Assessment of Revised Capacity of Kharo Reservoir using Remote Sensing and GIS

R.K. Jaiswal[1*], T. Thomas[1], S. Singh[1] and R.V. Galkate[1]

[1] *Scientist, GPSRC, National Institute of Hydrology, 567, Manorama Colony, Sagar (M.P.)*
email- rkjaiswal_sagar@yahoo.co.in

ABSTRACT

Reservoirs are artificial lakes created by constructing barriers across the river to arrest the flow of excess water. The silt, which gets deposited at different levels of reservoir, reduces its storage capacity. Reduction in the storage capacity beyond a limit prevents the reservoir from fulfillment of the purpose for which it is designed. Conventional methods of reservoir sedimentation survey are tedious, costly and require lot of man power. Data from space platforms can play a significant role in reservoir capacity estimation surveys. Satellite data provide information in the form of contours of revised water spread at different levels. In the present study, the revised capacity and rate of sedimentation in Kharo reservoir of Gujarat has been estimated using remote sensing data and image analysis technique of ILWIS 3.0 GIS. The Kharo reservoir is situated on river Kharo in the Palitana block of Bhavnagar district. The total catchment area up to reservoir site, gross storage capacity and live storage capacity are 241.06 sq. km, 15.25 MCM and 14.225 MCM respectively. Seven digital images of IRS 1D/P6 have been used to cover the whole range of live storage. From the analysis of results, it has been observed that the 4.332 MCM of gross storage has been lost in 22 years which is about 28 % of original gross storage. The average rate of siltation in the reservoir has been computed as 8.17 ha-m/100 km^2/year. The results obtained from the present remote sensing survey has been compared with the silt survey of 2000 which indicates that the rate of siltation in Kharo reservoir increased from 0.067 M cum/100 sq km/year (1985 to 2000) to 0.115 M cum/100 sq km/year (2000 to 2007). The rate of siltation which has doubled during last seven years emphasized the need for conservation measures and development of catchment area treatment plan.

INTRODUCTION

The soil erosion, movement and deposition are part of natural hydrological processes. But, the rate of sedimentation in reservoirs and lakes is accelerated due to environmental degradation, lack of conservation measures in catchment, change in land use, deforestation etc. Presently, the large dams in India having live storage capacity of 214 BCM out of which 1.95 BCM capacity of reservoirs is being lost annually. Reservoir surveys are necessary to get more realistic data/estimate regarding the rate of siltation and to provide reliable criteria for studying the implication of annual loss of storage over a definite period of time with particular reference to reduction of intended benefits in the form of irrigation potential, hydropower, flood absorption capacity and water supply for domestic and industrial uses etc; and periodic reallocation of available storage for various pool levels.

With the introduction of remote sensing techniques in the recent past, it has become convenient and far less expensive to quantify sedimentation in reservoirs and to assess its distribution and deposition pattern. Advantages of using remote sensing data are that it is highly cost effective, easy to use and requires lesser time in analysis as compared to conventional methods. Spatial, spectral and temporal attributes of remote sensing provide invaluable synoptic and timely information regarding the revised area after the occurrence of sedimentation and sediment distribution pattern in the reservoir.

White, 1978 examined a variety of measuring techniques for determining reservoir surface areas extracted from Landsat MSS near-IR imageries of different scales and compared their accuracy with field data. He concluded that none of the measuring techniques used was able to measure the reservoir water spread with consistent accuracy and no reason was attributed. The ability to map and estimate water spread from satellite data is well understood, and different techniques such as visual interpretation of satellite imagery, density slicing, and digital classification of water bodies have been employed for the delineation of water bodies (Work and Gilmer, 1976, Thiruvengadachari et. al., 1980; Jain and Goel, 1993, Goel and Jain, 1996;). Suvit et. al., 1988 used digital techniques in which density slicing of Landsat MSS near-IR (0.8- 1.1 mm) data was used to extract the water spreads of the Ubolratana reservoir of five different dates. Mangond et.al., 1985 employed digital classification techniques to estimate the water spread of the Malaprabha reservoir on March 02, 1973 using Landsat MSS data and reported a discrepancy of 8.29 % from the actual water spread. This discrepancy was attributed to the probable misclassification of boundary pixels.

