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Sedimentation Study of Hirakud Reservoir through Remote Sensing Techniques

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Abstract

Any reduction in water spread area at a specified elevation over a time period is indicative of sediment deposition at this level. This when integrated over a range of water stages helps in computing volume of storage lost through sedimentation. This study relates to estimation of capacity loss due to sedimentation of Hirakud reservoir, located in Orissa, India. Satellite data of 5 optimal dates corresponding to various water stages from minimum to maximum draw down levels were used in estimating the water spread areas. Simple ratiod (NIR/RED) image were generated to identify the water pixels and then verifying the standard FCC. The non-water pixels were then identified with the ratiod (GREEN/NIR) image and removed to have the total water spread. The water spread area on different satellite overpass dates and corresponding elevations were then used to find the total reservoir storage capacity with the help of Elevation area curve.

Introduction

Remote Sensing is a specialized subject and has tremendous potential for use in water resources sector, particularly in water resources development and its efficient management (Mukherjee, 2007, Mukherjee and Das 2007, Mukherjee et.al 2007, Mukherjee, 1998). The vast expense of the country needs more and more technologies like remote sensing & GIS to understand and exploit the utilization of water resources (Jaisawal et.al 2003).

Analysis of data from space platforms can help in reservoir capacity surveys. Multidate satellite remote sensing data provide information on elevation contours areas directly in the form of water spread. Any reduction in reservoir water spread area at a specified elevation observed by the satellite is indicative of sediment deposition (Shanker, 2004). Thus, by monitoring the changes of water-spread areas at various operating levels of the reservoir, the quantity of the sediment load that has settled down over a period of time can be assessed.

ABOUT HIRAKUD RESERVOIR

Background

The purpose of Hirakud reservoir is irrigation, power and flood control. The dam has been constructed across river Mahanadi about 15 Kms up-stream of Sambalpur. Hirakud Reservoir is spread between latitude 21 deg 25 min. to 21 deg 55 min. and longitude 83 deg 10 min to 84 deg 05 min and is covered in eight 1:50,000 SOI toposheets. Control of flood in the Mahanadi delta is one of the main purposes of the reservoir. The other important benefits are 200MW power generation and irrigation capacity of 1.52 lakh hectares.

Catchment Characteristics

The total catchment area of the Mahanadi at its mouth is about 1, 33,120 sq.km. out of which Hirakud Catchment is 83,395 sq. km. The catchment of the river can be broadly classified as up-land plateau. It is an undulating up-land tract, sloping generally from north to south and much

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broken up by rugged ranges of hills. Elevation falls from R.L. 173.73 M (570 ft) at North to R.L. 146.34 M (480 ft.) at Sambalpur. A number of channels leading to river Mahanadi traverse this area in all directions as a result of the undulations. Isolated hills rising abruptly from the plains are a common sight and ravines cut off a large portion of the area and ridges interspersed with plains. The Bargarh plain is the most fertile part of the plateau. The Seonath, the Jonk, the Hasdeo, the Mand and the Ib are the principal tributaries of Mahanadi above the Dam.

Monsoon in the catchment is generally from middle of June to end of September. Maximum average rainfall over the catchment above Hirakud is 1804 mm. (71.03 inches) and minimum is 889 mm. (34.99 inches.). The mean annual rainfall is of the order of 1370 mm. (53.9 inches.). December is the coldest month with the mean minimum temperature ranging between 10 and 13.7 degree C. May and June are the hottest months, when the mean maximum temperature ranges from 38 to 43 degree C.

Historic Sedimentation Surveys Conducted

Periodic sedimentation surveys are desirable to know the trend of sedimentation and to revise the capacity tables for efficient reservoir operation. Since the first impoundment of water in the reservoir in 1956, 3 series of sedimentation surveys during the years 1979, 1982 and 1986 have been conducted to access the rate of sedimentation and storage capacities at different levels of reservoir. The detail of the original provision, 2nd and 3rd sedimentation survey is listed in Table 1. The data corresponding to first sedimentation survey was not available and hence not used in the present study.

