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Influence of sediment yield over life of reservoir using Arc SWAT, to adjudge useful life of reservoir by Anova analysis for Sri Ram Sagar Project

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Abstract

Certain issues that includes stresses, floods, seismic loads could be observed inevitable and unpredictable in terms of occurrence, ultimately effect the functionality and life span for any Reservoir. Another important factor, which ultimately and strappingly influences any robust Reservoir and its storage capacity is Sedimentation. Appraisal of quantity of sediment and application of proper remedial measures could significantly sustain and enhance the storage capacity of the reservoir. This study primarily deals on evaluating the annual sediment deposit in Sri Ram Sagar Project's Reservoir using Arc SWAT (Soil and Water Analysis Tool), a plug-in of Arc GIS 10.4. The attained results from this tool are then compared with Godavari Sediment Year Book (2015-16) for validation. Also, the expedient life of this reservoir is calculated using Gill's Equation. Eventually, the variance analysis for a difference in deposited sediment and inflow and runoff is evaluated using Anova Analysis and the results are concluded.

Keywords: Anova Analysis, Gill Equation, Life of Reservoir, Reservoir Sedimentation Analysis, SWAT Analysis.

INTRODUCTION

In simple verses, a Reservoir could be termed as, "An artificial lake formed by building a dam across a valley by excavating the land to enable the river flow" [1]. A Reservoir is fed by precipitation rainwater runoff (or) from a constant flow of river. The water stored in the reservoir could be amusingly used for domestic, industrial and agricultural purposes. This water could also help in hydropower generation and controlling barrier during unexpected floods and droughts.

Coming to Sedimentation, it is one of the inevitable and a really grim challenge that every reservoir faces. Reservoir Sedimentation is a plodding process where the reservoir gets filled with sediments and other matter carried by the river during its flow process in the catchment. This process takes place as the construction of the dam or the barrier reduces the velocity of the flowing stream and subsequently the turbulence gets reduced, which causes the flowing sediments to settle down.

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The primary causes for Sedimentation could be: [2]

- It reduces in the storage capacity of Reservoir
- Decreases the ability to produce hydroelectric power
- Retrogressive deposition
- Increase in cost for maintenance

- Reduced availability for Irrigation
- Shortening of life of a reservoir

The other causes for sedimentation could also be: [3, 4]
- Nature of soil in catchment area
- Topography of the catchment area
- Cultivation in catchment area
- Vegetation cover in catchment area
- Intensity of rainfall in catchment area

Coming to Effects of Sedimentation, the devastating effects of this phenomenon are:
- Capacity to Inflow Ratio (C/I)
- Amount of Sediment flowing water
- Size and Texture of the Sediment
- Trap efficiency (Te) of the reservoir [5]
- The Reservoir Operation Method

Therefore, Sedimentation should be considered as a serious problem and need to be analyzed from time to time to have an expected working condition, serviceability and durability of a Reservoir. This study considers Sri Ram Sagar Dam and estimates the Sedimentation in it along with its Life expectancy using SWAT Analysis and Gill's Equation. Finally, the results are verified using Anova Analysis.

LITERATURE REVIEW

Gosain, A. K., Rao, S., Srinivasan, R., & Reddy, N. G. (2005)., After the implementation of canal irrigation in a basin in Andra Pradesh, India, SWAT's capacity to simulate return flow was evaluated. Under different situations, SWAT offered the assistance required by water management in preparing and maintaining their water supplies [6].

Reetesh Katiyar, P.K. Garg, S.K. Jain (2006)., To assess the sub-watershed that is most vulnerable to soil erosion, their analysis divided the catchment for Ramganga into nine sub watersheds. For the planning of the contour map and drainage network, topographical maps are digitalized. Sub-catchment leading to maximum soil erosion is calculated by drainage network, catchment delineation and sub catchment is conducted and then by producing slope and water pixels from satellite photographs. ILWIS image processing and GIS tools are also used for the evaluation of reservoir sedimentation by temporal IRS-1B LISS-III images between 2000 and 2001. The research concludes that Remote Sensing has good precision for determination of sediment rate [7].