STUDY AREA & DATA USED

The Kharo reservoir has been constructed across the river Kharo in Sonpari village of Palitana block of Bhavnagar district of Gujarat. The Kharo reservoir project is an irrigation project with a command area of 1850 hectare. The catchment area of reservoir up to dam site is 241.06 sq. km and average annual rainfall in the catchment is about 627 mm. An earthen dam of length of 1.925 km along with 163.4 m masonary spillway has been constructed to accumulate 15.25 MCM gross storage at full supply level (F.S.L.) of 54.12 m. The dead storage level (D.S.L.) and the capacity of reservoir at this level are 47.50 m and 1.025 MCM respectively. A 2.16 km long canal from the left bank of the dam has been constructed to irrigate 1850 hectare gross command area. The reservoir was first impounded in the year 1985. A location map of Kharo reservoir has been presented in the Fig. 1.

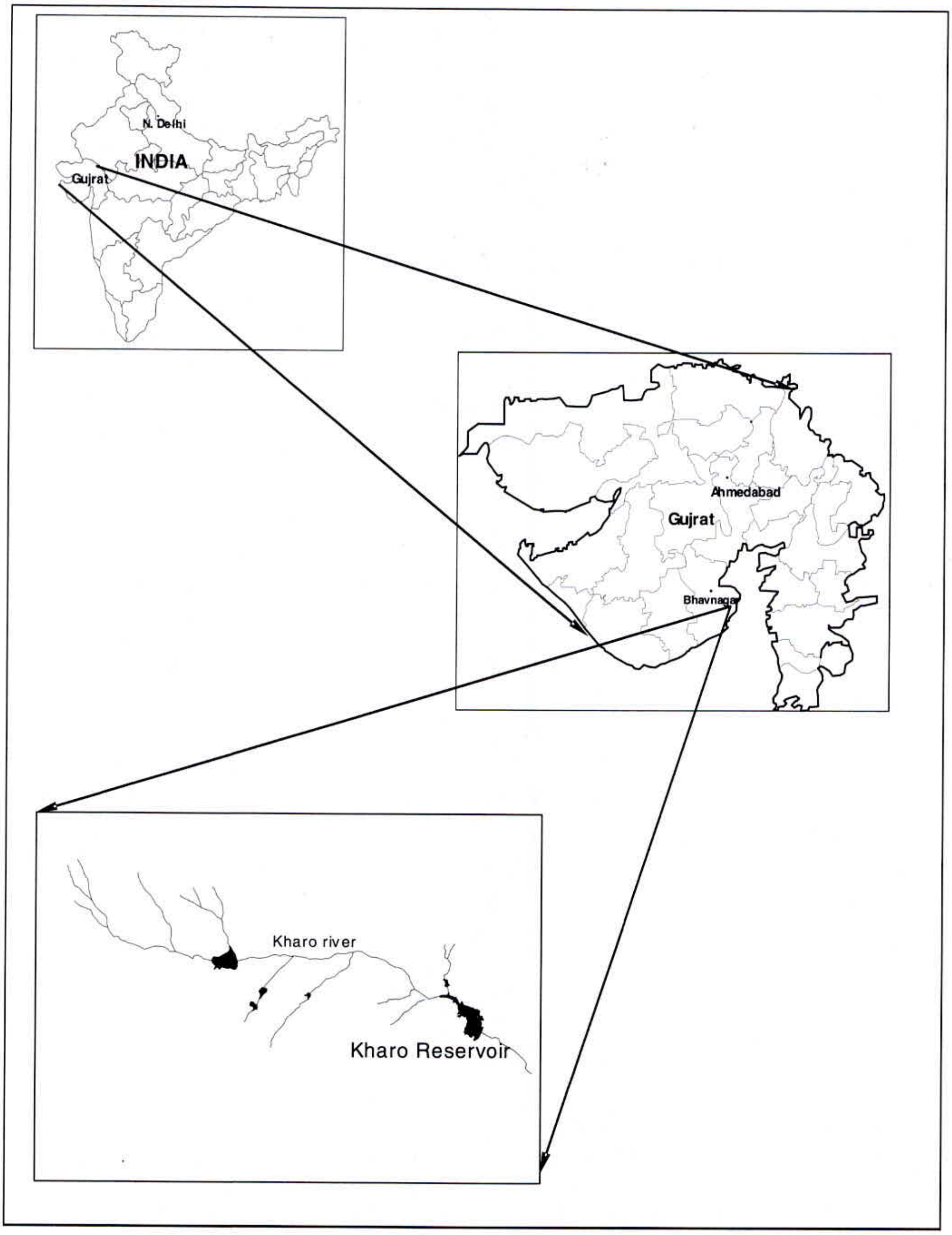

Fig. 1: Base map of the study area showing the Kharo reservoir

METHODOLOGY

The basic principal of revised capacity estimation using remote sensing and GIS is that when the sedimentation occurred in a reservoir its water spread reduced with respect to its original area before impoundment. The IRS 1D/p6, LISS 3 data of seven different dates have been used and digital image analysis have been carried out in ILWIS 3.0 GIS software. All the images have been geo-referenced with the help of Survey of India toposheets so that they can be overlaid and linked with the latitude and longitude and the geographical area also can be determined directly in sq. m. After geo-referencing, all the images have been cut down to small sizes to cover the water spread area of the reservoir and its surroundings.

