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Assessment of Revised Capacity In A Reservoir of Chhattisgarh State of India Using Digital Image Processing Technique of Remote Sensing Data

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Abstract : The process of sedimentation in reservoir embodies the sequential processes of erosion, entrainment, transportation, deposition and compaction of sediment and reduces the water storage capacity of reservoir and availability of water for its designated use. Negative effects of sedimentation tend to become more and more relevant on a global scale due to population growth. The study of erosion and sediment yield from catchments is of utmost importance as the deposition of sediment in reservoir reduces its capacity, and thus affecting the water availability for the designated use. The assessment of present capacity of the reservoir will be helpful to determine the loss in capacity, the rate of sedimentation and its pattern, development of modified operation plan etc. In the present study, an attempt has been made to determine the revised capacity of Kodar medium reservoir on river Kodar in Mahasamund district of Chhattisgarh state of India. The catchment area of the river up to Kodar dam site is 317.17 km2 and mean annual rainfall in the catchment area is about 1433.1 mm. The dead storage capacity and gross storage capacity of reservoir are 11.33 Mm3 and 160.35 Mm3 respectively. In order to cover the whole range of live storage, seven scenes of different dates were acquired from National Remote Sensing Centre, Hyderabad (India). After importing and Georeferencing the remote sensing data, different digital image processing techniques such as normalized deviation water index (NDWI), normalized deviation vegetation index (NDVI), band ratio (BR), false color composite (FCC) and field truth information were used to differentiate water pixels from rest of the image. The derived revised water spreads have been used to compute revised capacities and subsequently the losses of reservoir capacities of Kodar reservoir at various levels. The sedimentation analysis of Kodar reservoir indicated that 24.94 Mm^3 of gross storages and 4.89 Mm^3 of dead storage have been lost in 32 years (1976-77 to 2008-09). The revised capacity curve developed in the analysis may be used for reservoir operation and allocation of water for different uses. Considering the uniform loss in the storages, it can be concluded that 0.78 Mm^3 of gross storage and 0.15 Mm3 of dead storage of Kodar reservoir have been lost each year with average rate of 0.25 Mm^3/100 km^2/year.

Keywords: Sedimentation, remote sensing, GIS, digital image classification, revised capacity, normalized deviation water index (NDWI), normalized deviation vegetation index (NDVI),

1. INTRODUCTION

Reservoir sedimentation process is a universal phenomenon, which has been considered as a most critical environmental hazard of modern time (Jain and Kothyari, 2000). The range of problems caused by reservoir sedimentation is varied and wide. Apart from loss of capacity, increased flood risks, interruption in hydropower generation and downstream river bed degradation; other problems such as degradation of water quality, increased complexity in reservoir operation and maintenance lead to increase in their associated cost (Kothyari et al., 2002; Siyam et al., 2005). 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. Mangond et al (1985) employed digital classification techniques to estimate the water spread of the Malaprabha reservoir 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. Suvit et al (1988) used digital techniques in which density slicing of Landsat MSS near-IR (0.8- 1.1 μm) data were used to extract the water spreads of the Ubolratana reservoir of five different dates. 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 (i.e. Work and Gilmer, 1976, Thiruvengadachari et al, 1980; Jain and Goel, 1993, Goel and Jain, 1996, Jain and Kothiyari, 2000, Jaiswal et al, 2008, Thomas et al 2009).

As sediment deposition depletes reservoir storage volume, periodic assessment of revised capacity is essential for reallocation of available storage for different demands, efficient operation and management of reservoirs. To determine the useful life of a reservoir, it is essential to periodically conduct the surveys and assess the sedimentation rate in a reservoir. 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 utilisation of water. The conventional methods of reservoir sedimentation are time consuming, costly, cumbersome and require lot off manpower, therefore cannot be used frequently. But using the synoptic and repetitive viewing capacity of remote sensing sensors and the ability of image processing with Geographic Information System (GIS) makes this method economical, less time consuming and easy. The 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. In the present study, an attempt has been made to determine revised capacity of Kodar reservoir on river Kodar reservoir in Mahasamund district of Chhattisgarh state of India using digital image processing technique of remote sensing data.

