Long-Term Morphological Changes in the Nile River since High Aswan Dam Construction to Year 2010

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Abstract

Numerous studies to predict river bed degradation downstream the Old Aswan Dam "OAD" were extensively carried out. However, variation of both river bed and water surface levels downstream of "OAD" with time and location since the construction of High Aswan Dam "HAD" till now has not been fully explored. Therefore, the present study was carried out to identify the occurred variations in bed and water surface levels through the first reach which is located from downstream of "OAD" to upstream of the new Isna barrages. The daily records of flow discharges and the corresponding water surface levels along the first reach from year 1962 to 2010 were utilized to deduce the matching stage discharge rating curves.

Comparison of the deduced water surface levels for various periods and locations along the reach - at passing 200 million m^3 / day – revealed that El-Gaafra and Kom - Ombo gauge stations were the only subjected sites to degradation since "HAD" construction. This degradation turned over and recovered to sedimentation from the years 2002 and 1991 on El-Gaafra and Kom – Ombo respectively and reached to a maximum value of 0.011 and 0.315 m at El- Gaafra and Kom – Ombo in year 2010. On the other hand, the downstream part of the study reach has not been subjected to any degradation since "HAD" construction until the year 2010. The monitored sedimentation (deposition) within such reach in year 2010 reached a maximum value of 0.760, 0.989 and 1.405 m at Selwa – Bahary, El – Ramady, and Edfu gauge stations respectively with respect to the condition before "HAD" construction. Moreover, water surface slope – through the studied reach at passing flow discharge of 200 millions m^3/day – was reduced from 5.84 cm/km in year 1962 to 4.05 cm/km in year 2000. The achieved results concluded that the first Nile River reach is being subjected to sedimentation and not degradation after "HAD" construction.

***Keywords*:** High Aswan Dam Side Effects, Degradation, Sedimentation, Stage Discharge Rating Curves

1. INTRODUCTION

The High Dam at Aswan "HAD" was designed to serve mainly three functions; to store water from the annual flood to allow regulated release for irrigation and other purposes throughout the year; to generate hydraulic power; and to control high floods in the Nile. Those objectives were totally fulfilled in the early years of service when the dam protected Egypt from high floods during the late 1960s, and saved the country from devastating droughts in the 1980s, and preventing a disastrous famine in both the 1970s and 1980s. As the average annual suspended sediment downstream of "HAD" was enormously decreased from 1600 ppm before "HAD" to about 50 ppm. The flow regime was changed, river bed was eroded. Different national and international experts expected lowering of the river bed and water surface level downstream the existing main barrages from 3 to 20 m. While the intensive measurements indicated that the total drop in water levels would be ranged between 0.5 and 1.0 m which is due to the flat slope and self armored river bed. Therefore, in order to face the expected degradation downstream the main barrages, new Isna and Naga - Hammady barrages were constructed and the third one of New Assuit barrages is being under construction at the sites of the existing barrages which were built in early 20th century.

Constructions of "HAD" began in 1960 and the dam was completed in 1968 and by 1970 all major power facilities were in place. A powerhouse comprises 12 turbines of 175 MW each - with total gross capacity of 2100 MW - were installed at the downstream end of six tunnels. As a result of the dam construction, a huge lake – called Lake Nasser – of some 500 km length and an average width of 12 km was formed upstream the dam. The overall gross storage of the lake at level (183.00) m is 168.9 km^3, of which a total volume of 31.6 km^3 was allocated for dead storage of sediments below elevation (147.0) m during 500 years of dam life span age (Duivendijk, J. and Shalaby, A. 2004).

As most of total annual sediment load – which is carried from the watershed around the Equatorial Lakes – is deposited in these Lakes and the around swamp areas, only 5% of these sediment reaches Aswan. Some 95% of the annual sediment load that arrives during the flood seasons at Aswan originates from the Ethiopian Plateau. With this in mind, during the period 1903 – 1963 a yearly average of 124 million tons of sediment reached El-Gaafra gauge station which is located at 33.750 km downstream of the Old Aswan Dam "OAD" (El-Mottasem 1998 and 2001). However, the High Aswan Dam construction led to raising immense inquiries concerning the expected effects on river degradation, bank failure, coastal erosion, evaporation, seismic movement, and seepage…etc by interested scientists during early days of planning for the dam [White (1988), and Rao, et al (1994)]. Those were broadly studied and reported by the Ministry of Water Resources and Irrigation [Shalaby (1993) and ICOLD (1993)].

With the progress of "HAD" construction and filling the upstream reservoir, out of an average annual sediment load of 124 million tons, only about 26.3 million tons passed – after "HAD" construction in year 1968 - as measured at El-Gaafra station at 33.750 km downstream of "OAD" which was enormously decreased to about 2.0 million tons in year 2000 at El-Gaafra station. While after the impounding of Lake Nasser, the annual sediment inflow was gradually deposited in the Lake with trapped efficiency of more than 95%. While the total settled sediment in the lake up to December 2012 was estimated as 6.7 milliard m^3 (6.7 km^3). Therefore, extensive investigations for the changes in the river downstream of "OAD", which were caused by the reduction in peak discharge, the flattening of the hydrograph and the enormous reduction of annual sediment inflow through the river, were carried out.

The recorded annual bed degradation during the first 12 years after closure – as reported by White (1988) – amounted to 2.2, 3.0, 2.5, and 0.4 cm per year in the first reach from "OAD" to Esna barrages, second reach from Esna to Naga - Hammadi barrages, third reach from Naga - Hammadi to Assuit barrages, and fourth river reach from Assuit to Delta barrages respectively. Six years later – as reported by White (1988) - field observations indicated that the total drop in bed levels had been 0.25, 0.38, 0.48 and 0.70 m along the same four river reaches respectively. Moreover, the estimated drop in water level for 14 years period between "HAD" closure in 1968 and 1982 was published by Gasser et al (1991). This revealed 0.61, 0.80, 0.99 and 0.73 m drop of water surface level downstream of "OAD", Isna barrages, Naga-Hammady barrages and Assuit barrages respectively. Additionally, application of the deduced gauge discharge relations until 1997 – as reported by El-Mottasem (1998) - revealed 0.4 m, 0.3 m and 0.6 m drop in water surface level at passing discharge of 200 million m^3/day at El-Gaafra (km 33.750), and downstream of Isna barrages (km 169.085) and Naga - hammady barrages (km 360.00) respectively. .

