REMOTE SENSING BASED SEDIMENTATION STUDY FOR SHARAVATHY RESERVOIR, KARNATAKA

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

WATER RESOURCES DEVELOPMENT

By

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CANDIDATES DECLARATION

I hereby certify that the work which is being presented in this dissertation entitled **"Remote Sensing based Sedimentation study for Sharavathy reservoir, Karnataka"** in partial fulfillment of the requirement for the award of the degree of Master of Technology submitted in the department of Water Resources Development and Management of Indian Institute of Technology Roorkee, Roorkee, India is an authentic record of my work carried out during the period of August 2010 to October 2011 under the supervision of Dr. Nayan Sharma, HOD & Professor, WRD&M, Dr. Ashish Pandey, Ass. Professor, WRD&M, IIT Roorkee and Co-supervision of Shri Uday Roman, SRO, CWPRS, Pune. The matter included in this dissertation has not been submitted by me for the award of any other degree.

03/10/2011

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CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

As a result of runoff from rainfall or snowmelt, soil particles on the surface of a watershed can be eroded and transported through the processes of sheet, rill, and gully erosion. Once eroded, sediment particles are transported through a river system and are eventually deposited in reservoirs, in lakes, or at sea. The estimation of the deposited sediment volume is one of the most important tasks in river engineering.

Sediment particles originating from erosion processes in the catchments are propagated along with the river flow. When the flow of a river is obstructed by a dam the water is stored in a reservoir, the sediment settles down and reduces its capacity. Reduction in the storage capacity of a reservoir beyond a limit hampers the purpose for which it was designed. Thus assessment of sediment deposition becomes very important for the management and operation of reservoirs. Some conventional methods, such as Hydrographic survey and Inflow-Outflow approaches, are used for estimation of sediment deposition in a reservoir, but these methods are cumbersome, time consuming and expensive. There is a need for developing simple methods, which require less time and are cost effective.

In this study, a Satellite Remote Sensing (SRS) approach has been attempted for assessment of sedimentation in Sharavathy Reservoir, located on the Sharavathy River in the Shimoga district of Karnataka. Multi date remote sensing data (IRS P6, L1SS III) provided the information on the water-spread areas of the reservoir at different dates, which were used for computing the sedimentation volume and in turn to assess the revised capacity. The revised capacity of the reservoir was then compared with the original capacity of the year 2002 so as to give the loss in capacity from 2002 to 2010 i.e. in 9 years. It was found that the capacity was reduced to 53.682 Mm^3 from 58.689 Mm^3 showing 8.53 % of loss in capacity. The rate of sedimentation was estimated as 0.000259 $Mm^3/km^2/yr$ which is equivalent to 311 $T/km^2/yr$ considering total catchments of 2148 km^2. Considering free catchments of 151.50 km^2 the rate of sedimentation comes to 0.00367 $Mm^3/km^2/yr$ or 4406 $T/km^2/yr$. Considering the same percent reduction as above, the dead and live storages of Sharavathy reservoir will have a loss in storage to the tune of 6.158 Mm^3 and 11.165 Mm^3. On the basis of analysis of impact of whole catchments and free catchments, contributing sediment to Sharavathy reservoir the rate of sedimentation seems to be on higher side with respect to standard sedimentation rates in zone-7 of India.

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Chapter 1
Introduction

1.1 General

The management of water resources often requires the construction of dams, in order to control the irregularity of river discharges. A reservoir thus created serves many purposes including irrigation, water supply, power generation, industrial supply to name a few. Depending upon the purpose of the dam, the benefits will vary in place and time. So, for instance, the benefits drawn from a hydroelectric project will be felt immediately after its implementation, but not at the site of the dam due to the transmission of the electric current into the power system. On the contrary, the benefits of an irrigation project will be felt locally, but only after a lapse of time needed to activate the agricultural potential of the irrigated land.

Whenever a dam is constructed across a river, the reservoir is bound to silt as the rivers flowing into the reservoir carry considerable amount of silt due to erosion of soils in the catchment area. Sediment deposit reduces the storage capacity of the reservoir. The reservoir on a sediment carrying river will gradually become silted up, even though this process may take a long time. It is, therefore, most important to take care that the silting up of a reservoir does not occur before the benefits from it are fully achieved. It would be a gross error of the decision makers if the sedimentation of the reservoir was not foreseen and if no measures were taken in order to check it, or to reduce its effects to an acceptable level. Neglect in this respect would cost dearly in the future, since the available water resources are limited as are the economically suitable reservoir sites within a basin.

Reservoir-dependent societies range from technically advanced urban and agricultural systems in the western United States to village irrigation in the Indian peninsula (Morris and Fan 1998). Since India is the second most populous country in the world and agriculture is its largest economic sector, valuable water resources in the country is being harnessed with the help of more than 4,000 large dams apart from thousands of small dams (Central Water Commission _CWC_ 2001). Many of the Indian reservoirs have their storage capacities reduced because of sedimentation. The overall annual rate of reservoir storage capacity lost due to sedimentation is estimated to be typically 1–2% of the total storage capacity (Mahmood 1987; Yoon 1992; Yang 2003). For example, Nizam Sagar Reservoir, a major project in the State of Andhra Pradesh, was commissioned in year 1930 had lost 60.74% of storage capacity by the year 1992 (CWC 2001). If the present inventory of storage reservoirs is lost to sedimentation, neither the present nor the projected population and economic activity can be sustained. It has been reported by Central Water Commission (CWC, 2001) that the rate of sedimentation in some of the Indian reservoirs is higher than the design rate assumed at the planning stage. Many of these reservoirs are losing capacity at the rate of 0.2–1.0% annually (CWC 2001). Analysis of sedimentation surveys by Shangle (1991) with respect to 43 major, medium, and minor reservoirs in the country indicated that sedimentation rates vary between 0.34–27.85 ha m /100 km^2/year for major reservoirs, 0.15–10.65 ha m/100 km^2 /year for medium reservoirs and 1.0–2.3 ha m/100 km^2 /year for minor reservoirs.

Water resources sector has got high priority in all the developmental plans of the country, and accordingly a large number of dams have been constructed to supply water for drinking, irrigation and also hydropower generation. In any river catchment feeding water to a reservoir, natural processes of erosion and consequential silt transportation along the river take place continuously. Every river, thus, carries some amount of sediment load. When the silt laden water reaches a reservoir in the vicinity of a dam, the velocity and turbulence gets considerably reduced, resulting in deposition of sediment in the reservoir bed. This phenomenon is termed Reservoir Sedimentation.

It was felt that silting occurs initially in the dead storage area, and later encroaches on the live storage capacity; which is not correct. The life span of a reservoir is determined by the rate of sedimentation, which gradually reduces the useful storage capacity due to sedimentation. This loss in useful capacity affects the purpose for which it is created. Hence, to optimize the benefits from a project, it is necessary to have the knowledge of likely progressive reduction in storage due to sedimentation during planning and operation stages. Correct assessment of sedimentation rate is essential for assessing the balance useful life of the reservoir and to reallocate the available storage for various purposes.

Methods for estimation/prediction of sediment deposition in reservoirs that are currently in use include: Stream flow Analysis, Hydrographical Surveys, Satellite Remote Sensing (SRS) techniques Empirical Area Reduction method and Mathematical Modeling. Empirical method and Mathematical models are normally used during planning stage, for prediction of reservoir sedimentation. The remaining three methods are used for monitoring of sedimentation during operational stage. The conventional techniques like Hydrographic survey are cumbersome, costly and time consuming. Reservoir water spread area for a particular elevation can be obtained very accurately from the satellite data. Reduction if any, in the water spread area for a particular elevation indicates deposition of sediment at that level. This when integrated over a range of elevations using multidate satellite data over a water year helps in computing volume of storage lost due to sedimentation. Using the remote sensing techniques, it has become very cheap and convenient to quantify the sedimentation volume.

1.2 Objective

The objective of the study is to estimate capacity loss of Sharavathy Reservoir due to sedimentation through Satellite Remote Sensing technique. Following objectives were achieved in the study.

