SUSTAINABILITY OF THALPITIGALA DAM IN VIEW OF CLIMATE CHANGE INDUCED SEDIMENTATION

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1. INTRODUCTION

Reservoir sedimentation is worldwide issue and many reservoirs in Sri Lanka are also experiencing a similar threat. The country has got a topography where central part consists of hills with steep slopes. Almost all rivers start from the hill country and, as a consequence, carry large amount of silt during rain.

Sri Lanka has got nearly hundred major reservoirs and many are multi-purpose. Currently there are few ongoing reservoir projects and Thalpitigala reservoir is one of them. The proposed Thalpitigala reservoir is to be built across Uma-oya, a tributary of the Mahaweli River. The reservoir is to be constructed in the middle part of Mahaweli River basin and the dam will be 280 m in length. The capacity of the reservoir has planned to be 15.56 MCM. In addition to providing water for agriculture, it will generate 51.3 GWh of hydro energy. As the downstream area to the reservoir consists of a large extent of agricultural lands, Thalpitigala reservoir is a good intervention for drought risk mitigation. Further, the reservoir is capable of decreasing the probability of floods as Mahaweli river basin downstream areas are prone to flooding during rainy seasons.

A major part of the reservoir catchment consists of homesteads and agricultural land which are well known for poor land management. As a result, heavy soil erosion is occurring in the catchment. The heavy sediment load carried by the Uma-oya can be observed during rainy periods. The Rantambe hydro reservoir just located downstream to the proposed Thalpitigala reservoir location has silted up to almost half of its capacity by now.