On the other hand, Wail, A.F. (2012) revealed in his Ph.D. study titled "Effect of Barrage Components on Navigation Waterway" that the daily water surface level corresponding to flow discharge of 233 million m^3/day at Km 93.5 downstream of "OAD" in years 2004 and 2005 is 0.97 m higher than that before "HAD" construction in years 1963 and 1964. This result contradicts the previously conducted and published studies which indicated general degradation along the four river reaches downstream of "OAD" as a direct impact of "HAD" construction.

So far, numerous hydraulics and morphological studies to classify the side effects of "HAD" constructions were carried out. Most of those studies indicated general degradation along the four river reaches downstream of "OAD" as a direct impact of "HAD" construction (El-Ansary, 1976). This because most of the provided studies were limited to the emerged local conditions downstream the main hydraulic structures after "HAD" construction rather than the analysis of real data that covers adequate time and space (i.e. as function of distance). Consequently, no comprehensive study for any materialized degradation or sedimentation developments in time and locations along the River Nile since "HAD" construction has been made. For this reason the current study would employ the daily recorded observations for water surface levels and the corresponding flow discharges along the first reach to produce the stage discharge rating curves leading to work out the resulted variations in bed and water surface levels along the study reach since "HAD" construction up to year the 2010.

2. METHODOLOGY

As the main objective of the present investigation is to study the development of Nile River bed degradation and sedimentation since "HAD" construction until now, the daily records of flow discharges and the corresponding water surface levels would be utilized. The study would be limited to the first river reach which extends from downstream of "OAD" until upstream of the New Isna barrages at km 169.085 downstream of "OAD". Variations of daily flow discharges and the corresponding water surface levels along a steady flow condition part of the first river reach would be examined from the year 1962 before "HAD" construction up to the year 2010. On the other hand, as such hydrological information is of a stochastic nature, long time-series data records of at least one year would be demonstrated (Jansen et al, 1979). For this reason, the analyzed flow discharges and the corresponding water surface levels records would cover two successive years each ten years within the study period of almost 50 years. The available hydrologic data would be used to establish stage-discharge relationships (rating curves) which would be utilized to determine the corresponding river bed and water surface levels at an adopted flow discharge.

With this in mind, the resulted drop in water surface level can be utilized as an indicator of degradation which consequently could be the result of one or more reasons such as bed erosion, massive bank failure or change in channel roughness. While the increase in water surface level can be utilized as an indicator of sedimentation which consequently could be the result of one or more reasons such as general sedimentation, possible external source of sediment supply by wind and/or flash flood flows, bank erosion or change in channel roughness. This consequently means that any attainable variation in water surface level could be more often than general sedimentation or degradation.

3. COLLECTED DATA

As the first reach of the Nile River is the earliest effected reach by "HAD" construction, the present study was focused on that reach. Daily record of flow discharges downstream "OAD" and the corresponding water surface levels at 6 installed gauging stations from year 1962 to year 2010 was utilized as listed in Table (1). In this case, the daily river flow discharge was considered constant (no subtraction or inflows) along the entire study reach between "OAD" and Esna barrages. Selection of the used gauging stations was carried out in such a way as not influenced by the generated flow turbulence downstream of "OAD" and the backwater curve "BWC" upstream the New Isna barrages as shown in Figure (1). Figure (1) revealed that the backwater curve "BWC" extends for about 40 km upstream the New Isna barrages at passing 275 million m^3/day**.** This in other words means that the downstream boundary of the studied reach at Edfu – El-Mahatta gauge station is located upstream of the backwater curve by 13.985 Km at passing the maximum possible flow discharge downstream "OAD" which equals to 275 million m^3/day. On the other hands, the used gauge stations cover 81.350 km which equivalent to 48.1% of the total length of the first river reach with maximum and minimum spacing of 23.000 and 12.600 km respectively.

Table 1: Available Data for the Hydrological Study

Year	Daily Discharge (mm^3/day)	Daily Water Surface Levels (m) at Gauging Stations with Distance Downstream "OAD"					
		El-Gaafra (Km 33.750)	Kom Ombo (Km 49.650)	Ekleet (Km 62.450)	Selwa- Bahary (Km 85.450)	El-Ramady (Km 102.500)	Edfu (Km 115.100)
1962	•	•	•	•	•	•	•
1963	•	•	•	•	•	•	•
1979	•	•	•	•	•	•	•
1980	•	•	•	•	•	•	•
1989	•	•	•	•	•	•	•
1990	•	•	•	•	•	•	•
1999	•	•	•	X	•	•	•
2000	•	•	•	X	•	•	•
2009	•	X	•	X	•	•	•
2010	•	X	•	X	•	•	•

Where

X Unreachable data

• Available Data

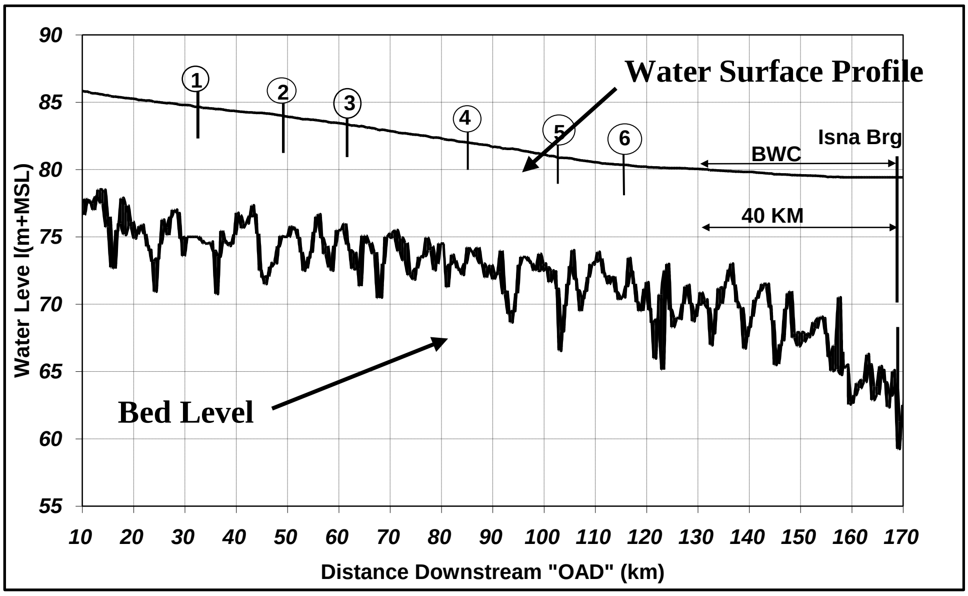

Figure 1: Gauge Stations and Back Water Curve Locations along the Study Reach

The collected data for the daily flow discharges downstream "OAD" and the corresponding water surface levels at the 6 gauge stations covered about 50 years in steps started before "HAD" construction in year 1962 to about 40 years after "HAD" construction in year 2010. On the other hand, it can be seen from Table (1) that some data were not available such as the last four years for at Akleet gauge station and two successive years of 2009 and 2010 for the daily water surface levels at El-Gaafra gauge station.