- **i)** To estimate total siltation in reservoir
- **ii)** To estimate present gross storage capacity of reservoir
- **iii)** Updating Elevation-Area-Capacity curve
- **iv)** To establish the rate of sedimentation of the area
- **v)** To highlight uncertainties in adopting SRS technique.

1.3 Study Area

This study deals with the application of the SRS technique for sedimentation assessment of Sharavathy reservoir popularly known as Gerusoppa reservoir across Sharavathy river in Shimoga district of Karnataka state (Fig 1). The first impoundment of reservoir was done in the year 2002 . The catchment area at the dam site is 2148 km^2 including free catchment of 151.51 km^2. The Gross and Dead capacities of the reservoir are 130.879 Mcum and 72.19 Mcum at FRL 55.00 m and MDDL 43.50 m respectively thus creating Live storage of 58.689 Mcum. The total catchment area of the river up to its confluence with the Arabian Sea is 2,774 Km^2. The basin receives a rainfall ranging between 5000-7500 mm. The catchment is covered with steep sloped scattered forest (Photo 2, Chapter 5) which leads to high velocity of excess rainfall. More over rock outcrops on the banks of the river reach (as seen from Photo 3, Chapter 5) indicates the high erosive nature of the river. The steep slopes cause intensive soil movement and carry runoff from interrill areas. The topography of the Sharavathy catchment shows that sheet and interrill erosion are major mode of sediment removal and transport. Also the part of sediment composed of the relatively coarser material due to fragmented rocks and boulders which moves along the stream bed which is executed by rolling, sliding along the bed or saltation of bed particles by the action of moving water due to heavy rainfall.

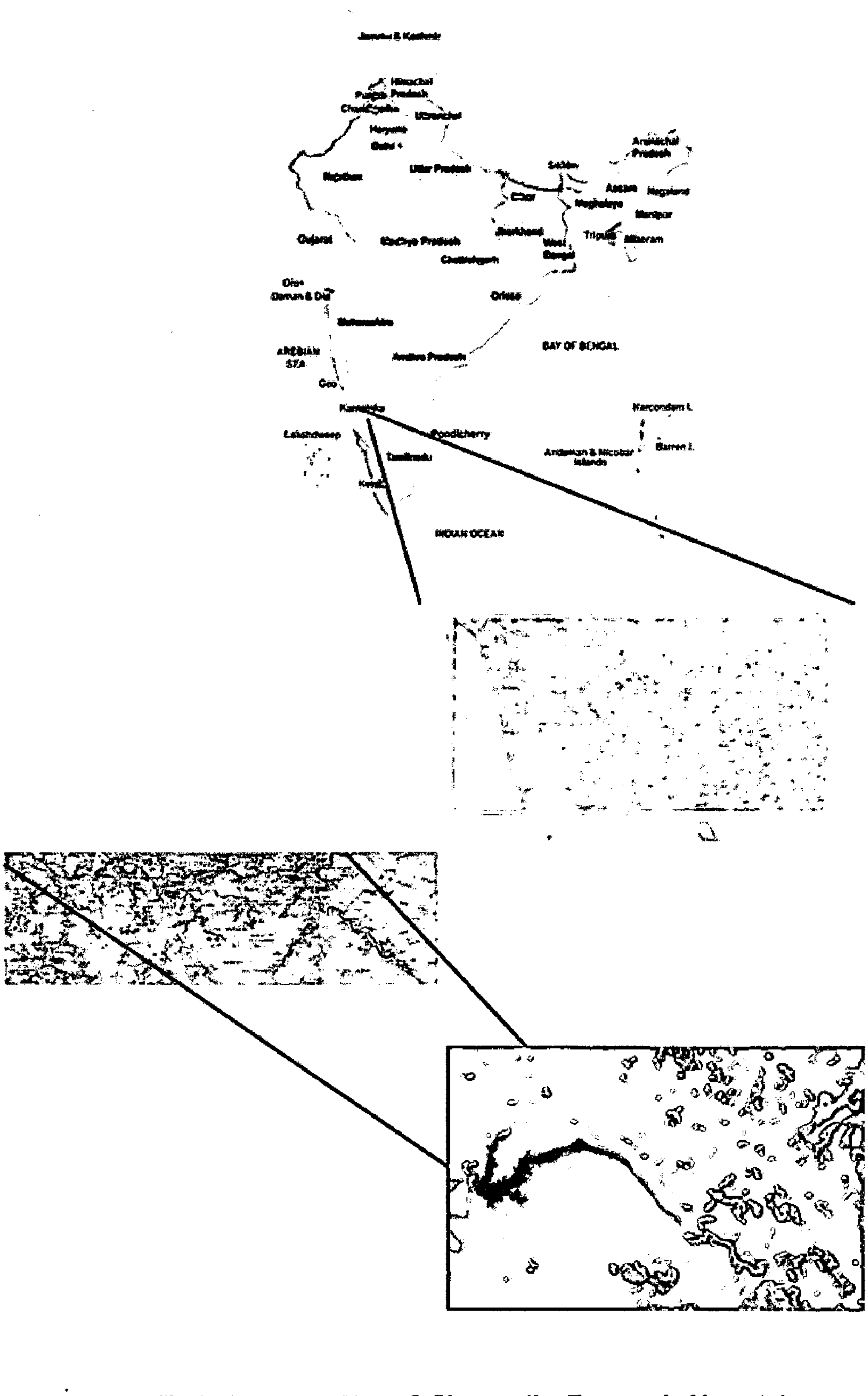

Fig 1 : Location Plan of Sharavathy Reservoir, Karnataka.

Chapter 2
Literature Review

2.1 General

This chapter deals with the research work carried out by various researchers in the field of reservoir sedimentation and the application of remote sensing for the estimation of reservoir sedimentation. The topics were divided as follow:

2.2 Definition of sediment

Many researchers have defined sediment as follow:

- Loose no cohesive material through which river flows is generally called as sediment (Garde, 1977)
- Sediment is the end product of erosion or wearing of the land surface by the action of water, wind, ice and gravity .
- Sediment is derived from soil erosion. Sedimentation is the last process of the soil erosion process (Poransiri, 2009)
- Sediments are aggregates of particles that come to rest in some place after having been transported laterally or vertically for some distance (Trask, 1988)
- Sediment is a substance or material which is transported by the action of water, wind and gravity, detaching and deposition.
- Sediment is the fragment of a parent material which breaks up by chemical and physical reaction and moving by action of gravity, water or wind .

In conclusion, sediment is substance or material which is transported by the action of water, wind or gravity and then deposited in some place.

2.3 Sedimentation Process

Sedimentation is the natural process that has been active throughout geological times and shapes the present landscape of the world. Sedimentation consists of five fundamental processes including weathering, erosion, transportation, deposition and consolidation to rock (Trask,1988, Physical Process of Sediment, Ladlen , Shelly, 1988).

The silt deposited at different levels reduces the storage capacity of the reservoir (de Araújo *et al.*, 2006; Smith and Pavelsky, 2009; and Sreenivasulu and Udayabaskar, 2010).

i) Weathering

Weathering is a process that breaks up the parent rock. Weathering consists of two processes, a mechanical process and a chemical process. Mechanical process implied by force which overcomes the internal strength of rock such as in its shearing by glacier movement or break up by freezing of water in the pores. Chemical process weathering is essentially a question of the exchange and movement of ions. Base (cation) exchange is the dominant process.

ii) Erosion

Erosion is defined as the detachment and removal of rock particles prepared from the weathering process by an agent such as water, wind, ice, gravity, volcanic eruption, plant or animal.

iii) Transportation

Transportation is the process that moves the particle which is controlled by the same six agents as erosion but in various degrees. With water, the principle factors that affect transport are turbulence, ratio of settling velocity to lateral motion of water, shape, size, density and quantity of particles and movement along the bottom by saltation, rolling or undermining.

iv) Deposition

Deposition is the most important factor in sedimentation. Once the sediments have accumulated in their final resting place, their general nature is fairly well formulated.

v) Consolidation to rock

After the sediments have been deposited, the water is squeezed out of pore spaces by the effect of superimposed loads, thus causing a reduction in thickness. This compaction of the deposit presses the constituents more firmly together and gives the sediments greater strength. Materials are deposited in the pore spaces and cement the particles together. Ultimately the sediment is consolidated to rock.