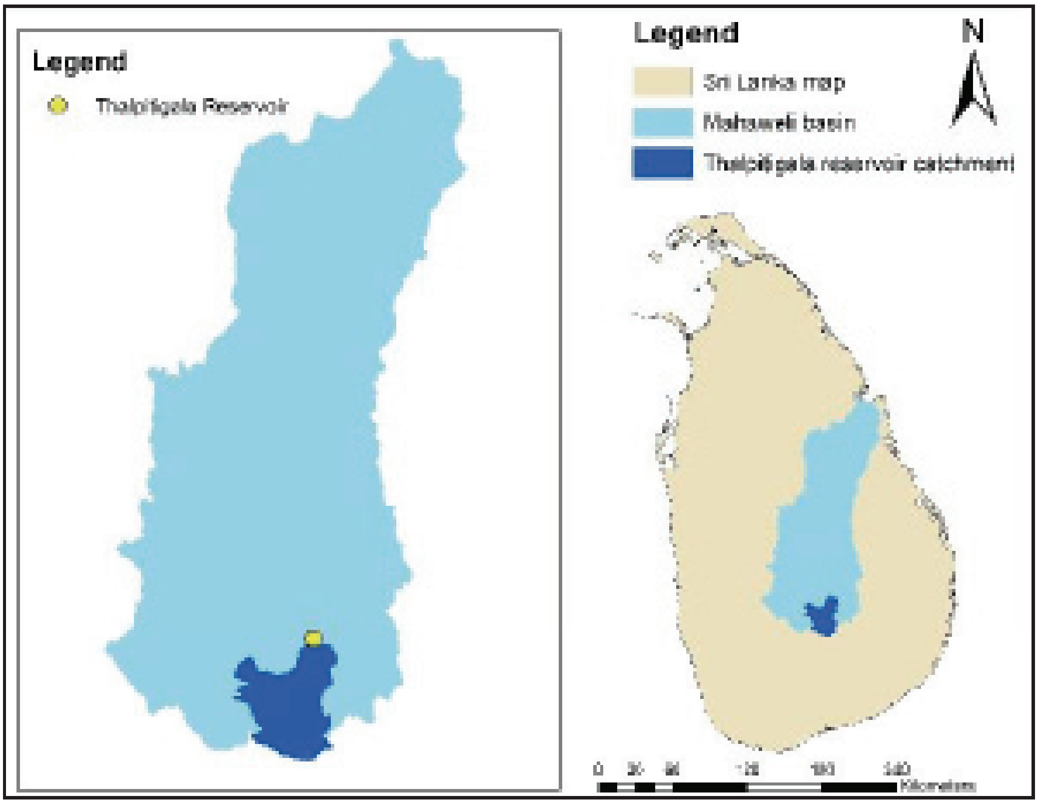

Fig. 1 : Location of the proposed reservoir

The catchment area of proposed Thalpitigala reservoir is 53,075.6 ha, where 37.7 % of it consists of slopes above 30%. Therefore, the potential for soil erosion is high which can be aggravated by probable high intensity rainfalls due to climate change. Eventually, this would cause rapid sedimentation of the reservoir. Although, sedimentation cannot be completely avoided rate of sedimentation is very important as far as expected lifespan of the reservoir is concerned. When expected objectives like providing water to agriculture and hydropower generation are concerned capacity reduction due to sedimentation will reduce such benefits.

The feasibility study for the project has already been done, where lifespan of the reservoir has been taken as 50 years. Accordingly, the Internal Rate of Return (IRR) of the project has been calculated to be 11.77%. If the active design storage does not remain constant during that lifespan of 50 years, the expected benefits related to agriculture and energy generation in will reduce. Accordingly, the IRR will be less than what has been calculated at the feasibility stage. Therefore, rate of sedimentation and consequent capacity reduction during the lifespan of the reservoir should be considered for economic viability of the project.

Further, it is important to control soil erosion in the catchment to mitigate reservoir sedimentation. Hence, it is necessary to identify erosion prone areas. Accordingly, proper mitigation options has to be planned and executed in order to retard soil erosion. As such, soil erosion rates in the catchment is also examined under this study.

Therefore, this study analyses mainly the rate of sedimentation of the reservoir and consequent loss of its capacity together with the sediment yield pattern in the catchment. The Soil Water Assessment Tool (SWAT), a semi distributed hydrological software model, is used for this analysis.

2. LITERATURE REVIEW

2.1 Soil Erosion Process

The Modified Universal Soil Loss Equation (MUSLE) is widely used around the world to estimate soil erosion [Eq.1]. The SWAT model, which was used for this study and described under methodology, also uses the same equation to calculate erosion outputs (*Sed*) of a basin area [1].

$$Sed = 11.8 \times (Q_{surf} \times q_{peak} \times area_{hru})^{0.56} \times K_{USLE} \times C_{USLE} \times P_{USLE} \times LS_{USLE} \times CFRG \quad [1]$$

Where; Q_{surf} - Surface runoff volume (mm/ha)

q_{peak} - Peak runoff rate (m^3/s)

$area_{hru}$ - Area of hydrologic response unit (ha); defined under methodology

K_{USLE} - USLE soil erodibility factor

C_{USLE} - USLE cover and management factor

P_{USLE} - USLE support practice factor

LS_{USLE} - USLE topographic factor

$CFRG$ - Coarse fragment factor

As per the MUSLE all other factors except Q_{surf} and q_{peak} are unique characteristics of a basin area. As the same land use and soil map were used throughout the modelling period (1980-2016) of this study, as described under methodology, only Q_{surf} and q_{peak} were the varying parameters. Hence, any increase or decrease in erosion rates during the period considered for the analysis can be attributed to the variability of rainfall.

2.2 Reservoir Sedimentation Process

Although, the coarse inflowing sediment is deposited in a reservoir, a portion of sediments containing silt and clay can be moved out of the reservoir with spill water especially during periods of high inflows. In addition, regular water releases for agriculture or power generation through bottom outlets can also contain sediment. Thus, the rate of sediment accumulation of a reservoir is called trap efficiency of a reservoir. The trap efficiency (*TE*) is the portion of inflowing sediment deposited in the reservoir, which is the ratio of deposited sediment to the total sediment inflow [Eq.2].

Modelling sediment deposition process within a reservoir is possible with SWAT. For that parameters like sediment particle size distribution and equilibrium sediment concentration in the reservoir must be known. As no such information is available, some other methodology had to be followed.

However, a limited number of studies has been reported in the field of reservoir sedimentation. Brune has proposed an empirical method to determine trap efficiency of reservoirs [3]. The trap efficiency is to be obtained according to the capacity and inflow to the reservoir. At present the Brune curve, extracted from Reservoir Sedimentation Handbook by Morris et.al. (Fig. 3), is being generally used for estimating trap efficiency of reservoirs. Therefore, Brune curve was used to determine the sediment trap efficiency of the reservoir.