2. MATERIAL AND METHOD

2.1 Study Area

The Kodar reservoir is constructed across river Kodar, a tributary of river Mahanadi. The dam is constructed on Raipur – Sambalpur national highway at a distance of 65 km from Raipur near village Kowajhar in Mahasamund district. The base map showing location of Kodar reservoir has been given in Fig 1. The catchment area of the river up to dam site is 317.17 km2. and mean annual rainfall in the catchment area is about 1433.1 mm. The dead storage capacity and gross storage capacity of reservoir are 11.33 Mm3 and 160.35 Mm3 respectively. The length of earthen dam is 2363 m with a maximum height of 23.32 m, a waste weir 183m long to pass designed flood and head regulators on both the flanks to feed the canal system. Two canals of length 23.30 km (Left Bank Canal) and 10.60 km (Right Bank Canal) are envisaged from the sluices located on left and right flanks of the earthen dam to provide irrigation to 16,066 ha and 7,406 ha respectively. The reservoir was first impounded in the year 1976-77 and now it is necessary to revise original elevation-area-capacity table for efficient management of available water. The topography of the catchment area of Kodar river is undulating and agriculture area is more from where soil loss is more due to lack of conservation measures, therefore the erosion from the catchment and rate of sedimentation in the reservoir may be more than the designed rate. The original elevation capacity curve of Kodar reservoir has been presented in Fig 2.

2.2 Data Used

The reservoir details including elevation capacity table/curve, reservoir levels on different dates have been used in the study. Eight multi-date LISS III scenes of Indian remote sensing IIRS) satellite data have been purchased from NRSC, Hyderabad and used in the analysis (Table 1).