2.4 Reservoir Sedimentation

Many advantages and problems occur from the sedimentation process in natural phenomena. The deposition of sediment may produce new land, i.e. delta, on the other hand the erosion process may cause the reduction of the fertility and productivity of soil. .Sedimentation is the virtual concern of water resource management, especially in a reservoir operation. The major problem of sedimentation toward the reservoir is the loss of storage capacity.

Sedimentation in the reservoir has become important in the operation of reservoirs because of the increasing number of dams and reservoirs threatened by sedimentation. When a dam is constructed across a stream to form a reservoir, the dam changes the morphology of the water channel. When a flow enters a reservoir, the cross-sectional area of the flow is increased, the velocity of the stream will immediately begin to decline and the sediment load carried by the flow starts dropping in the reservoir.

2.4.1 Sediment source

Basically, the sediment transported to a reservoir comes with the stream where the dam is sited. All natural streams carry sediment which is derived from erosion in their drainage basin. However, not all the eroded particles enter the stream, some of the particles are deposited on the slopes, the bottom of slopes within the watershed and some may be deposited within the channels and their flood plain. The portion of eroded material which is transported through the drainage network to a downstream measuring or control point is referred to as the "sediment yield".

The total quantity of sediment carried in a river, called its **total load,** includes the bed load and the suspended load. The **bed load** moves along the bottom of the channel by saltation, rolling, or sliding. The **suspended load** is carried above the stream bed by the turbulence of the flowing water.

2.4.1.1 Sediment size

The nomenclature for classifying sediment size as a standard terminology in sedimentation engineering. (American Geophysical Union Sediment Classification, EM 1110-2-4000, 95) Four different sizes of sediments were classified as follows:

Gravel	:	64 mm	-	2 mm
Sand	:	2mm	-	62 micron
Silt	:	62 micron	-	4 microns
Clay	:	4 microns	-	0.24 microns

2.4.1.2 Sediment Transport and Deposition

The inflow to a reservoir contains suspended load and bed load, besides water. The amount of suspended load is often much larger than the bed load. When the silt laden water reaches a reservoir in the vicinity of a dam, the velocity and the turbulence are considerably reduced. At the river mouth into the reservoir, the bed load settles due to gravitational forces and contributes to the delta development. The grains of the suspended load settle close to the delta, and finer particles are taken into the reservoir. Due to upward current, the turbulent flow is able to overcome the gravity force, and finally they settle mainly at the stagnation water zones. Extremely fine sediments remain suspended and leave the reservoir with water again through the sluices, turbines, spillways, etc.

The inflow is a mixture of water and sediment. Due to the difference in density, density currents develop from the mixture of water and fine sediments. Density currents in general are two-phase flows with small density differences, such as cold and warm water, water and sludge but not air-water flows, where the density difference is nearly 1,000. Also, the two fluids should be mixable and the density difference should be a function of differences in temperature, the salt content or the sediment content, independent of the fluids involved.

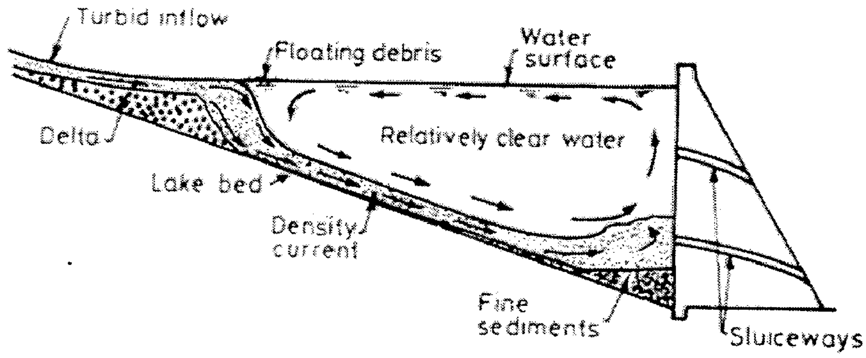

Fig. 1a: Sediment Transport and Deposition

Due to local sediment deposition, the density current gets diluted along the trajectory. In the delta, where the velocity of the density current is already reduced, particles larger than 0.05 mm are deposited. The finest silt particles with a diameter less than 0.1 m are carried up to the outlet, while the intermediate fraction is deposited in the zone of the clear water reservoir. The deposition of sediments in the reservoir is known as 'reservoir silting' or reservoir sedimentation'. The content of various sediment sizes depends on the reservoir. A typical measure is the ratio between the storage volume and the annual sediment transport. The larger this ratio, the better is the retention potential of the reservoir to catch all sediments. For a small ratio, the reservoir degrades to a storage basin for gravel.

2.5 Sedimentation in Indian reservoirs

Most parts of India being dependent for water on 3-4 month long monsoon, Reservoirs are created to store water for use in non monsoon months. The reservoirs, created by dams on rivers, also get silt in the water of the rivers that enters the reservoirs and a significant proportion of the silt settles down in the reservoir, thus reducing the space available for storage of water. Moreover, studies over the years have shown that the silt gets deposited in both the dead storage (the storage at the bottom, below the Minimum Draw Down Level, which is not used under normal circumstances) and in the Live Storage (LS). This process of accumulation of silt in the reservoirs is called siltation. Siltation results in reduction in benefits from the projects constructed at huge costs to the nation. Siltation of reservoirs can also have a number of other impacts, including increased evaporation losses, increased backwater flooding and also could damage the power house turbines.

Gregory Morris, (author of Reservoir Sedimentation Handbook, 1997) in a paper presented at the Sixth International Symposium on River Sedimentation in New Delhi in 1995 wrote, "Planned Obsolescence due to sedimentation affects most reservoirs worldwide, not just in India, and will render many of them unusable in the foreseeable future... Dams are uniquely different from engineering infrastructure such as roads, harbours, and cities, and which can be reconstructed on the same site occupied by obsolete infrastructure. Dams cannot be reconstructed at the same site once the reservoir has filled with sediment; the sediment must either be removed or the site abandoned. The cost of sediment removal at a large reservoir can easily exceed the original dam construction cost by an order of magnitude."

India has by now about 4500 large reservoirs and lakhs of smaller reservoirs. Periodical capacity surveys of reservoir help in assessing the rate of siltation and reduction in storage capacity. This information is necessary for efficient management of the reservoir. Periodical capacity survey of reservoirs in a basin is also necessary to arrive at a realistic siltation index for planning of future reservoir projects in the basin. Recently obtained siltation studies of 27 reservoirs in India from the Central Water Commission (CWC), they were done through Satellite Remote Sensing (SRS) technology, also These studies for the respective reservoir done through the more traditional hydrographic method. Some of the major findings from these studies are given below. (Reservoir Siltation in India: Latest Studies Reservoir, Himanshu Thakkar & Swarup Bhattacharyya)

The Big Picture

In most cases, the actual rate of siltation is found to be higher than the design rate. For the 23 reservoirs (excluding the four reservoirs from the 27 SRS reports for which the SRS surveys give LS greater than the original surveys), the annual loss in live storage capacity is 214.2 MCM, that is 0.912% of the original live storage capacity. These 23 reservoirs have already lost 23.11 % of LS by 2006. The distribution of reservoirs with respect to proportion of original LS lost through siltation is as follows

Lost capacity, as % of LS	> 40%	25-40%	20-25%	15-20%	10-15%	5-10%	<5%
Number of Reservoirs	2	3	3	5	4	2	4

Considering that we now have about 214 BCM of live storage capacity through large reservoirs and if we apply the same loss rate (since the reservoirs in this sample are well distributed geographically and represent both small and large and also low and high siltation rate reservoirs, we may not be too much off the mark), we are losing about 1.95 BCM capacity annually. This shows that the annual loss figure of 1.3 BCM arrived at by the Govt of India's National Commission for Integrated Water Resources Development may prove to be an underestimate.