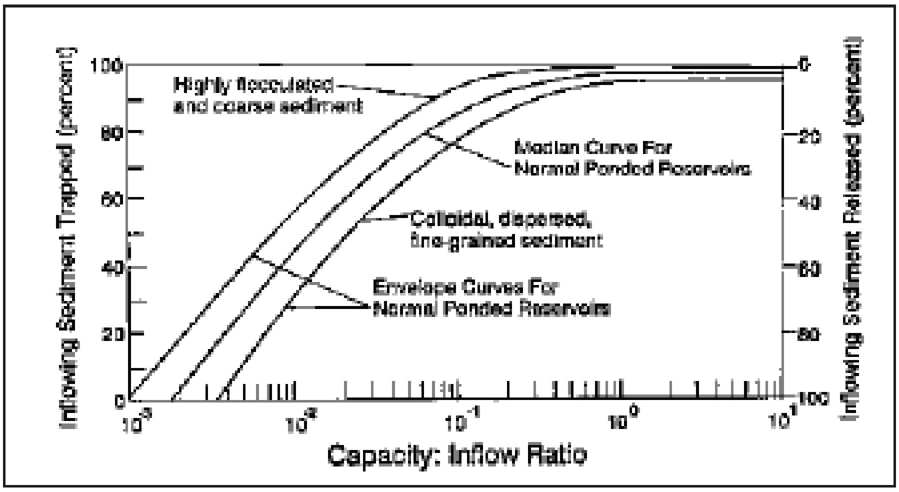

Fig. 2 : Brune curve

$$TE = \frac{\text{Quantity of sediment depositing in reservoir}}{\text{Quantity of sediment inflowing to reservoir}}$$ [2]

2.3 Trend Analysis for A Time Series

One objective of this study was to check whether climate change has any impact on sedimentation of the reservoir. For finding that the sedimentation time series data had to be checked for presence of any trend.

The Spearman's rank correlation method is a useful tool for trend analysis of a time series [1]. The Spearman's rank correlation coefficient R_{SP} is defined as follows [Eq. 3].

$$R_{SP} = 1 - \frac{6 \times \left(\sum_{i=1}^{n} D_i^2\right)}{n(n^2-1)}$$ [3]

Where *n* is the total muber of data and *D* is difference, and *i* is chronological order number.

The difference between rankings is computed with;

$$Di = Kxi - Kyi$$ [4]

Where *Kx* is the rank of the variable *x* which is the chronological order number of the observations. The series of observations, y_i is transformed to its rank equivalent *Kyi* by assigning the chronological order number of an observation in the original series to the corresponding order number in the ranked series *y*.

$$t_t = R_{sp}\left[\frac{n-2}{1-R_{sp}^2}\right]^{1/2}$$ [5]

Where t_t, has Student's t-distribution with $v = n - 2$ degrees of freedom. At a significance level of 5 per cent (two-tailed) and the time series has no trend if;

$$t\{v, 2.5\%\} < t_t < t\{v, 97.5\%\}$$ [6]

Accordingly this methodology was applied to check whether sediment data time series has any trend.

3. METHODOLOGY

3.1 Model Description

Soil Water Assessment Tool (SWAT) was used as the modelling software for this study. SWAT is a continuous hydrological simulation tool jointly developed by USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research [6]. It is GIS-based and simulations can be done at daily time intervals. In addition to hydrological modelling SWAT is capable of calculating the sediment yield of a river basin as well. Accordingly, a SWAT model was developed for the study at a daily time-step for the period 1980 to 2016. Although all the reservoirs has not been constructed yet, a longer period was taken into account to get a more realistic sedimentation rate.

The primary inputs to the model were the basin Digital Elevation Model (DEM), digital land use map, digital soil map, daily rainfall and temperature data of meteorological stations within the study area. A Subtle Radar Terrain Model (SRTM) downloaded from United States Geological Survey was used as the digital elevation model. The resolution of the model was adjusted to 60m. The elevation of the area varied from 411 m to 2064 m MSL. The land use data were obtained from Land Use Planning Policy Department and digital soil data from Agriculture Department. Daily rainfall data and temperature data were obtained from Meteorological Department.

