

Morphological analysis of river streams is highly important for many reasons such as navigation safety, allocation of intake structures and scour calculations at bridges. It also plays an important rule in planning of the area on the river sides for sustainable development.

River bathymetry (bed topography) plays a critical role in numerical modeling of flow hydrodynamics, sediment transport, ecological and geomorphologic assessments. Conventional way of measuring river bathymetry is through cross-sectional surveys where ground profiles are collected at certain locations along the river depending on available resources, river morphology and end use of the data. A recent technological development in bathymetry measurement includes the use of boat-mounted SONAR (Sound Navigation And Ranging) devices such as single or multi-beam echo sounder in conjunction with global positioning system (GPS) to give a series of (x, y, z) bathymetry points.

The Morphological analysis accuracy depends mainly on the captured details level while collecting the bathymetric data. However, collecting dense data with high details is costly and time consuming during both the collection and data processing phases.

The first reach of the Nile River is located between Downstream Aswan Dam and Upstream Esna Barrage with a total length of 166.65 km. This reach was selected to carry out this comparison as this reach has clear water, with low sediment load. This reach tends to have high scour potential and great morphological changes as a result. The analysis was made to study the morphological changes during flow events between 1982 and 2007 for a 4 km stretch of the reach that includes the New Bridge on the Nile at Aswan. A focused analysis near it was also carried out to check the changes of bed surface around its piers and abutment.

2. OBJECTIVE

The objective of this research is to study the morphological changes in a 4 km reach of the Nile River from km 906 to km 910, measured from El-Roda gauging station, during the period from 1982 to 2007 using Geographic Information Systems (GIS) spatial analyst application as a tool for morphological analysis.

The objective is divided into three main parts:-

1- Develop a new algorithm to calculate the morphological changes using the Digital Terrain Models (DTM).
2- Analyze the morphological changes of the study area during the period from 1982 to 2007.
3- Compare the traditional technique with the DTM approach for the calculation of scour and deposition in the study area at different elevations.
4- Calculate and compare scour and deposition rates for both the study reach and at the bridge site.

3. THE STUDY AREA

A study area with a length of 4 km from 906 to 910 km from El-Roda gauging station was selected. The study area has a new bridge that was built on 1998 crossing the Nile River, near Aswan City, at a site located 907.93 km from El-Roda gauging station. The River at the bridge site is nearly straight. There are some low lands in the eastern side of the river, at the bridge site. It extends from 1300 m upstream the bridge axis to 400 m downstream the bridge axis.

The bridge is supported on six supports across the river as shown in figure (9) [1]; two main piers at the middle and another two on each side of the river. The main middle piers are about 25 m wide each. The width of the other piers is about 8 m. The span between the two main middle piers is 250 m, however the other spans are 76 m and 49 m on each side[2]. The two main piers and the western small piers are located inside the main river channel, meanwhile one of the eastern small piers are located in the eastern shallow area of the river channel and the other one is located on the east river bank.

4. METHODOLOGY

This section describes the different techniques in calculating the morphological changes and illustrating the new developed DTM algorithm.

4.a) DTM Algorithm

The calculation of the morphological changes, scour and deposition, in a river bathymetry could be predicted if the data about bed surface for different time steps is available. By comparing these data sets and calculating the difference in volumetric changes between them, the morphological changes, can be monitored.

The first main step when using GIS is to obtain a three dimensional bathymetry for the study reach. To obtain this target, data collected for the bed level in a form of scatter points was first interpolated to form the contour lines forming the bed and flood banks of the reach under study. Two data sets were obtained from the Nile Research Institute (NRI). These data sets were in form of contour lines and spot level points and were available for the year 1982 and 2007, figures 1 and 2.

The contour lines forming Nile bed level and the flood banks at the reach under study were extracted from data files then used to generate scatter points that will be used to form a triangles irregular net (TIN) using an interpolation technique, figure 3.

One of the most commonly used techniques for interpolation of scatter points is the inverse distance weighted (IDW) interpolation method. Inverse distance weighted method is based on the assumption that the interpolating surface should be influenced mostly by the nearby points and less by the more distant points. The interpolated surface is a weighted average of the scatter points and the weight assigned to each scatter point diminishes as the distance from the interpolation point to the scatter point increases.[5]

