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Sedimentation Analysis on Reservoir (A Case Study of Sukkur Barrage)

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ABSTRACT

A study was conducted on the 145 largest rivers in the world with consistent long-term sediment records, and the findings indicate that 50% of the rivers statistically tend towards significantly lower flow because of sedimentation. According to reports, the global reservoir gross storage capacity is approximately 6000 km3 and annual reservoir sedimentation rates are approximately 31 km^3 (0.52%). This indicates that by the year 2100, the capacity of the world's reservoirs will have been reduced by 50% due to sedimentation. Since Sukkur Barrage is one of the largest and severely affected reservoirs in Pakistan. This paper involves the HEC-RAS 6.1 to determine sediment transport and deposition of Sukkur Reservoir. The model was calibrated and validated for bathymetric survey of the year 2020. The sedimentation analysis was carried out during the flood season. The results of HEC-RAS 6.1 were incorporated into a GIS software to visualize sediment accumulation in reservoir.

KEYWORDS: Bathymetry, Geomorphological, HEC-RAS, Hydrology, Sedimentation

1 INTRODUCTION

In the process of sedimentation, soil particles are eroded, carried by flowing water or other transporting media, and then deposited as layers of solid particles in bodies of water like reservoirs and rivers. Therefore, reservoir sedimentation refers to the process of filling a reservoir behind a dam with sediments that have been deposited there by streams. Sedimentation, or the final stage of sediment transport, is frequently used in geology as the opposite of erosion. In that regard, sedimentation poses serious issues for the reservoir that can be very difficult to address, such as the termination of transport by siltation or true bed load transport. The dams which are constructed without adequate bottom sluices may need extensive and costly reconstruction to carry out the flushing of sediments and siltation [1]. Annual reservoir depletion rate due to sedimentation and siltation ranges between 0.5%-1% [2]. Pakistan is among the countries that are facing reservoir depletion issues in almost all of the main reservoirs, whether it be hydroelectric, or irrigation based. All of the rivers in the world possess certain amount of sediment load which is reliant on the properties and nature of that particular river [3]. For the past few years, a number of software have been developed to study the reservoir which has accumulated sedimentation and siltation [4]. Prior to the construction of dams and barrages, the Indus River carried between 270 and 600 million tons (MT) of silt annually [5]. HEC-RAS 6.1 and GSTARS are among the software which utilizes a numerical approach and develop multi sediment transport functions which can then be compared to the hydrographic survey conducted on the reservoir by the respected governing body. HEC-RAS 6.1 is designed to perform 1 dimensional and 2 dimensional hydraulic calculations for a full network of natural and constructed channels, overbank-flood plain areas, levee protected areas etc. HEC-6 has been the industry standard for one dimensional mobile bed modelling since 1976 [6].

2 STUDY AREA AND DATA COLLECTION

Sukkur Barrage is located about 225 air miles northeast of Karachi (68° 55'E, 27° 41'N) in the Sindh Province of Pakistan. The Barrage is about 100 miles downstream of Guddu Barrage and about 300 miles upstream of Kotri Barrage. The location of the barrage is shown on drawing 510187/SBRMP/KP/001. The old Lansdowne bridge is roughly three miles upstream of the Sukkur Barrage. Sukkur and Rohri are located on the river's right and left banks, respectively. The approach to the barrage from Lansdowne Bridge. Sukkur Barrage comprises of a 66 spans main barrage, 4725' (Approx 1.4 km) long constructed across the Indus. The structure is primarily made of stone masonry, with two bridges having 60' (18.29m)-long reinforced concrete arches that span openings on an upper deck used for controlling the gates and a lower road deck. The four left bank canals of Khairpur Feeder East, Rohri, Khairpur Feeder West, and Nara Canals, as well as the three right bank canals of Dadu, Rice, and Northwestern Canals, are all controlled by the canal head regulator structures on both banks. Low-level structures known as canal regulators include a road bridge and a deck area for operating the gates. Divide walls, a submerged weir, an approach/tail channel with outer and middle banks within the river and an inner bank next to the right guide bank are all parts of the training works upstream of the main barrage. Between the middle bank and approach channel, there is also an island. The study area extends from approximately 8000' (2.5km) upstream of the barrage to 2500' (0.8km) downstream as shown in Figure 1.