This should alarm everyone, for what this means is that firstly, we have already lost about a quarter of the LS capacity of the 23 reservoirs studied here, due to siltation. The proportion of capacity lost from reservoirs all over India would be similarly order of magnitude. This has huge implications as this means significant reduction in benefits from the reservoirs in terms of hydropower generation, irrigation, water supply and flood management. In economic terms, creation of 1.95 BCM of capacity would at today's costs would require at least Rs 2017 crores. This means that we are daily losing reservoir capacity worth Rs 5.53 crores.

Reservoir Capacity Loss (Live Storage)

Name of reservoir	Year of impounding	Org. LS (MCM)	Ressessed LS cap. Through SRS/ earlie surveys		Capacity loss (MCM)	Span	% loss	Annual loss	Siltation rate MCM/yr	Capacity loss anticipated till	
			Year	MCM						MCM	%
Bhadra	1964	223.703	2000	187.79	35.913	36	16.05	0.446	0.998	41.916	18.
Damanganga	1983	502	1999	464.46	37.54	16	7.48	0.4675	2.35	54.05	10
Gumti	1984	312.9	2003	249.07	63.83	19	20.40	1.074	3.36	73.91	23
Halali	1976	226.94	2003	188.583	38.357	27	16.91	0.626	1.42	42.62	18
Isapur	1983	928.262	2003	899.629	28.633	20	3.08	0.154	1.43	32.92	3.5
Kadana	1983	1712	1994	1491.71	220.29	11	12.87	1.17	20.03	460.65	26
Kallada	1985	423.953	2003	376.705	47.248	18	11.14	0.62	2.62	55.13	13
Krishnaraj-sagar	1932	1275.70	2000	1215.94	59.79	68	4.68	0.068	0.88	61.96	4.8
Kyrdemkulai	1983	3.824	2002	3.414	0.410	19	10.72	0.56	0.02	00.49	12.
Lower Bhawani	1955	780.546	2000	702.025	78.521	45	10.06	0.224	1.74	89.01	11.
Maithon	1955	607.268	2001	453.69	153.578	46	25.29	0.549	3.34	170.25	28.
Matatila	1956	1132.7	1999	702.33	430.37	43	38	0.884	10.01	500.43	44.
Mayurakshi	1955	547.59	2000	474.82	72.77	45	13.29	0.295	1.617	80.47	50.
Narayanpur	1982	867.889	1997	740.345	127.544	15	14.70	0.98	8.50	204.07	23.
Palitana	1959	374.832	1996	304.226	70.606	37	18.84	0.509	1.908	89.69	23.
Panam	1977	689.567	2003	660.993	28.574	26	4.14	0.16	1.09	31.88	4.6
Parbati	1963	102.893	2003	86.405	16.488	40	16.02	0.40	0.41	17.72	17.
Ramsagar	1905	29.397	2003	24.663	4.734	98	16.10	0.165	0.05	04.88	16.
Ranapratp-sagar	1970	1861.36	2002	1720.13	141.23	26	7.59	0.237	4.41	158.88	8.5
Rengali	1983	3412	2001	3217.74	194.26	18	5.69	0.32	10.79	248.85	7.2
Sondur	1988	179.611	2003	134.788	44.823	15	24.95	1.66	2.99	53.77	29.
Srisilam	1984	7165.83	1999	5152.50	2013.33	15	28.10	1.87	134.22	2952.84	41.
Umiam	1965	131.70	2002	130.124	1.576	37	1.19	0.03	0.04	1.73	1.3
Total		23492.465		19582.08	3910.385		16.65	0.912	214.223	5430.116	23.

Morris, in his paper in 1995 cited earlier had said, "the overall picture indicates that reservoir sedimentation is a serious national problem which requires immediate action." (Reservoir sedimentation rates in India (based on Morris, 1995)., Erosion and sedimentation problems in India, U. C. KOTHYARI, Department of Civil Engineering, University of Roorkee, Roorkee 247667, India, Erosion and Sediment Yield: Global and Regional Perspectives (Proceedings of the Exeter Symposium, July 1996). IAHSPubl. no. 236, 1996.)

Heavily silted reservoirs As revealed by the SRS studies, some of the heavily silted reservoirs of India are listed below.

- Matatila 38% gross capacity lost between 1956 and 1998-99. The dead storage up to the original MinimumDraw Down Level (MDDL) of 295.66 m is completely filled with silt. Even further level upto 296.15 m is now completely filled with silt. Total capacity loss by 1999 = 430.47 MCM
- Gumti (Tripura): Lost 63.83 MCM, that is 20.4% live storage capacity in 19 years.
- Maithon 25.29% Live Storage Capacity silted up in 46 years.
- Kadana 12.85% LS capacity (278.6 MCM) silted up in 11 years.
- Srisailam 2013.33 MCM or 28.096% live storage capacity lost in 15 years.

High Siltation Rates In case of at least 14 of the 23 reservoirs, the actual siltation rate was found to be higher than the design siltation rate, as given in table below.

Actual Vs Design Siltation Rates

Reservoir	**River**	**Design rate mm/yr**	**Acual rate , mm/yr**	**Actual rste as % of design rate**
Gumti (Tripura)	Gumti	0.362	9.94	2746
Kyredemkulai (Meghalaya)	Umtru	0.138	0.144	104.35
Halali (MP)	Betwa	0.476	2.032	427
Matatila (UP)	Betwa	0.132	0.37	280.3
Parbati (Rajasthan)	Parbati (Chambal)	0.157	0.524	333.8
Ramsagar (Rajasthan)	Bamani (Chambal)	0.081	0.274	338.3
Kadana (Gujarat)	Mahi	0.13	1.146	881.5
Panam (Gujarat)	Mahi	0.357	0.475	133.1
Isapur (Mah)	Penganga (Goadavari)	0.357	0.379	106.2
Mayurakshi (Jharkhand)	Mayurakshi	0.364	0.696	191.2
Maithon (Jharkhand)	Damodar	0.3905	1.282	141.7
Sondur (Chhattisgarh)	Mahanadi	0.357	5.768	161.7
Rengali (Orissa)	Brahmani	0.39	0.427	109.5
Kallada (Kerala	Kallada	1.45	4.78	330
Ukai (Gujarat-1992)	Tapi	0.149	0.184	546.3

Note: Most design siltation rates are given for gross storage, while the actual rates above are for live storages.

Tungabhadra (Siltation rate 1.01 mm/year), Panchet Hill (1.05 mm/year), Pong (2.785 mm/year), Ramganga (2.294 mm/year) and Koyna (1.52 mm/year) are some other dams with high siltation rate. (Reservoir Siltaion, H Thakkar, S. Bhattacharya, 2006)

In view of the importance of the reservoir sedimentation, the Ministry of Water Resources, Govt. of India had desired to carry out the sedimentation Assessment Study of important reservoirs using remote sensing technique, Accordingly, Central Water Commission .had taken up 144 major reservoirs located all over the country for sedimentation survey using remote sensing technique during the 10th Five Year Plan under the plan scheme " Studies of reservoir sedimentation and other Remote Sensing Application".

Chapter 3

Material and Methods

3.1 General

The assessment of economic viability, safety and cultural considerations as well as the environmental and social impact should form an integral part of any large dam project. This assessment has many facets, one of the most important being the estimation of the sediment deposition in a reservoir and its 'life'.

Sediment runoff in many rivers is continuously increasing- mainly as a result of human influence. Sediment concentration in rivers fluctuates greatly and is a function of sediment supply and discharge. In some rivers it can be extremely high, with hyper concentrations over 200g/l. In the Yellow river basin, mudflows containing up to 1600 g/ l have been recorded, while concentrations of 5000 g/l (ppm) are certainly not unusual on many Asian rivers. In many Indian reservoirs, the annual loss of storage due to sedimentation is between 0.5 % and 1 %. At Tarbela on the Indus in Pakistan, the loss has been about 1.5 % per year during the 14 years since completion.