In the visible region of the spectrum (0.4 - 0.7 mm), the transmittance of water is significant and the absorption and reflectance are low. The reflectance of water in the visible region seldom rises above 5%. The absorption of water rises rapidly in the near-IR where both, the reflectance and transmittance are low. The normalized difference water index (NDWI) and image ratio (IR) have been used to identify the water pixels in the images. The NDWI can be written as:

$$NDWI = \left[\frac{GREEN - NIR}{GREEN + NIR}\right] \tag{1}$$

$$IR = \left[\frac{NIR}{GREEN}\right] \tag{2}$$

The slicing operation of the NDWI and ratio images has been carried out to extract the water pixels from the rest. The revised areas obtained from this operation may be used to estimate the revised volume between two consecutive elevations with the help of cone formula. In the cone formula, the volume of water (ΔV) between two consecutive spread A_1 and A_2 can be expressed as:

$$\Delta V = \frac{h}{3}\left(A_1 + A_2 + \sqrt{A_1 A_2}\right) \tag{3}$$

Where, h is the height between two elevations.

The revised cumulative capacities have been obtained by adding the revised volumes between consecutive intervals. For comparison, the original cumulative capacities on different stage of pass have been obtained from the original elevation-area-capacity table.

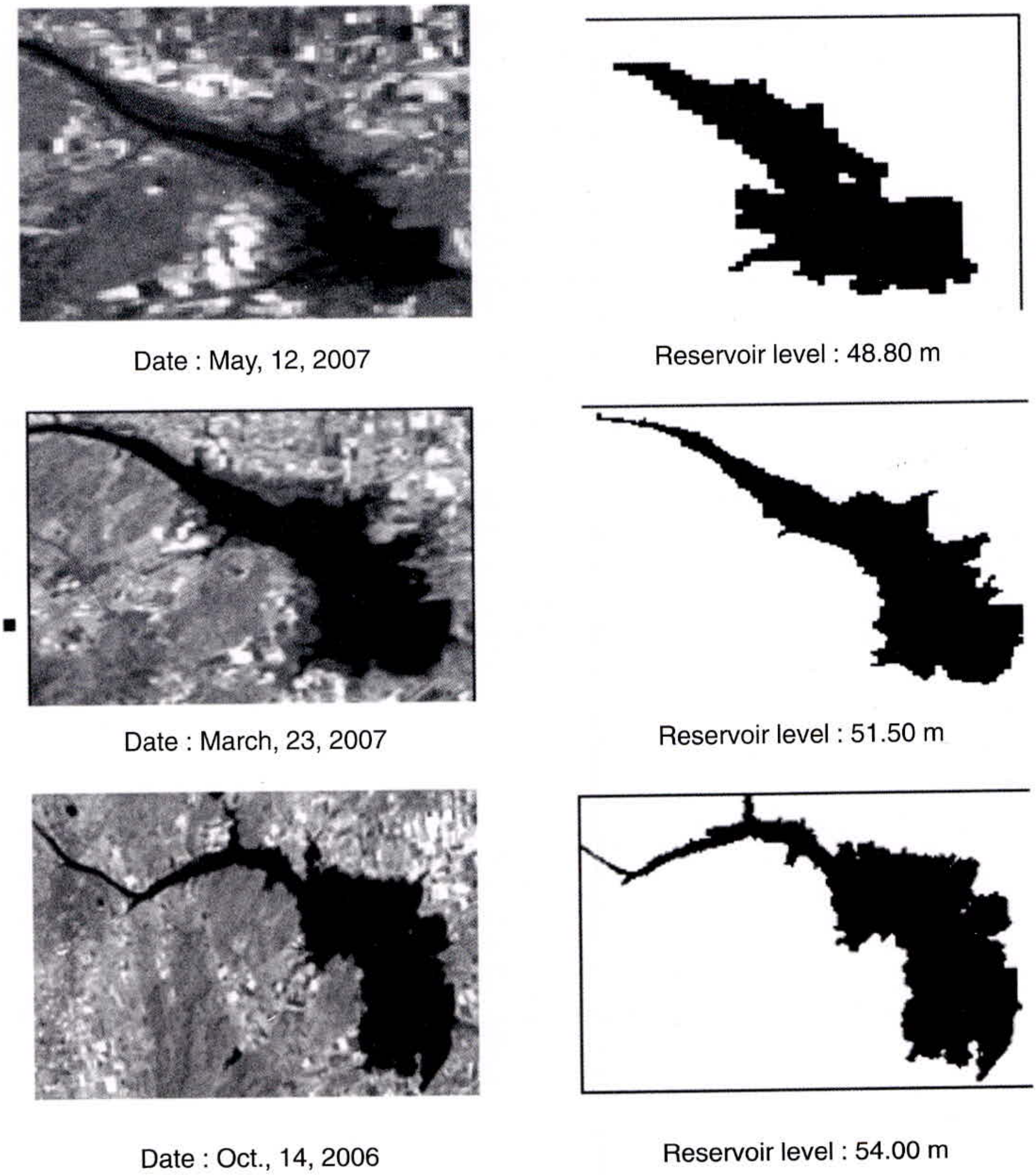

Fig. 2 : Band III images and masked out water spread areas of Kharo reservoir

RESULTS & ANALYSIS

The periodical assessment of capacity of reservoirs is necessary for determination of extent of degradation in the catchment areas, allocation of existing water for different purposes, determination of useful life of reservoir and rate of siltation etc. In the remote sensing technique of assessment of reservoir sedimentation, revised spread areas at different levels have been obtained and revised capacities between these levels estimated using these areas. Initially, all the images were imported in ILWIS 3.0, GIS software and geo-referenced with the index map/topo-sheets. The digital image analysis has been performed to estimate the revised water spread. The Normalized Deviation Water Index (NDWI), Image rationing and slicing methods of image classification have been used to differentiate the water pixels from other land uses. The band-3 images and the masked out water spread area of some selected dates have been presented in Fig. 2. The satellite data at D.S.L. i.e. 47.50 m. and