4. HYDROLOGICAL STUDY

This study was carried out to determine the corresponding water surface level at passing flow discharge of 200 millions m^3/day at each of the used gauge station sites during various selected years. The adopted flow discharge was arbitrary chosen to suit the condition through the River Nile before and after "HAD" construction. In this case, the lag time between the released water downstream "OAD" to reach the farest gauge station located at Edfu (km 115.100) was estimated to be one day. Stage discharge rating curves which establish the relationships between the daily recorded flow discharges downstream "OAD" and the corresponding water surface levels at each gauge station for all adopted years (60 stage discharge relationships) were deduced. The attained results for some selected gauge stations and years are shown in Figures (from 2 to 7). Regression analysis to determine the best fitting mathematical expression for the scatter of the data – which is known as the least square line or curve - was worked out for all adopted sites and years as listed in Table (2). This because applying such regression minimizes the squared residuals and consequently deviation of the determined values from the real measure.

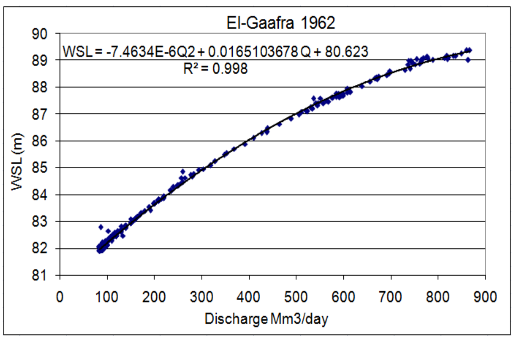

Figure 2: Rating Curve at El Gaafra (1962)

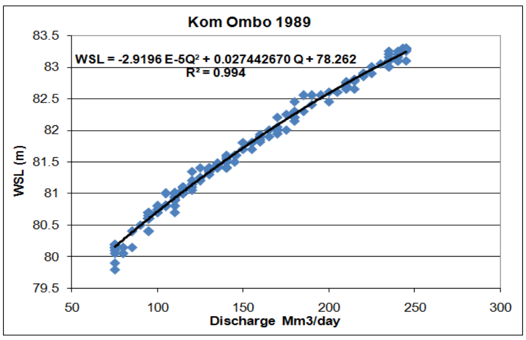

Figure 3: Rating Curve at Kom Ombo (1989)

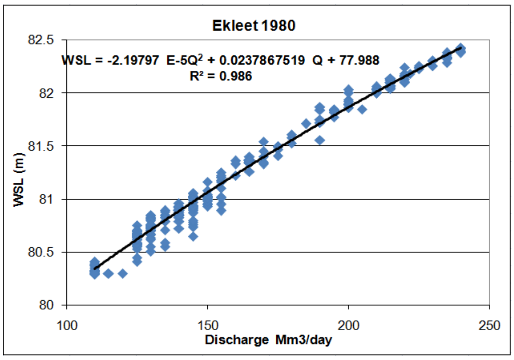

Figure 4: Rating Curve at Ekleet (1980)

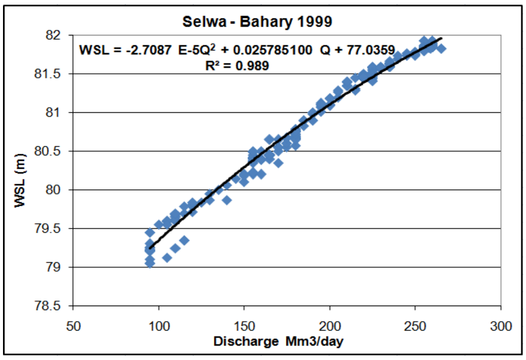

Figure 5: Rating Curve at Selwa- Bahary (1999)

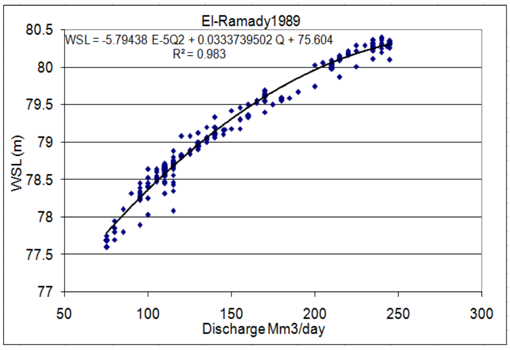

Figure 6: Rating Curve at El-Ramady (1989)

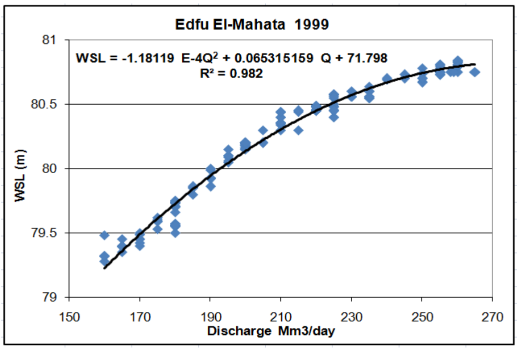

Figure 7: Rating Curve at Edfu (1999)

Table 2: Produced Stage Discharge Relationships Numbers

Years	Derived Rating Curve Equations					
	El-Gaafra (Km 33.75)	Kom Ombo (Km 49.65)	Ekleet (Km 62.45)	Selwa-Bahary (Km 85.45)	El-Ramady (Km 102.50)	Edfu El-Mahatta (Km 115.10)
1962	Eq. No. (1)	Eq. No. (11)	Eq. No. (21)	Eq. No. (31)	Eq. No. (41)	Eq. No. (51)
1963	Eq. No. (2)	Eq. No. (12)	Eq. No. (22)	Eq. No. (32)	Eq. No. (42)	Eq. No. (52)
1979	Eq. No. (3)	Eq. No. (13)	Eq. No. (23)	Eq. No. (33)	Eq. No. (43)	Eq. No. (53)
1980	Eq. No. (4)	Eq. No. (14)	Eq. No. (24)	Eq. No. (34)	Eq. No. (44)	Eq. No. (54)
1989	Eq. No. (5)	Eq. No. (15)	Eq. No. (25)	Eq. No. (35)	Eq. No. (45)	Eq. No. (55)
1990	Eq. No. (6)	Eq. No. (16)	Eq. No. (26)	Eq. No. (36)	Eq. No. (46)	Eq. No. (56)
1999	Eq. No. (7)	Eq. No. (17)	-	Eq. No. (37)	Eq. No. (47)	Eq. No. (57)
2000	Eq. No. (8)	Eq. No. (18)	-	Eq. No. (38)	Eq. No. (48)	Eq. No. (58)
2009	-	Eq. No. (19)	-	Eq. No. (39)	Eq. No. (49)	Eq. No. (59)
2010	-	Eq. No. (20)	-	Eq. No. (40)	Eq. No. (50)	Eq. No. (60)

The above Table (2) did not contain the two equations Numbers (9 and 10) for El-Gaafra gauge station and the four Equations number (27, 28, 29 and 30) for Ekleet gauge station which is due to the unavailability of daily water surface levels data at these locations. On the other hand, to guarantee the validity of the generated equations, the coefficient of determination (R^2) - which represents the percent of the data that closest to the line of best fit – were determined. The best mathematical relationship form - between the daily passing flow discharge and the corresponding water surface level – was determined through fitting regression analysis for all sites and years as listed in Tables (3 and 4).