Figure 1: Aerial view of barrage and river approach to the barrage from Lansdowne Bridge

2.1 Geometry Data

The geometric data includes the u/s channel cross-sections and the bed elevations in X-Y coordinate system. The channel geometry was created using a projection file and at a terrain file. The latter was than use in RAS-Mapper to create a geometry file and then 5-Cross sections were plotted on the geometric file for the aid of HEC-RAS model. Multiple points were appointed for construction of channel geometry. Lateral locations were plotted on the X coordinate, and it was appointed a dedicated reference point which covered the section in ascending order from left hand side to right hand side with respect to the bed elevation at specific point. The bathymetry was also carried out along with topographic survey.

2.2 Sediment Data

The sediment data includes Suspended Sediment Load and the Bed Gradation. The data was acquired from ISRIP Survey which was conducted in 2005 and later in 2012 sediment samples were collected on a regular basis for grain size distribution of the sediments. The representative suspended sediment material is a very fine sand with a D^{50} of approximately 0.125mm. The sediment gradation is given in Figure 2.

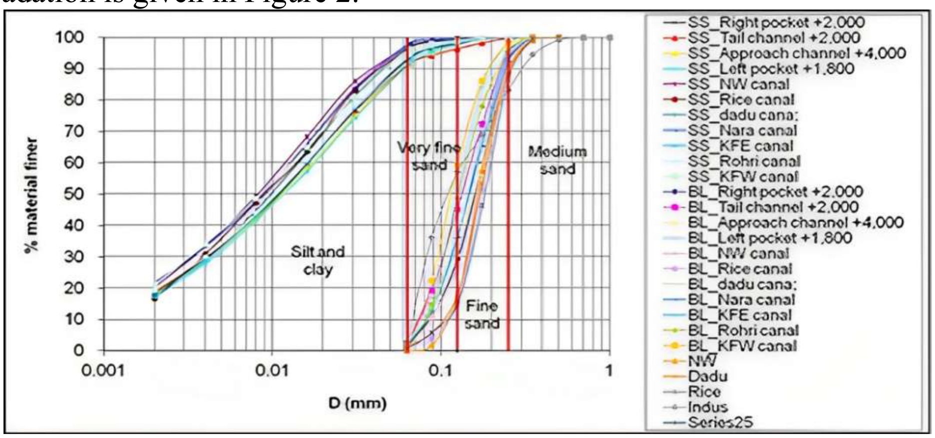

Figure 2 Sediment Gradation

2.3 Hydrological Data

The hydrological data comprises of Water Surface Elevations, Water Discharges and Temperatures were collected from the Year 1970 to Year 2012. Daily discharges were collected from irrigation department, The Government of Sindh Pakistan.

3 RESEARCH METHODOLOGY

The sedimentation analysis was carried out in HEC-RAS 6.1. The sedimentation analysis requires two files, a plan file, and a sediment file. A plan file is composed using a geometry file and a flow file (either steady or un-steady). Once the said files are ready, sediment compotation can be executed in HEC-RAS 6.1. Hydrologic data from the year 1970-2012 was used to simulate un-steady flow. The model was calibrated using Yang's 1973+84 Sediment Transport Function. Sedimentation during the flood periods was plotted on a graph. The validation of model is performed by using the bathymetry data for the year 2020.

Since sedimentation and siltation does not only occur because of water being held back by the dam or weir, there are some other discrete causes and reasons which may subject to higher probability of sedimentation. These causes were studied during the aerial and topographic survey. The hydrology of Indus River basin is also of key reason for extreme sedimentation and siltation. Sedimentation was studied along with these major causes to propose some effective remedial measures. Numerical modelling flow conditions are given in Table 1.