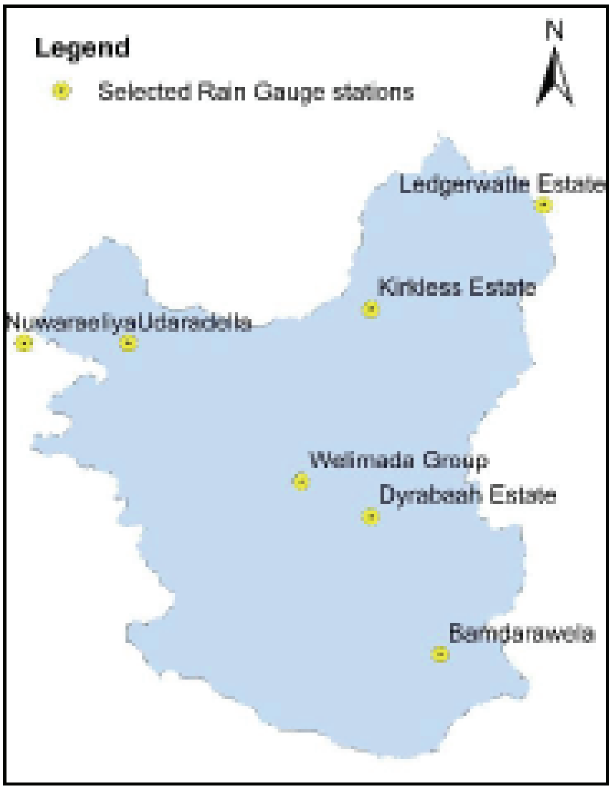

Fig. 3 : Rain Gauge Stations

As no previous land use data maps were available the latest map was used for the total modelling period. In fact, there had not been any significant land use changes in the area and it was a valid reason for using the same map for the whole modelling period. The description of major land use categories are given with the percentages available in the study area (Table 1). It is interesting to note that nearly 30% of the area consists of homesteads which would highly contribute to overall sediment yield.

Daily rainfall data of seven rain gauge stations located within the area were used. For daily minimum and maximum temperature data three climatic stations, within and around the basin were used. Unavailable climatic data; solar radiation, wind speed and relative humidity were generated by the model itself using a weather generator provided with SWAT [4].

Table 1 : Land use categories in the study area

SWAT code	Descriptive Term	% of Catchment Area
URLD	Homestead	29.9
FRSE	Forest	24.9
AGRR	Tea	16.9
RICE	Paddy	14.9
AGRL	Other crops	4.5
SHRB	Scrub	4.3

3.2 Model Simulation

Model development was done using the QGIS QSWAT interface and associated SWAT Editor tool. The model generated the river network based on the DEM where the threshold value selected was 2 km2. According to this river network the model delineated 157 sub basins within the study area.

The DEM was categorized into four slope bands as 0-10%, 10-20% and 20-30% and above 30%. During the simulation model created similar sub units with similar hydrological response known as Hydrological Response Units (HRUs). HRUs are areas within the sub basins where slope, land use and soil types are similar. An area threshold of 10% was applied to land use types in order to avoid minor land use types in sub basins to simplify HRU creation. The model was run for the period 1980-2016 in a daily time steps and outputs were obtained in monthly time steps.