Table 3: Regression Results for the Upstream Gauge Stations

No.	Station and year		Eq. No.	Rating Curve Equations	R^2	W.S.L. (m)**
1	El-Gaafra	1962	1	$WSL = -7.4634E\text{-}6Q^2 + 0.0165103678\ Q + 80.623$	0.998	(83.63)
2		1963	2	$WSL = -7.3054\ E\text{-}6Q^2 + 0.0165248949\ Q + 80.580$	0.998	(83.59)
3		1979	3	$WSL = -8.777\ E\text{-}6Q^2 + 0.019774143\ Q + 79.775$	0.994	(83.38)
4		1980	4	$WSL = -1.5780\ E\text{-}5Q^2 + 0.022415846\ Q + 79.518$	0.995	(83.37)
5		1989	5	$WSL = 1.6127\ E\text{-}5Q^2 + 0.011672368\ Q + 80.234$	0.982	(83.21)
6		1990	6	$WSL = -3.86\ E\text{-}5Q^2 + 0.0301843\ Q + 78.813$	0.983	(83.31)
7		1999	7	$WSL = -1.84088\ E\text{-}5Q^2 + 0.0247078155\ Q + 79.330$	0.996	(83.53)
8		2000	8	$WSL = -2.59333\ E\text{-}5Q^2 + 0.0271634188\ Q + 79.188$	0.999	(83.58)
9	Kom-Ompo	1962	11	$WSL = -9.614\ E\text{-}6Q^2 + 0.018878211\ Q + 79.335$	0.997	(82.73)
10		1963	12	$WSL = -7.88\ E\text{-}6Q^2 + 0.01717786\ Q + 79.349$	0.993	(82.47)
11		1979	13	$WSL = 4.9702\ E\text{-}6Q^2 + 0.0152165973\ Q + 79.319$	0.969	(82.56)
12		1980	14	$WSL = -1.956\ E\text{-}7Q^2 + 0.0170736137\ Q + 79.152$	0.967	(82.56)
13		1989	15	$WSL = -2.9196\ E\text{-}5Q^2 + 0.027442670\ Q + 78.262$	0.994	(82.58)
14		1990	16	$WSL = -3.6956\ E\text{-}5Q^2 + 0.030473085\ Q + 77.989$	0.995	(82.61)
15		1999	17	$WSL = -1.11153\ E\text{-}5Q^2 + 0.0208212579\ Q + 79.026$	0.991	(82.75)
16		2000	18	$WSL = -2.41676\ E\text{-}5Q^2 + 0.0246972713\ Q + 78.844$	0.993	(82.82)
17		2009	19	$WSL = -3.6152\ E\text{-}5Q^2 + 0.029761333\ Q + 78.416$	0.970	(82.92)
18		2010	20	$WSL = -2.4891\ E\text{-}5Q^2 + 0.025401531\ Q + 78.832$	0.977	(82.91)
19	Akleet	1962	21	$WSL = -8.327\ E\text{-}6Q^2+ 0.017637026\ Q + 78.466$	0.998	(81.66)
20		1963	22	$WSL = -8.363\ E\text{-}6Q^2 + 0.017576125\ Q + 78.578$	0.995	(81.76)
21		1979	23	$WSL = -1.21985\ E\text{-}5Q^2 + 0.0201489253\ Q + 78.315$	0.987	(81.86)
22		1980	24	$WSL = -2.19797\ E\text{-}5Q^2 + 0.0237867519\ Q + 77.988$	0.986	(81.87)
23		1989	25	$WSL = -6.95024\ E\text{-}6Q^2 + 0.017924985\ Q + 78.546$	0.997	(81.85)
24		1990	26	$WSL = -7.1954\ E\text{-}6Q^2 + 0.0182243059\ Q + 78.521$	0.995	(81.88)

Where:
WSL (W.S.L.) is the water surface level (m)
Q is the passing flow discharge (million m^3/day)
R^2 is the coefficient of determination
(m)** is Water surface levels coresponding the HAD release of 200 mm^3/day

