EVALUATION OF THE LOSS OF CAPACITIES DUE TO SEDIMENTATION IN RESERVOIRS BY HYBRID METHOD

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ABSTRACT
Reservoirs are created to store water. These Reservoirs created by dams on rivers get silted due to soil erosion in the catchment and the subsequent transportation and long term deposition of the silt over the bed of the reservoir causes reduction in the storage capacity of the reservoir and also affect the useful life of the reservoir which ultimately defeat the purposes for which they are created [1]. The systematic evaluation of sedimentation on a continuous basis therefore becomes utmost necessary for assessing useful life of reservoir [2]. A high tech approach of satellite Remote sensing technique in conjunction with DGPS based Bathymetric survey provides useful solution for the quantitative and qualitative estimation of silt in the reservoir. In the present paper an attempt has been made to assess the loss in net storage capacity due to long term siltation and rate of siltation in the live storage capacities of Panshet, Warasgaon, & Khadakwasla reservoirs in Pune district of Maharashtra India. From the analysis efforts have been made to predict long term sedimentation rates which are useful in assessment of net siltation to be considered for computation of the net storage.

KEYWORDS: *Long Term Reservoir Sedimentation, Bathymetric survey data, Remote Sensing Method, Hybrid Method, Losses in Storage Capacity*

I. INTRODUCTION

Natural water reaches are usually in state of morphological equilibrium, where the sediment inflow on an average balances the sediment outflow. Reservoir construction dramatically affect this equilibrium due to change in hydraulic condition and induce sedimentation. The storage capacity of reservoirs gradually reduce due to silting. The eroded material transported in the reservoir is deposited at the different level progressively reducing their storage capacity throughout their depth. Reduction in the storage capacity of a reservoir due to sedimentation defeats the purpose for which the reservoir has been designed.

Assessment of sediment deposition become very important for the management and operation of reservoir, including periodical assessment of siltation. Different conventional methods of assessing sedimentation in reservoir are in vogue today viz.

i . Conventional bathymetric survey
ii . Inflow outflow method
iii. Remote sensing method
iv. Empirical methods- Area reduction method
v. Mathematical model etc.

Empirical method and mathematical models are the methods for prediction of reservoir sedimentation and are normally used during planning stage. Remaining three methods are used for monitoring of sedimentation during operation stage. Stream flow analysis method needs daily measurements of water and sediment flow at upstream and downstream of reservoir right from the day of reservoir impoundment [2]. The present day bathymetric surveys are conducted with modern hi - tech survey systems consisting of DGPS and depth measuring units such as Echo sounders. The bathymetric surveys for reservoirs in hilly region with thick vegetation within and around reservoir pose great

difficulties in spite of high -tech systems. Even with such modern system, surveys of large fan shape reservoirs require a period of 12 to 18 months or more. Apart from time factor, these bathymetric surveys are not cost effective and therefore cannot be carried out regularly at shorter intervals for purpose of monitoring of reservoir sedimentation. Comparatively, use of satellite imageries offers a cost and time effective alternative for monitoring purpose. Moreover remote sensing technique, offering data acquisition over a long period and broad spectral range, are superior to conventional methods. It is highly cost effective, easy to use and it requires lesser data and time in analysis as compared to other methods. The advantages of satellite data over conventional sampling procedures include repetitive coverage of a given area every three to four days, availability of spatial data over the areas of interest. More accurate data about water spread area of a reservoir on a given date could be collected instantaneously which is practically impossible even with high- tech survey systems. These advantages have led to development of remote sensing technique in study of sedimentation. More ever each of these methods has some merits and demerits over each other when applied independently [2]. The limitations of these two methods were overcome by the use of the Remote sensing method and DGPS –Bathymetric survey in combination called Hybrid technique which can be applied to cover the entire reservoir portion from its bed level to FRL.