at F.S.L., i.e. 54.12 m were not available. To compute revised spread area on these levels, a graph has been prepared between reservoir elevation and revised water spread area. A best fit line has been plotted and the revised water spread at 47.50 m and 54.12 m have been computed as 30.30 hectare and 337.90 hectare respectively. The revised water spread area and corresponding volume at different elevations have been computed and given in the Table 3.

Table 3: Revised water spread and loss in capacity of Kharo reservoir

Date of pass	Reservoir elevation (meter)	Number of water pixel	Revised area (M Sq.m)	Revised volume (MCM)	Original cumu. capacity (MCM)	Original volume (MCM)	Loss in volume (MCM)	% Loss in volume between successive elevations
River bed	40.17		0.00		0.000			
				0.741		1.025	0.284	27.73
DSL *	47.50	549	0.303		1.025			
				0.544		1.039	0.495	47.64
12-May-07	48.80	988	0.546		2.064			
				1.823		2.798	0.975	34.85
17-Apr-07	50.80	2418	1.335		4.862			
				0.842		1.207	0.365	30.23
29-Apr-06	51.40	2667	1.473		6.069			
				0.152		0.202	0.050	24.87
23-Mar-07	51.50	2830	1.563		6.271			
				0.770		0.905	0.135	14.92
26-Feb-07	51.95	3375	1.864		7.176			
				2.234		3.210	0.976	30.41
16-Feb-06	52.90	5207	2.876		10.386			
				3.409		3.800	0.391	10.28
14-Oct-06	54.00	6028	3.329		14.186			
				0.402		1.064	0.662	62.18
FSL *	54.12	6118	3.379		15.250			

Using revised water spread areas, the revised cumulative capacity and percentage loss in gross storage at different levels have been estimated. The computation of loss in storage of Kharo reservoir from the year 1985 to 2007 has been depicted in Table 4. The graphical representation of the elevation v/s original (1985) and revised cumulative capacities (2007) of Kharo reservoir have been presented in Fig. 3. The Kharo reservoir has started its functioning since 1985 and 4.332 M. cum of gross storage has been lost in 22 years. The rate of silting in Kharo reservoir is 0.197 M. cum/year. The comparison of the results of silt survey of 2000 and remote sensing survey of the present study in 2007 indicated that the rate of siltation in Kharo reservoir increased to 0.115 M cum/100 sq km/year during 2000 to 2007 from the earlier rate of 0.067 M cum/100 sq km/year from 1985 to 2000. The rate of siltation during 2000 to 2007 has nearly doubled from the previous silting rate and it emphasizes the need for conservation measures and catchment area treatment plan to arrest the entry of silt in to the reservoir.