Table 1: Area Capacity Chart of Hirakud Reservoir

R.L (Fts.)	R.L (Mtrs.)	Original Provision			After 2nd Sedimentation Survey			After 3rd Sedimentation Survey		
		Area M.Sq.m.	Capacity M.Cu.m.	Cumulative Capacity (M.Cu.m.)	Area M.Sq.m.	Capacity M.Cu.m.	Cumulative Capacity (M.Cu.m.)	Area M.Sq.m.	Capacity M.Cu.m.	Cumulative Capacity (M.Cu.m.)
500	152.40									
505	153.92									
510	155.45									
515	156.96				0.000	0.00	0.00			
520	158.49	Cumulative Capacity from 500 ft.			.055	0.03	0.03			
525	160.00				.420	0.32	0.35			
530	161.54				0.870	0.96	1.31			
535	163.07				1.840	2.02	3.33			
540	164.59				5.360	5.25	8.58	3.040	1.540	1.540
545	166.11				15.870	15.48	24.06	12.380	10.950	12.490
550	167.64	42.97	366.28	366.28	39.330	40.77	64.83	24.230	31.473	43.963
555	169.16	70.56	86.48	452.76	50.320	68.19	133.02	44.210	56.387	100.350
560	170.69	97.15	127.25	580.02	60.680	84.51	217.53	64.210	82.140	182.490
565	172.21	115.67	161.96	741.98	104.030	124.12	341.65	89.090	116.300	298.790
570	173.74	134.18	190.21	932.19	134.340	181.27	522.92	127.634	164.263	463.050
575	175.26	182.62	240.45	1172.64	146.760	210.81	733.73	152.665	213.304	676.360
580	176.78	231.05	314.49	1487.13	157.000	228.19	961.92	165.140	242.110	918.470
585	178.30	254.35	369.73	1856.86	177.970	255.42	1217.34	192.115	271.973	1190.443
590	179.83	277.66	405.26	2262.12	215.920	299.88	1517.22	226.300	318.481	1508.924
595	181.36	322.09	456.59	2718.71	256.510	359.78	1877.00	249.045	362.080	1871.004
600	182.83	366.58	524.36	3243.07	311.550	432.47	2309.47	331.260	440.710	2311.714
605	184.40	416.49	596.26	3839.33	369.600	518.75	2828.22	382.170	543.172	2854.886
610	185.98	466.46	672.45	4511.78	447.250	621.91	3450.13	428.300	617.244	3472.130
615	187.45	525.48	754.66	5266.44	481.580	708.08	4158.21	471.520	685.400	4157.530
620	189.10	582.50	843.13	6109.57	527.050	768.83	4927.04	509.910	747.660	4905.190
625	190.50	651.91	942.37	7051.94	536.240	810.76	5737.80	561.110	815.810	5721.000
630	192.02	727.31	1053.06	8105.00	630.010	888.61	6626.41	612.110	893.700	6614.700

Data Used

Satellite Data

The multi-spectral data from Satellite IRS-1A, for the water year 1988-89 is used to evaluate the seasonal changes in water spread and capacity loss. The five satellite overpass dates for which data has been used are October 15th 1988, December 20th 1988, February 24th 1989, March 18th 1989 & May 1st 1989. Accordingly Survey of India (SOI) toposheets of the scale 1:50,000 & 1: 2, 50,000 were used.

Field Data

Following information was obtained from Hirakud dam (HD) authorities for analysis.

- Stage-Area, Stage-Capacity data corresponding to pre- impoundment survey in the year 1957 and subsequent hydrographic surveys in the years 1979 (the data was not available),1982 and 1986 (Table I).

Methodology

Geometric Correction

Raw digital satellite data contain geometric distortions due to instability of the satellite platforms, altitude & attitude variations and earth rotation. In order for remote sensing data to be useful for resource and environmental users it must be having same scale and projection properties as that of a map. Registration is the related technique of geometric correction in which coordinates of the image can be transformed according to the referenced topographic map so that image and map has the same scale and projection properties. Measurement techniques to correct geometric errors involve re-sampling the image by collection of GCPs (ground control points) distributed evenly over the whole image. The image of one date is registered using the toposheets and subsequent scenes have been registered using that georeferenced scene.

Error estimate in this work is .04% (31 meters) while tying down the image to topographic map and RMS error is 0.28% & 0.11% in X coordinates and Y coordinates respectively for second order polynomial. The nearest neighbor algorithm is used for the registration.

Mosaicking

Except for the May data, the images are covered in two adjacent scenes. In order to view the whole image at an instant, it is required to mosaick the scenes in one radiometrically balanced scene. Figure 1 shows Geocoded & mosaicked satellite images of different satellite overpass dates.

Water Spread Area Estimation

Water is one of the most easily delineable features on the satellite data due to high contrast between land and water boundaries in Near Infrared Band (NIR), wherein, water absorbs almost entire incident energy depending on nature and status of water body while land feature absorbs less depending on cover type, roughness, composition etc.