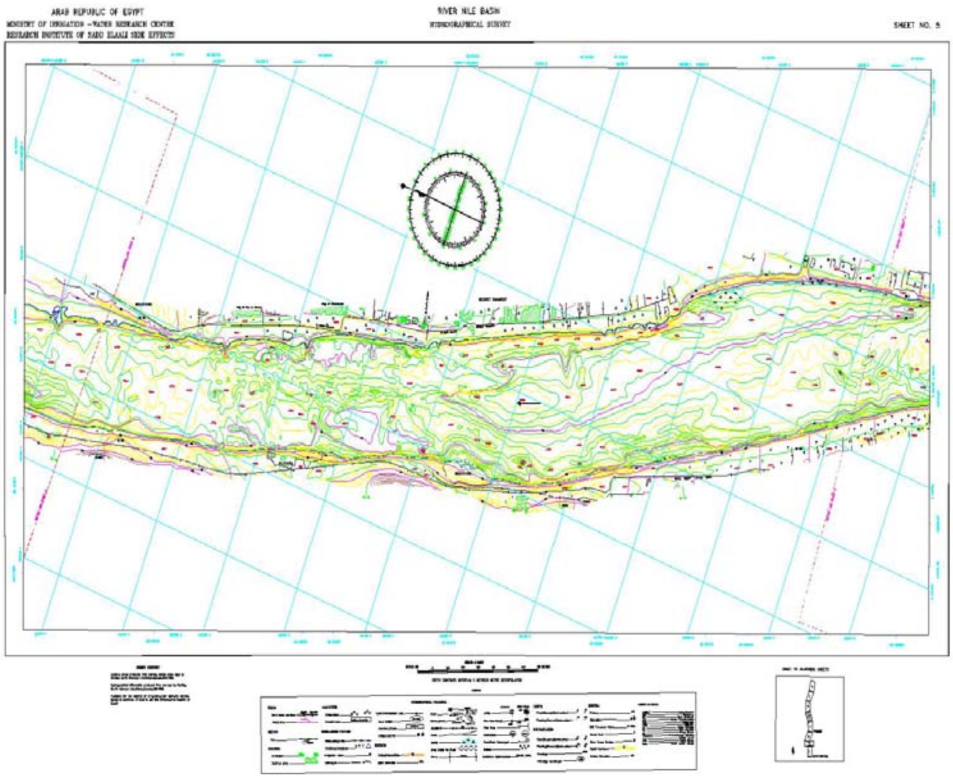

Figure 1, Nile bed contour map 1:5,000 at the location of Aswan Bridge.
Source; Nile Research Institute-1982 [3]

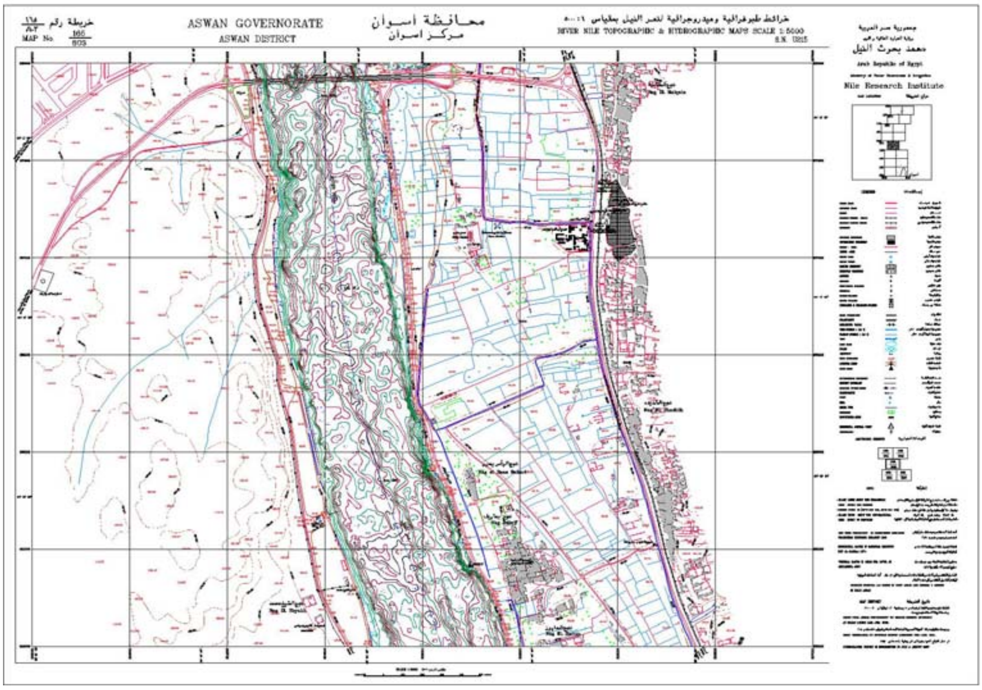

Figure 2, Nile bed topographic and hydrographic map 1:5,000 at the location of Aswan Bridge. [4]
Source; Nile Research Institute-2007

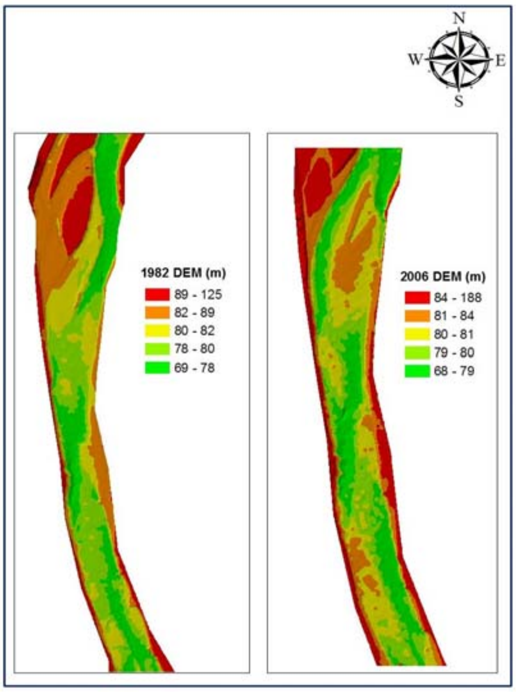

Figure 3, The Interpolated TINs for 1982 and 2007

The generated TIN had to be converted to a raster files to form the digital terrain model (DTM) that represents the bathymetry, figure 4, all DTM files generated had the same cell size of (10m x 10m). This type of files was used in the statistical analysis/calculations in the next stages.