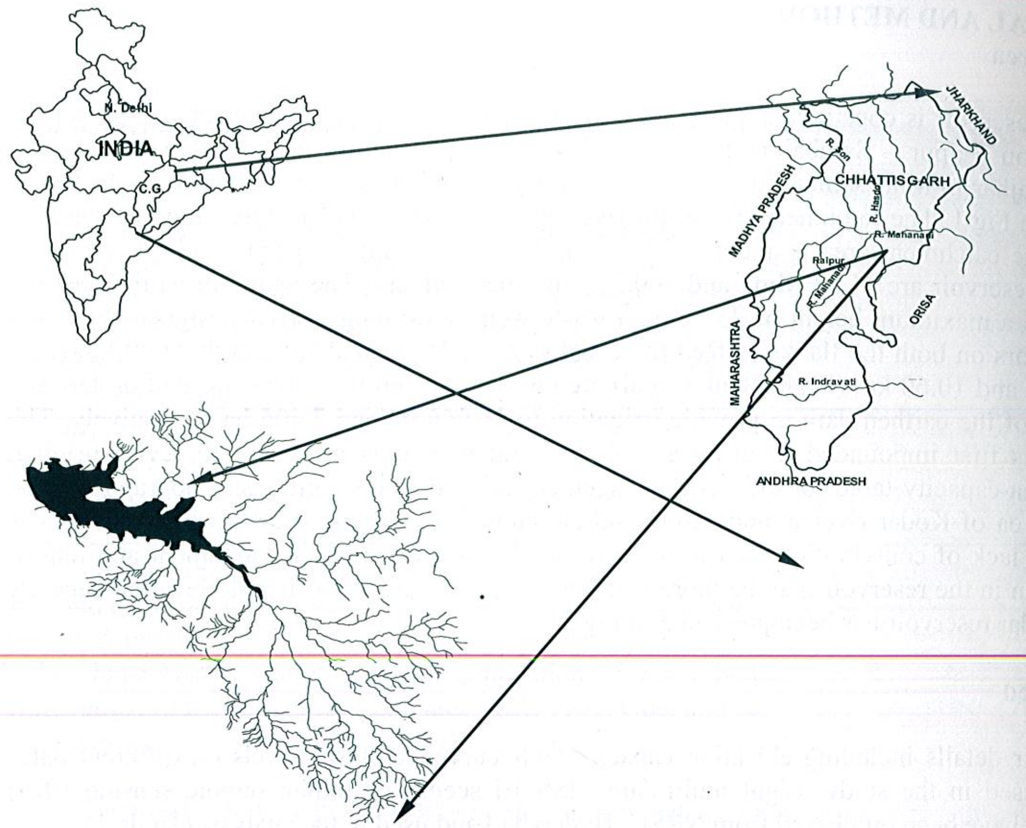


Figure 1. Base map of study area

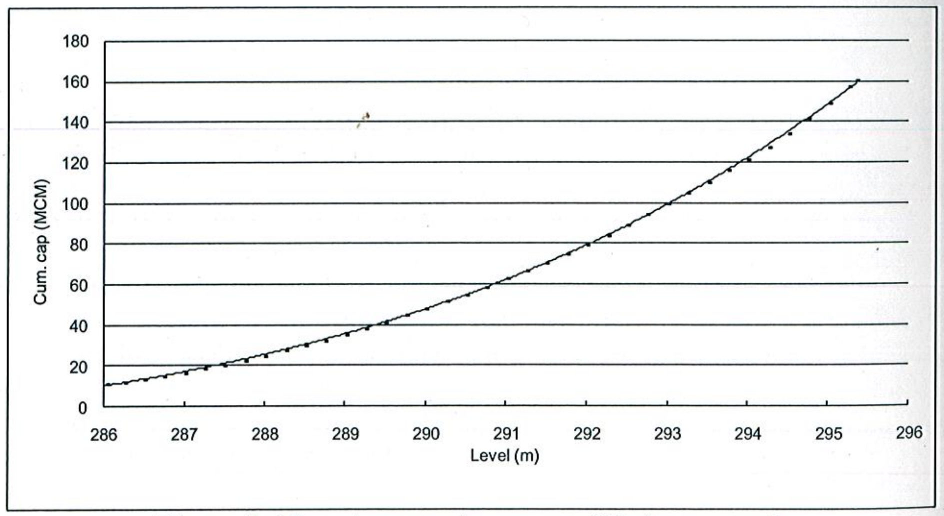


Figure 2. Elevation capacity curve of Kodar reservoir

Table 1. Satellite data used in the study

S.N.	Date	Satellite	Sensor	Path	Row	Reservoir levels (m)
1.	09-May-2009	IRS P6	LISS III	102	57	287.39
2.	22-Mar-2009	IRS P6	LISS III	102	57	288.49
3.	29-Oct-2008	IRS P6	LISS III	102	57	289.37
4.	14-May-2008	IRS P6	LISS III	102	57	290.68
5.	24-Oct-2009	IRS P6	LISS III	102	57	291.69
6.	03-Mar-2008	IRS P6	LISS III	102	57	293.03
7.	15-Jan-2008	IRS P6	LISS III	102	57	293.94
8.	11-Oct-2007	IRS P6	LISS III	102	57	295.16

2.3 Methodology

The basic principle 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 and the revised water spreads at different levels can be computed with the help of image analysis technique of GIS software. In the present study, the digital image analysis has been carried out using Integrated Land and Water Information System (ILWIS 3.0). All images were geo-referenced with the help of index map/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. In remote sensing technique, the transmittance characteristics of different objects recorded by sensors are used to distinguish various land uses on the earth surface. The remote sensing images consist of digital numbers and need to be converted in radiance values according to radiance characteristics of different sensors. These radiance values can be used to make a relative comparison. The radiance $L(\lambda)$ can be computed using following equation:

$$L(\lambda) = L_{\min}(\lambda) + [L_{\max}(\lambda) - L_{\min}(\lambda)] * \frac{Q_{cal}}{Q_{cal,\max}} \quad (1)$$

The minimum radiance $L_{\min}(\lambda)$ and maximum radiance $L_{\max}(\lambda)$ of a sensor can be obtained from its radiometric characteristics. The radiometric characteristics of different sensors in IRS 1D/P6 LISS III sensors are given in Table 2. (NIH, 2003-04).

Table 2. Radiometric characteristics of various bands of IRS 1D/P6 sensors.

