Controlling Sedimentation through Regulating the River by Thalpitigala Reservoir Project

Thanura Lasantha Babarande Guruge¹, Bandara Palugaswewa¹, and Shinji Egashira²

¹Ministry of Irrigation, Colombo 07, Sri Lanka
²ICHARM, Tsukuba, Japan

Correspondence: Thanura Lasantha Babarande Guruge (thanuralasantha@gmail.com)

Received: 20 July 2023 – Revised: 3 October 2023 – Accepted: 14 November 2023 – Published: 19 April 2024

Abstract. Mahaweli is the main river in Sri Lanka and it has many main multipurpose reservoirs, especially to cater power and irrigation requirement of the country. Reservoir capacity loss which is the major problems causing to the effectiveness of the major reservoirs in Sri Lanka, is mainly caused by sedimentation due to upstream erosion.

Hence proper monitoring, calculating and adopting measures are very important in planning a reservoir. But due to the complex nature of factors effect on sedimentation and lack of long-term data make calculation difficult. This study discusses how different data obtained from numerical modelling and bathymetric surveys of different locations of the catchment and those are used to select and verify the empirical equation, calculation of capacity loss and make proposals to minimise sedimentation for proposed Thalpitigala Multipurpose Project in Mahaweli upper catchment.

The outcomes indicate high erosion (690 m³ km⁻²) and sediment transportation making rapid loosing of the capacity (5.13 MCM in 15 years) of the proposed reservoir. Thus, upper catchment protection with reforestation to reduce erosion, introduction of check dams in the upstream flow to trap the transported sediment and introduction of proper removal measures of deposited sediment are discussed for the proposed reservoir project.

1 Introduction

Sediment load is one of the most important parameters required for the selection of the dam type, the estimation of dead storage and for the design of proper sediment flushing facilities.

Among the catchments in Sri Lanka, the highest sediment yield has been reported from the Uma Oya catchment by a study done in 2019 (Dias, 2019). It is shown that erosion is 3 to 130 times faster than the soil loss tolerance (5 t ha⁻¹ annum⁻¹) in Sri Lanka.

Uma Oya catchment (between 6°45'23" N, 81°03'08" E and 6°59'29" N, 81°00'58" E), a sub basin of Mahaweli river basin is located in the South-Eastern slopes of the central hills of Sri Lanka with an area of 720 km² (Fig. 1)

The last reservoir about to construct in this catchment is Thalpitigala which is considered as a multipurpose reservoir project.
In Figs. 3 and 4, the aerial photos in rainy and dry seasons in the proposed reservoir stretch.

The magnitude of sediment transportation in the water can be evidently seen by comparing the dry and flood flows shown in following Figs. 3 and 4. The spill water characteristic of upstream Dayraba reservoir in rainy seasons is shown in Fig. 5.

2 Characteristics of sediment yield in study basin

The sediment quantity transported with the upstream flows deposited and travelled in a reduced rate in the reservoir system governing the distance by the decreased water velocity, making complex analyses in sediment studies.

In the study of the erosion rates in the catchment, the land cover properties, land use properties, geography, soil parameters etc. have to be considered.

When we have to study the sediment inflow, settling, and degradation courses relation with known factors such as water velocity, particle size, particle type, turbidity, cross flows etc. The difficulty of analysing the Sedimentation processes in a reservoir can be reduced by truncating minor factors and considering most influencing factors.

Because of this complexity, many mathematical models and empirical relationships are being developed to simulate the physical processes of sediment transport and deposition in reservoirs.

The results of modelling and simulations can be verified by bathymetric measurements of sediment loads in known
points and volumetric measurements of partials in runoff water. Those can be spatially and temporally analysed to understand the variation of sediment transportation throughout the river flow.

Hereewith we are going to discuss some empirical measurements and simulations used to determine the reservoir sedimentation, life reduction and measures intended to implement to minimize the vulnerability.

The following calculations show three different methods used in three different occasions, for three different locations of the same catchment.