Garg, V., & Jothiprakash, V. (2008)., For sediment load estimation, they have developed artificial neural network models. The hydrometry findings vary over time and discharge, and for different discharges, they differ very significantly. This technique was, therefore, established. It was reported that for small reservoirs, hydrographic measurements are expensive and it was therefore proposed that this approach could be used for small reservoirs in the absence of hydrographic surveys [8].

Roman, Uday C. Suneeta, Jatwa Singh, M. N. Selvan, S. (2010)., The sedimentation assessment using the SRS method was identified for the Ujjani reservoir on the Bhima river in the Solapur district of Maharashtra state of India. Satellite imaging was used to measure the water spread of the reservoir region at various water levels between FRL and MDDL IN each month of the year. A new elevation-capacity curve will be developed and compared to the availability of LISS-III sensor imagery from IRC 1C, 1D and P6 satellites. And thus, power depletion was calculated by comparing both the initial and updated curves [9].

OBJECTIVES

- Calculating the Sediment Yield for the Sri Ram Sagar reservoir in Nizambad District, Telagana using SWAT Analysis.
- Comparing the sediment yield obtained from SWAT analysis to sediment data from sediment year book Godavari basin.
- Estimation of useful life of reservoir is computed and compared with Gill's Equation.
- Analysis of variance between annual sediment, inflow, runoff results are analyzed and modelled.

STUDY AREA

This study works on the Sedimentation caused from the inflow by Godavari River for Sri ram Sagar dam. This dam is also called as Pochampad Project. It is situated in Nizamabad district and at a distance of 3km from National Highway 44. This dam lies at 18°58′03″N and 78°20′35″E on the Earth.

This dam severs water for agriculture in Waragal, Adilabad, Karimnagar, Nalgonda and Khammam Districts. This dam is situated at an altitude of from 333m MSL. This dam has got a catchment area of 451 km^2. The majority of this area is situated in Maharashtra. It holds a water of 90TMC(ft) with an active capacity of 2,322,000,000 m^3. This dam has 42 flood gates. It also provides 36MW of Electricity every year. This dam is stated as "Line-line for a large part of Telangana" by The Hindu [10].

The Figure 1 below presents the pictorial view of Sri Ram Sagar project, Figure 2 presents its Catchment area, Figure 3 Slope map of the Catchment area from Bhuvan.

Figure 1. Sri Ram Sagar Project.

Figure 2. Catchment area of Sri ram Sagar Project.

