Sediment rate evaluation of Somasila Reservoir, Andhra Pradesh using Remote Sensing Technique

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ABSTRACT

Periodic surveys of reservoirs are essential to evaluate the decrease in storage capacity due to inflow and trapping of sediment. Conventional hydrographic surveys are time consuming, labour intensive and expensive. Satellite remote sensing techniques provide time and cost effective approach for the periodical capacity surveys. Water-spread area, estimated from satellite data at different storage levels in a hydrologic year provides an important input for the estimation of the revised capacity of a reservoir. Comparison of previous and revised capacity yields the loss in storage due to sediment deposition. In this study Somasila reservoir located on Pennar River that flows through Nellore district of Andhra Pradesh, South India has been chosen for evaluating the capacity loss using Indian Remote Sensed Satellite, LISS-III image data. Digital satellite data pertaining to 2002 was acquired for seven different elevations and the revised water spread areas were extracted. Using trapezoidal formula, the revised volume between the elevations 83.17 m and 94.39 m was computed. The results show that the loss in capacity is 23.96 million cubic metre during the period 1987 to 2002. If uniform rate of sedimentation is assumed, in 15 years of operation of the reservoir, then the sedimentation rate would be 1.597 M Cum per year.

INTRODUCTION

The natural process like erosion in the catchment area, movement of sediment and its deposition in various parts of the reservoir require careful consideration in the planning of major reservoir projects. The silt which gets deposited in different levels, reduces the storage capacity of the reservoir. Reduction in the storage capacity beyond a limit prevents the reservoir from the fulfillment of the purpose for which it is designed. Periodical capacity surveys of reservoir help in assessing the rate of sedimentation and reduction in storage capacity. With the correct knowledge of the sedimentation processes going on in a reservoir, remedial measures can be undertaken well in advance and reservoir operation schedule can be planned for optimum utilization of water. The conventional technique such as hydrographic survey and inflow-outflow approaches are cumbersome, time consuming, expensive and involve more man power. In addition to the above disadvantages, the task of carrying out the field surveys are often hampered due to restrictions posed by dense forests, wild life, heavy monsoon rains, limited accessibility and steep foreshores. Under such circumstances, data provided by remote sensing satellites are considered superior since they provide multi-spectral and repetitive synoptic information regarding changes in the water spread area after deposition of sedimentation in the reservoir (Agarwal 2000; Baburao 1999; Chandrasekar 2000; Goel 1996; Gupta 1999; Jain 2002 and Manavalan 1993). Apart from this, remote sensing based approach is economical and requires less time in analyzing the data, compared to the conventional methods. To utilize these advantages, in this study an attempt has been made to evaluate the loss in capacity of Somasila reservoir, Andhra Pradesh for the period 1987 to 2002.

STUDY AREA

Somasila reservoir is located (Figure 1) on the river Pennar that flows through the Nellore district in Andhra Pradesh. The reservoir is at a distance of about 80 k.m from Nellore town which is also the district capital. The present storage level of the reservoir is 310 feet (94.488 m) and the designed FRL is 330 feet (100.584 m). The River Pennar or the Uttara Pinakini is the fourth largest river and is next to River Cauvery that flows east and drains into the Bay of Bengal. The Pennar rises at the Chinna Kesava hill of the Nandidurg range, in Karnataka State. The fan shaped basin extends over an area of 55,213 sq.km and is bounded on the North by the Erramala range, on the east by the Nallamala and Velikonda ranges of the Eastern Ghats, on the south by the Nandidurg