The loss of storage is only one of the deleterious effects of sedimentation in reservoirs; the others are increased flood levels upstream to the reservoir, retrogression of the river bed and water levels downstream of the dam, the elimination of nutrients carried by the fine sediments, the effect of sedimentation on the reservoir quality, etc. A useful life of a reservoir less than 100 years should certainly be a matter of concern, and one has to consider whether the drastic environmental effects are outweighed by the economic advantages during a relatively short effective life. Therefore, in order to see that the capacity does not fall short of the requirement ever during the design period, this silting must be taken into account.

Sedimentation of a reservoir reduces the storage capacity. According to International Commission on Large Dams (ICOLD:1988), the average loss of capacity due to silting amounts to 1 percent per year when the existing storage volumes of all dams worldwide are summed up. This loss is considerable and reservoir sedimentation is one of the primary problems to be dealt with in the 21st century. Reservoir sedimentation is thus of great relevance to the management of water resources. We are currently at an early stage of predicting the deposition pattern in reservoirs, and much effort has to be taken in the future.

3.2 Loss in Capacity of Reservoir due to Sedimentation

In order that the capacity does not fall short of the requirement during the design period, the total volume of silt likely to be deposited during the designed life period of the dam is, therefore, estimated; and approximately that much of volume is left unused to allow for silting, and is known as dead storage. The remainder is known as live storage. The dead storage generally varies from 15 % to 25 % of the total capacity. This loss in useful storage capacity due to sedimentation could adversely affect planning for long term utilization of reservoir storage capacity for irrigation, power generation, industries, urban water supply and flood moderation. A great amount of sediment is carried annually by the Indian rivers down to reservoirs, lakes, estuaries, bays and oceans. Soil erosion in river catchments in India is taking place at the rate of 2000-3000 tonnes/ km^2/ year, in north-north east to 500-1000 tonnes/ km^2/ year in the central and southern region. Out of which about 29 % is transported to the sea and 10 % is deposited in reservoirs.

3.3 Effects of Reservoir Sedimentation

The ill effects of reservoir sedimentation are listed below.

i) Reduced live storage capacity, which adversely affect power generation/ irrigation/ water supply

ii) Increase in backwater levels in head reaches of the reservoir

iii) Increased flood levels in upstream reaches/ water logging/ swamps

iv) Formation of islands/ deltas

v) Choking of irrigation, navigation and power outlets

vi) Increased weed growth resulting in more evapotranspiration

vii) Increased rate of evaporation of same storage volume

viii) Reduction in dissolved oxygen at lower depth due to decomposition of organic sediment deposition

ix) Stratification of reservoir due to density currents affecting water qualities

x) Degradation of river bed in the reach downstream of dam which in turn will have following ill effects:

   a) Lowering of tail water levels may affect performance of energy dissipation arrangement and cause severe erosion
   b) Foundations of bridges and intakes on river bed may be exposed
   c) Intakes and locks in downstream reach affected due to lowering of water levels

Hence, to optimize the benefits from any project, it is necessary to have knowledge of likely progressive reduction in reservoir storage during planning stage. Considering the complexities involved in the sediment related processes namely sediment erosion in the catchments, transport of sediment through river channels and deposition of sediment in the different parts of the reservoir, it is rather difficult to accurately estimate the rate of siltation and distribution of sediment in reservoirs over a long period. Erosion in catchments depends upon catchment characteristics, shape, slopes, type of soil, drainage density, vegetation cover, rainfall duration and intensities and land use pattern. Transport of sediment mainly depends upon flood discharge, channel geometry, slope, roughness, nature of river channel bed and banks.

3.4 Factors Affecting Reservoir sedimentation

The sediment deposition in a reservoir, which is of utmost concern to the engineers in the present scenario, depends on the following factors:

i) Longitudinal and lateral shape of the valley
ii) Length and shape of the reservoir
iii) Flow patterns in the reservoir
iv) Capacity to inflow volume ratio (trap efficiency)
v) Grain size distribution of sediment
vi) Water and sediment discharges
vii) Mode of reservoir operations
viii) Nature of incoming floods

3.5 Process of Sedimentation

A reservoir created by the construction of a dam across a river, decreases the water surface gradient and reduces the velocity of flow and ultimately leads to reduction in the capacity of the river channel to transport the sediment. The result is deposition of unwanted sediment in the full length of the reservoir forming delta, lake bed and density currents(Fig 2)

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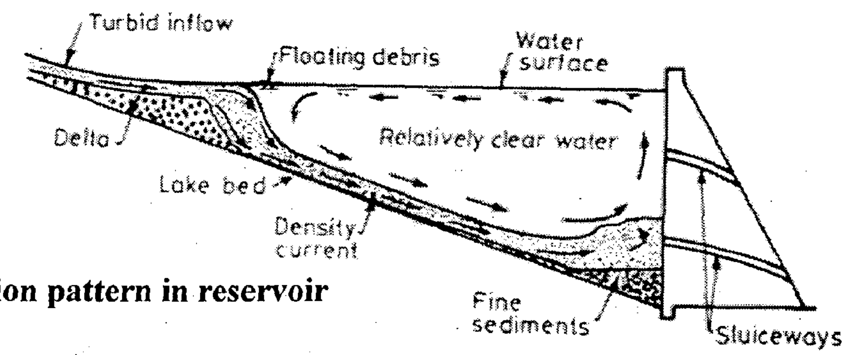


Fig 2 Sediment deposition pattern in reservoir

This phenomenon which progressively impairs the utility of the reservoir needs attention not only at project planning stage but also during operation stage. However, mere accurate estimation of sediment volume likely to be deposited in the reservoir is not adequate. The distribution of the estimated volume of sediment in different regions of the reservoir is also equally important. As per the old design practice, volume of dead storage of most old dams was kept equal to likely inflow of sediment during designed life period, assuming that the entire sediment will be tapped in the dead storage zone. But reality may be different. Depending upon the shape of the reservoir, mode of reservoir operation, sediment inflow rates and grain size distribution, the incoming sediment will be deposited in different zones. Therefore in order to plan reservoir operation schedule for optimum utilization of water and to undertake remedial measures well in advance the knowledge of location and quantity of sediment is important. The loss in useful storage capacity due to sedimentation could adversely affect long-term planning of reservoir water storage for irrigation, power generation, industries, urban water supply and flood moderation. Therefore, monitoring or assessment of sedimentation in reservoir during operation stage is as important as prediction of reservoir sedimentation during planning stage.

3.6 Objectives of Capacity Surveys

Capacity surveys are important to assess sedimentation in the reservoir as well as for optimum reservoir operation based on realistic assessment of available storage. The silt, which gets deposited at different levels, reduces the storage capacity of reservoir. Reduction in the storage capacity beyond a limit prevents the reservoir from fulfilment of the purposes for which it was built. Periodical capacity surveys of reservoirs help in assessing the rate of sedimentation and reduction in the storage capacity. This helps for efficient management of reservoir and also helps in taking decisions about treatment of catchment area, if the rate of siltation is excessive. These are also useful to arrive at a realistic sedimentation index for planning of future reservoir projects in the basin. Since the major cause of reduction in storage capacity is sediment deposition, the capacity survey helps in determining:

i) Storage depletion caused by sediment deposition since closure of dam
ii) Annual sediment yield rates
iii) Sediment density
iv) Lateral and longitudinal distribution of deposited sediment

v) Reservoir trap efficiency

vi) The balance life of a reservoir

vii) Periodic allocation of available storage for various reservoir levels

3.7 Important Aspects of Reservoir sedimentation

In order to know the natural processes of sedimentation like erosion in catchment areas, movement of sediment and its deposition in various levels of reservoir, careful consideration of following aspects is necessary:

i) Amount of sediment brought in to a reservoir: This depends on the following factors:

a) Watershed characteristics/geology of catchment/land slides/seismic characteristics

b) Type of soil covers

c) Watershed slopes

d) Channel density in catchment and channel slopes

e) Vegetation cover and type of vegetation

f) Land use/agricultural/forest/urban/barren land

g) Climatic conditions/hydrological characteristics/rainfall duration and intensities

h) Watershed developments in catchment areas

ii) Sediment deposition in reservoir: This will be governed by

a) Sediment grain size

b) Reservoir level at the sediment inflow/mode of reservoir operation

c) Inflow velocities and sediment concentration

d) Operation of reservoir spillways/river sluices

Normally the sediment will be deposited in following three distinct zones:

1) Backwater reaches

- Coarser sediment ,Growth of water plants

2) Delta region

- Elongated or fan shaped delta depending upon the shape of the reservoir at entry of stream
- Coarse and medium sediment settles in the reach

3) Bottom Deposits

- From the foot of delta to the dam, Fine sediment/clay

iii) The trap efficiency of reservoir: This depends upon

a) *Sediment load characteristics*
b) Detention time of flow in reservoir
c) Shape of reservoir
d) Mode of reservoir operations
e) Type of outlets
f) Capacity to annual inflow ratio

3.8 Methods of Estimating Sedimentation in Reservoirs

Following methods are presently in use for estimation/prediction of sediment deposition in reservoirs: (Research papers under reference 24, 28, 29)

a) Stream Flow Analysis (sediment and water inflow and outflow measurements)
b) Reservoir capacity surveys/ Hydrographic surveys
c) Mathematical models
d) Empirical methods - Area reduction Method
e) Use of satellite imageries (SRS techniques)

3.8.1 Stream Flow Analysis

Stream flow analysis is a continuous observation process consisting of measurement of water inflows and outflows with collection of water samples for estimating sediment concentrations. The method consists of two main parts (a) measurements of water inflows and outflows and (b) simultaneous measurement of sediment concentration. The method gives quantity of deposit in gravimetric terms and conversion into volumetric units calls for the estimation of the average unit mass of the deposited sediment material. The accuracy of analysis depends a great deal on the proper estimation of unit-mass of the deposited material from the point of view of volumetric conversion.

3.8.2 Reservoir Capacity Survey

Conventional Method:

The method involves the use of conventional equipment e.g. theodolite, plane table, sextant, echo sounder, moving boat etc. The depths of the reservoir are recorded along predetermined range lines, normally spaced up to one km apart along the length of reservoir. With the help of data collected, the volume of silt deposited in the reservoir is calculated between the two successive surveys. The surveys conducted are time consuming and may take up to three years for large reservoirs.

Modern technique - Hi-tech System

The system consists of the following components:

1) Positioning system which includes transponder or GPS units
2) Depth Measuring Units consisting of Echo-sounder and Transducers
3) Computer System

The survey is carried out in a rapid and efficient manner. A boat equipped with the bathymetric equipment, the GPS system mounted on board and a lap-top computer is used for bathymetric survey while its reference station is positioned on a known geographical benchmark. The survey software enables fixing of grid lines and interfacing of bathymetre and DGPS, taking x, y, and z values at required interval/grid. Boat navigation is also controlled by the software so that the boat tracks the grid line accurately. The surveys can also be carried out at random mode. The data collected is then processed and analyzed. Using specially developed software to obtain the results in various forms e.g. point plots, contour and three dimensional maps of reservoir bed, area capacity elevation tables and cross-sections of reservoir.

DGPS hydrographic surveying allows faster data acquisition with better accuracy than any previous hydrographic survey technique. The line of sight from the base station to the boat is not necessary. The base is set up only once per day, instead of the usual once per cross section. A DGPS survey can be completed between control points (even on opposite side of mountain) without having to traverse or even to see the other point. Other advantages are the ability to achieve centimetre accuracy and the ability to efficiently collect large amount of data. The data collecting system with GPS is compact and can be accommodated in smaller boats.

Limitations

1. The time period required for carrying out hydrographic survey is 12 to 18 months which is more compared to remote sensing survey
2. The method is not cost effective

3.8.3 Mathematical Models

Several one and two dimensional mathematical models are available for computing mobile river bed changes. Basically all these models solve water and sediment flow equations (continuity and momentum equations for water and sediment). The models differ from one another in sediment transport laws, consideration of lateral inflows armouring effects etc. Depending upon whether water flow and a bed level change computations done simultaneously (i.e. in same time step) or separately the models are called as coupled or decoupled. Exhaustive topographic, hydraulic and sediment requirement to stimulate bed topography and to supply appropriate boundary conditions are major limitations of these models especially for long term simulation for sedimentation predictions. HEC-6 model has been widely applied to estimate longitudinal bed profiles.

The sediment transport and water flow are inter-related in such a way that they can never be disassociated completely. Out of many formulations the simplest acceptable mathematical description expressing inter-relationship in unsteady flow situation is given as below:

Continuity equation for liquid flow:

$$\frac{\partial h}{\partial t} + u\frac{\partial h}{\partial x} + h\frac{\partial u}{\partial x} = 0$$

Dynamic equation for liquid flow:

$$\frac{\partial u}{\partial t} + \frac{\partial u}{\partial x} + g\frac{\partial h}{\partial x} + g\frac{\partial z}{\partial x} + g\,S = 0$$

Continuity equation for solid discharge:

$$(1-n)\,\tilde{b}\,\frac{\partial z}{\partial x} + \frac{\partial G}{\partial x} = 0$$

Together with sediment transport formula:

G = G (u, h)

Where x is the abscissa measured along the river axis, t is time, h the depth of water, u the average velocity within a section, z the level of the river bed, S the steady state energy line slope, G the solid load transported, in units of volume per time.

These are a set of differential equations with x and t as independent variables and h(x, t), u(x, t), z(x, t) as dependent variables. These equations are solved by using numerical technique (FDM, FEM etc). The above equations are full equations of unsteady flow and suitable for simulating rapidly varying flows/phenomenon. Normally changes in river bed levels especially in case of reservoir are at much smaller rate than that predicted by the models which uses the simplified form of these equation. In some cases even water flows also remain unchanged over a period of few days. In such quasi steady flow situations, these equations could be simplified.

Limitations

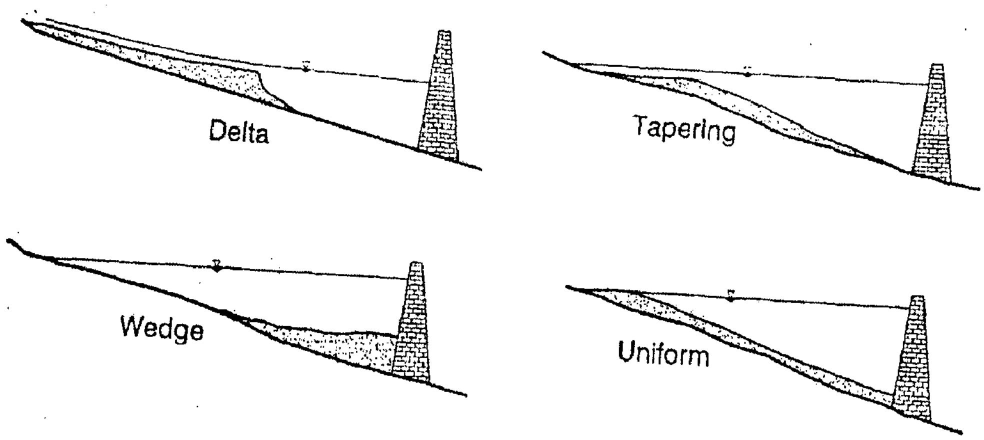
1) Exhaustive data requirement for simulation of topography and boundary conditions.

2) Uncertainties regarding friction coefficient, diffusion coefficient and sediment transport relationship.
3) Long term simulations (50 to 100 years) with 2 dimensional or 3 dimensional models are difficult.

3.8.4 Empirical Method : Area Reduction Method

This method proposed by Borland and Miller (1985) of USBR has been based on hypothesis that there exists a definite relationship between the shape of the reservoir and the percentage of the sediment volume deposited into various depths of reservoir. They analyzed deposition patterns of more than 40 reservoirs in USA with capacities ranging between 1.6 million ha-m to 492 million ha-m. These reservoirs varied in location, catchment characteristics and operation schedules. The method uses depth-relationship to decide type of reservoir. The reservoirs are classified into 4 types (Fig 3).