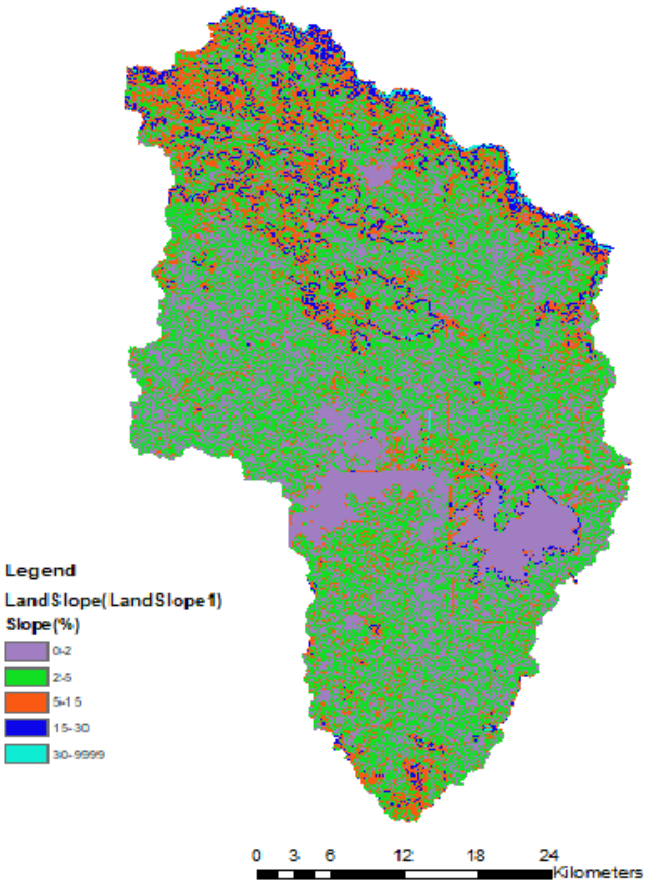


Figure 3. Slope Map of the Catchment area from Bhuvan.

METHODOLOGY

The process of the flow of this study is clearly showcased by the Flow Chart: 1, presented below.

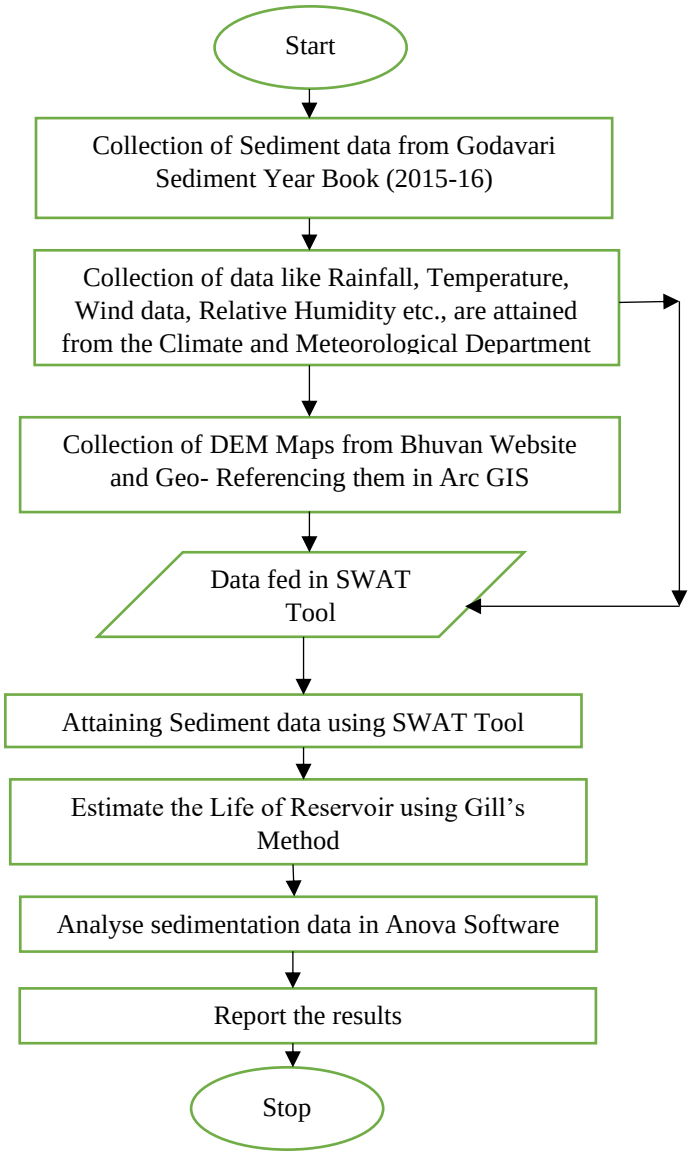
Elucidation of Methodology

By observing the Flow Chart: 1 stated above, the process of this study goes as explained below:

- To begin with, initially the Sedimentation yield data from Godavari Sediment Year Book (2015-16) of this dam from the Irrigation Department was collected.
- Then the Digital Elevation Model Maps (DEM Maps) are obtained from Bhuvan website. Those maps are merged and Geo-Referenced using Arc GIS 10.4.1 Software. Other physical data like Rainfall, Temperature, Wind data, Relative Humidity etc., are attained from the Climate and Meteorological Department.
- Using Arc SWAT Watershed Delineation and hydrologic response units analysis of DEM maps are obtained by giving the inputs like Rainfall, Temperature, Wind data, Land Use, Relative humidity, Soil Properties etc. After completion of HRU analysis, edit the input data after editing the input data.
- Now this data is proceeded further for SWAT Analysis. SWAT stands for "Soil and Water Assessment Tool". By that, it is possible to attain the sedimentation yield from SWAT Tool. Then a comparative analysis is done among the Sedimentation from Godavari Records and SWAT Analysis.
- Then comes estimating the Life Capacity of the Reservoir, Life of the reservoir is calculated using trap efficiencies values. For calculating trap efficiencies sediment inflow values and reservoir annual inflow and out flow values are collected. Using Browns method trap efficiencies are

calculated. Using trap efficiencies and reservoir initial reservoir capacity and annual flood inflow values life of reservoir is calculated.

- Finally, using Anova Tool, it is likely to analyze and model the data. First the collected values like sediment inflow and runoff and water inflows for every year. The collected values are tabulated in the excel sheet. After that using one way Anova in the xlstat software analyze the tabulated values.



Flowchart 1. Methodology of this study.

RESULTS AND DISCUSSIONS:

Step 1: Sedimentation Analysis

As stated in the methodology, we have initially attained the sedimentation data from Godavari Year for the year (2015-16). Then we have also attained the Sedimentation results from SWAT Analysis. The sediment yield in tonnes per hectare of every year is presented in Table 1. Also, the results and a comparison statement for the sediment yield from the year 1983 to 2014 is presented in metric tonnes in the Table 1.

Table 1. Comparison of Sedimentation Yield from Godavari Sediment Year Book and our SWAT Analysis.

Year	Sediment Yield (t\ha)	Sediment yield from sediment year book 2015-16 (m.t)	Sediment yield from SWAT (m.t)
1983	2.65	19927478	23827735
1984	0.13	210041	1168907.7
1985	0.75	360156	6743698.5
1986	2.65	4477097	23827735
1987	0.36	272203	3236975.3
1988	6	3002070	539495.88
1989	1.75	NA	15735297
1990	3.58	12646554	32189921
1991	0.29	1802150	2607563.4
1992	1.43	701896	12857985
1993	0.79	158075	7103362.4
1994	1.76	388671	15825212
1995	2.21	4144891	20321011
1996	0.54	411357	4561462.9
1997	0.56	50894	5035294.9
1998	0.41	1041635	3686555.2
1999	0.96	278469	8631934.1
2000	0.67	1865799	6024370.7
2001	0.96	196851	8631934.1
2002	2.4	1274830	21579835
2003	1.03	549114	9261345.8
2004	0.08	66693	719327.84
2005	1.88	2556806	16904204
2006	1.75	2565304	15735297
2007	1.23	42984	11059606
2008	0.87	277184	7822690.3
2009	0.47	22373	4226051.1
2010	0.66	1589272	5934454.7
2011	2.58	302000	23198323
2012	1.79	215439	16094960
2013	1.21	974895	10879834
2014	0.55	90676	4945378.9

Step 2: Estimation of Life of Reservoir using Gill's Method:
Annual sediment inflow = 8.3×10^4 metric tonnes (From Table 1)

Volume of sediment inflow = $8.3 \times 10^4/6 = 0.13$
Using Brown's Equation.,

Trap Efficiency (T_e)=((Vi-Vo)/Vi)*100 [11]

Therefore, through Gill's Analysis we have found the Theoretical Life of Reservoir as 224 Years.

Step 3: Sedimentation Analysis using Anova

In the next step, the Run-off, sediment, Inflow results are fed into Anova Software, various comparisons are made and the results are presented below. The Figure 4 presents the Run-off V/s Sediment V/s Inflow in Anova. The Figure 5 presents the Sediment V/s Inflow Comparison in Anova and Figure 6 presents the Sediment V/s Run-off Comparison in Anova., whereas Graph 1: Sediment V/s Inflow Analysis in Anova and Graph 2: Sediment V/s Run-off Analysis in Anova.