Table 1: Numerical Modelling Flow Conditions

Flow Condition	Q (Cusecs)	d/s WL (ft)
Silt Drop	150,000	193.1
Low Flood	250,000	195.4
Medium Flood	400000	197.5
Very High Flood	850,000	200.1
2010 Peak	1,140,000	202.1
1 in 100	1,340,000	202.9
1 in 200	1,410,000	203.1
1 in 500	1,500,000	203.4

4 RESULTS

4.1 Sedimentation Analysis

The sediment transport and accumulation were calibrated in HEC-RAS 6.1 by using a suitable model. The sediment accumulation and siltation deposition rates were produced for the flood season. The sedimentation deposition for the flood season is given in the (Figure 3). Moreover, the climate change and hydrology of the Indus River basin have also posed large damage to the reservoir. The analysis of the gate opening records also showed that the canal gates typically remain open during floods. This approach is different to the operating procedures of other barrages in particular in Punjab where the canal gates are closed when flows exceed a certain threshold level or sediment concentration exceeds a threshold level. This approach takes account of the fact that sediment concentration and sediment quantities are highest during floods. Sediment concentration at Sukkur barrage is shown in Figure 3.

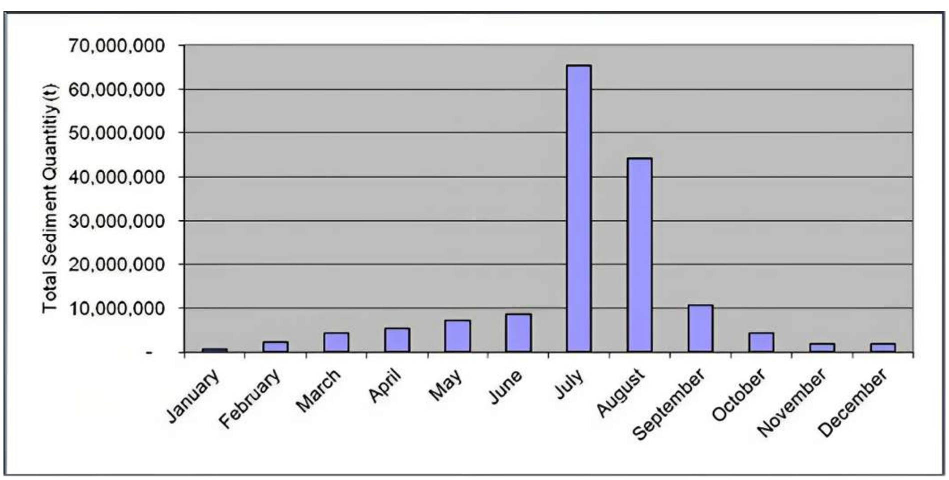

Figure 3: Sediment Concentration at Sukkur Barrage

4.2 Sedimentation Analysis

The Indus River is a dynamic river that changes drastically over time. The limestone outcrops upstream of Sukkur, on the other hand, represent a stable section of the Indus in this area. The river widens downstream towards the barrage. The river upstream of the limestone outcrops can be described as braided, whereas the river downstream can be described as a meandering river channel. The Indus' overall gradient is relatively flat, with a gradient of about 0.47'/mile (about 1 in 11,200) between Mithankot and the Sea. The channel's geometry in RAS-Mapper can be seen in in Figure 4.