II. ORGANISATION OF MANUSCRIPT

The present research paper contain eight main headings. A brief review of different methods of assessment of reservoir sedimentation is given under introduction and advantages of hybrid method are highlighted. Background of the study area presented in details of the study. Literature review provides a theoretical background & work carried out by earlier researchers related to present study. Methodology gives the idea of overall flow of the study. Result and discussion provides the overview of the entire study and estimated trend of sedimentation in these reservoirs. Rate of siltation for the year of impounding and the present survey years is compared and preferable solution to increase the storage capacity of reservoir is given in the conclusion. If the recent data is available results of the present study can be correlate and confirmed as discussed in the further studies

III. DETAILS OF STUDY

Figure 1. Location map of study area

Table 1. Salient features of the dams

Sr.No.	Particulars	Name of the reservoir		
		Panshet	**Warasgaon**	**Khadakwasla**
1	General location	Near village Panshet Taluka Velhe District Pune, Maharashtra Latitude 18^0 14'N Longitutude $73^0$38' E	Near village Warasgoan Taluka Velhe District Pune, Maharashtra Latitude 18^0 22'N Longitutude $73^0$35' E	Near village Khadakwasla Taluka Velhe District Pune, Maharashtra Latitude 18^0 26'29.4"N Longitutude $73^0$46' 07"E
2	Nearest city	Pune	Pune	Pune
3	River	Ambi	Mose	Mutha
4	Year of impounding	1970	1987	1863
5	Total catchment area at dam site	120.30 Sq.Km	130 Sq Km	501.80 Sq Km
6	Reservoir levels MDDL FRL	 597.41 635.81	 600.25 639.50	 574.30 582.62
7	Reservoir capacity Gross storage Live storage Dead storage	 303.93 Mm^3 294.93 Mm^3 9.00 Mm^3	 375.36 Mm^3 363.48 Mm^3 11.88 Mm^3	 86 Mm^3 56 Mm^3 30 Mm^3
8	Total area of submergence at FRL	1860 Ha	1487 Ha	1480 Ha
9	Dam details Max height of dam Length of dam	 67.58 m 785 m	 60.04 m 765 m	 32.81 m 1939 m

IV. REVIEW OF LITERATURE

S.K.Kalvit, S.N.Kulkarni *et .al.2010* used Remote sensing technique for monitoring sedimentation in lakes in Maharashtra. While conducting the sedimentation studies of the reservoirs located in different parts of the state, they observed that many reservoirs were affected by sedimentation as well as by the growth of semi aquatic weeds in the submergence area. This is predominantly observed in the some reservoirs / lakes in flatter Deccan plateau of Maharashtra. After assessing the sedimentation in reservoirs quantitatively, the necessity of applying some treatment to the catchment areas to reduce the soil erosion was examined.

U.C.Roman . D.N. Deshmukh ,Suneeta Jatwa V.K. Barodiya *et .al. 2009* Use the satellite Remote Sensing method for assessment of sedimentation in Panshet reservoir, and shows that water spread area of reservoir at various levels goes on decreasing due to sedimentation .During 1977 to 2002 .

M.S.Mundhe , V.B.Pandhare, M.B. Nakil, S.S. Pande .*et.al. 2009* analyse the sedimentation surveys and rates in live storage capacity of reservoirs, The analysis was based on the available data of 28 reservoirs from different basins in Maharashatra. The live storages of these 28 reservoirs range from 27.476 Mm3 to 2677 Mm3. The sedimentation rate assumed to be 3.57 to 7.15 Ha m/100 Km^2 / year where as the observed sedimentation rate in live storage of reservoir varies from 0.90 to 38.33 ha m/100 km^2/year. This gives the idea that the rate of siltation was much higher than designed.

