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MOSUL DAM RESERVOIR SEDIMENTATION CHARACTERISTICS, IRAQ

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Sediment transported by rivers and finally deposited in reservoirs directly affects dam performance and causes a reduction in their storage capacity and hence operating efficiency. In this study, the sedimentation characteristics of Mosul dam reservoir have been evaluated using two topographic maps of the reservoir area at different times (1986 and 2011) via Arc/GIS software. The dam is located on the Tigris River in the northern part of Iraq and started operating in 1986. The water surface area of its reservoir is 380 km² with a designed storage capacity of 11.11 km³ at a maximum operating level (330 m a.s.l). The results showed that the annual sediment deposition rate is 45.72×10^6 m³ year⁻¹ of which 23.2×10^6 and 22.52×10^6 m³ year⁻¹ are in the dead storage and live storage zones respectively. As a consequence, the live and dead storage zones lost 6.9% and 19.66% respectively of their storage capacity during the 25 year of operation of the dam. The water-spread area (water surface area) of the reservoir at dead storage level (300 m a.s.l) was reduced annually by about 1.34 km². Furthermore, the stage-storage capacity curves for future periods (prediction curves) were assessed and compared with adopted prediction curves using 2011 bathymetric survey data.

INTRODUCTION

The water resources in the Middle East are decreasing due to increased water demand and climate change (Altinbilek 2004; World Bank 2006; Droogers et al. 2012; Voss et al. 2013; Al-Ansari 2013). Until 1970, Iraq was regarded as a rich country in water resources due to the presence of the Tigris and Euphrates rivers (Naff 1994; Al-Ansari 1998; Al-Ansari and Knutsson 2011a). The idea of construction of irrigation and flood control systems in Iraq started in the first half of the twentieth century by the Board of Development created by the Kingdom of Iraq (Al-Ansari and Knutsson 2011b). The main reason was to protect the capital city Baghdad and other major cities from flooding. The period 1970-1990 was the best period for construction and development of Iraq's water resources systems. This stopped in 1990 due to the first Gulf War and UN sanctions. At the end of the 1970s, the Turkish Government started to utilize the water of the Tigris and Euphrates Rivers by implementing the South-eastern Anatolia Project (GAP). The project consists of 22 multipurpose dams and 19 hydraulic power plants with a total storage capacity of 100 km³ which is three times more than the overall capacity of Iragi and Syrian reservoirs (Altinbilek 2004; Al-Ansari 2013). The irrigation projects in GAP will irrigate 17103 km² of land that will consume about 22.5 Km³ year⁻¹ of water after completion (Altinbilek 2004; Al-Ansari and Knutsson 2011a; Al-Ansari 2013). The total irrigated area within the Euphrates–Tigris river basins in Iraq in the 1970s was around 40000 km² which decreased to 27800 km² after the second Gulf war in 2003 (Al-Ansari 2013). Furthermore, the annual reduction of the water inflow for the Tigris and Euphrates Rivers before entering Iraqi territory is 0.1335 km³ year⁻¹ and 0.245 km³ year⁻¹ respectively (Issa et al. 2014). Figure 1 shows the rate of reduction and the trend lines of the average monthly water discharge for the Tigris and Euphrates rivers in Iraq. The reduction of flow for both rivers in Iraq is considered to be a national crisis and will have severe negative consequences on health and on environmental, industrial and economic development (Al-Ansari and Knutsson 2011a and b; Al-Ansari et al. 2012; Al-Ansari 2013). In addition, recent studies indicate that water demand in the Middle East and North Africa (MENA region) will increase to reach up to 393 km³ year⁻¹ in 2050 (Droogers et al. 2012; Al-Ansari et al. 2014a and 2014b).