After analyzing the histogram of the ratioed (RED/NIR) image the ranges for land/water boundary demarcation shall be identified. The ratioed image shall then be threshold by roaming the cursor on FCC image with numeric display of ratioed image on. These values containing all water pixels were verified by consulting standard FCC to change the threshold value. But, in most of the cases, criterion of thresholding ratioed image has not yielded satisfactory results in identifying the correct water pixels due to shallow depth of water at some of the locations along the periphery and the tail portion of the reservoir. Hence actual water pixels in that case were estimated by thresholding the ratioed (GREEN/NIR) image.

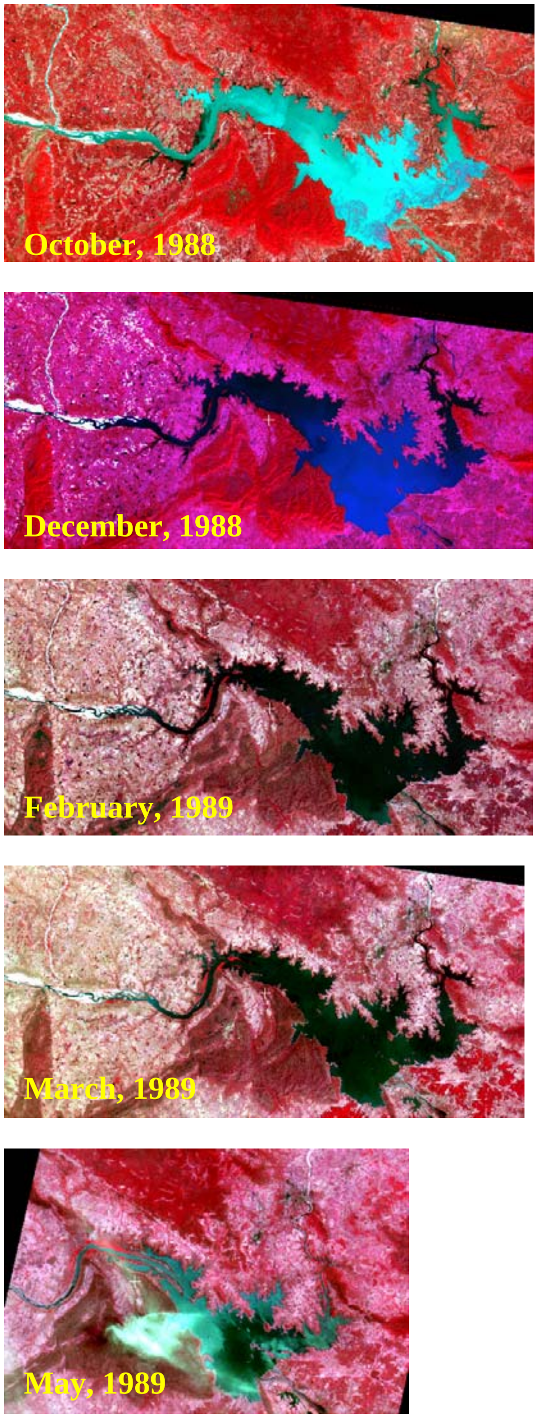

Figure 1: Geocoded & mosaicked satellite images of different satellite overpass dates.

Finally, the isolated water patches, which do not have any hydraulic connectivity with contiguous water area, were eliminated. Table 2 shows satellite-estimated reservoir water spread areas for different satellite overpass dates. The elevations corresponding to the dates of satellite data during 1988-89 obtained from Hirakud dam authorities is also given in Table 3. The elevation 191.96 corresponding to Oct 15,1988 satellite overpass is closer to Full Reservoir Level (FRL) +192.024 where as elevation 185.08 corresponding to May 1, 1989 is the lowest amongst all the satellite overpass elevations. Figure 2 shows the satellite derived water spread of Hirakud reservoir for the dates of overpass considered for the study.