V. METHODOLOGY

Reservoir sediment survey was carried out by Hybrid technique which is combination of DGPS Bathymetric survey and Remote sensing method. DGPS survey was conducted when the water level

in the reservoir had depleted well below FRL. Taking into consideration the minimum draft of about 2.5 to 3 m required for correct sounding readings and free movement of the boat in the reservoir, the findings of DGPS survey are restricted to a certain level due to limitations in data collection requirement of minimum clearance of about 3 meters. Area calculations were made using Grid Volume module in the surfer software. The gross and net volume was calculated by using prismoidal formula. [3]

The area above these levels was covered by The Indian Remote Sensing Satellite IRS P6 LISS III. The basic concept was to find out the water -spread area from the satellite images for different water levels. The difference between aerial spread of water between current year and earlier was the aerial extent of silting at these levels. The live storage capacity estimation of reservoir using remote sensing consists of following major heads

- Digital data base creation
- Estimation of water-spread area
- Calculation of reservoir capacity
- Comparison with previous surveys
- Estimation of loss of live capacity due to sedimentation.

Digital data base creation

All the satellite images were first loaded in the system. Satellite images were the geo- referenced using pre-rectified satellite images of same path and row with the help of ERDAS IMAGINE software from all the rectified satellite images, an area of interest i.e. the study area covering entire reservoir was extracted. It can be done by Normalised difference vegetation index (NDVI) or classification NDVI is one index, which enhances vegetation and water. NDVI is generated using the formula given below.

NDVI=(NIR-R)/(NIR=R) Where 'NIR' is digital number in near infrared band and R is digital number in red band. The ratioed image is then density sliced. Water pixel generally occupy lower range of histogram in ratioed image. For these reservoir, both NDVI analysis and classification technique were tried to measure the water spread area from the satellite images of the reservoir.

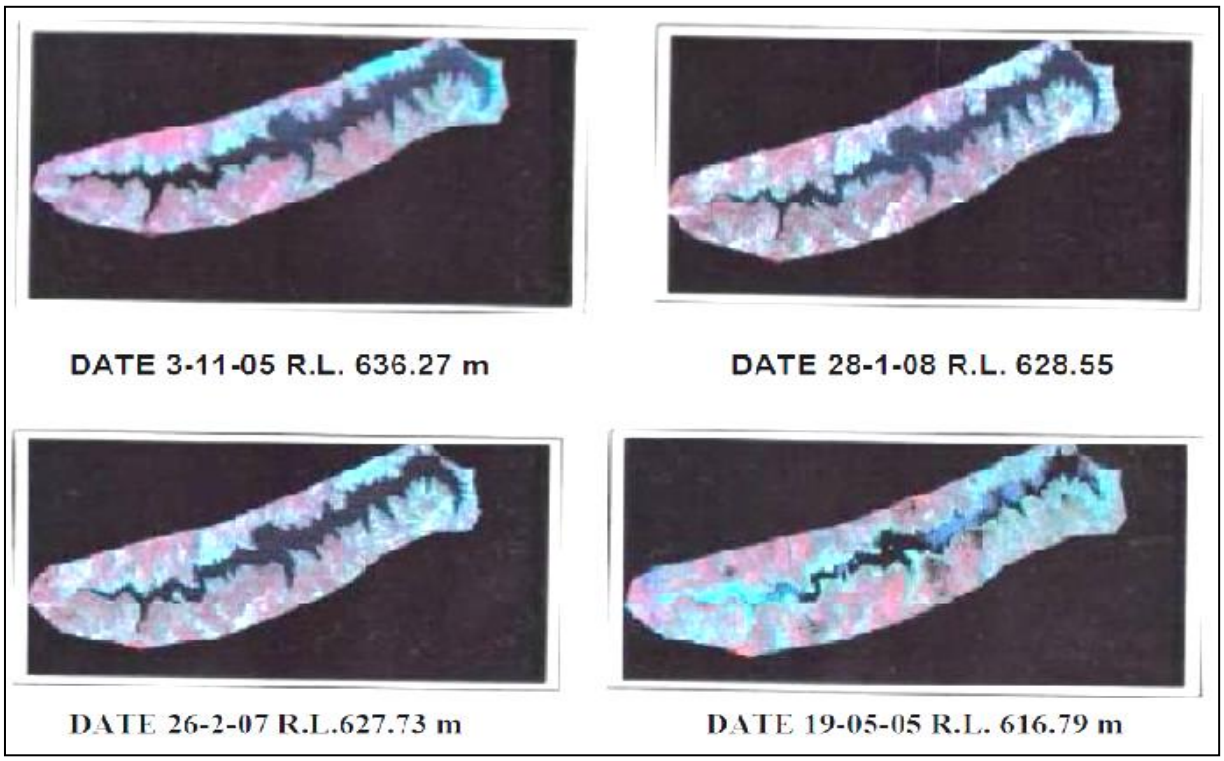

Figure 2. Water spread area at Minimum and Maximum water levels for Panshet reservoir