Table 2. Calculation of Life of Reservoir using Gill's Method [12].

Capacity		Capacity inflow ratio(C/I Ratio)	Trap efficiency	Avg. Trap efficiency for the interval	Annual sediment trapped (St)	Year to fill =6/St
in (%)	*Volume *10^6(m^3)*					
100	2377.37	1.94	0.974	0.951	0.12	50
80	1901.8	0.754	0.928	0.915	0.11	54
60	1426.42	0.542	0.902	0.874	0.11	54
40	950.42	0.302	0.846	0.74	0.9	66
20	475.47	0.134	0.64	-	-	-
Useful Life of Reservoir						224 Years

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
RUNOFF	34	281793	8288.029	108943323.6
INFLOW	34	8528.328	250.8332	73890.05482
SEDIMENT	34	64225493	1888985	1.65515E+13

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8.0517E+13	2	4.03E+13	7.296870479	0.001106	3.08824
Within Groups	5.462E+14	99	5.52E+12			
Total	6.2672E+14	101				

Figure 4. Run-off V/s Sediment V/s Inflow summary in Anova.

Summary statistics (Quantitative data):

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
SEDIMENT	34	0	34	0.000	19927478.000	1888985.088	4068351.886

Regression of variable SEDIMENT:

Goodness of fit statistics (SEDIMENT):

Observati	34.000
Sum of we	34.000
DF	2.000
R^2	0.998
Adjusted I	0.962
MSE	627082830612.510
RMSE	791885.617
MAPE	
DW	
Cp	32.000
AIC	891.258
SBC	940.102
PC	0.076

Analysis of variance (SEDIMENT):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	31	544944907628430.000	17578867988013.900	28.033	**0.035**
Error	2	1254165661225.020	627082830612.510		
Corrected	33	546199073289655.000			

Computed against model Y=Mean(Y)

Figure 5. Sediment V/s Inflow Comparison in Anova.

Regression of variable SEDIMENT:

Goodness of fit statistics (SEDIMENT):

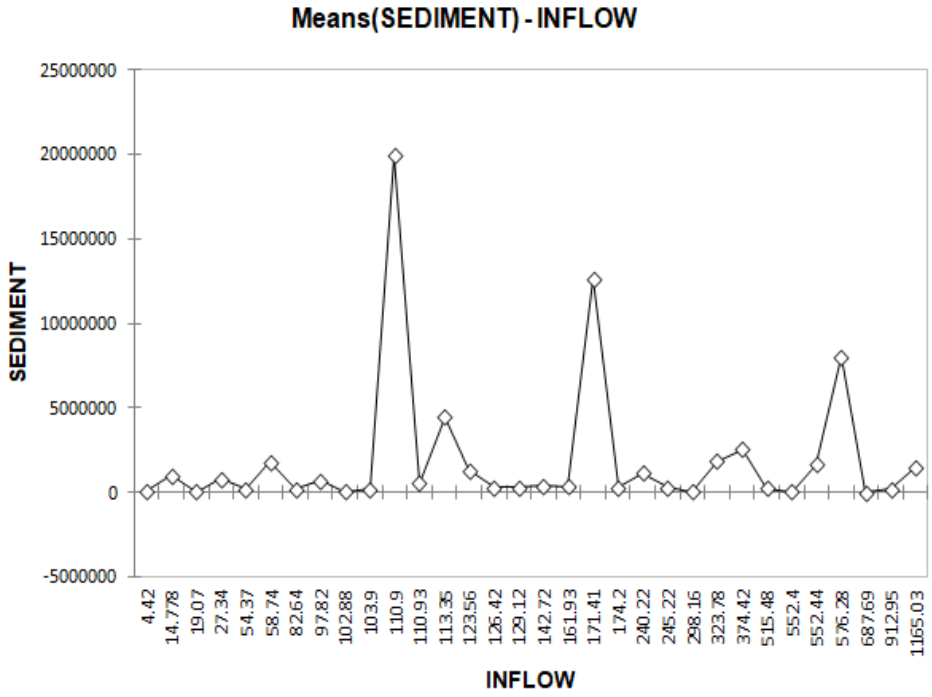
Observati	34.000
Sum of we	34.000
DF	0.000
R^2	1.000
Adjusted R^2	
MSE	
RMSE	
MAPE	
DW	
Cp	
AIC	
SBC	
PC	