In view of the foregoing, the Iraqi government should take effective action to overcome the water shortages. Among these procedures is the assessment of the sedimentation rates in the reservoirs to determine their actual storage capacities and rate of reduction of storage capacity through time (Al-Ansari and Knutsson 2011; Al-Ansari 2013). Mosul Dam is the biggest and one of the most important strategic projects in Iraq. It is a multipurpose project, constructed to serve many purposes. One of its functions, is to provide water at a rate of 48 m³.sec⁻¹ for an irrigation project known as the *"North Al-Jazira Irrigation project"* that covers an area of 625 km² (Mohammed 2001; ECB 2010). The pumping station for this project is located in the upper zone of Mosul dam reservoir. In 1991 and 2005, the station stopped for several days due to sediment accumulation at its inlets (Mohammed 2001; ECB 2010). Furthermore, the dam has operated since 1986 and no detailed studies have yet been carried out to establish the sedimentation characteristics, evaluate the stage-storage capacity curves and determine sediment distribution within the reservoir.

In the present study, two topographic maps of Mosul reservoir dated 1986 and 2011 in Triangular Irregular Network *"TIN"* format were used for the assessment of sedimentation rate, determining the locations of sediment deposited and computing the reduction in the storage capacity for the live and dead storages as well as for the whole of Mosul reservoir during its operational period. In addition, the

2011 TIN map was used to evaluate the adopted stage-storage capacity curves that were calculated by Imatran Voima Osakeyhtio (IVO), Consulting Engineers, Finland (1968).



Figure 1. Average monthly inflow of Tigris-Euphrates Rivers at Mosul and Hit gauging-stations.

MOSUL RESERVOIR (RESEARCH SITE)

Mosul dam is one of the most important strategic projects in Iraq for the management of its water resources. The project was built on the Tigris River in the north of Iraq, located 60 km north west of Mosul city at a latitude of 36°37'44"N and longitude of 42°49'23"E (Iraqi Ministry of Water Resources 2012) (Fig. 2). The dam is a multipurpose project and it started operating on July 7th, 1986 to provide water for three irrigation projects, flood control and hydropower generation. The dam is an earth filled dam, 113 m high and 3650 m long with its spillway (Iraqi Ministry of Water Resources 2012).

The maximum, normal and dead storage levels of the reservoir are 335, 330 and 300 m a.s.l respectively. The dam was designed to impound 11.11 km³ of water at normal operation level including 8.16 and 2.95 km³ of live storage and dead storage respectively. The shape of the reservoir is almost elongated where then River Tigris enters the upper zone and expands close to the dam site. Its length is about 45 km with width ranging from 2 to 14 km at the normal level with 380 km² of water area (Iraqi Ministry of Water Resources 2012) (Fig. 2). The main source of the water and sediment entering the reservoir flows from the River Tigris. The catchment area of the River Tigris above Mosul dam site is about 56,275 km² shared by Turkey, Syria and Iraq (Swiss consultants 1979; Muhammad and Mohamed 2005; Saleh 2010). Figure 3 shows the average annual water inflow and outflow of the reservoir from 1986 to 2013.



Figure 2. Location of Mosul Dam.



Figure 3. Annual mean inflow and outflow of the Mosul Reservoir for 1986-2013.

DATA PRODUCTION AND ANALYSIS USED

The hydrographic survey or bathymetric survey is a direct measurement technique which is regarded to be the most accurate method in order to determine the total volume of sediment deposited in a reservoir, sedimentation rates, the shape of the bottom profile of the reservoir and the sedimentation pattern (Ferrari and Collins 2006). Recent advances in Global Positioning Systems (GPS) echo sounding survey techniques and computer software has led to a significant reduction in the effort, time and cost of collecting and analyzing survey data (Morris and Fan 1998; Jain and Singh 2003; Ferrari and Collins 2006). The 1986 and 2011 topographic maps for Mosul reservoir area in TIN format were

used to evaluate the sedimentation characteristics. These included; first, determining rates of sedimentation within the live and dead storages and in the whole reservoir in general. Secondly, is finding out the pattern of sediment distribution within the reservoir and identify the locations of sediment accumulation. Finally, is determining the shifting in the stage-storage capacity curve. The maps were provided by Issa et al. from a survey conducted in 2012 (Issa et al. 2013) (Fig. 4). The 1986 map was developed by converting the pre-construction topographic map at a scale of 1:50000 to a digital map in a TIN format using Arc/GIS software while the second map was created from the bathymetric survey results that had been conducted during May of 2011 after 25 year of reservoir operation (Issa et al., 2013).