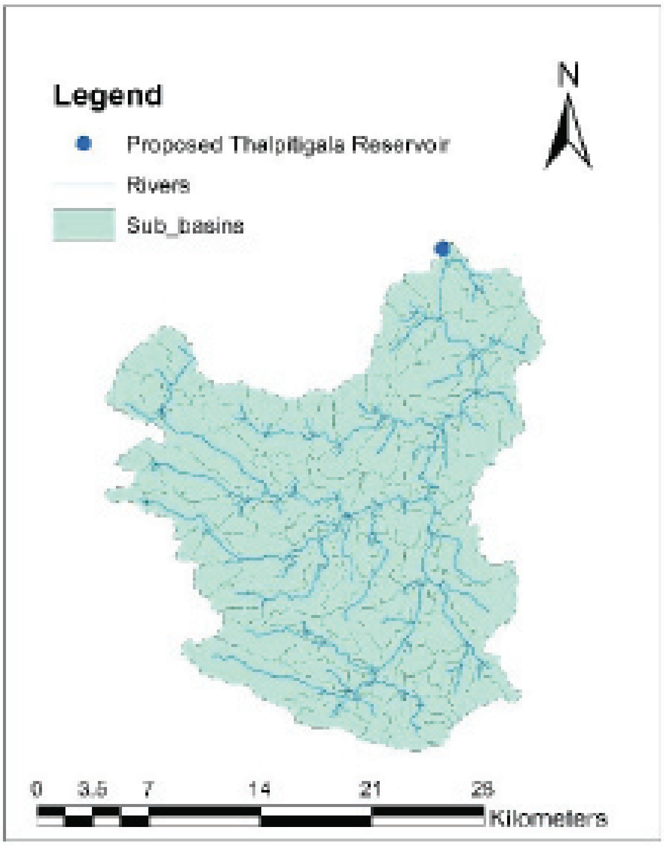

Fig. 4 : Sub-basin Map

4. RESULTS AND DISCUSSION

The model calculated daily sediment load reaching the reservoir location from the beginning of 1980 to the end of 2016. As the rainfall is varying throughout the year the annual series of sediment load is more appropriate for calculating the average sediment load. The annual totals were plotted for analysis excluding the first two years of the modeling period to avoid modeling errors. Hence, model outputs from 1982 to 2106 are considered for the calculations.

It can be observed that highest sediment load at the reservoir location has been 497,847.2 t as reported in 2011. The average sediment load during the total period (1982-2016) has been 281,535.8 t/year. Accordingly, average sediment load is 8,043.88 t/ km2/year. According to a separate study carried out in the basin the sediment yield varies from 1,260 to 9,549 t/km2/year [5]. Hence, results given by the model is within that range and results are acceptable given the fact that no measured sediment data are available for calibrating the model.

The time series of sediment load calculated by the model were checked to see whether there was a trend. For that Spearman's Rank-Correlation Method was applied and the results are summarized in Table 2.

If there is no trend in the time series data the value of student's distribution, t_t should be such that; $-2.01 < t_t < 2.01$. As this condition is not satisfied where the calculated value of t_t equals to 2.46 (Table 2) it can be concluded that annual average sediment load from 1982 to 2016 has a considerable increasing trend. Accordingly, sediment load reaching the proposed reservoir site is on the rise.

Table 2 : Results of Spearman's rank correlation test

Parameter	Value
Spearman's rank correlation coefficient; (*Rsp*)	0.45
For Student's t distribution; (t_t)	2.46
Degree of freedom; v (= n −2)	35
For significance level of 5% values from t distribution;	
Upper level value	2.03
Lower level value	-2.03

Although, there is an increasing trend in the annual sediment load it is not known whether this same increasing trend will prevail for the future or not. Therefore, for the prediction of capacity reduction of the proposed reservoir the annual average sediment load is taken as a conservative approach. The annual capacity loss is calculated as in the table.

Table 3 : Reservoir sedimentation rate calculation

Parameter	Value
Average sediment load	281,535.8 t/year
Trap efficiency of reservoir	79%
Sediment amount trapped in the reservoir	222,413.3 t/year
Equivalent volume reduction in the reservoir (specific density of sediment =1.3)	171,087.2 m^3/year
Annual % reduction in volume	1.10 %

When sub basins of the catchment are considered soil erosion has a spatial variation (Fig. 5). For finding exact reasons for this variation requires physical inspection of the catchment in a detailed manner. Therefore, making conclusion on erosion rates of different areas within the study area is beyond the scope of this study.