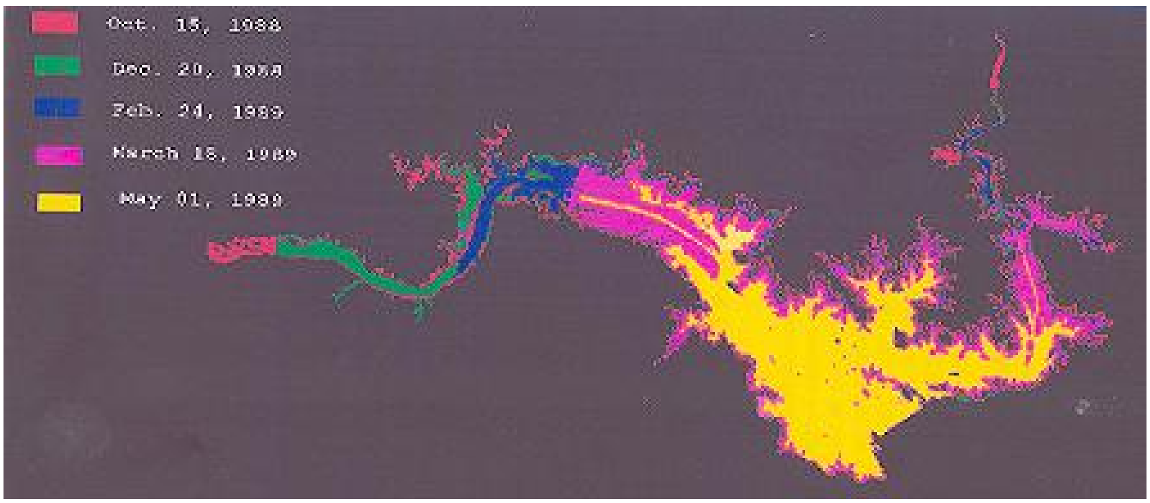

Figure 2: Satellite derived water spread for various overpass dates

Table 2: Satellite Derived Reservoir Water Spread Area.

S.No.	**Date of Overpass**	**Elevation**	**Area (M.Sq.m)**	**Capacity between Elevations (M.Cu.m.)**	**Cumulative Capacity (M.Cu.m)**
1.	01.05.89	185.08	294.03		-
2.	18.03.89	187.99	445.01	1067.74	1067.74
3.	24.02.89	188.89	497.33	423.83	1491.57
4.	20.12.88	190.96	578.51	1112.44	2604.01
5.	15.10.88	191.96	667.39	622.42	3226.43

Estimation of Reservoir Capacity & Capacity Loss due to Sedimentation

After determination of reservoir water spread for different data sets, the elevations corresponding to the satellite over pass dates are determined. The Reservoir Level Monitoring System provides this data over NICNET (Mehta, 2000). The Reservoir capacity between two successive elevations were calculated using the cone formula (Murthy, 1968)

V = h/3*(A1 + A2 + sq.rt (A1 * A2)

Where V is the volume between two successive elevations h1 and h2.
h is the elevation difference (h1 h2)
A1 & A2 are areas of reservoir water spread at elevation h1 & h2.

Cumulative capacity above lowest elevation was calculated by adding the successive volumes between elevations. Table 2 shows water spread areas at different elevations, capacities between elevations & cumulative capacities. Figure 3 shows the curve between elevation and water spread area obtained through remote sensing data.

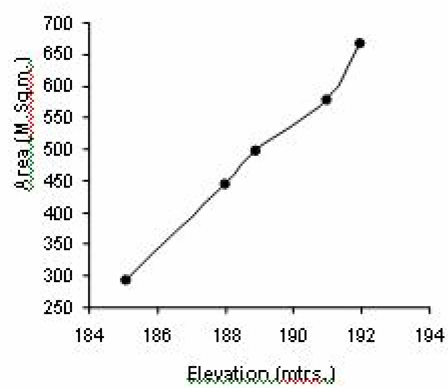

Fig. 3 : SRS derived Elevation - Area Curve

This curve is plotted together with the historic sedimentation survey curves and examining the trend of sedimentation survey curves, the curve is then modified to locate the actual point of zero water spread as shown in Figure 4. Several points at regular interval on this curve were taken and with a regular set of data (elevation & capacity) the cumulative capacity was recalculated using the murthy's formula.