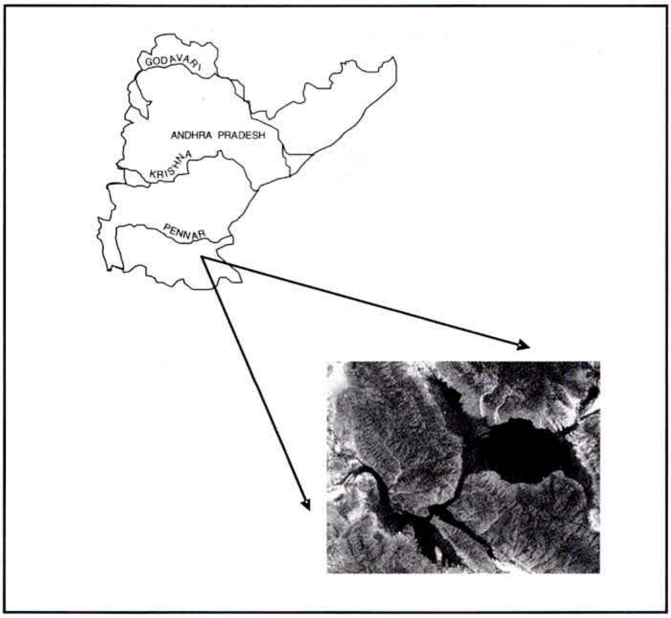

Fig. 1 : Location of Study Reservoir

hills and on the west by the narrow ridge separating it from the Vedavati Valley of the Krishna basin. The other hill ranges in the basin to the south of the river are the Seshachalam and Paliconda ranges. The basin receives rainfall during both the monsoon seasons (NE & SW) with major contribution form the Northeast monsoon. The normal annual rainfall at Nellore is 988 mm. The mean maximum and mean minimum temperatures are 40.9^0 C and 16.9^0 C respectively. The principal soil types in the basin are red loam, red sand, black loam and black clay. Red soils cover major portion of the basin. The general crops grown in the basin are paddy, groundnut, Bajra, Jowar, Ragi, Vegetables and Sugarcane. With the aforementioned topography, rainfall and landuse, it is evident that an appreciable amount of sediment is carried by the streams in the basin into the Somasila reservoir, thereby reducing its capacity.

DATA USED

Satellite Data

The image data used in this study were obtained by the Indian Remote Sensing (IRS) satellites IRS-1C & 1D (LISS-III sensor) which provides a spatial resolution of 23.50 m and spectral resolution in four different bands (0.52-0.59, 0.62-0.68, 0.77-0.86, 1.55-1.70 ìm). The different dates of satellite data used and the respective water level during the pass of the satellite over the reservoir are given in Table 1.

Table 1 : Details of the satellite data used and the water level during the pass of the satellite over the reservoir.

Sl.No.	Date of Pass	Satellite	Reservoir Elevation (m)
1.	17.01.2002	IRS-1C	94.39
2.	22.03.2002	IRS-1D	93.47
3.	16.04.2002	IRS-1D	92.10
4.	11.05.2002	IRS-1D	90.14
5.	05.06.2002	IRS-1D	88.30
6.	27.11.2002	IRS-1D	85.69
7.	13.09.2002	IRS-1D	83.17

Collateral Data

Reservoir water level data on the day of satellite pass and the available hydrographic survey details have been collected from the Somasila reservoir authority responsible for the maintenance and operation of the reservoir.

METHODOLOGY

Any reduction in capacity of the reservoir is an indication of deposition of sediment. The reduction in capacity also reduces the water spread area at every elevation of the reservoir. This could be vividly estimated by analyzing the aerial spread of the reservoir over a period of time at different elevations using the satellite data. Estimation of water spread area and computation of capacity loss of the reservoir is discussed in the following sections.

Geo-referencing of Satellite Data

The image scene of 17^{th} June 2002 was geo-referenced with respect to 1:50,000 SOI topographic map. For this the geometric correction module of ERDAS image processing software was used. The geo-referencing was done using nearest neighborhood re-sampling technique to create a geo-referenced image of pixel size 23.5 m x 23.5 m. Subsequently the other satellite images corresponding to various water elevations, obtained from NRSA data centre, were also registered with the geo-referenced image using the image to image registration technique.