Table 4: Regression Results for the Downstream Gauge Stations

No.	Station and year		Eq. No.	Rating Curve Equations	R^2	W.S.L. (m)**
25	Selwa- Bahary	1962	31	$WSL = -8.103\,E\text{-}6Q^2 + 0.017090650\,Q + 77.415$	0.998	(80.51)
26		1963	32	$WSL = -8.5099\,E\text{-}6Q^2 + 0.0173007490\,Q + 77.429$	0.990	(80.55)
27		1979	33	$WSL = -1.185318\,E\text{-}5Q^2 + 0.01918997\,Q + 77.534$	0.975	(80.90)
28		1980	34	$WSL = -2.196385\,E\text{-}5Q^2 + 0.02316341\,Q + 77.161$	0.973	(80.92)
29		1989	35	$WSL = -4.0180\,E\text{-}5Q^2 + 0.028889937\,Q + 76.725$	0.994	(80.90)
30		1990	36	$WSL = -3.43623\,E\text{-}5Q^2 + 0.0268667561\,Q + 76.874$	0.992	(80.87)
31		1999	37	$WSL = -2.7087\,E\text{-}5Q^2 + 0.025785100\,Q + 77.0359$	0.990	(81.11)
32		2000	38	$WSL = -2.2256\,E\text{-}6Q^2 + 0.0127512207\,Q + 78.781$	0.977	(81.42)
33		2009	39	$WSL = -2.4158\,E\text{-}5Q^2 + 0.021319711Q + 77.999$	0.942	(81.30)
34		2010	40	$WSL = -2.4562\,E\text{-}5Q^2 + 0.020740798\,Q + 78.119$	0.952	(81.28)
5	El-Ramady	1962	41	$WSL = -7.9446\,E\text{-}6Q^2 + 0.0168831005\,Q + 76.346$	0.995	(79.40)
36		1963	42	$WSL = -7.7520\,E\text{-}6Q^2 + 0.0162672741\,Q + 76.585$	0.982	(79.53)
37		1979	43	$WSL = -1.46262\,E\text{-}5Q^2 + 0.0192025047\,Q + 76.763$	0.923	(80.02)
38		1980	44	$WSL = -4.60999\,E\text{-}5Q^2 + 0.0313468904\,Q + 75.664$	0.961	(80.09)
39		1989	45	$WSL = -5.79438\,E\text{-}5Q^2 + 0.0333739502\,Q + 75.604$	0.983	(79.96)
40		1990	46	$WSL = -5.86019\,E\text{-}5Q^2 + 0.0340959718\,Q + 75.504$	0.971	(79.98)
41		1999	47	$WSL = 1.4102\,E\text{-}6Q^2 + 0.0136482425\,Q + 77.454$	0.969	(80.24)
42		2000	48	$WSL = -2.17867\,E\text{-}5Q^2 + 0.0182335939\,Q + 77.726$	0.949	(80.50)
43		2009	49	$WSL = -1.74319\,E\text{-}5Q^2 + 0.0171856666\,Q + 77.781$	0.919	(80.52)
44		2010	50	$WSL = 3.9059\,E\text{-}6Q^2 + 0.0079607622\,Q + 78.649$	0.910	(80.40)
45	Edfu El-Mahatta	1962	51	$WSL = -1.0401\,E\text{-}5Q^2 + 0.017723731\,Q + 75.703$	0.978	(78.83)
46		1963	52	$WSL = -6.6452\,E\text{-}6\,Q^2 + 0.0150066357\,Q + 76.153$	0.952	(78.89)
47		1979	53	$WSL = -9.4391\,E\text{-}6Q^2 + 0.0172325269\,Q + 76.734$	0.928	(79.80)
48		1980	54	$WSL = -2.4896\,E\text{-}5Q^2 + 0.023577381\,Q + 76.146$	0.956	(79.87)
49		1989	55	$WSL = -5.97226\,E\text{-}5Q^2 + 0.0339297737\,Q + 75.370$	0.985	(79.77)
50		1990	56	$WSL = -5.84119\,E\text{-}5Q^2 + 0.0340363362\,Q + 75.306$	0.969	(79.78)
51		1999	57	$WSL = -1.18119\,E\text{-}4Q^2 + 0.065315159\,Q + 71.798$	0.983	(80.14)
52		2000	58	$WSL = 1.821\,E\text{-}5Q^2 - 0.00015182\,Q + 79.601$	0.956	(80.30)
53		2009	59	$WSL = -1.74852\,E\text{-}5Q^2 + 0.0168859935\,Q + 77.650$	0.935	(80.33)
54		2010	60	$WSL = 4.5238\,E\text{-}6Q^2 + 0.0078717797Q + 78.444$	0.907	(80.20)

The above Table (3) did not contain the two equations numbers (9 and 10) for El-Gaafra gauge station and the four equations numbers (27, 28, 29 and 30) for Ekleet gauge station which is due to unavailable daily water surface levels data at those locations.

5. ANALYSIS OF THE ATTAINED RESULTS

The water surface level at passing 200 millions m^3/day flow discharge as determined from the equations in Tables (3 and 4) were utilized to work out the average values for every two successive years at the 6 gauge stations as listed in Table (5). In this table the mean value of water surface level during the successive years 1962 and 1963 at each gauge station was assigned as the condition before "HAD" construction. While the mean values for each two other successive years at each of the used gauge stations were worked out to demonstrate the water surface level after "HAD" construction. Therefore, considering the mean values of water surface level at each gauge station before "HAD" construction as the reference line for the expected variations after "HAD" construction, the difference in the calculated average water surface level with respect to the reference level at each gauge site was determined as listed in Table (5). In this Table, the negative and positive signs signify lower and higher bed and water surface levels respectively with respect to the condition before "HAD" construction. This in other words can be considered as degradation and sedimentation respectively with respect to the condition before "HAD" construction.

Table 5: Degradation and Sedimentation Process Calculations

No.	Gauge Station and year	Average W.S.L. of each two successive years (m)	Difference (m)
1	El-Gaafra (1962 + 1963)	(83.610)	0.00
2	El-Gaafra (1979 + 1980)	(83.375)	- 0.235
3	El-Gaafra (1989 + 1990)	(83.260)	- 0.350
4	El-Gaafra (1999 + 2000)	(83.555)	- 0.055
5	El-Gaafra (2009 +2010)	No DATA	No DATA
6	Kom-Ompo (1962 + 1963)	(82.600)	0.00
7	Kom-Ompo (1979 + 1980)	(82.560)	- 0.040
8	Kom-Ompo (1989 + 1990)	(82.595)	- 0.005
9	Kom-Ompo (1999 + 2000)	(82.785)	+ 0.185
10	Kom-Ompo (2009 +2010)	(82.915)	+ 0.315
11	Akleet (1962 + 1963)	(81.710)	0.00
12	Akleet (1979 + 1980)	(81.865)	+ 0.155
13	Akleet (1989 + 1990)	(81.865)	+ 0.155
14	Akleet (1999 + 2000)	No DATA	No DATA
15	Akleet (2009 +2010)	No DATA	No DATA
16	Selwa- Bahary (1962 + 1963)	(80.530)	0.00
17	Selwa- Bahary (1979 + 1980)	(80.915)	+ 0.385
18	Selwa- Bahary (1989 + 1990)	(80.885)	+ 0.355
19	Selwa- Bahary (1999 + 2000)	(81.265)	+ 0.735
20	Selwa- Bahary (2009 +2010)	(81.290)	+ 0.760
21	El-Ramady (1962 + 1963)	(79.467)	0.00
22	El-Ramady (1979 + 1980)	(80.054)	0.584
23	El-Ramady (1989 + 1990)	(79.970)	0.500
24	El-Ramady (1999 + 2000)	(80.371)	0.901
25	El-Ramady (2009 +2010)	(80.459)	0.989
26	Edfu El-Mahatta (1962 + 1963)	(78.860)	0.00
27	Edfu El-Mahatta (1979 + 1980)	(79.835)	+ 0.975
28	Edfu El-Mahatta (1989 + 1990)	(79.775)	+ 0.915
29	Edfu El-Mahatta (1999 + 2000)	(80.220)	+ 1.360
30	Edfu El-Mahatta (2009 +2010)	(80.265)	+ 1.405

The attained results in Table (5) were utilized to demonstrate the occurred variations in bed and water surface levels along the studied reach through investigated time between years 1962 and 2010. This was carried out with respect to the location along the river reach and since "HAD" construction till now according to the following two aspects:

1. Considering the mean value of water surface level - at passing 200 millions m^3/day at each of the studied gauge stations before "HAD" construction - as the reference line. The determined mean values for each two other successive years at each of the used gauge stations would be plotted as function of time to demonstrate the variation in river bed and water surface level at those years after "HAD" construction till year 2010. This – in other words – can demonstrate the developed degradation or sedimentation along the first river reach downstream "OAD" after "HAD" construction till year 2010 as illustrated in Figure (8).