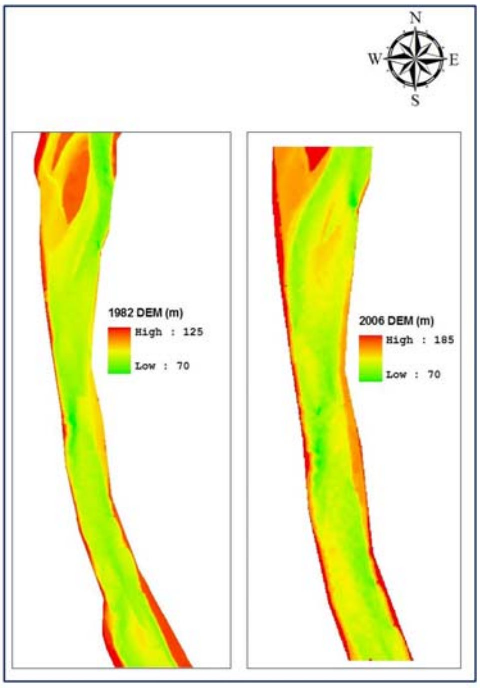

Figure 4, The generated DTMs for 1982 and 2007 bathymetry

Spatial Analysis

The two generated raster files were then used in a proposed logical and mathematical procedure (Algorithm) to calculate scour and deposition volumes. A logical function, equation 1, was applied to the DTM to isolate the topographical surface that is below the 86 m level which is the water level corresponding to the maximum expected flow through this reach (350 million m^3/day).

If (DTM is less or equal than 86) = Logical DTM less than or equal 86 (1)

The logical function on the left hand side of equation 1, If (DTM is less or equal than 86), will generate a logical raster file with the same number of cells as the original DTM file but with cells values equal to 1 if the DTM cell value is less than or equal 86 and a cell value of 0 if the value is greater than 86. The resulted logical expression raster, (1,0) cells, will then be multiplied by the original DTM so all the values above 86 m will have a zero value while the others will keep their original values. The previous logical and analytical processes were carried out for the data set of the year 2007 and the result is presented on figure 5.

To locate the areas where scour and sediment occurs, the two bathymetric DTMs (Figure 4) of 2007 and 1982, were subtracted from each others and then multiplied by the logical DTM of equation 1.

Morphological Raster =
[2007 DTM - 1982 DTM] x [Logical DTM less than or equal 86] (2)