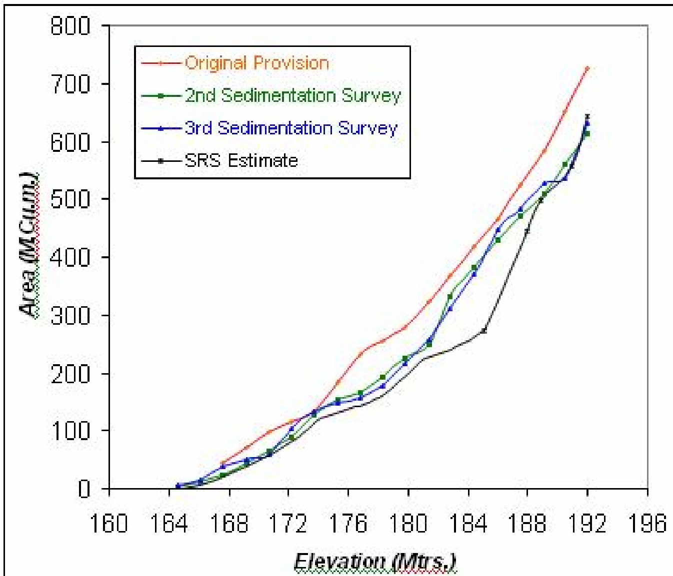

Fig. 4 : Updated Elevation - Area Curve

Table 3 shows computations of satellite derived reservoir capacity & field data provided by the dam authorities. The capacity thus obtained through remote sensing data is then compared with the original capacity data provided by dam authorities and the volume of sediment is the difference of original capacity and that obtained through satellite data, which can be treated as the loss of capacity due to sedimentation.

Dead, live and gross storage capacities from 1957 to 1989 are shown in Table 4. From Table 4, it is observed that the annual rate of capacity loss from the year 1957 to 1982 is 59.15 M.Cu.m., 1957 to 1986 is 51.39 and 1957 to 1989 is 61.05 M.Cu.m. since the year of impoundment in 1957 to 1989, the year of SRS survey.

RESULTS

From the above analysis following conclusions were derived:

1. The live and gross storage capacities of the reservoir were estimated to be 6151.30 M.Cu.m. during 1989, since the dead storage has been estimated as zero.
2. The capacity loss of 1953.70 M.Cu.m.(24.10 percent) from 1957 to 1989.
3. Annual rate of siltation is found to be 61.05 M.Cu.m, since impoundment of reservoir in 1957 to 1989.

The project had been carried out in 1999. However, in view of excellent results obtained through this approach, the exercise may be replaced with the latest satellite data.

Table 3: Computations of Satellite Derived Reservoir Capacity and Capacity Loss

	RL* (m)	Area (M.Sq. m.)	Capacity Between Elevations (M.Cu.m.)		Cumulative Capacity (M.Cu.m.)		Silt Deposited Between Elevations (1957 to 1989)		Cumulative Capacity Loss (1957 to 1989)	
			SRS	**Original**	**SRS**	**Original**	**M.Cu.m.)**	**(%)**	**(M.Cu.m.)**	
	164	0			0				-	**(%)**
			11.33	-			-	-		-
	166	17			11.33				-	
			52.72	-			-	-		-
	168	37			64.05	386.76 **			322.71	
			97.01	135.87			38.86	28.60		83.44
	170	61			161.06	522.63			361.57	
			145.34	196.98			51.64	26.22		69.18
	172	85			306.40	719.60			413.20	
			204.94	253.72			48.78	19.23		57.42
	174	121			511.34	973.32			461.98	
			215.30	352.43			137.13	38.91		47.46
	176	160			726.64	1325.75			599.11	
			365.03	458.14			93.11	20.32		45.19
	178	216			1091.67	1783.89			692.22	
			400.53	478.23			77.7	16.25		38.80
MDDL* **	**179.83**	**232**			**1492.20**	**2262.12**			**769.92**	
			39.61	50.73			11.12	21.92		**34.06**
	180	234			1531.81	2312.85			781.04	
			495.74	634.15			138.41	21.83		33.77
	182	262			2027.55	2947.00			919.45	
			534.96	740.41			205.45	27.75		31.20
	184	273			2562.51	3687.42			1124.91	
			606.94	834.63			227.69	27.28		30.51
	186	335			3169.45	4522.05			1352.55	
			767.83	1025.44			257.61	25.12		29.91
	188	435			3937.28	5547.48			1610.20	
			976.01	1167.90			191.89	16.43		29.03
	190	543			4913.29	6715.38			1802.09	
			1238.01	1389.62			151.61	10.91		26.84
FRL****	**192.024**	**683**			**6151.30**	**8105.00**			**1953.70**	
										24.10

* Reduced Level, ** Cumulative capacity up to 168 m, ** minimum Draw down Level, *** Full Reservoir Level

Table 4: Capacities of Hirakud Reservoir from 1957 to 1989

Year of Survey	**Capacity upto R.L. 167.64 m (Dead Storage Capacity) (M.cu.m.)**	**Live Storage (Between R.L. 167.34m & FRL 192.02m) (M.cu.m.)**	**Gross Storage (M.cu.m.)**	**Capacity Loss Per Year (Between Year 1957 and Year of Survey) (M.cu.m.)**
1957	366.28	7738.72	8105.00	
1979	The data was not available			
1982	64.83	6561.58	6626.41	59.15
1986	43.963	6570.74	6614.70	51.39
1989	**NIL**	**6151.30**	**6151.30**	**61.05**

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