Type I (Lake) **Type 2 (Foot Hill)**



Type 4 (Gorge) **Type 3 (Hill)**

Fig 3 : Types of Reservoir and Sediment deposition patterns as per Borland and Miller

The deposition pattern in the lake type reservoir is like delta while in flood plain and foot hill reservoirs, the deposition pattern is tapering. In case of hill a wedge formation due to sedimentation may be seen while in the gorge type reservoirs, a uniform distribution of sedimentation is observed. The reciprocal (M) of the slope (S) of the line obtained by plotting reservoir depth as ordinate and reservoir capacity as abscissa on log-log scale is used as key to decide the reservoir type as per the following table:

Table: Relation between Reservoir Type and M

M	Reservoir Type	Standard Type
≥ 3.5	Lake	I
2.5 - 3.5	Flood plain foot hill	II
1.5 - 2.5	Hill	III
1.0 - 1.5	Gorge	IV

For each of the type above, sediment storage curve and area design curve were developed using observed data of the reservoirs. From these curves or the equations representing the curves, the sediment deposition at various levels in the reservoir could be computed. Theory and details of computational procedure is presented by Borland et al (1985) and Murthy (1977).

The method facilitates to know, how the total incoming sediment in a given life span of the reservoir will be deposited in the different zones (at different elevations). It is possible to estimate how much sediment will deposit in the live storage zone and in dead storage zone. The simplicity and minimum data requirement are the main advantages due to which the method is widely used during planning stage of the projects.

Limitations

1. Deciding type of reservoir becomes sometimes tricky when value of 'M' is close to limits
2. New bed level near dam to be given to perform iterations
3. Actual deposition pattern may be some what different than the reservoir type indicated by Borland and Miller procedure
4. There is need to monitor actual sedimentation pattern in reservoir with the help of hydrographic survey so as to verify and modify if necessary the deposition pattern of the reservoir for further predictions.

3.8.5 Satellite Remote Sensing Technique

Digital analysis has an edge over visual analysis in identifying water spread and turbidity levels in detail and more accuracy because of minimizing human error or subjectivity. Digital image analysis using Image Processing System on computer is very good for mapping water spread, turbidity levels and aquatic vegetation. Multi-date IRS-1C/1D/P6 LISS III data is used for image analysis. The analysis comprises:

i) Data base geo-referencing
ii) Water spread area estimation
iii) Estimation of reservoir capacity
iv) Comparison with hydrographic survey
v) Capacity loss estimation due to sedimentation

The Satellite Remote Sensing (SRS) method of assessment of reservoir uses the fact, that the water spread area of reservoir at various elevations keeps on decreasing due to sedimentation. The water spread areas of the reservoir at different levels between FRL and MDDL in different month of the year are computed from satellite imageries. Knowing the reservoir levels(as ground truth) at the time of imageries new elevation capacity curve could be established and compared with that at the time of dam construction or earlier survey. Shift in the capacity curve will indicate extent of loss reservoir capacity.

It is felt that with the availability of the imageries from IRS 1 C-D and P6 with better resolutions (ranging from 5.8 m to 24 m) the accuracy of estimating area of water spread will further improve SRS technique provides relatively cost and time effective method for assessing reservoir sedimentation.

Advantages

1. Cost effective
2. Time saving
3. Requires less manpower
4. Since satellite imageries are available at an interval of about 4 days, it is possible to choose appropriate imageries for the year/period during which reservoir water level vary from MDDL to FRL
5. Capacity can be established for earlier years also at desired time intervals
6. Accuracy is better for fan shaped reservoirs with large reservoirs with large variation in area for small change in water level. Hydrographic surveys of such reservoirs are very difficult and time consuming.

Limitations of SRS techniques

1. Revised capacity below MDDL and above MWL cannot be determined. Sedimentation rate could be established within zone of fluctuation water level (i.e. method mainly useful in live storage zone which is of most importance)
2. Hydrographic survey below MDDL may be essential to estimate changes below

MDDL

3. Less but specialized manpower required along with availability of image processing software
4. Special care required at land water interface to distinguish water pixels from land/ soil. Accuracy of method depends on this.
5. SRS techniques can give accurate estimates for large size fan shape reservoirs, which show large change in the area for small change in water levels. Thus, for elongated shaped reservoirs with V or U shape valley with steep banks the accuracy of method will reduce.
6. In SRS techniques, there is a need to separate the water area in extended tail and the main river channels where water level could be higher than this reservoir level. This will also need some experience and insight in to the reservoir under flood conditions.

3.9 Satellite Remote Sensing (SRS) Based Reservoir Sedimentation Survey

Satellite Remote Sensing (SRS) technique for assessment of reservoir sedimentation is very useful for sedimentation assessment due to its synoptic and repetitive coverage. After analyzing water level data of the reservoir, the period of maximum fluctuation on water levels was selected as the study period. Cloud-free imageries for the selected period were procured from the National Remote Sensing Center (NRSC), Hyderabad. The base-map for the imageries was created and geo-referenced using the respective toposheets. EASI/PACE software was used for digital image processing and subsequent water spread area extraction after due correction. The cumulative volume of the reservoir at different elevations was then computed using the prismoidal formula so as to give the present capacity of the reservoir.

The methodology of SRS technique involves geo-referencing, estimation of water spread area and reservoir capacity, inter-comparison with previous survey results, capacity loss estimation, updating of area-elevation-capacity curve and sediment index determination. The data requirement for the above method includes cloud-free imageries, relevant toposheets, reservoir water levels, original elevation-area-capacity curve, and salient features of the project under study. SRS method is essentially based on mapping of water-spread areas at the time of satellite over pass. It uses the fact that water-spread area of the reservoir reduces with the sedimentation occurring at different levels (fig-4).

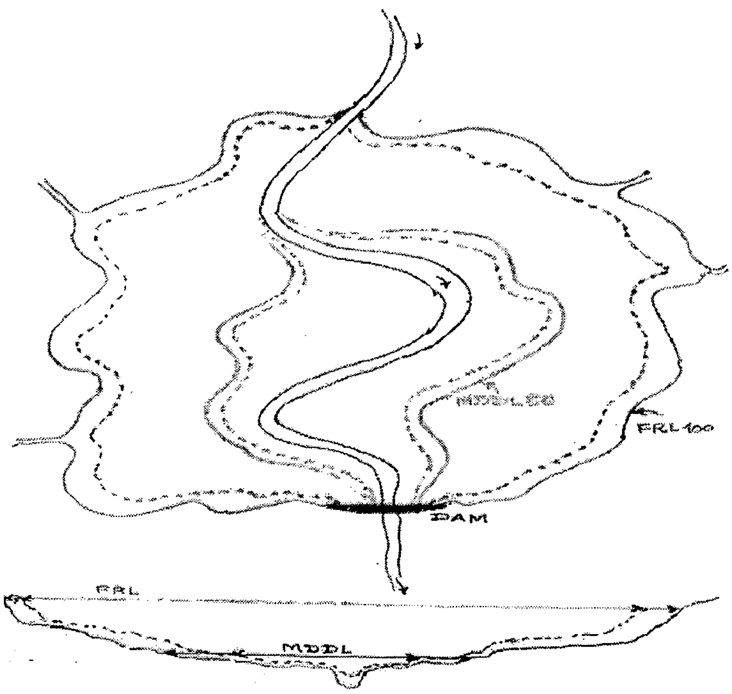


Figure 4: Water spread areas of reservoir at different Levels

Advantages of the technique include cost effectiveness, time-saving, less manpower requirement, accuracy, reliability and flexibility of carrying out surveys relating to earlier time periods. The capacity can also be established for earlier years also which is the greatest advantage of the method. The method is more accurate for fan shaped reservoirs, as there will be large variation in the area for small change in water level. Hydrographic surveys of such reservoirs by conventional methods are very difficult and time consuming. Moreover, since satellite imageries are available at an interval of about 4 days, it is now possible to choose appropriate imageries for the year/period during which reservoir water level vary from Minimum Draw-Down Level (MDDL) to Full Reservoir Level (FRL).