Estimation of Water Spread Area Using Remote Sensing Data

Water reflects most of the visible wavelengths but the energy at near-infrared (NIR) wavelength is almost absorbed by water, thus providing a good contrast between land and water in the NIR images. This helps in extracting the water spread area of the reservoir. There are different procedures (Rathore 2006, Xu, 2006) available to precisely delineate the water spread of a reservoir. The following model equation has been used in ERDAS/IMAGINE image processing software to delineate the water spread area at different storage levels of the reservoir. The adopted model equation states that:

If $P_{V4} > T_{L4}$ and
$P_{V4} < T_{H4}$ then the pixel is in water spread.

Where, P_{V4} is pixel value in NIR band, T_{L4} and T_{H4} are lower and higher thresholds for the NIR band. (Different slicing threshold values for NIR band were obtained by analyzing the histograms and pixel values of the periphery of the reservoir). Waterspread area has been estimated by multiplying the number of water pixels with the ground resolution (23.5m X 23.5m) of the sensor.

Estimation of Reservoir Capacity

Computation of reservoir capacity at various elevations has been made using the following trapezoidal formula:

$$V = h/3\ (A1+A2+ \mathrm{Sqrt}(A1*A2)) \quad (1)$$

Where V = Reservoir volume between any two successive elevations h1 and h2.
h = Elevation difference (h1 – h2)
A1&A2 = water spread contour area at elevation h1 & h2.

Estimating Capacity Loss due to Sedimentation

Capacities calculated using equation (1) between the consecutive levels was added up so as to arrive at the cumulative revised capacity. The revised capacity has to be compared with any recent survey carried out (this may be hydrographic survey or remote sensing based survey) if not available, with the estimations of impoundment survey of the reservoir. The difference between the original and revised cumulative capacities represents the loss in capacity of the reservoir.

RESULTS AND DISCUSSION

Estimation of water-spread area for the year 2002

Based on the live storage elevation of the reservoir seven intermediate water levels have been selected to calculate the water-spread area that prevailed during the year 2002. The water level of the reservoir during the hydrologic year 2002 varied from 82.3 m (MDDL) to 94.488 m. The satellite data pertaining to these water levels or elevations were procured and revised water spread areas (2002) were extracted from the satellite image data (Fig.2). The loss in capacity of a reservoir is calculated between only the water levels selected for the analysis. Therefore it is mandatory to select the water levels which include both MDDL and FRL (The designed FRL of the reservoir is 100.584 m). However, in practice it may not be possible to include MDDL and FRL due to non-availability of cloud free satellite data. Also remote sensing data can not be obtained due to various satellite functioning conditions. In this study MDDL could be included whereas from 94.488 to FRL couldn't be included due to the various above said reasons.

Estimation of water-spread area for the year 1987

Water spread areas of 1987 (henceforth elevation-area-capacity data of 1987 will be called as original data) against the selected elevations are drawn from the elevation area table obtained from the dam authority.

Estimation of Capacity during 2002 and comparison with 1987 Survey

From the known values of original (1987) and revised (2002) water-spread areas the corresponding original and revised capacities were worked out using the trapezoidal formula (Equ.1).

Estimation of cumulative revised capacity of the reservoir is explained below. The cumulative revised capacity (255.35 Mm^3) of the reservoir at the lowest observed level (83.17 m) was drawn from the 1987 capacity area table. Above the lowest observed