Figure 4. TIN maps of Mosul reservoir.

The TIN maps were used to compute the storage capacity and water-spread area (water surface area) (WSA) for the live and dead storage zones using Arc/GIS software (Table 1). The reduction in storage capacity of the reservoir for the two surveys at different times represents the total volume of sediment accumulated (Morris and Fan 1998; Ferrari and Collins 2006). Therefore, the above results were used to compute the volume of sediment deposited and the reduction in the WSA for the reservoir over the 25 year period of operation (Table 1).

Storage	Storage capacity (SC)				Water-spread area (WSA)			
	Survey 1986 km ³	Survey 2011 km ³	Difference in SC km ³	% Reduction in SC	Survey 1986 km ²	Survey 2011 km ²	Difference in WSA km ²	% Reduction in WSA
Live	8.16	7.597	0.563	6.9	380	380	0.0	0.0
Dead	2.95	2.37	0.58	19.66	170	136.54	33.46	19.7
Reservoir	11.11	9.967	1.143	10.29	380	380	0.0	0.0

Table 1. Storage capacity and water-spread area of Mosul reservoir for two surveys.

RESULTS AND DISCUSSION

Dams are usually built to achieve many purposes, e.g. water storage for irrigation, hydropower generation, flood control, navigation, urban water supply, and environmental purposes, etc. Reservoir

sedimentation and consequent loss of storage capacity affects directly the future performance of the reservoir. Consequently, it is of prime importance to monitor the rate of sedimentation and the changes in the capacity of the reservoir with time.

According to the observed results (Table 1) the annual reduction rate of the storage capacity of the Mosul reservoir is 45.72×10^6 m³ year⁻¹ (23.2×10^6 m³ year⁻¹ dead and 22.52×10^6 m³ year⁻¹ live storages). This implies that the dead and live zones have been losing 19.66% and 6.9 % of their storage capacity during the 25 year of operation of the dam. Furthermore the annual loss in WSA of the reservoir at dead storage level (300 m a.s.l) zone is 1.34 km² year⁻¹ (Fig. 5). But on the contrary, the WSA at maximum operation or live storage level did not change because the water levels in the reservoir not exceed it during this operation period (ECB 2010). Figure 5 shows the maximum loss in WSA at the dead storage level in the north part of the reservoir.



Figure 5. The boundary of WSA at dead storage level for two surveys calculated using Arc/GIS program.

Furthermore, the longitudinal profiles were plotted along the thalweg of the River Tigris within the reservoir area for both the 1986 and 2011 surveys (Fig. 6). Longitudinal profiles were established using two TIN maps and topographic map before dam construction by Arc/map program within Arc/GIS (Fig. 6). The difference between the 1986 survey and 2011 survey represents the sediment deposited within the reservoir during this period. These longitudinal profiles represent the deepest part of the reservoir bottom along the central portion for the 1986 survey. The diagram shows that the greatest differences in bed elevations were within the upper zone of the reservoir. This implies that most of the sediment had been deposited in this zone where the River Tigris enters the reservoir and has started to create a delta. This sequence is very common in reservoirs as identified by Fan and Morris (1992). The overall bed slope of the river thalwag within the reservoir area changed from 0.65 m km⁻¹ to 0.71 m km⁻¹.

The sedimentation in the reservoir caused a shift in the stage-storage capacity curve. The 2011 TIN map (Fig. 4) was used to compute storage capacity as a function of water elevation for Mosul reservoir using the *"3Danalyst"* command within Arc/GIS program (Table 2).