### 2.1 Calculation of Sediment Delivery Ratio and Sediment Yield

The sediment delivery ratio (SDR) of a river basin reflects the conveyance status of sediment which occurs due to erosion of soil, through runoff of the stream flow. The sediment delivery ratio calculation models have certain related conditions such as environmental factors, rainfall, land topography, soil type and texture etc. The drainage basin area method (Vanoni, 1975) is used to determine SDR considering the similarities of above factors to model catchment.

\[
SDR = 0.42A^{-0.125}
\]

Total catchment area of Uma Oya at the confluence of Mahaweli (Upstream of Ranteme reservoir) is 720 km²; Catchment Area = 281.25 sq. miles; Therefore SDR = 0.21

\[
SDR = \frac{\text{Sediment yield}}{\text{Gross Erosion}}
\]

Universal soil loss equation

\[
A = R \times K \times LS \times C \times P
\]

#### Table 1. Specific sediment yield at Welimada Station.

<table>
<thead>
<tr>
<th>Months</th>
<th>t km⁻²</th>
<th>Max</th>
<th>Avg</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>644</td>
<td>160</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Feb</td>
<td>302</td>
<td>92</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Mar</td>
<td>67</td>
<td>15</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Apr</td>
<td>65</td>
<td>25</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>248</td>
<td>44</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>87</td>
<td>19</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>137</td>
<td>25</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Aug</td>
<td>253</td>
<td>46</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Sept</td>
<td>91</td>
<td>27</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Oct</td>
<td>322</td>
<td>112</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Nov</td>
<td>1145</td>
<td>264</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Dec</td>
<td>367</td>
<td>146</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Annual</td>
<td>1983</td>
<td>974</td>
<td>454</td>
<td></td>
</tr>
</tbody>
</table>

2.2 Annual Sedimentation for Proposed Reservoir Location.

As per the sediment analyses done by Ministry of Irrigation, the following results have been obtained in feasibility report. The analyses have been done through bathymetric mapping done for downstream of Uma Oya for a catchment area of 556 km² at Bathmedilla weir section (SDR = 0.22) in 2013.

Annual sediment yield = 18.30tha⁻¹annum⁻¹
Annual sediment yield = 690 m³haannum⁻¹
Annual Sediment Yield = 1128 m³km⁻²annum⁻¹

2.3 Annual sedimentsations at Puhulpola and Dayaraba Reservoirs

The study done by Ministry of Irrigation and Farab in 2010 in above reservoirs in the upstream of Uma Oya using EPM method and sediment sampling data for 8 years, shows the results as follows.

This is a very comprehensive study which has considered most of the complex parameters in simulation of mathematical model. Table 1 shows the summary of compiled data of 8 years.

Table 2 shows the results obtained for upper catchment reservoirs from simulation of sediment bulk density.

https://doi.org/10.5194/piahs-386-1-2024
Table 2. Results of sediment yield in Uma Oya catchment.

<table>
<thead>
<tr>
<th>Location</th>
<th>SDR (m³ km⁻² annum⁻¹)</th>
<th>Annual Sediment Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Puhulpola</td>
<td>0.30</td>
<td>661</td>
</tr>
<tr>
<td>Dyaraba</td>
<td>0.32</td>
<td>724</td>
</tr>
</tbody>
</table>

Figure 6. Erosion rate in Uma Oya basin.

Figure 6 shows the variation of erosion rate in Uma Oya basin according to the simulation done using EPM model.

Herewith, as indicated in Table 3 the practical results obtained from BM and SBD are considered for further analyses as USLE shows fairly high values than experienced.

Accordingly, the specific sediment yield in each location can be showed in following Fig. 7.

Considering the annual sediment yield to proposed Thalpitigala Reservoir, the deposition was projected.

Initial Reservoir capacity = 15.56 MCM
Project Life time = 50 years
Trap Efficiency
Assume percentage filled with t years; 0.43 %
First C/T = 0.066
First Trap Efficiency = 82 %
Final C/T = 0.037
Final Trap Efficiency = 73 %
Average TE = 77.5 %
Time period = 14.4 years
Sediment yield = 5.13 MCM

Accordingly, within one third of life time, the reservoir losses one third of its capacity which implies the total dead storage vanishes. Hence sediment management is very essential

Table 3. Comparison of results with calculated results using universal soil loss equation.

<table>
<thead>
<tr>
<th>Location</th>
<th>Catchment Area (km²)</th>
<th>SDR</th>
<th>Annual Sediment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Puhulpola</td>
<td>180</td>
<td>0.30</td>
<td>1630</td>
</tr>
<tr>
<td>Dayaraba</td>
<td>157</td>
<td>0.32</td>
<td>1739</td>
</tr>
<tr>
<td>Thalpitigala</td>
<td>556</td>
<td>0.22</td>
<td>1195</td>
</tr>
<tr>
<td>Rantebe</td>
<td>720</td>
<td>0.21</td>
<td>1128</td>
</tr>
</tbody>
</table>


Figure 7. Schematic diagram of Reservoir system in Uma Oya.

3 Sediment Control and Management Methods

In controlling and managing the sedimentation, it is needed to outline an allowable sediment discharge from the point we consider, to the downstream. Then the sediment volume should be controlled at the considered point.