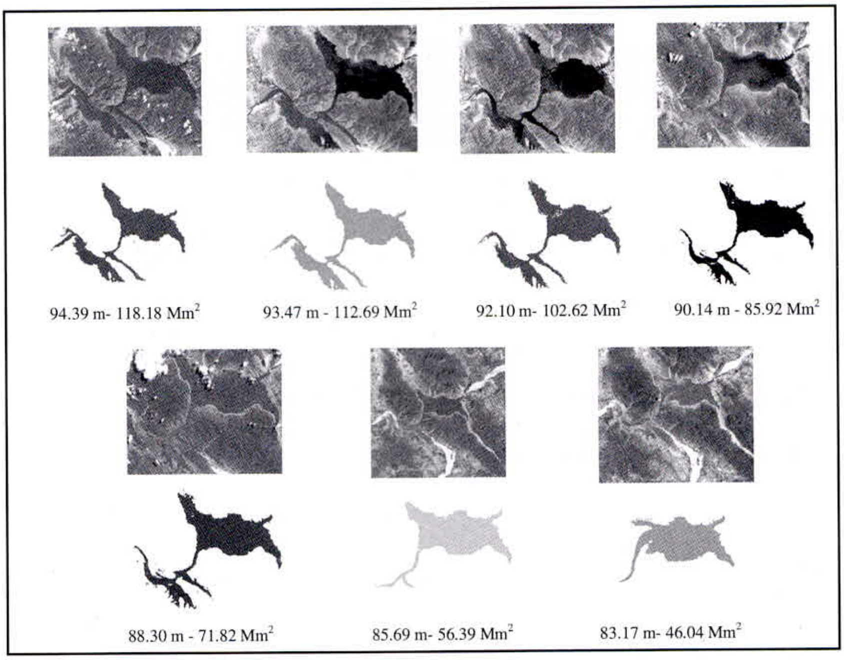

Fig. 2 : Water-spread area extracted from satellite image data at different water levels of Somasila Reservoir

level the cumulative capacities between the consecutive levels were added up so as to reach at the cumulative original and revised at the maximum observed level.

The calculations of capacity loss of the reservoir are presented in Table 2. The

Table 2 : Calculation of capacity loss in Somasila Reservoir Using Remote Sensing.

Date of Satellite Pass	Reservoir Elevation (m)	Original Area - 1987 (Mm^2)	Revised Area – 2002 (RS) (Mm^2)	Original Volume (Mm^3)	Revised Volume (Mm^3)	Original Cumulative Volume 1987 (Mm^3)	Revised Cumulative Vol.2002 (RS) (Mm^3)
17.01.2002	94.39	118.73	118.18	107.43	106.19	1158.12	1134.16
22.03.2002	93.47	114.82	112.69			1050.69	1027.94
				150.11	147.43		
16.04.2002	92.10	104.39	102.62			900.59	880.54
				186.41	184.53		
11.05.2002	90.14	86.11	85.92			714.18	696.01
				149.40	144.93		
05.06.2002	88.30	76.38	71.82			564.78	551.09
				175.49	166.90		
27.11.2002	85.69	58.49	56.39			389.29	384.18
				133.94	128.84		
13.09.2002	83.17	47.98	46.04			255.35	255.35

difference between the original (1987) and revised cumulative capacity (2002) represents the loss of capacity due to sedimentation. The results show that the volume of sediment deposition is 23.96 M cum (1158.12 – 1134.16) for the period 1987 to 2002. If a uniform rate of sedimentation is assumed in 15 years of occurrence of the reservoir then the sedimentation rate is 1.597 M cum per year. Fig 3 shows the comparison between original and revised capacity of the reservoir.