Table 4 : Reduction in reservoir volume

Time after construction / Years	Reduction in reservoir volume (%)
10	11
25	27.5
50	55
75	82.5
91	100

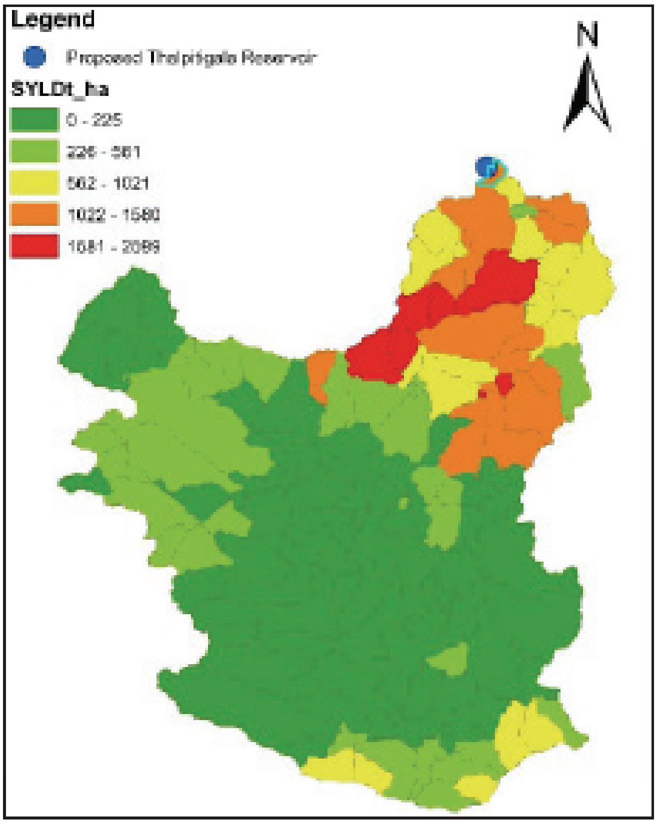

Fig. 5 : Sediment Yield Map

5. CONCLUSION & RECOMMEDATIONS

The expected annual average capacity loss of the proposed Thalpitigala reservoir due to sedimentation is 1.1 %. Therefore, it can be predicted that according to the rate of sedimentation the reservoir will lose its whole capacity 91 years after its commissioning (Table 4). For the IRR calculations in the feasibility report the active lifespan has been taken as 50 years. Hence, during this lifespan of 50 years the active capacity will be gradually decreased to 55% (Table 4). Thus, the available capacity after 50 years will be 7.0 MCM. Therefore, economic benefits will be less than what has been calculated in the feasibility report. In order to calculate the actual economic benefits of the project the gradual capacity loss of the reservoir due to sedimentation has to be taken into account. Eventually, the real IRR can be examined, which is a vital factor for deciding the economic viability of the project.

Soil erosion was not spatially uniform throughout the study area and comparatively higher in some of the sub basins (Fig. 5). It is worth finding reasons for this higher erosion rate, which is beyond the scope of this study.

Suitable soil conservation methods in agricultural lands, especially in homestead, and afforestation of bare lands are to be envisaged as measures for erosion mitigation. Further, the future developments within the area, which may take place to cater demands of increasing population, have to be well planned to minimize soil erosion.

ACKNOWLEGEMENTS

Most of the data used for this study were obtained from World Bank funded Climate Resilience Improvement Project (CRIP) under the Ministry of Irrigation and Water Resources Management. Therefore, the author would like to convey his sincere gratitude to Eng. (Mrs) P.A.A.P.K. Pannala, Deputy Project Director of component I of CRIP for giving the permission to use the data.

REFERENCES

[1] DAHMEN E.R., HALL M.J. Screening of hydrological data: Tests for stationarity and relative consistency, ILRI, The Netherlands, 1990

[2] Feasibility study report of Thalpitigala reservoir project, Ministry of Irrigation and water resources management, Sri Lanka.

[3] MORRIS G.L., FAN J. Reservoir sedimentation handbook, 2010

[4] NEITCH S.L. et al. Soil and water assessment tool, Theoretical documentation, version 2009. Texas water resources institute, 2011

[5] Uma Oya Multipurpose Development Project- Final Report – Ministry of Irrigation and water resources management, Sri Lanka, Nov 2010

[6] http://swat.tamu.edu

Key Words

Internal Rate of Return, Thalpitigala Reservoir, Sedimentation, SWAT