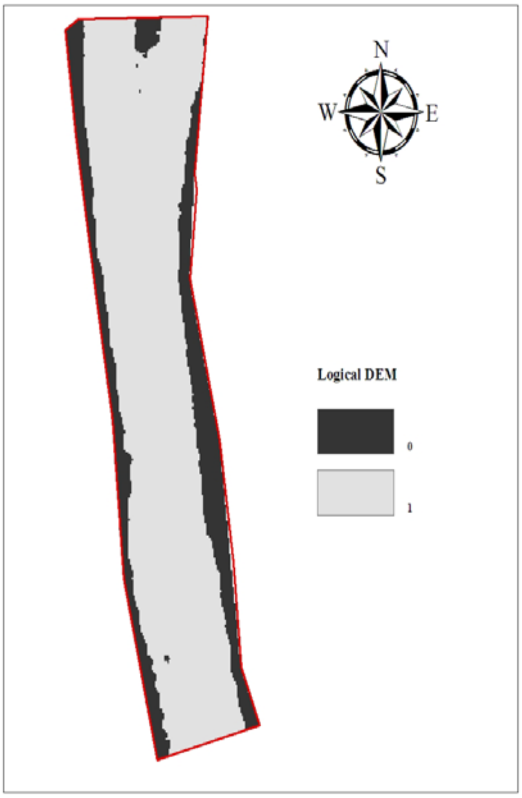

Figure 5, Bathymetry lower than 86.0 m

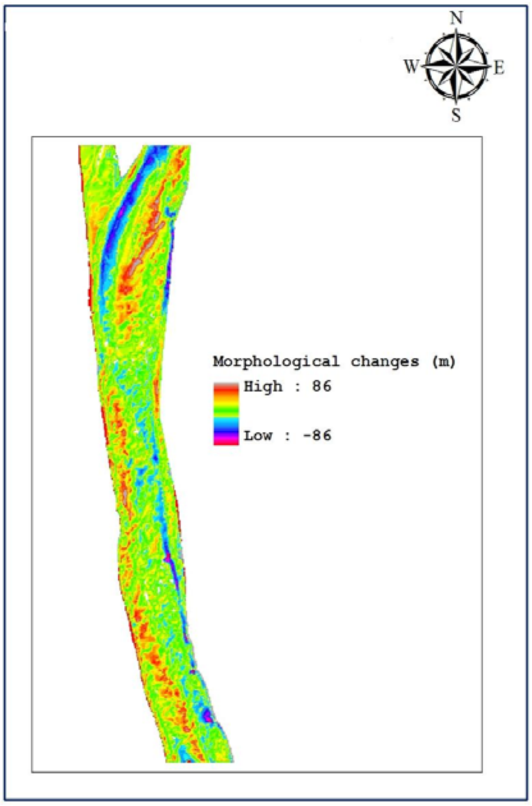

Figure 6, Morphological changes between 1982 and 2007

Volumetric calculations

The resulted raster file, figure 6 shows the changes that occurred to the bed during the period from 1982 to 2007. Yet, the resulted raster can not be used to calculate the volume of the scour nor the volume of deposition. However, it can be helpful to locate the locations that were subjected to severe morphological changes.

In order to calculate the volume of bed changes occurred during the period from 1982 and 2007 the following logical and analytical expressions were applied to the resulted morphological changes raster, figure 6.

Deposition Changes Raster =
If (Morphological raster greater than 0) x (Morphological Raster) (3)

Scour Changes Raster =
If (Morphological raster Less than 0) x (Morphological Raster) (4)

The first part of the right hand side of equation 3, If (Morphological raster greater than 0), will generate a logical raster file with the same number of cells as the original file but with cells values equal to 1 where deposition occurs and a cell value of 0 if scour occurs. The resulted logical expression raster, (1,0) cells, will then be multiplied by the original Morphological changes raster so all cells where scour occurs will have a zero value while those where deposition occurs will keep their original values. The previous logical and analytical processes were carried out to extract the deposition and scour values as per equations 3 and 4. The results of equations 3 and 4 are two different raster files. One with all the cells where deposition occurred are having the deposition depth value while the rest of the cells have zero values. And the other one shows the scour values for the cells where scour occurred the rest of the cells have zero values, figure 7.

To calculate the total volume of scour or sediment occurred the summation of all cells values, for each raster resulted from equation 3 and 4, will be multiplied 100 m^2 that is the area of each cell is (10m x 10m).

The same previous steps were repeated for the area only below the (82.00) m level, the level corresponding to the lowest flow expected through this reach. And the resulted deposition and scour raster are presented on figure 8.

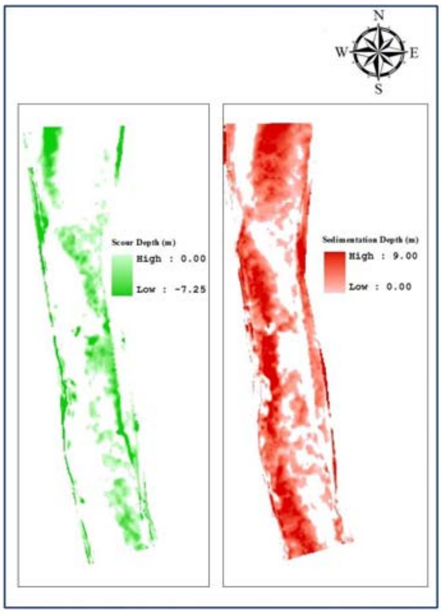

Figure 7, Deposition and Scour rasters for levels below 86.0 m

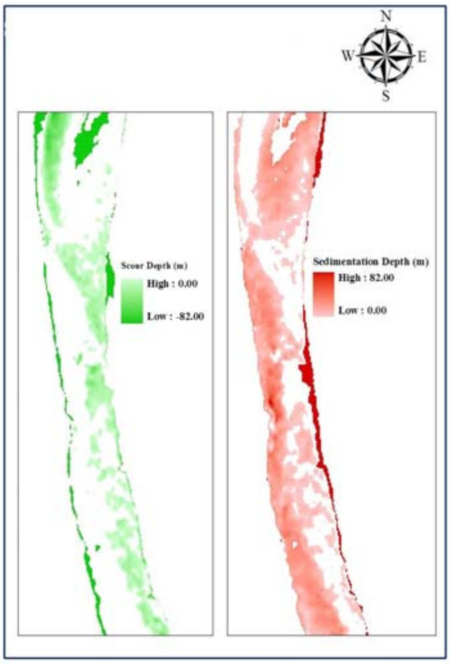

Figure 8, Deposition and Scour rasters for levels below 82.0 m

To estimate the percentage of deposition and scour occurred around Aswan Bridge piers and abutment, clipping was made to the raster files generated in figure 7 using a polygon that was built using the (86.00)m contour and the cross sections 100m U.S. and D.S. of the bridge location, those at station (km 908.03) and (km 907.83). The results are given on figure 10.