The data in Table (2) and the adopted curves that proposed by IVO (Fig. 7A) were used to compare the established curves in this work (Fig. 7B). In figure 7B it can be seen that the stage-storage

curve of the 2011 survey falls between the initial volume and 40 years operation curves but closer to the latter. It can also be seen that the curve coincides with the 40 years operation curve at a water elevation above 316 m a.s.l. or more. This might be due to the accumulation of sediment at a greater rate than expected by IVO or due to the fact that the curves proposed by IVO (1968) for the dam were constructed using topographic maps older than that of 1968 while the dam was constructed in 1986. In addition the difference in the dates of map construction and the techniques might have caused these differences.



Figure 6. Longitudinal bed profiles for the thalweg of the River Tigris within Mosul reservoir for the 1986 and 2011 surveys.

Pool Elevation (m a.s.l)	Storage Capacity km ³	Pool Elevation (m a.s.l)	Storage Capacity km ³	Pool Elevation (m a.s.l)	Storage Capacity km ³
250	0	276	0.318	302	2.655
252	0.0000115	278	0.401	304	2.962
254	0.00070	280	0.497	306	3.296
256	0.00244	282	0.609	308	3.662
258	0.0061	284	0.739	310	4.062
260	0.01375	286	0.887	312	4.494
262	0.0279	288	1.051	314	4.961
264	0.0474	290	1.229	316	5.468
266	0.0720	292	1.422	318	6.016
268	0.1024	294	1.633	320	6.606
270	0.141	296	1.862	322	7.260
272	0.189	298	2.108	326	8.610
274	0.248	300	2.371	330	9.967

Table 2. Observed storage capacity of Mosul reservoir at different water levels for 2011 bathymetric survey.

SUMMARY AND CONCLUSION

Reservoir sedimentation and consequent loss of storage capacity directly affects water availability and project operation. In the present study, two topographic plans in TIN format of 1986 and 2011

surveys were used for the assessment of reservoir sedimentation in live and dead storage zones using Arc/GIS software. The results showed that the annual deposition rate in the reservoir is 23.2×10^6 m³ year⁻¹. It is 22.52×10^6 m³ year⁻¹ for the dead storage zone and live storages that equivalent 0.787% and 0.276% annual reduction in the dead and live storage capacities respectively. The water-spread area of the reservoir at dead storage level reduces annually by 1.34 km² (4% of total area at dead storage level). The accumulation of sediment in the reservoir was greater than expected by the previous study undertaken by IVO.



Figure 7. Stage-storage capacity curves for Mosul reservoir.

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REFERENCES

- Al-Ansari NA (1998) Water resources in the Arab countries: Problems and possible solutions. UNESCO International conf. (Water: a looming crisis) Paris pp. 367-376.
- Al-Ansari NA, Knutsson S (2011a) Toward Prudent management of Water Resources in Iraq. J. Advance Science and Engineering Research 1: 53- 67.
- Al-Ansari NA, Knutsson S (2011b) Possibilities of restoring the Iraqi Marshes known as the Garden of Eden, Water and Climate Change in the MENA-Region, International Conference, Germany, 28-29 April, 2011.