S.N.	Band	Wavelength range	Satellite radiance for LISS III of IRS 1D/P6	
			L_{min}	L_{max}
1.	Band II	0.52-0.59	-2.8	296.8
2.	Band III	0.62-0.68	-1.2	204.3
3.	Band IV	0.77-0.86	-1.5	206.2
4.	Band V	1.55-1.70	-0.37	27.19

In the visible region of the spectrum (0.4 - 0.7 μm), the transmittance of water is significant and the absorption and reflectance are low. The reflectance of water in the visible region scarcely 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), normalized difference vegetation index (NDVI), band ratio, NIR (Band III) and false color composite (FCC) have been used to identify the water pixels in the images. The NDWI, NDVI and band ratio (BR) can be written as:

$$NDWI = \left[\frac{GREEN - NIR}{GREEN + NIR}\right] \quad (2)$$

$$NDVI = \left[\frac{RED - NIR}{RED + NIR}\right] \quad (3)$$

$$BR = \frac{GREEN}{NIR} \quad (4)$$

where, *GREEN* is *Band II*, *RED* is *Band III* and *NIR* is *Band IV* of IRS satellites (IRS ID and P6). The slicing operation of the NDWI, NDVI, Band IV or BR 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 (V) between two consecutive water spread areas A1 and A2 can be expressed as:

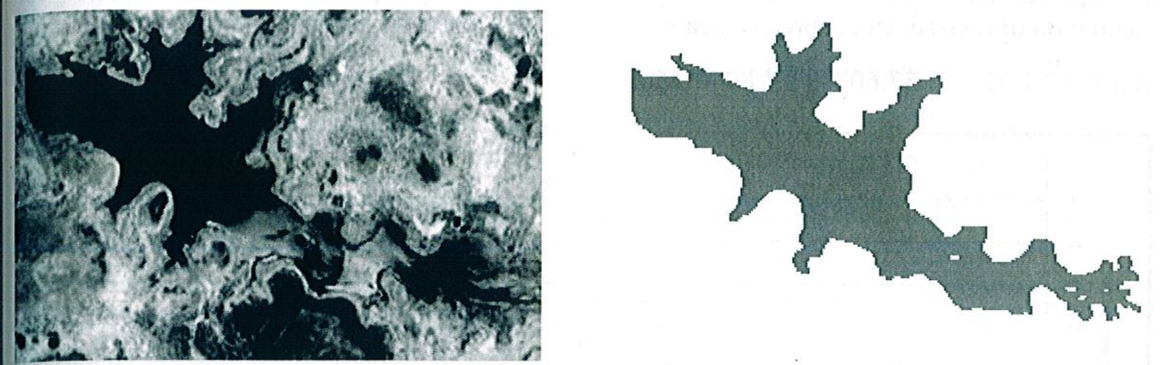
$$V = \frac{h}{3}\left(A_1 + A_2 + \sqrt{A_1 A_2}\right) \quad (5)$$

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 curve. The loss in capacity at different level can be computed by deducting the revised capacity from original capacity at that level.

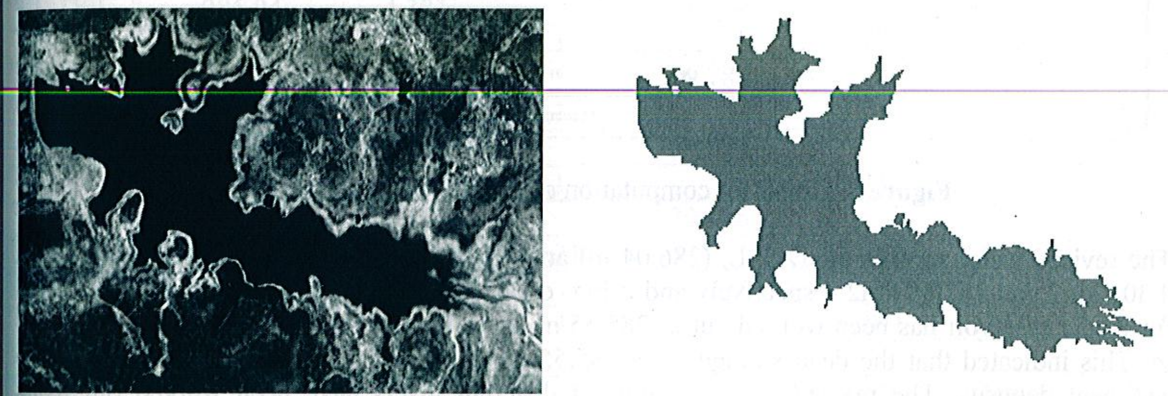
3. RESULTS AND ANALYSIS

For estimation of revised capacities at different levels of Kodar reservoir, NDWI, NDVI and band ratio (BR) followed by slicing methods of image classification has been used to differentiate the water pixels from other land uses. Different selected remote sensing scenes have been purchased