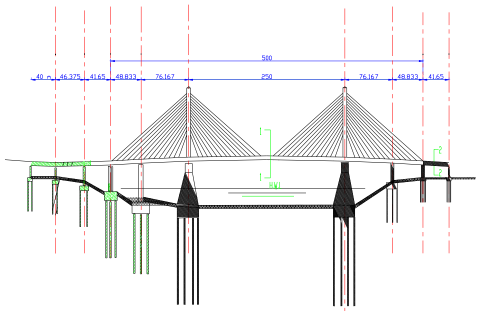

Fig.9. Layout of Aswan Bridge

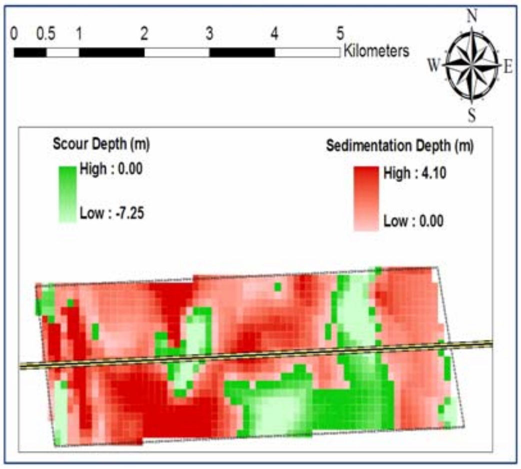

Figure 10; Deposition and Scour from km 908.03 to km 907.83.

4.b) Traditional Method

To test the proposed algorithm it will be tested against the traditional approach of estimating deposition and scour in rivers, which is based on the comparison of the surveyed cross sections in different years to estimate the sediment or scour volumes of the river.

The total amount of deposited sediment or scour was evaluated by assuming gradual distribution to the amount of sediment or scour between two successive cross sections.

The volumes were calculated by measuring the area of the cross sections and lengths between these sections. The volume was calculated as the sum of the product of the mean area of every two successive sections and the length between them. Three different scenarios were selected to cover the minimum, average and maximum river flood limits corresponding to level (82.00, 84.00, and 86.00).

Tables 1 and 2 show the calculation of Aggradation and degradation for the reach corresponding to various water levels (82, 84, and 86 m).

Table (1) The aggradation and degradation for different cross sections at different water levels for the study area

Km from El-Roda Ganging Station	W.l (m)	Aggradation (m^3)	Degradation (m^3)	Net (m^3)
910	82	595.1	118.2	476.9
	84	620.68	118.2	502.5
	86	622.15	118.2	504
909	82	436.36	120	316.4
	84	466.2	168.04	298.2
	86	492.95	189.32	303.6
908.5	82	242.93	174.89	68.04
	84	250.42	205.98	44.44
	86	344.68	207.56	137.1
908	82	439	275.8	163.2
	84	506.68	319.28	187.4
	86	791.48	319.28	472.2
907	82	212.06	133.39	78.67
	84	340.75	133.39	207.4
	86	345.59	249.51	96.08
906.5	82	652.8	74.45	578.4
	84	657.8	134.31	523.5
	86	725.45	141.81	583.6
906	82	1010.41	454.16	556.3
	84	1078.62	471.27	607.4
	86	1078.62	497.51	581.1

Table (2) The aggradation and degradation for different cross sections at different water levels at Aswan Bridge

Distance from Bridge (m)	W.l (m)	Aggradation (m^3)	Degradation (m^3)	Net (m^3)
100 - Up	82	416	228.21	187.8
	84	489.66	278.57	211.1
	86	768.76	278.57	490.2
50 - UP	82	342.38	232.83	109.6
	84	423.75	253.03	170.7
	86	688.3	256.36	431.9
Bridge	82	367.21	138.97	228.2
	84	483.77	196.76	287
	86	854.7	196.76	657.9
50 - Down	82	318.45	149.35	169.1
	84	411.47	171.65	239.8
	86	807.38	171.65	635.7
100- Down	82	488.53	72.25	416.3
	84	608.57	105.56	503
	86	651.62	295.27	356.4

5. RESULTS AND DISCUSSION

Figure (11) and table (1) show that, for cross section at Km 910 from El-Roda, there is degradation at the east part and deposition at the west part of the river this suggests that the main current is flowing at the eastern part of the river. However, the banks are fixed (no change), and this is because of the bank protection provided for the both sides of the river at that place where the bridge was constructed.

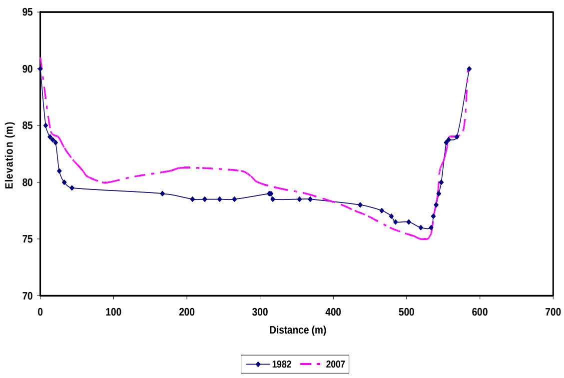

Fig.11. 1982 and 2007 cross sections (910 km from El-Roda gauging station)

Figure (12) shows that there are spur dikes in the east bank of the river that change the direction of flow causing degradation in the bed and the east bank of the river. Finally, the slope of the bed level is steeper at the upstream than the study area, leading to erosion upstream and deposition at the study area. The net area at that section shows generally deposition at different levels of comparison between the cross sections of 1982 and 2007.