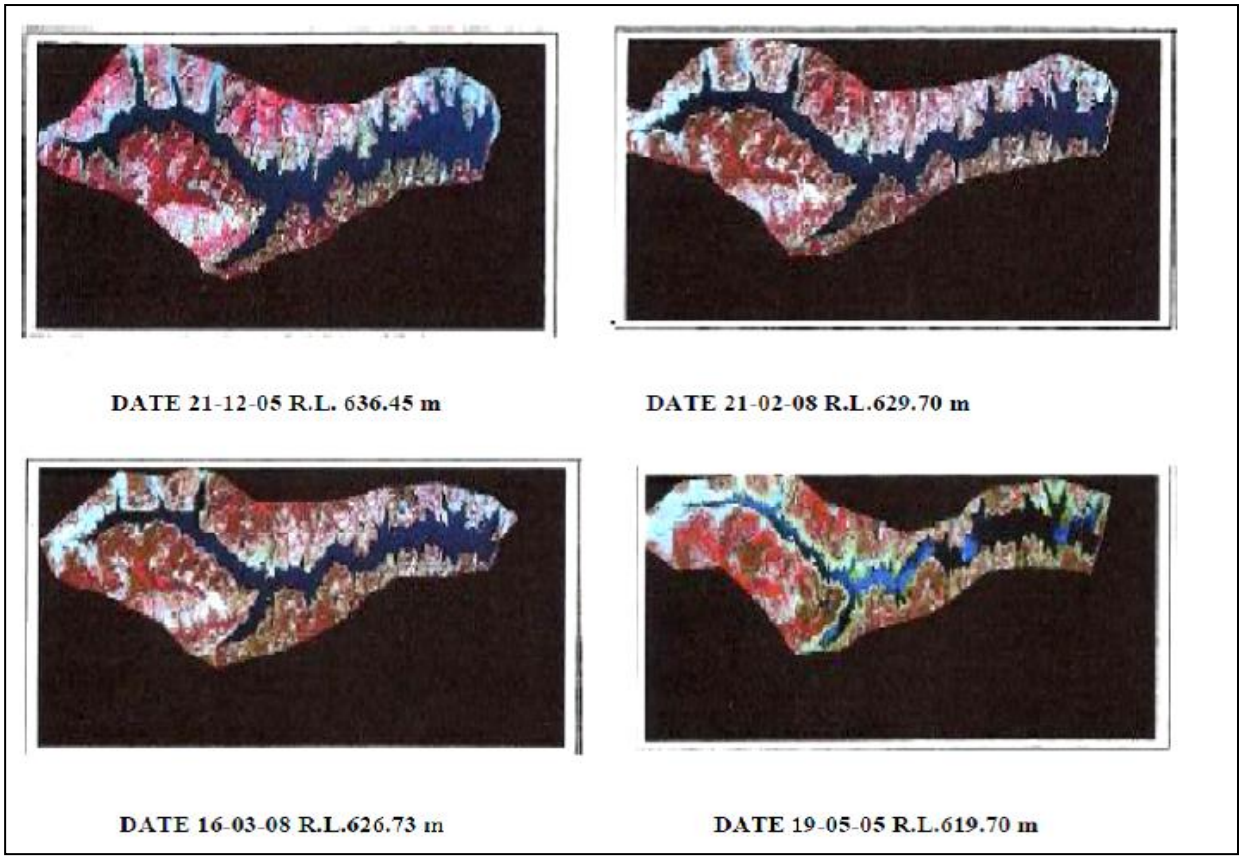

Figure 3. Water spread area at Minimum and Maximum water levels for Warasgaon reservoir