- Al-Ansari NA, Ibrahiem N, Alsaman M, Knutsson S (2014a) Water Demand Management in Jordan. J. Engineering 6: 19-26. <u>http://dx.doi.org/10.4236/eng.2014.61004</u>
- Al-Ansari NA, Ibrahiem N, Alsaman M, Knutsson S (2014b) Water Supply Network Losses in Jordan. Journal of Water Resource and Protection 6: 83-96. <u>http://dx.doi.org/10.4236/jwarp.2014.62013</u>
- Al-Ansari NA, Knutsson S, Ali A (2012) Restoring the Garden of Eden, Iraq. J. Earth Science and Geotechnical Engineering 2: 53-88.
- Al-Ansari NA (2013) Management of Water Resources in Iraq: Perspectives and Prognoses. J. Engineering 5: 667-684. <u>http://dx.doi.org/10.4236/eng.2013.58080</u>
- Altinbilek D (2004) Development and Management of the Euphrates–Tigris Basin. Water Resources Development 20: 15–33. doi:10.1080/07900620310001635584
- Droogers P, Immerzeel WW, Terink W et al (2012) Water resources trends in Middle East and North Africa towards 2050. Hydrol. Earth Syst. Sci. 16: 3101–3114. doi:10.5194/hess-16-3101-2012.
- ECB (2010) Sedimentation study at the intake of North Jazira Irrigation project. Final report, College of Engineering, Mosul University, Iraq: 1-112. Engineering Consulting Bureau
- Fan J, Morris GL (1992) Reservoir sedimentation. I: delta and density current deposits. J. of Hydraul. Eng. 118: 354–369.
- Ferrari RL, Collins K (2006) Reservoir Survey and Data Analysis. In: Erosion and Sedimentation Manual.
 Bureau of Reclamation, Sedimentation and River Hydraulics Group, Denver, Colorado, Ch. 9, 66 pp.
 http://www.usbr.gov/pmts/sediment/kb/ErosionAndSedimentation/chapters/Chapter9.pdf Accessed 15 March 2011.
- IVO (1968) Hydrological and Reservoir information. Republic of Iraq, Ministry of Agrarian Reform. No. RU3ML0166. Imatran Voima Osakeyhtio, Consulting Engineers, Finland.
- Iraqi Ministry of Water Resources, (2012) Mosul dam. <u>http://www.mowr.gov.iq/cwaterresourceview.php?id=54</u> Accessed 11 May 2012.
- Issa EI, Al-Ansari NA, Knutsson S (2013) Sedimentation and New Operational Curve for Mosul Dam, Iraq. Hydrological Sciences Journal 58: 1-11. doi: 10.1080/02626667.2013.789138
- Issa IE, Al-Ansari NA, Sherwany G, Knutsson S (2014) Expected Future of Water Resources within Tigris-Euphrates Rivers Basin, Iraq. Journal of Water Resource and Protection 6: 421-432. http://dx.doi.org/10.4236/jwarp.2014.65042
- Jain SK, Singh VP (2003) Water resources systems planning and management. Elsevier Science B.V, Amsterdam: 883 pp.
- Morris GL, Fan J (1998) Reservoir sedimentation handbook, Design and management of dams, reservoirs, and watersheds for sustainable use. McGraw-Hill Book Co., New York, 805 pp.
- Mohammed Y T (2001) Evaluation of Sediment Accumulation at the Intakes of the Main Pumping Station of North Al-Jazira Irrigation Project. MSc. thesis, College of Engineering, Mosul University, Iraq, 170 pp.
- Muhammad AM, Mohamed YT (2005) Estimating Water Yield From all Wadies That Flows to Eastern Bank of Mosul Dam Reservoir. Al-Rafidain Engineering Journal 11: 46-56.
- Naff T (1994) Conflict and Water Use in the Middle East. In: Rogers, P. and Lydon, P., Eds., Water in the Arab World: Perspectives and Prognoses, Harvard University Press, Boston, pp. 253-284.
- Swiss consultants (1979) Mosul dam Project-planning report. State organization of dams: Republic of Iraq,

Ministry of Irrigation 1:34 pp.

- Saleh DK (2010) Stream Gage Descriptions and Stream flow Statistics for Sites in the Tigris River and Euphrates River Basins, Iraq. U.S. Geological Survey. Data series 540: 154 pp. http://pubs.usgs.gov/ds/540/pdf/ds540.pdf Accessed 10 April 2011.
- Voss KA, Famiglietti JS, Lo M et al (2013) Groundwater depletion in the Middle East from GRACE with implications for trans boundary water management in the Tigris-Euphrates Western Iran region. Water Resource Research 49: 904-914. doi:10.1002/wrcr.20078
- World Bank (2006) Iraq: Country Water Resources, Assistance Strategy: Addressing Major Threats to People's Livelihoods. Report No. 36297-IQ: 1-97. <u>http://siteresources.worldbank.org/INTWAT/Resources/Iraq.pdf</u> Accessed 10 May 2012.

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