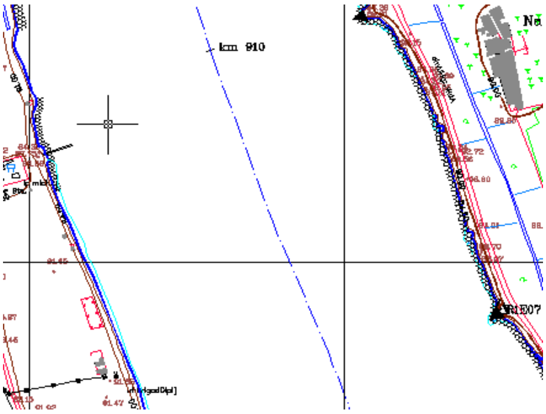

Fig.12. The plan of the area at Km 910 from El-Roda gauging station and the Spur Dicks (The black triangle)

Figure (13) and table (1) show that for cross section at Km 906 from El-Roda there is degradation at the West part of the bed and deposition at the East part of the bed because the direction of flow has changed from East to West. In addition, at the beginning of a bend the outer part of the bend causes degradation at the left side and the inner part causes aggradation at the right part. The net area at that section shows there is deposition at different levels of comparison between the cross section in 1982 and 2007.

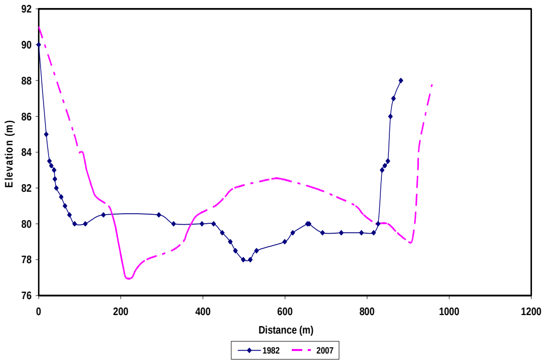

Fig.13. 1982 and 2007 cross sections (906 km from El-Roda gauging station)

For the distance between cross section at Km 908 and 907 on the main channel, there is a aggradtion at the whole distance on the West side also and degradation on the East side. There is a low land at the eastern side and it extends from 1300 m upstream the bridge axis to 400 m downstream the bridge axis in 1982 to be 1300 m upstream the bridge axis to 1000 m downstream the bridge in 2007.

Figure (14) and table (2) show that, for cross section at the axis of the bridge at Km 907.82 from El-Roda, there is a local scour around the piers of the bridge. The local scour at the two main middle piers was found to be about 2.5 m.

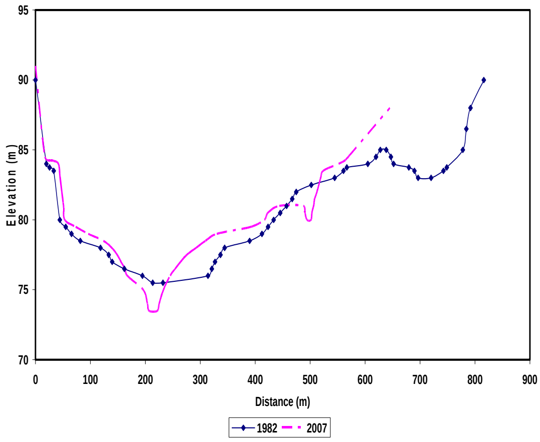

Fig.14. 1982 and 2007 cross sections (At the axis of Aswan Bridge)

Figures (15 and 16) show the morphological changes at 100 upstream and downstream the bridge.

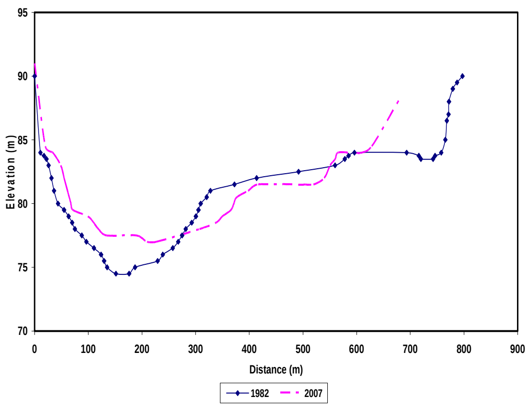

Fig.15. 1982 and 2007 cross sections (100 m Upstream of Aswan Bridge)

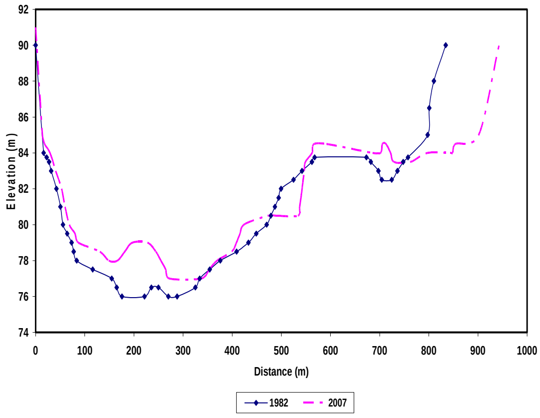

Fig.16. 1982 and 2007 cross sections (100 m Downstream of Aswan Bridge)

The results of the two approaches were summarized in the form of scour volume and deposition volume corresponding to each water level for both the whole stretch from 906 to 910 km and at the bridge site (from 100 m upstream to 100 m downstream the bridge center line) are presented in tables 3.4 and 5. Also a comparison between the two methods results were shown on figures 17 to 20.