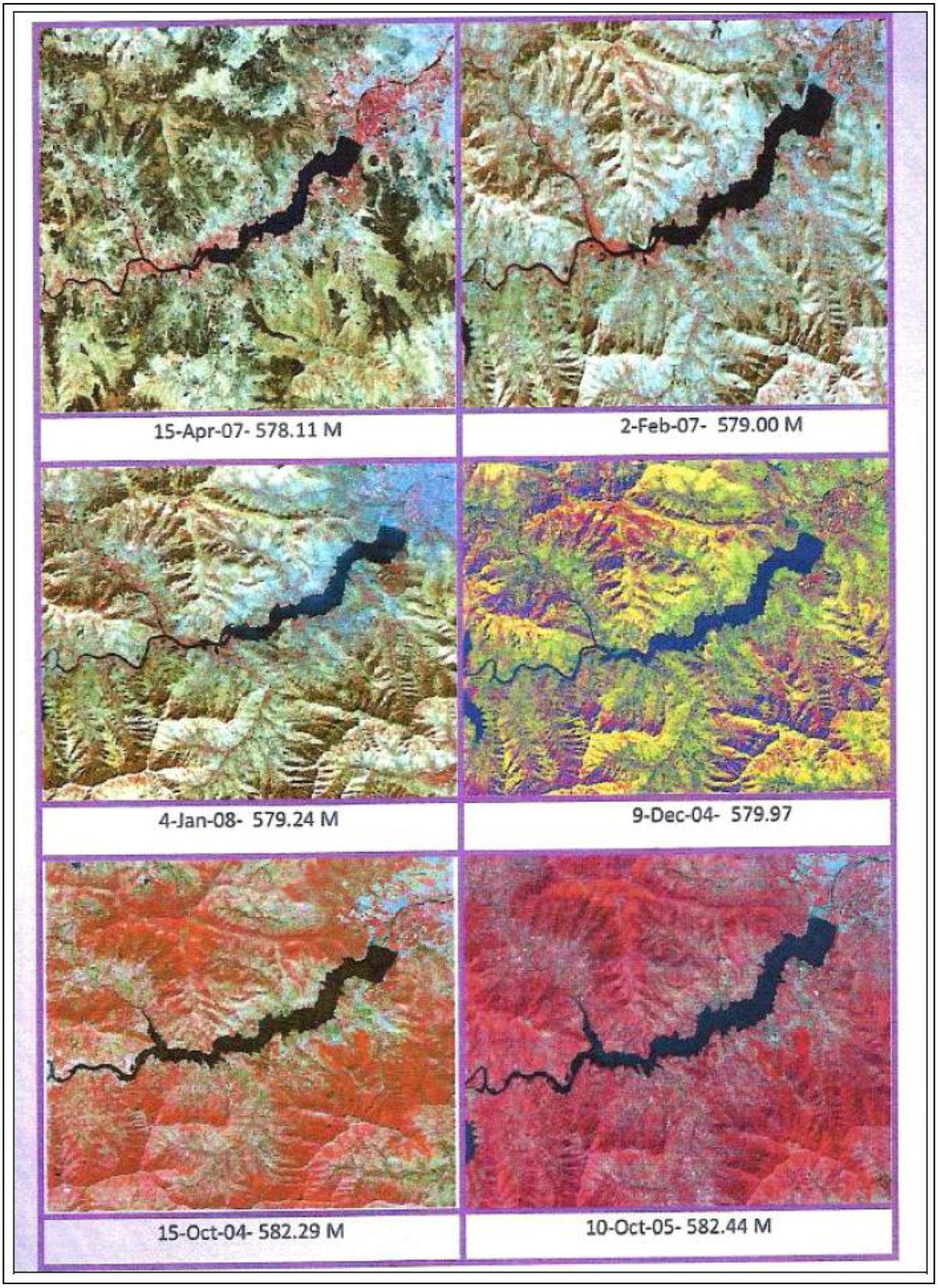

Figure 4. Water spread area at Minimum and Maximum water levels for Khadakwasla reservoir