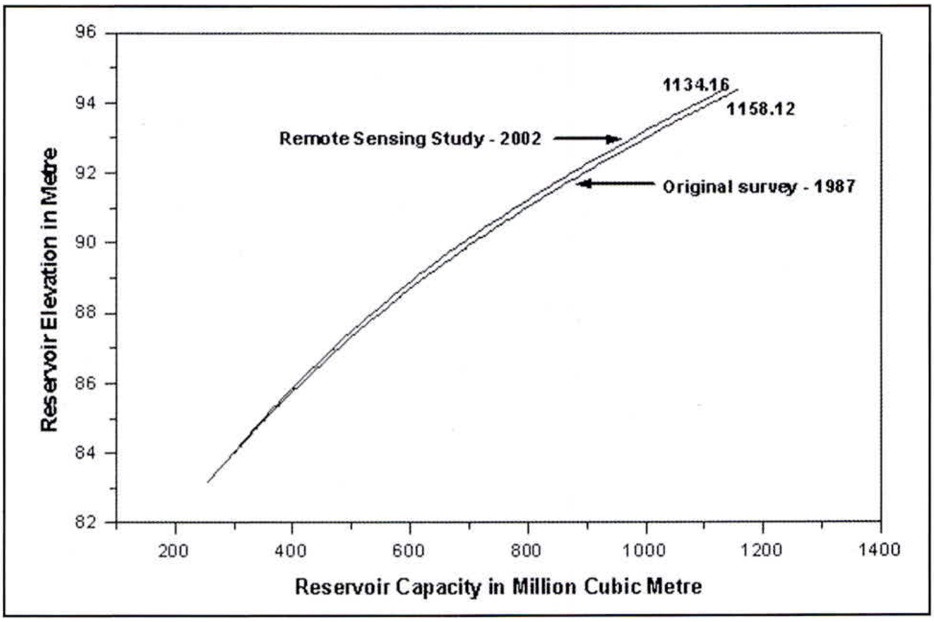

Fig. 3 : Capacity Curves of Somasila Reservoir for the Year 1987 and 2002

CONCLUSION

This study has demonstrated that repetitive imaging by remote sensing satellites can provide significant information on the loss of capacity of the reservoirs. The sediment evaluation of Somasila reservoir using remote sensing shows that the average annual sedimentation rate during the period 1987-2002 is 1.59 Mm^3/year.

Usually it is a practice to compare the results of remote sensing technique with the hydrographic survey conducted, but the present study could not be compared due to the reason that no hydrographic survey was carried out in the reservoir during the recent past.

REFERENCES

1. Agarwal K.K, C.K.Agarwal, Praveen Kumar (2000), Remote sensing in Reservoir Sedimentation – A case Study of Sriram Sagar Reservoir, Tenth National Symposium on Hydrology, p509-522.

2. Babu Rao Y, R.Visvanatham (1999), Capacity Estimation and Sedimentation Studies of Gajuladinne Reservoir by Using Remote Sensing Data, Proceedings of Brainstorming Session on Hydrological and Water Resources Problems in Godavari and Krishna Basins, p 14-22.
3. Chandrasekar K, A.T.Jayaseelan, Jithendra Jain, A.K.Chakraborti (2000), Sedimentation study of Tawa Reservoir Through remote Sensing, Tenth National Symposium on Hydrology, p523-532.
4. Goel, M.K., and Jain, S.K. (1996) Evaluation of reservoir sedimentation using multi-temporal IRS-1A, LISS-II data, *Asian Pacific Remote Sensing and GIS Journal,* 8, 39-43.
5. Gupta S.C, R.N.Sankhula, G.P.Mathur (1999), Sedimentation Analysis of Nagarjuna Sagar Reservoir Through Satellite Remote Sensing, A report by Remote Sensing Directorate, CWC, India.
6. Jain S.K., Pratap Singh (2002), Assessment of sedimentation in Bhakra reservoir in the western Himalayan region using remotely sensed data, *Journal of Hydrological Sciences,* 47, 203-212.
7. Manavalan, P., Sathyanath, (1993), Digital image analysis technique to estimate water-spread for capacity evaluations of reservoirs, PE&RS, 59, 1389-1395.
8. Rathore, D.S., Anju Choudhary and P.K. Agarwal, (2006), Assessment of Sedimentation in Harakud reservoir using digital remote sensing Technique, *Journal of the Indian Society of Remote Sensing*, Vol.34, No.4, 377-383.
9. Xu Hanqiu (2006), Modification of the normalized difference water index (NDWI) to enhance open water features in remotely sensed imagery, *International Journal of Remote Sensing*, Vol.27, No.14, 3025-3033.