2. Considering mean values of bed and water surface levels before "HAD" construction - at each installed gauge station – as reference level point, variation of degradation or sedimentation along the reach (i.e. as function of distance) after "HAD" construction can be independently worked out at each gauge station location with respect to the applied years up to 2010 as illustrated in Figures (9 and 10).

The listed results in Table (5) were utilized to demonstrate various variations in bed and water surface levels with respect to each gauge site and its location which can be demonstrated as follows:

5.1 Sedimentation and Degradation Developments

The reached calculations in Table (5) were utilized to demonstrate various variations in bed and water surface levels at each gauge stations as listed in Table (6) and shown in Figure (8).

Table 6: Average Water Surface Level Variations at Various Gauges

Years	Average water surface level variation (cm)					
	El-Gaafra Km 33.70	Kom Ombo Km 49.65	Ekleet Km 62.45	Selwa-Bahary Km 85.45	El-Ramady Km 102.50	Edfu El-Mahatta Km 115.10
(1962 + 1963)	0.0	0.0	0.0	0.0	0.0	0.0
(1979 + 1980)	- 23.5	- 4.0	+ 15.5	+ 38.5	+ 58.4	+ 97.5
(1989 + 1990)	- 35.0	- 0.5	+ 15.5	+ 35.5	+ 50.0	+ 91.5
(1999 + 2000)	- 5.5	+ 18.5	NA	+ 73.5	+ 90.1	+ 136.0
(2009 + 2010)	NA	+ 31.5	NA	+ 76.0	+ 98.9	+ 140.5

[NA] in the above Table is related to unavailable water surface data at El-Gaafra gauge station in years 2009 and 2010 and also at Ekleet gauge station in years 1999, 2000, 2009 and 2010.

Table (6) and Figure (8) signify that only the upstream parts of the study reach at El-Gaafra and Kom - Ompo gauge stations were subjected to degradation. This degradation took place since "HAD" construction till years 2002 at El-Gaafra and 1990 at Com - Ompo gauge stations. This degradation reached its maximum value of 0.35 and 0.04 m at El-Gaafra and Kom - Ompo gauge stations at years 1990 and 1980 respectively. The recorded degradation at the mentioned two upstream gauge stations turned over and recovered to sedimentation at years 2002 and 1991 for El-Gaafra and Kom – Ompo gauge stations respectively which reached to a maximum value of 0.011 and 0.315 m at El- Gaafra and Kom – Ompo gauge stations respectively in year 2010. This in other words means that the river bed at the upstream parts at El-Gaafra and Kom – Ompo gauge stations were subjected to sedimentation starting from years 2002 and 1991 at the two mentioned gauge stations respectively till year 2010.

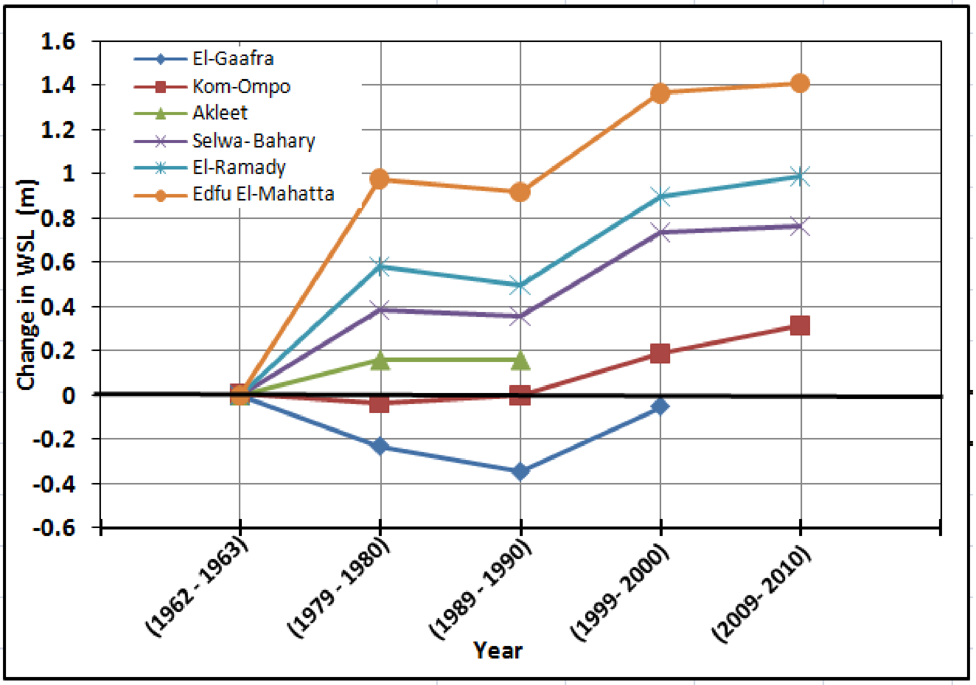

Figure 8: Bed and Water Surface Level Variations at different Gauge Stations

On the other hand, Figure (8) shows that at the rest of the studied river reach from Akleet to Edfu El - Mahatta gauge stations have not been subjected to any degradation since "HAD" construction till year 2010. The monitored sedimentation (deposition) within such reach reached a maximum value of 0.760, 0.989 and 1.405 m at Selwa – Bahary, El – Ramady, and Edfu – El-mahatta gauge stations respectively in year 2010 with respect to the condition before "HAD" construction. Also Table (5) and Figure (8) illustrate some reduction in the accumulated average sedimentation at the downstream three gauge stations which took place between years 1980 and 1990. This reduction in the accumulated sedimentation within the assigned period could be an indicator for impermanent degradation through the study reach. This reduction reaches 0.030, 0.084 and 0.060 m at Selwa - Bahary, El - Ramady and Edfu El - Mahatta gauge stations respectively. The mentioned reduction in developed deposition was followed by such significant sedimentation depth between years 1990 and 2000 which reaches 0.380, 0.401 and 0.445 m at the mentioned three gauge stations respectively.