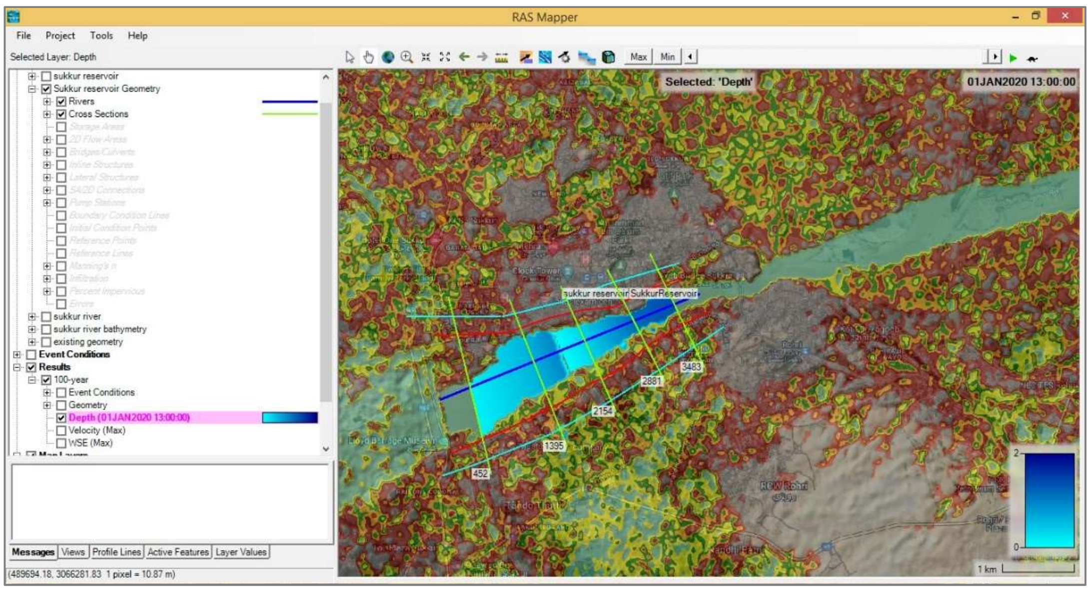

Figure 4: Sukkur Reservoir geometry in RAS-Mapper

The river undergoes frequent morphological changes upstream and downstream of the barrage and deposition has been occurring including upstream of the left pocket, upstream of gates (37 to 54) although this section remains submerged for the majority of the year, upstream and downstream of the closed gates, and adjacent to the right and left divide wall in the pockets.

Deposition on the left bank upstream of the pocket narrows the cross section by up to 400m and possibly encouraged by human intervention as this area is now used for agriculture. Deposition downstream due to the reduction in discharge downstream while sediment concentrations remain the same as upstream or may increase as the clearer, less sediment laden water is diverted into the canals.

5 CONCLUSIONS

Following conclusions are made as a result of sedimentation and geomorphological assessment:

1. Sukkur barrage shows different trend of sedimentation/siltation accumulation unlike any other reservoir in Pakistan.

2. Despite the pockets and the training efforts on the right bank, sediment intake into the canals is still high.
3. The analysis of the gate opening records also showed that the canal gates typically remain open during floods.
4. The direction of flow towards the pocket is affected by deposition upstream of the left pocket.

The above said outcomes shed a light on the behaviour of reservoir. With the help of latest bathymetry and flow data, more accurate and comprehensive results can be achieved in the future.

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REFERENCES

1. Fan, J. and G.L. Morris, *Reservoir sedimentation. I: Delta and density current deposits.* Journal of Hydraulic Engineering, 1992. **118**(3): p. 354-369.
2. GR, B., *Management of siltation in existing and new reservoirs. General Report, paper presented at the 23rd congress of the international commission on large dams, Int. Com. on Large Dams, Brasili.* (2009).
3. Mohammad, M.E., et al., *Sediment in Mosul Dam reservoir using the HEC-RAS model.* Lakes & Reservoirs: Research & Management, 2016. **21**(3): p. 235-244.
4. Ali, M. and A.S. Shakir, *Sustainable sediment management options for reservoirs: a case study of Chashma Reservoir in Pakistan.* Applied Water Science, 2018. **8**(4): p. 103.
5. Mahessar, A.A., et al., *Sediment transport dynamics in the Upper Nara Canal off-taking from Sukkur barrage of Indus River.* Engineering, Technology & Applied Science Research, 2020. **10**(6): p. 6563-6569.
6. Brunner, G.W. and S. Gibson, *Sediment transport modeling in HEC RAS*, in *Impacts of global climate change*. 2005. p. 1-12.