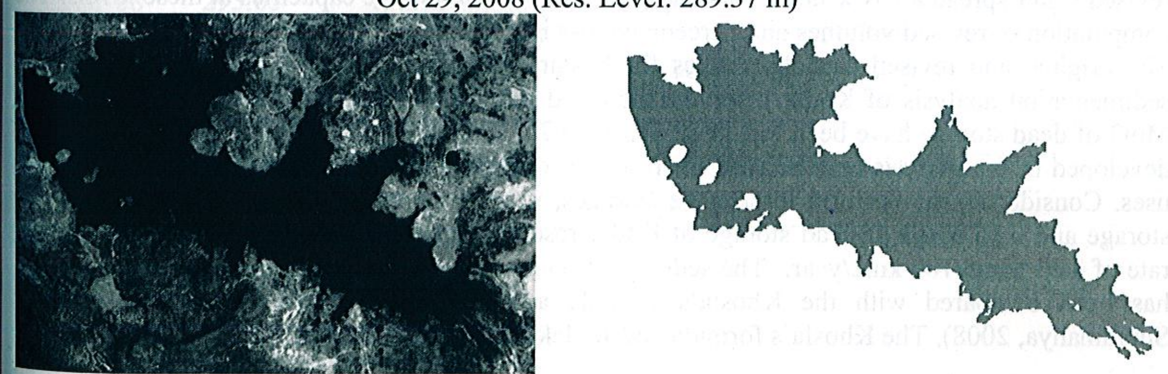
from National Remote Sensing Centre Hyderabad have been imported in ILWIS GIS and georeferencing of each scenes have been performed to extract revised area directly in sq. m. The False Color Composite (FCC) and masked out water spread areas of selected dates have been presented in Fig. 2.



May 09, 2009 (Res. Level: 287.39 m)



Oct 29, 2008 (Res. Level: 289.37 m)



Oct 11, 2007 (Res. Level: 295.16 m)

Figure 2. False color composite and extracted water spread on different dates for Kodar reservoir

The satellite data at dead storage level (D.S.L.) i.e. 286.04 m and at full supply level (F.S.L.), i.e. 295.24 m were not available. To compute revised spread area on various levels, a graph has been plotted between reservoir elevation and revised water spread area. The best fit line using revised water spreads have been presented in Fig. 3. The following equation has been obtained for computation of revised water spreads area in sq. km. using reservoir levels (L) in m.