Table 2. Water spread area extracted from the satellite data

Date of pass	Elevation in m.	Area in Mm^2
A) Panshet reservoir		
19-5-2005	619.79	7.34
13-3-2004	618.07	7.85
15-4-2007	622.46	9.19
16-3-2008	623.31.	9.48
21-02-2008	625.87	10.26
19-3-2005	626.72	10.39
26-2-2007	627.73	10.72
28-1-200	628.55	11.34
02-02-2007	630.26	11.67
4-1-2008	631.42	12.27
9-12-2004	633.67	13
15-10-2004	636.2	13.57
10-10-2005	636.2	13.62
3-11-2005	636.27	13.72
B) Warasgaon reservoir		
19-5-2005	619.70	7.94
13-3-2004	621.55	9.08
15-4-2007	624.20	10.7
16-3-2008	626.73	12.42
19-3-2005	629.55	13.88
21-2-2008	629.70	13.99
26-2-2007	630.82	15.1
28-1-2008	632.66	16.15
4-1-2008	634.47	17.13
21-12-2005	636.45	18.09
3-11-2005	639.50	19.16
C) Khadakwasla reservoir		
15-04-2007	578.11	7.94
02-02-2007	579.00	9.08
04-01-2008	579.24	10.7
09-11-2004	579.97	12.42
15-10-2004	582.29	13.88
10-10-2005	582.44	13.99

Water levels on the date of pass of satellite were not at regular interval .Then water spread area at regular interval was calculated using best fit polynomial equation. Computation of capacity at different elevation was made using following formula $V= H/3 \times (A_1+A_2+SQRT (A_1 \times A_2)$. Where V- reservoir capacity between two successive elevation. H- Elevation difference H_1-H_2. The capacities estimated by DGPS method at a regular interval as well as capacities find out by remote sensing method are clubbed together to get the cumulative capacities from bed level to FRL. Then estimated capacities were compared with the original capacities of the reservoir to get the loss of storage in these reservoir. Following table 3 shows Loss of live storage for reservoir.

Table 3. Loss of storage capacities for reservoirs

Year	Reservoir storage capacity Mm3		Loss of storage capacity Mm^3		Period years	Rate of siltation Mm^3/year	% Loss of capacity from year of impounding		% Annual loss	
	Gross storage	Live storage	Gross storage	Live storage			Gross storage	Live storage	Gross storage	Live storage
A) Panshet Reservoir										
1970	303.93	294.93	-	-	-	-	-	-	-	
2007	273.68	273.67	30.25	21.25	37	0.574	9.94	7.205	0.268	0.194
B) Warasgaon Reservoir										
1987	375.36	363.48	-	-	-	-	-	-	-	-
2007	373.23	361.56	2.121	1.912	20	0.0956	0.565	0.526	0.028	0.0263
C) Khadakwasla Reservoir										
1870	86	56								
2007	88.247	63.96	No reduction in storage							

VI. RESULT AND DISCUSSIONS

1. The sedimentation study by Hybrid technique of combination of DGPS Bathymetric survey and remote sensing survey, covers entire reservoir portion and hence siltation in reservoir at different elevations could be estimated**.**

2. After the 1st impounding of Panshet Dam in 1970, the attempt for estimation of sedimentation carried out in 1977 using hydrographic survey. The storage capacity of reservoir was 303 Mm^3. No survey was conducted till 1991 and the 2nd remote sensing survey was carried out during 1991-2002.. In this paper efforts have been made to co-related the storage capacity under above survey at 1977 and between1977-2007, which indicates a net change of 273.68 Mm^3at FRL 635.81 m (Ref. table. 3). After estimation of capacities of Panshet reservoir for the recent survey for the year 2007 it could be seen that the gross storage capacity of the reservoir was reduced to 273.68 Mm^3. The present study indicate that the gross and live storage was reduced by 30.25 Mm^3 (9.94%) &2 1.25 Mm^3 (7.20%) respectively within a period of 1970-2007and the rate of siltation for live was 0.574 Mm^3 (i.e 47.74 Ha-m/100Km^2/year) .