Table (3) Total deposition and scour at the study area by using GIS method

	Total (m^3)		At Bridge (m^3)	
Max Level	Scour	Deposition	Scour	Deposition
82	581,383	1,755,562	33,335	67,371
84	623,466	1,991,051	33,675	77,547
86	732,830	2,188,100	39,892	88,999

Table (4) Total deposition and scour at the study area by using Traditional method

	Total (m3)		At Bridge (m3)	
Max Level	Scour	Deposition	Scour	Deposition
82	694,203	1,813,583	33,569	74,015
84	812,595	2,019,328	40,675	93,405
86	926,745	2,338,310	45,585	153,029

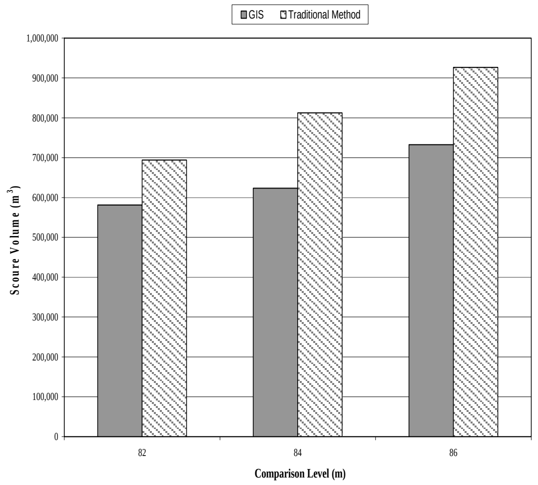

Figure (17) GIS and traditional methods scour values for the whole reach

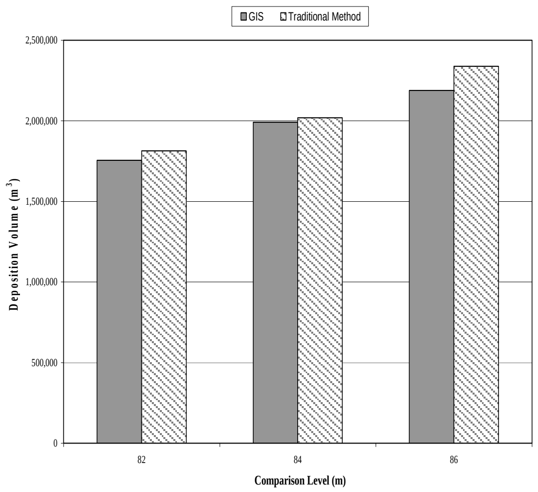

Figure (18) GIS and traditional methods deposition values for the whole reach

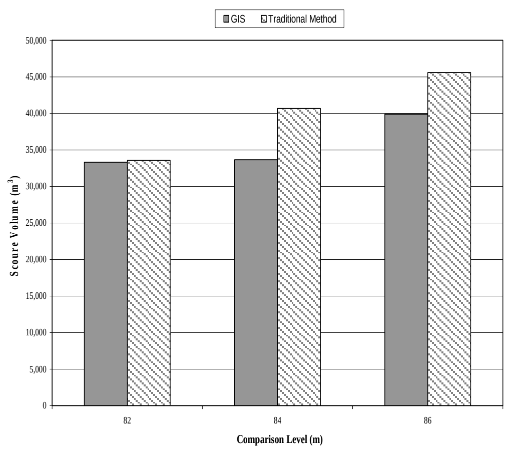

Figure (19) GIS and traditional methods scour values for the bridge location

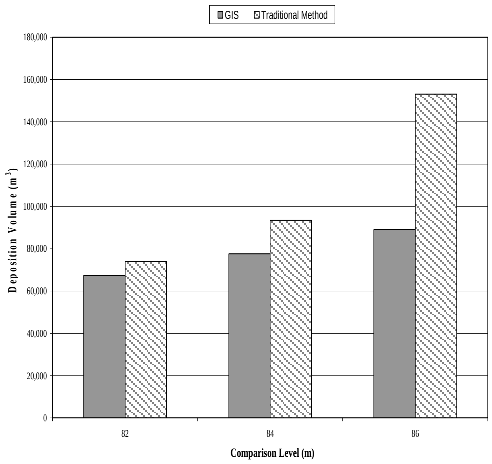

Figure (20) GIS and traditional methods deposition values for the bridge location

The rates of scour and deposition per km along the study reach and around the bridge were calculated and the comparison is presented on figures 21 and 22.