$$Area = 0.10132L^2 - 57.60799L + 8040.25633 \quad (6)$$

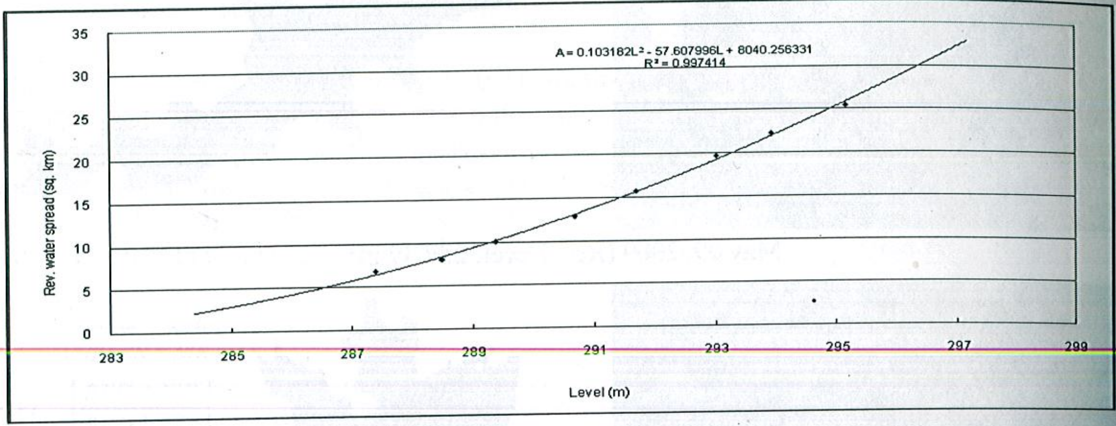


Figure 3. Graph for computation of revised water spread area

The revised water spreads at D.S. L. (286.04 m) and F.R.L. (295.24 m) have been computed as 4.301 km2 and 26.088 km2 respectively and using eq. 6. From the analysis, the revised bed level for Kodar reservoir has been worked out as 285.55 m. as compared to original river bed of 275.67 m. This indicated that the dead storage from 285.55 m to 275.67 m has been filled up with the sediment deposits. The revised storages between different levels have been worked out using revised water spread areas which ultimately gave revised cumulative capacities at these levels. The computation of revised volumes and percentage loss in volumes has been presented in Table 3 & 4. The original and revised capacity curves for Kodar reservoir has been depicted in Fig. 4. The sedimentation analysis of Kodar reservoir indicated that 24.94 Mm3 of gross storages and 4.89 Mm3 of dead storage have been lost in 32 years (1976-77 to 2008-09). The revised capacity curve developed in the analysis may be used for reservoir operation and allocation of water for different uses. Considering the uniform loss in the storages, it can be concluded that 0.78 Mm3 of gross storage and 0.15 Mm3 of dead storage of Kodar reservoir have been lost each year with average rate of 0.25 Mm3/100 km2/year. The sedimentation rate computed from remote sensing approach has been compared with the Khosla's formula and Joglekar's equation (Mutreja, 1986 & Subramanya, 2008). The Khosla's formula and Joglekar's equation may be written as:

Khosla's formula

$$Q_s = \frac{0.323}{A^{0.28}} \quad (7)$$

Joglekar's equation

$$Q_s = \frac{0.597}{A^{0.24}} \quad (8)$$

Table 3. Computation of revised volume in Kodar reservoir

Date of Pass	Reservoir Elevation (meter)	Revised Area (Sq. km)	Revised Volume (M cu.m)	Original Cumu. Capacity	Original Volume (M cu.m)	Loss in Volume (M cu.m)	% Loss in Volume
Original River Bed	275.67			0			
Revised River Bed	281.55	0					
DSL *	286.04	4.301	6.444	11.330	11.330	4.886	43.12
9-May-09	287.39	6.407	7.181	19.787	8.457	1.276	15.09
22-Mar-09	288.49	8.400	8.119	29.924	10.137	2.018	19.91
29-Oct-08	289.37	10.175	8.161	39.906	9.982	1.821	18.25
14-May-08	290.68	13.113	15.213	57.733	17.827	2.614	14.66
24-Oct-09	291.69	15.620	14.492	74.022	16.289	1.797	11.03
3-Mar-08	293.03	19.271	23.334	100.052	26.030	2.696	10.36
15-Jan-08	293.94	21.961	18.747	120.252	20.200	1.453	7.19
11-Oct-07	295.16	25.837	29.125	154.234	33.982	4.857	14.29
FSL *	295.337	26.088	4.595	160.350	6.116	1.521	24.86

Table 4. Percentage loss in revised volume at different levels in Kodar reservoir

Reservoir Elevation (meter)	Original Capacity (M cu. m)		Revised Capacity (M cu. m)		Loss in Cum. Capacity (M cu.m)	Percentage Loss in Cumulative Capacity
	Volume	Cumu. Capacity	Volume	Cumu. Capacity		
275.67#		0				
281.55##				0		
286.04*	11.330	11.330	6.444	6.444	4.886	43.12
287.39	8.457	19.787	7.181	13.625	6.162	31.14
288.49	10.137	29.924	8.119	21.744	8.180	27.34
289.37	9.982	39.906	8.161	29.905	10.001	25.06
290.68	17.827	57.733	15.213	45.117	12.616	21.85
291.69	16.289	74.022	14.492	59.609	14.413	19.47
293.03	26.030	100.052	23.334	82.943	17.109	17.10
293.94	20.200	120.252	18.747	101.690	18.562	15.44
295.16	33.982	154.234	29.125	130.815	23.419	15.18
295.337**	6.116	160.350	4.595	135.411	24.939	15.55