3. Gross storage capacity of Warasgaon reservoir was lost by 2.122 Mm^3 which was the order of 0.56% of the total storage and loss of live storage capacity was 1.912 Mm^3 within a period of 1987-2007.

4. The gross capacity of Khadakwasla reservoir for the year 2007 was 88.247Mm^3 at FRL against the original gross capacity of 86 Mm^3.The reservoir shows increase of capacity in the live storage zone of reservoir by 7.96 Mm^3.However siltation was only seen in the dead storage zone of the reservoir of order of 6.09 Mm^3, As per ref. [8] rate of siltation was 6.74 Ha-m/100Km^2/year, no survey data were available during 1940 to 1977 so rate of siltation was 1.21 Ha-m/100Km^2/year for 100 years, As such the average rate of siltation during 137 years from 1870-2007 works out to be 0.88 Ha-m/100Km^2/year which indicate that there is decrease in rate of siltation for Khadakwasla reservoir.

VII. CONCLUSION

1. The Hybrid technique of DGPS bathymetric survey in combination with remote sensing survey is found to be very useful for conducting reservoir sedimentation studies. It is faster, economical, less laborious and reliable also. This survey covered entire reservoir portion from bed level to FRL.

2. In the Panshet reservoir during 1970-2007, study indicate that net losses in gross & live storage were 30.25 Mm^3 and 21.25 Mm^3 respectively. Hence it is seen that as against the design rate of siltation 3.57 Ha-m/100Km^2/year, the net rate of siltation works out to be of the order of 67.96 Ha-m/100Km^2/year and 47.74 Ha-m/ 100Km^2/year in the gross and live storage respectively.

3. Gross storage capacity of Warasgaon reservoir was lost by 2.122 Mm^3 and loss of live storage capacity by 1.912 Mm^3 within the period of 1987-2007and the rate of siltation was of the order of 0.0956 Mm^3/year (35 Ha-m/100Km^2/year) against the design rate of 3.57 Ha-m/100Km^2/year.
4. There is increases in gross storage and the live storage capacities of Khadakwasla reservoir which was 88.247 Mm^3 and 63.96Mm^3 respectively as against the original capacities of 86 Mm^3 and 56 Mm^3. This increase in storage capacities may be due to large scale erosion of the live storage zone of the reservoir after the breach of Panshet dam in 1961 which is located upstream of the Khadakwasla. Siltation was found in the dead storage zone of the reservoir of the order of 6.09 Mm^3 which may be due to the large amount of water, which was rushed along with the residues of the failed dam into the downstream portion.
5. Since the Panshet dam is located on the upstream region of other two dam major silt is restricted at the Panshet dam site which was observed in the present studies. As such the results obtained from the above hybrid method for siltation was in agreement with previous survey done for Khadakwasla dam during 1940 since impounding in 1870 which indicate a very low siltation of order of 0.33 Mm^3 (i.e 6.74 Ha-m/100 Km^2/year).
6. As such , as indicated in table 3 above the net siltation of the order of 9.94% could be dredged suitably to recover the storage water of 30.25 Mm^3 which contributes for the future need of pune water supply scheme.

VIII. FUTURE SCOPE OF STUDY

1. Number of remote sensing data at regular interval needs to be made available in order to assess the average long term siltation patterns as well as losses in the storage capacities of the dams under references**.**
2. Sufficient remote sensing data is required to assess the net siltation in the region from Panshet to Khadakwasla in order to obtain the losses and siltation pattern in future**.**
3. It could also be mentioned that acceptable rate of siltation could be estimated if the future surveys are conducted at shorter interval of 3 to 4 years and the trend of long term rates of siltation observed from the long term analysis needs to be confirmed from the field data after 2007 till date and in future**.**

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