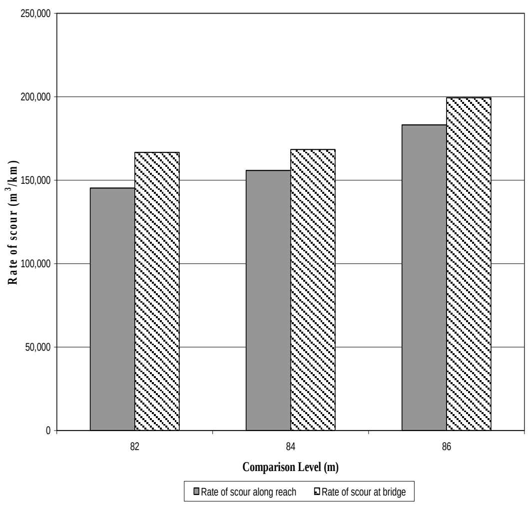

Figure 21, Comparison of scour rates

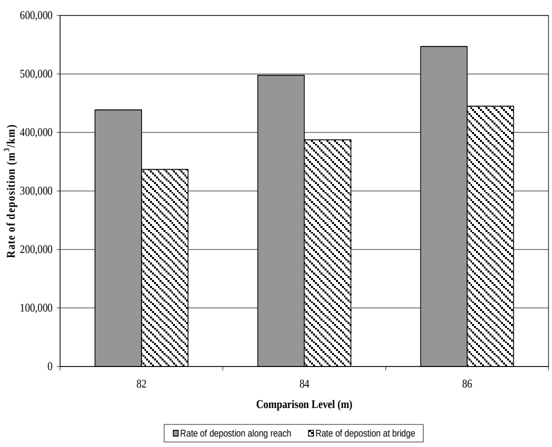

Figure 22, Comparison of deposition rates

6. CONCLUSION

The results and comparison between the proposed algorithm and the traditional approach shows that the new algorithm application results are matching with high accuracy with the results of the traditional approach. Its accuracy will depend on the density of the input data and the resolution of the DTM used within the analysis.

The analysis also showed that the morphological changes for the reach under study were significant. In general, the deposition appears to be of more significant effect, the 4 km study reach became shallower and wider in its northern part than it was on 1982. The river shifted its path to the East while a submerged island appears on the North-West of the reach. The East abutment embankment affects the results of the deposition calculated by the traditional approach at high levels, figures 14 to 16 and 20.

The digital terrain models proved to be accurate and fast tools to be used in the calculation of the morphological changes, compared to traditional method, specially if the cell size is of a significantly high resolution. However, it should be mentioned that the production of a DTM with high resolution requires a dense bathymetric survey like those produced from the depth measuring devices using eco waves.

The comparison between GIS and traditional method shows that there is a slight difference in the estimate of both Aggradation and degradation volume. This is because the accuracy of the analysis using DTM (10m x 10m) is much higher if compared with the traditional method specially with large distance between the cross sections used in the analysis.

It can be seen from the comparison of scour rates along the reach and at the bridge area, that the rate of scour at the bridge location is about 11% higher than that along the reach, figure 21 and it is almost concentrated around piers and abutments due to the scour holes generated at piers and abutments. While the deposition rates at the bridge location is about 27% lower than that along the reach, figure 22 due to high velocities expected at the contracted section of the bridge.

It is recommended to estimate the scour near structures using small intervals between cross sections and/or using hydraulic models that calculate the scour around structure using velocity fields and live bed approaches.

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ملخص البحث

يهدف البحث إلى دراسة التغيرات المورفولوجية في منطقة كوبري أسوان خلال الفترة من عام 1982 وحتى عام 2007 ومقارنة كميات النحر والترسيب خلال تلك الفترة باستخدام نظم المعلومات الجغرافية والطريقة التقليدية. حيث تم تجميع الخرائط الكونتورية والطبوغرافية واستخراج القطاعات العرضية وكذلك التصرفات والمناسيب للمنطقة موضوع الدراسة ثم تم عمل تحليل للتغيرات المورفولوجية في منطقة كوبري أسوان ومقارنة كميات النحر والترسيب خلال تلك الفترة لثلاثة سيناريوهات تمثل حالات الفيضان المختلفة باستخدام تقنية رياضية لاستخدام برنامج نظم المعلومات الجغرافية في حساب كميات النحر و الترسيب ومقارنة النتائج بالطريقة التقليدية التي تعتمد على مقارنة القطاعات العرضية وحساب مساحات النحر والترسيب ثم ضربها في المسافات البينية بين القطاعات العرضية للحصول على كميات النحر والترسيب. حيث أثبتت الدراسة حدوث تغير كبير في مورفولوجية النهر في تلك المنطقة نتيجة لطول فترة الدراسة والتي تمتد لفترة 25 عام بالإضافة إلى وجود كوبري أسوان والذي أنشأ في عام 1998كما أثبت البحث أن حساب كميات النحر والترسيب في المنطقة موضوع الدراسة باستخدام الطريقة التقليدية تعطى نتائج جيدة مقارنة باستخدام GIS ويوصى البحث بالتوسع في استخدام نظم المعلومات الجغرافية في الدراسات المورفولوجية لنهر النيل.

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