Original river bed, ## Present river bed, * Dead storage level, ** Full reservoir level

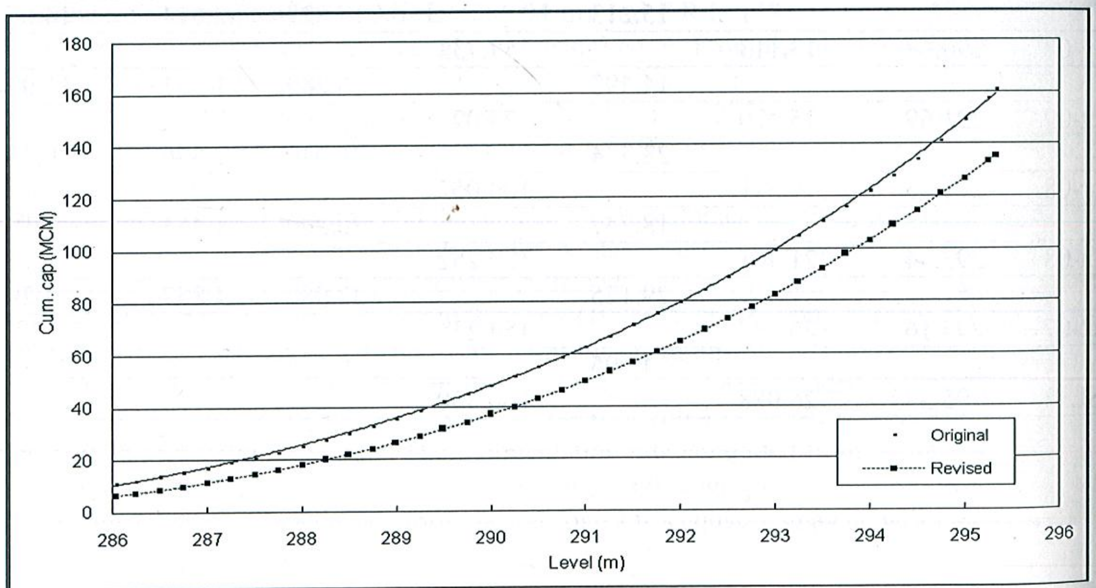


Figure 4. Original and revised capacity curves of Kodar reservoir

where, Qs is annual silting rate from 100 sq. km of watershed area (Mm3/100 km2/year) and A is the catchment area (sq. km). As the catchment area of Kodar reservoir is 307.17 sq. km, the rate of sedimentation has been computed from Khosla's formula and Joglekar's equation are 0.06 Mm3/100 km2/year and 0.15 Mm3/100 km2/year respectively. It has been proved that Khosla's formula gives rate of siltation on lower side, but the present rate of siltation in Kodar reservoir is more than the results obtained from joglekar's equation. Therefore, it is necessary to take appropriate soil conservation measures in the Kodar catchment to reduce the intake of silt and sediment into Kodar reservoir.

4. CONCLUSIONS

The remote sensing technology has emerged as a unique and extremely important tool in understanding, assessing and monitoring the natural resources. Remote sensing data provides unbiased information related to status of earth resources and generally free from human interferences. The conventional methods for estimation of sediment deposits in the reservoir are time consuming and costly, therefore cannot be done frequently. The remote sensing data having the capability of interpretation in GIS platform may be used to supplement the conventional technique in live storage zone of reservoirs. In the present study, digital image processing technique of remote sensing data has been used for determination of revised capacity of Kodar reservoir. From the analysis it has been observed that, 24.94 Mm3 of gross storages and 4.89 Mm3 of dead storage have been lost in 32 years (1976-77 to 2008-09). Considering the uniform loss in the storages, it can be concluded that 0.78 Mm3 of gross storage and 0.15 Mm3 of dead storage of Kodar reservoir have been lost each year with average rate of 0.25 Mm3/100 km2/year. The sedimentation rate in the Kodar reservoir has been found more than computed from Joglekar's formula, therefore it is necessary to adopt appropriate measures and general awareness for soil conservation in the study area.

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