Justification of the observed decline in the sedimentation developments between years 1980 and 1990 along most of the installed gauge stations was carried out in the view point of the maximum annual daily flow discharges downstream of "OAD" between years 1962 and 2010 as listed in Table (7).

Table 7: Annual Maximum Flow Discharge Downstream "OAD"

No.	Year	Max. Discharge (m.m^3/day)	No.	Year	Max. Discharge (m.m^3/day)	No.	Year	Max. Discharge (m.m^3/day)	No.	Year	Max. Discharge (m.m^3/day)
1	1962	867	14	1975	225	27	1988	225	40	2001	270
2	1963	862	15	1976	220	28	1989	245	41	2002	275
3	1964	911	16	1977	220	29	1990	240	42	2003	260
4	1965	400	17	1978	230	30	1991	240	43	2004	250
5	1966	237	18	1979	240	31	1992	240	44	2005	230
6	1967	213	19	1980	240	32	1993	240	45	2006	245
7	1968	220	20	1981	240	33	1994	240	46	2007	250
8	1969	225	21	1982	240	34	1995	250	47	2008	250
9	1970	225	22	1983	240	35	1996	250	48	2009	255
10	1971	230	23	1984	230	36	1997	270	49	2010	255
11	1972	230	24	1985	240	37	1998	250	50	2011	260
12	1973	230	25	1986	245	38	1999	260			
13	1974	230	26	1987	235	39	2000	270			

Table (7) revealed that although the maximum annual flow discharge downstream of "OAD" after "HAD" construction reached 275 million m^3/day which was recorded in year 2002, the maximum recorded value between years 1980 and 1990 reached 245 million m^3/day in years 1986 and 1989. This led to conclude that the increasing daily flow discharge downstream of "OAD" can not be considered as a reason for the observed decrease in the sedimentation developments between years 1980 and 1990 along the most of the installed gauge stations. Moreover, the construction of the New Isna barrages can not be considered as reason for such decline in degradation because such project took place between years 1991 and 1994. Therefore, more studies should be carried out to explain the observed reduction in the average sedimentation between years 1980 and 1990 which is out of the scope of the present research.

On the other hand, as the achieved results for the variation in the bed and water surface levels after "HAD" construction disagree with the most published studies which expected general degradation along the first river reach, more investigations should be carried out.

5.2 Longitudinal Water Profiles

The reached calculations in Table (5) were also utilized to show the derived variations in water surface levels at each gauge stations for all years as listed in Table (8) and shown in Figure (9). While Figure (10) demonstrates the determined degradation and sedimentation developments as a vertical coordinate along the studied reach

Table 8: Longitudinal Water Surface Profile Developments

Years	Variation in W.S.L. at different gauges (m)					
	El-Gaafra Km 33.750	Kom Ombo Km 49.650	Ekleet Km 62.450	Selwa-Bahary Km 85.450	El-Ramady Km 102.500	Edfu El-Mahatta Km 115.100
(1962 + 1963)	83.610	82.600	81.710	80.530	79.467	78.860
(1979 + 1980)	83.375	82.560	81.865	80.915	80.054	79.835
(1989 + 1990)	83.260	82.595	81.865	80.885	79.970	79.775
(1999 + 2000)	83.555	82.785	NA	81.265	80.371	80.220
(2009 + 2010)	NA	82.915	NA	81.290	80.459	80.265

(NA) in the above Table is related to unavailable water surface data at El-Gaafra gauge station in years 2009 and 2010 and also at Ekleet gauge station in years 1999, 2000, 2009 and 2010.