In order to reduce reservoir sedimentation, we may have two possible methods: One is to reduce the inflow rate of sediment to the reservoir, and the other is to reduce sedimentation within the reservoir.

The prior methods implicate various erosion controls by means of structural and non-structural measures by using check dams, soil conservation performances, etc. The latter is to reduce the sediment deposition within the reservoir by means of dam operations such as sediment flushing, sediment sluicing, sediment bypassing, etc. Figure 8 illustrates a sample of the check dam to reduce sediment erosion.

4 Conclusion and Recommendations

Among the said measures, for this project the following measures are considered.

- Reduce sediment yield from upstream – Introduce check dams to capture sediments
– Introduce upper catchment management to reduce erosion. – Reforestation

– Route Sediments/Remove sediments – Introduce two bottom outlets to the dam flush through separate channel to adjacent basin- Wela Oya which do not have reservoirs in downstream

4.1 Check dams

In this regard our main intention is to trap sediments. Accordingly, 50% of sediment specially the bed load is intended to be trapped and removed by dredging. Therefore, the closed type check dams (about 3 in selected locations) are recommended. The collected or dredged sediments can be used for other purposes such as construction sand from coarse material and fertilizer by fine organic layer after drying. Those options should be checked and verified with annual collected sediments volume, and verify the feasibility.

4.2 Bottom outlets

Two bottom outlets are suggested for the dam, from each side of the spillway. The sediment flushing is suggested while the reservoir water level is at low levels in order to increase the efficiency if sediments removing. As mention early when the sediment flushing is in operation the sediments could be mixed and disturbed via mechanical methods in order to increase the sediment outflow. Then the trapped or deposited sediments also could be deposited and removed. However frequent and timely flushing can reduce the requirement for mechanical mixing. Those should be carefully mentioned in operation manuals.

In a flushing process, mainly the finer particles are extracted. However, the flushed sediment can’t be allowed to transport in the same basin further downstream river flow since there are some important reservoirs in Mahaweli system. Therefore, the flushed bed load could be trapped just downstream of the dam with a structure such as sedimentation tank, small check dam type walls or cascade, etc. The collected sediments could be removed and used as suggested in check dams.

The suspended sediment can be transported with the flush water to the adjacent catchment Wela Oya which doesn’t have any reservoir in its downstream.

When these structures are designed, design Sediment discharges, flood volumes and levels, required sediment removing frequency, the access and machineries to be used, etc. should be thoroughly examined and analysed in crucial locations.

The monitoring of sediments is very important even after the construction of structures. Hence periodical bathymetric mapping in the reservoir and check dams are essential for timely removals of sediment. The volumetric measurement of sediment yield in identified control points in daily basis is required for integrated sediment management of total reservoir system.

4.3 Upper Catchment Protection Measures

The most sustainable sedimentation control measure among all is the upper catchment development to minimize the erosion. Accordingly, reforestation in steep slopes of the catchment is introduced with soil protection methods. 200 ha new forest plantations have been introduced as an initial step of this.

Code availability. The software EPM is not used in this research. Uma Oya multipurpose project used it for analysing their data. Their results were taken only to verify this research results. Reference is given for that.

Data availability. This study is a part of designing of Thalpitigala Reservoir Project. The designing process is not yet finished. So, some of the data is still not published.

Author contributions. TLBG: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing – original draft preparation, BP: Data curation, Funding acquisition, SE: Supervision, Writing – review & editing.

Competing interests. At least one of the (co-)authors is a guest member of the editorial board of Proceedings of IAHS for the special issue “ICFM9 – River Basin Disaster Resilience and Sustainability by All”. The peer-review process was guided by an independent editor, and the authors also have no other competing interests to declare.
Disclaimer. Publisher’s note: Copernicus Publications remains neutral with regard to jurisdictional claims made in the text, published maps, institutional affiliations, or any other geographical representation in this paper. While Copernicus Publications makes every effort to include appropriate place names, the final responsibility lies with the authors.

Special issue statement. This article is part of the special issue “ICFM9 – River Basin Disaster Resilience and Sustainability by All”. It is a result of The 9th International Conference on Flood Management, Tsukuba, Japan, 18–22 February 2023.

Acknowledgements. We would like to express our special thanks to ICHARM for giving us this opportunity through ICFM-9, guiding the report and funding. We extend our thanks to Ministry of Irrigation, Department of Irrigation, Central Engineering Consultancy Bureau of Sri Lanka and Uma Oya Multipurpose project for providing data, support and guidance.

Review statement. This paper was edited by Kensuke Naito and reviewed by two anonymous referees.

References