Analysis of variance (SEDIMENT):

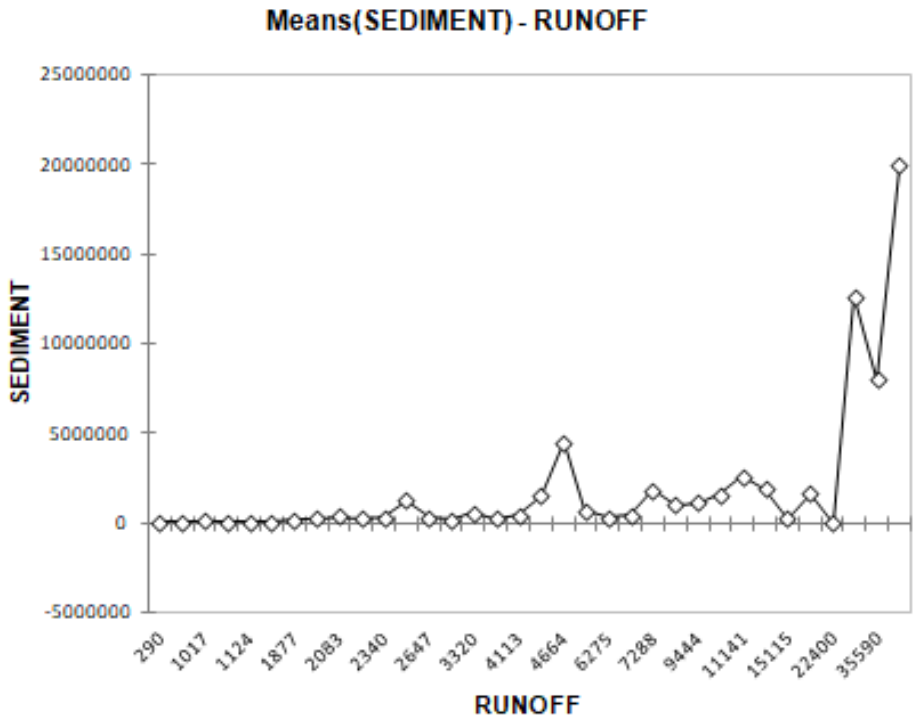
Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	33	546199073289655.000	16551487069383.500		
Error	0	0.000			
Corrected	33	546199073289655.000			

Computed against model Y=Mean(Y)

Figure 6. Sediment V/s Run-off Comparison in Anova.



Graph 1. Sediment V/s Inflow Analysis in Anova.



Graph 2. Sediment V/s Run-off Analysis in Anova.

CONCLUSIONS

- This study has achieved all its objectives, initially the features of the Sri ram Sagar dam are explored and are presented in the study area.
- Initially, the influence of Sediment Yield over the Life of Reservoir has been calculated by the period from 1983 to 2014, and it was found increasing from 2.65 to 0.55 tonnes/ hectare.
- The required data is fed into SWAT Tool and have attained the sediment yield of every year. The Sedimentation results from SWAT tool are compared with that of Godavari Sedimentation Records and the results are almost same.
- The Life of Reservoir through Annual Sedimentation Inflow of $8.3*10^4$metric tonnes has been used to find the Life of Reservoir and has been found to be 224 Years through Gill's Equation. Finally, the Sediment Inflow and Sediment Run-off relationships are studied using Anova Analysis, and are clearly elucidated in Results Topic.

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