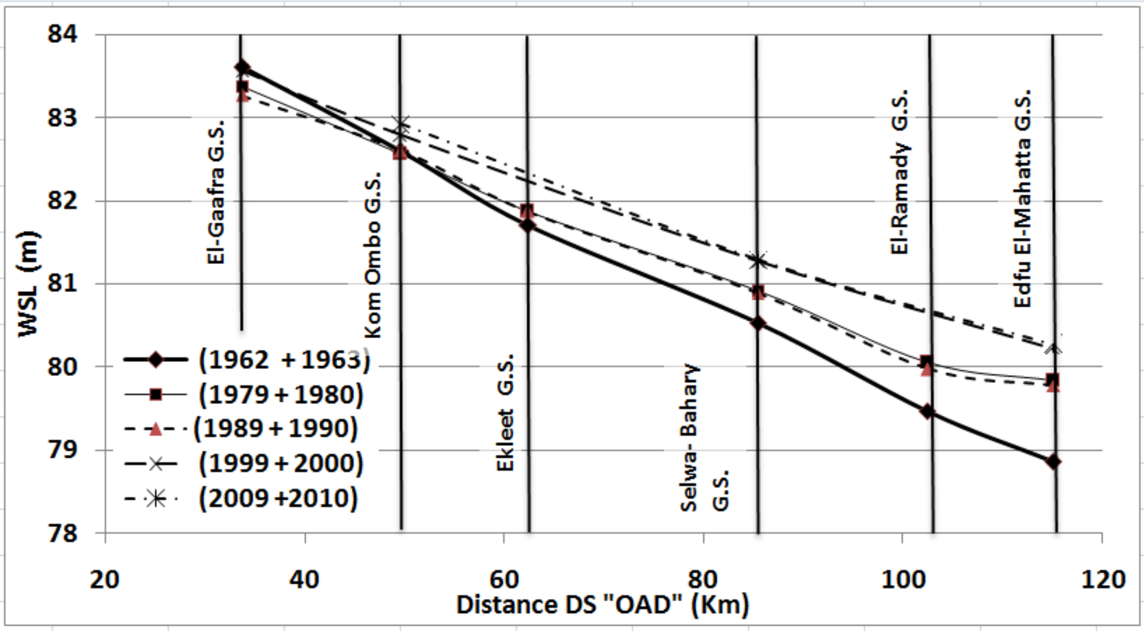

Figure 9: Water Surface Level Profiles along the Studied Reach

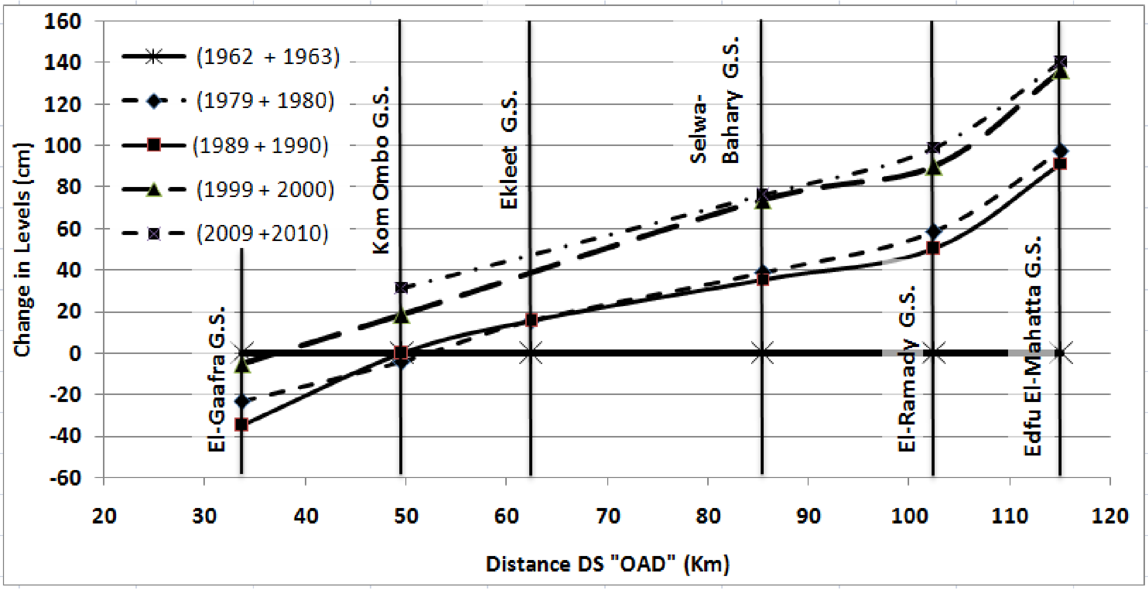

Figure 10: Degradation and Sedimentation Developments along the Studied Reach

Considering the condition before "HAD" construction – which is represented by years 1962 and 1963 – the water surface levels at El-Gaafra and Edfu El-Mahatta were (83.610) m and (78.860) m respectively. As the distance between the two mentioned sites is 81.35 km, the longitudinal water surface slope can be worked out as 5.84 cm/km. Considering the latest condition after "HAD" construction – which is represented by years 2009 and 2010 – the water surface levels at Kom – Ompo and Edfu El-Mahatta were (82.915) m and (80.265) m respectively. As the distance between the two mentioned sites is 65.450 km, the longitudinal water surface slope can be worked out as 4.05 cm/km. This leads to conclude that one major impact of "HAD" construction is reducing the water surface slope – through the studied reach at passing flow discharge of 200 millions m^3/day – from 5.84 cm/km in year 1962 to 4.05 cm/km in year 2010. Since the flow through the studied reach is steady condition, therefore the observed variations in water surface slope between years 1962 and 2010 can be considered similar to that for the bed levels. Considering that the average width for the first river reach is 717 m (Wail, A.F. 2012), therefore the total deposited materials on the bed along the represented river reach (sedimentation) would be worked out as 42.5 million m^3. This led to conclude that the first River Nile reach is being subjected after "HAD" construction to sedimentation and not degradation as expected from several studies.

6. CONCLUSIONS

1. Numerous studies to justify and quantify the side effects of "HAD" constructions - concerning river bed degradation and sedimentation downstream of "OAD" – were reviewed and summarized which anticipated general degradation. However, so far no detailed results for specific time and locations have been materialized.
2. Employing daily recorded observations for water surface levels and the corresponding flow discharges to produce stage discharge rating curves leading to judge such sedimentation and degradation processes downstream of "OAD" is the best and accurate technique to fulfill such purpose.
3. El-Gaafra and Kom - Ompo gauge stations were the only sites subjected to degradation since "HAD" construction which turned over and recovered to sedimentation at years 2002 and 1991 for El-Gaafra and Kom – Ompo respectively which reached to a maximum value of 0.0111 and 0.315 m at El- Gaafra and Kom – Ompo in year 2010.
4. The downstream part of the study reach was not subjected to any degradation since "HAD" construction till year 2010. The monitored sedimentation (deposition) within such reach in year 2010 reached a maximum value of 0.760, 0.989 and 1.405 m at Selwa – Bahary, El – Ramady, and Edfu – El-mahatta gauge stations respectively with respect to the condition before "HAD" construction.

5. Also Table (6) and Figure (8) illustrate some reduction in the accumulated average sedimentation at the downstream three gauge stations which took place between years 1980 and 1990. This reduction reaches 0.030, 0.084 and 0.060 m at Selwa - Bahary, El - Ramady and Edfu El - Mahatta gauge stations respectively. Thereafter the mentioned reduction in developed deposition was followed by an extensive sedimentation depth between years 1990 and 2000 which reaches 0.380, 0.401 and 0.445 m at the mentioned three gauge stations respectively.
6. The slightly increased daily flow discharge downstream of "OAD" can not be considered as a reason for the observed decrease in the sedimentation developments between years 1980 and 1990 along the most downstream three of the installed gauge stations. And the construction of the New Isna barrages can not be also considered as reason for such decline in degradation because such project took place between years 1991 and 1994. Therefore, one possible explanation for such inconsistency between the expected and the attainable results might be due to the instability in hydro morphological conditions that govern the reach before "HAD" construction.
7. This led to conclude that the first River Nile reach is being subjected after "HAD" construction to increase in water surface level which can be utilized as an indicator of sedimentation and could be the result of one or more reasons such as general sedimentation, possible external source of sediment supply by wind and/or flash flood flows, bank erosion or change in channel roughness.
8. One major impact of "HAD" construction is reducing water surface slope – through the studied reach at passing flow discharge of 200 millions m^3/day – from 5.84 cm/km in year 1962 to 4.05 cm/km in year 2000. A possible reason for such variation could be a reduced bed friction in the considered reach.
9. Providing the historical hydrological information for water surface levels and passing discharges at different gauge stations and hydraulics structures are very essential and fundamental to conduct such research.

7. RECOMMENDATIONS

1. The resulted increase in water surface level through the first river reach can be utilized as an indicator of sedimentation which consequently could be the result of one or more reasons such as general sedimentation, possible external source of sediment supply by wind and/or flash flood flows, bank erosion or change in channel roughness. Therefore, such completing study would be carried out to analyze the real cause for the increase of water surface level.
2. Complementary studies should be carried out to investigate the impact of "HAD" construction on the second, third and fourth Nile River reaches which could be achieved similar to the applied technique in the current study.
3. Subjection of the recorded sedimentation along the studied gauge station sites in the first Nile River reach to some sort of degradation between years 1980 and 1990 could be investigated in more details for every year during the mentioned period.
4. The recorded sedimentation downstream "OAD" after "HAD" construction – which is against all the previously expected studies – should be investigated in more details. Such study can be carried out by focusing on the variation in river bed and water surface levels at only El-Gaafra gauge station site for a long period before "HAD" construction.

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