Table 4: Estimation of loss in storage of Kharo reservoir (1985-2007)

Date of pass	Reservoir elevation (meter)	Original capacity (MCM)		Revised capacity (MCM)		Loss in cum. capacity (MCM)	% Loss in cumulative capacity
		Volume	Cumulative capacity	Volume	Cumulative capacity		
River bed	40.17		0.000		0.000		
DSL *	47.50	1.025	1.025	0.741	0.741	0.284	27.73
12-May-07	48.80	1.039	2.064	0.544	1.285	0.779	37.75
17-Apr-07	50.80	2.798	4.862	1.823	3.108	1.754	36.08
29-Apr-06	51.40	1.207	6.069	0.842	3.950	2.119	34.92
23-Mar-07	51.50	0.202	6.271	0.152	4.102	2.169	34.59
26-Feb-07	51.95	0.905	7.176	0.770	4.872	2.304	32.11
16-Feb-06	52.90	3.210	10.386	2.234	7.106	3.280	31.58
14-Oct-06	54.00	3.800	14.186	3.409	10.515	3.671	25.88
FSL *	54.12	1.064	15.250	0.402	10.918	4.332	28.41

CONCLUSION

Periodic assessments of revised capacities of reservoirs are essential to know the rate and pattern of sedimentation, need of conservation measures in the catchment and modification of reservoir operation plan. The remote sensing technique for the assessment of reservoir sedimentation is based on estimation of revised water spread at different elevations. The following conclusions can be drawn from the study:

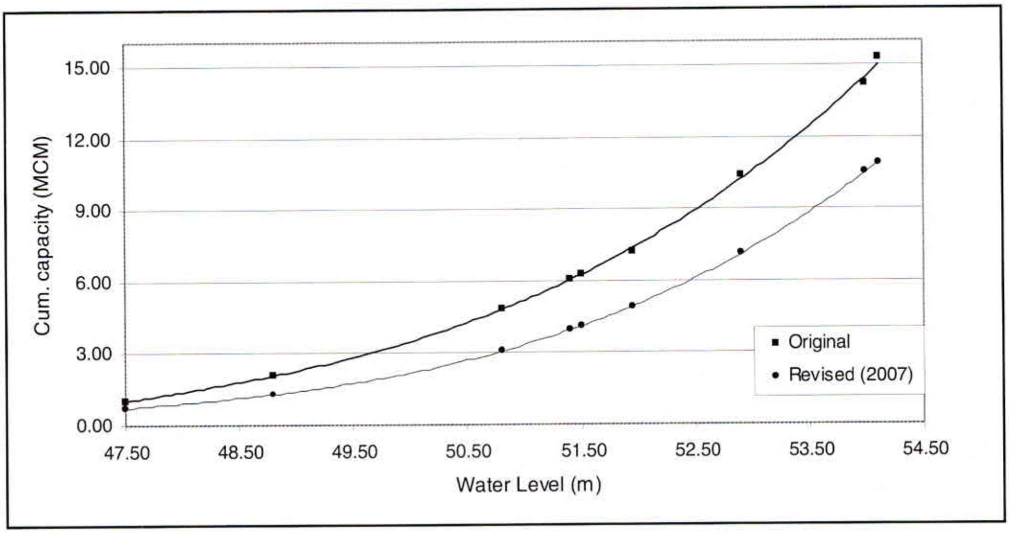

Fig. 3: Comparision of Original (1985) and Revised (2007) Cumulative Capacities of Kharo Reservoir

- The satellite remote sensing has emerged as an important tool in carrying out reservoir capacity surveys rapidly, frequently and economically.
- The Kharo reservoir has lost 4.332 MCM of gross storage and 0.284 MCM of dead storage in 22 years (from 1985 to 2007).
- The average rate of silting in Kharo reservoir is 0.197 MCM/year.
- The catchment area up to the dam site of the Kharo reservoir being 241.06 sq. km, the silting rate in common unit is computed to be 8.17 ha-m/100 km^2/year.
- The rate of siltation in Kharo reservoir doubled during the last seven years. Therefore, it is necessary to take suitable conservation measures and development of catchment area treatment plan to control soil erosion from the catchment.
- The revised capacity table/curve obtained in the analysis may be used in future reservoir operation.

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