Using above methodology the capacity estimation of Sharavathy reservoir was carried out for the year 2007 - 10. The data for elevation -capacity was available for the survey of the year 2002; therefore, it is taken as base for present study. Revised Area-Elevation-Capacity curves for Sharavathy reservoir are plotted and compared with the original curves to determine the loss of capacity due to silting. The present study was conducted to assess the sedimentation rate in the Sharavathy reservoir since its impoundment in 2002. The studies show that the Live storage capacity of the reservoir was reduced by about 8.53 percent in nine years. Sedimentation rate of Sharavathy reservoir is established within the zone of fluctuation in water level i.e from RL 43.50m to 55.00m . This method was proved to be useful in the live storage zone, which is of most importance.

3.10 Role of Satellite Remote Sensing For Water Resources Management

Measurements from satellite remote sensing provide a means of observing and quantifying land and hydrological variables over geographic space and support their temporal description. Remote sensing instruments capture upwelling electromagnetic radiation from earth surface features which is either reflected or emitted. The former is reflected solar radiation and the latter is in thermal infrared and microwave portions of electro-magnetic spectrum. Active microwave radars obtain reflected/returned microwave signals. The reflected solar energy is used for mapping land & water resources like land use, land cover, forests, snow & glaciers, surface water features, geologic & geomorphologic features, water quality, etc. The thermal emission in the infrared is used for surface temperature, energy fluxes and microwave for soil moisture, snow & glacier, flood, etc.

Remote sensing has several advantages over field measurements. First, measurements derived from remote sensing are objective; they are not based on opinions. Second, the information is collected in a systematic way which allows time series and comparison between schemes. Third, remote sensing covers a wide area such as entire river basin. Ground studies are often confined to a small pilot area because of the expense and logistical constraints. Fourth, information can be aggregated to give a bulk representation, or disaggregated to very fine scales to provide more detailed and explanatory information related to spatial uniformity. Fifth, information can be spatially represented through geographic information systems, revealing information that is often not apparent when information is provided in tabular form.

Various applications have been developed, since last 3 decades, wherein SRS data is being put into use to provide quantitative and reliable information in the following areas , there by facilitating improved water resources management.

3.11 Remote sensing technique for assessment of reservoir sedimentaiton

Reservoirs lose their storage capacity due to sedimentation. The analysis of sedimentation data of Indian reservoirs show that the annual siltation rate has been generally 1.5 to 3 times more than the designed rate and the reservoirs are generally losing capacity at the rate of 0.30 to 0.92 per cent annually. The consequence of loss in storage due to sedimentation is precluding the intended usages such as flood protection/moderation, irrigation, hydro-power generation, etc. Sedimentation in reservoirs occurs not only in dead storage but also in live storage region simultaneously, which reduces the useful storage and affects the water utilization pattern of the water resources project. Periodic assessment of sedimentation rates is essential to ascertain the current reservoir live storage capacity for efficient and productive management of water resources. This information is also necessary to plan for the upstream catchment area treatment in order to control the rate of sedimentation. Such assessment would also facilitate characterization of basins/catchments in terms of their siltation rate potential and provide realistic basis for planning new reservoir schemes.

3.11.1 Methodology

The reduction in storage volume results from the decrease in water spread area due to sedimentation at different elevations. Therefore, capturing the water spread at various reservoir operating levels would help in estimating the current reservoir storage and a comparison with previous or original storages would provide the loss in storage due to sedimentation. In this context, satellite remote sensing plays a very useful role due to its synoptic and repetitive coverage. Water, by virtue of its typical spectral response characteristics is noticeably manifested on satellite data. Multi-spectral satellite data facilitates distinct separation between water bodies and the surrounding land- use/landcover. The water spread boundary captured by the satellite data provides water spread contour at that particular reservoir water level. By taking a series of satellite data covering various reservoir operating levels, the water spread contours can be derived for the corresponding elevations. Using mathematical formulae, the actual reservoir storage between the observed water levels can be computed. This helps in generating present area- capacity curves and a comparison with previous curves provide the changes in reservoir storage.

Reduction in the storage capacity beyond a limit prevents the reservoir from fulfilling the purpose for which it is designed. Periodical capacity surveys of the 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, the remedial measures can be undertaken well in advance and the reservoir operation schedule can be planned for the optimum utilization of water. The conventional technique, such as hydrographic survey and inflow-outflow approaches are cumbersome, time-consuming and expensive and they involve significant manpower. In addition to the above disadvantages, the task of carrying out the field surveys are often hampered due to the restrictions posed by the dense forests, wild life, heavy monsoon rains, limited accessibility and steep foreshores. Under such circumstances, the data provided by the remote sensing satellites are considered superior since they provide multispectral and repetitive synoptic information regarding changes in the water-spread area after the deposition of sedimentation in the reservoir (Manavalan and Sathyanath, 1993; Goel and Jain, 1996; Babu Rao and Visvanatham, 1999; Gupta et al., 1999; Agarwal et al., 2000; Chandrasekar et al., 2000; and Jain et al., 2002). Apart from this, remote sensing-based approach is economical and requires less time in analyzing the data, compared to the conventional methods.

Multi-temporal satellite data have been used as an aid to capacity survey of many reservoirs in a cost and time effective manner in India. While this technique helps in revising capacity table between minimum and maximum draw down level observed in satellite data, loss of dead storage capacity can be obtained only through conventional hydrographic surveys. A National action plan of sedimentation survey of 144 reservoirs using remote sensing technology was taken up in India during the 10th Five Year plan by Ministry of Water Resources. CWPRS and NRSC have jointly executed two reservoir sedimentation projects viz. Sri Ram Sagar Project reservoir in Andhra Pradesh State (2003-2004) and Ujjani reservoir sedimentation survey project in Maharashtra. NRSC carried out satellite data based updation of elevation-area capacity curves and sedimentation assessment of Hirakud reservoir, Orissa state for the year 2005-06.

The method for assessment of reservoir sedimentation using satellite imageries comprise following stages:

i. **Analysis of daily reservoir water level**

This data is required to be collected for the years/ period for which reservoir sedimentation is to be assessed. From the analysis of this data the period in which the reservoir has undergone maximum variation in the reservoir levels preferably from FRL to MDDL should be identified.

ii. **Identifying dates for availability of cloud free imageries**

The availability of cloud free satellite imageries during the period identified for variation of reservoir level from FRL to MDDL is required to be checked from the available satellite data. About 8 to 10 digital satellite imageries for the cloud free dates should be available covering the total period of water level variation from FRL to MDDL. For the desired accuracy in the analysis, the satellite imageries with appropriate resolution need to be selected.

iii. Geocoding of satellite imageries

The relevant toposheets are first georeferenced precisely by collecting Ground Control Points (GCPs) within the Area of Interest (AOI). These toposheets after Georeferencing and mosacing are used as a base map for Geocoding of satellite imageries chosen for the analysis. If toposheets are not available then, GPS can be used to obtain Lat-Long of selected GCPs.

iv. Digital image processing for delineation of water and land boundary

This is the most important stage of the satellite data analysis since the reservoir water spread is decided during this stage. Therefore, utmost care is required while delineating water and land boundary using image processing software. Special care is taken for removal of discontinuous pixels, removal of extended tail of river, presence of islands, cloud cover, floating vegetation in reservoirs and marshy land without any water depth on the fringe of the reservoir.

v. Estimation of reservoir water spread areas on different dates

The water spread areas on different dates are available after completion of delineation of water and land boundary by using image processing software. Necessary corrections are applied in order to get actual water spread area.

vi. Estimation of reservoir volumes at different elevations

Using the reservoir water spread areas at different elevations computed above, the reservoir volume between any two successive elevations is estimated using prismoidal formula as below

$$\Delta V_{1-2} = \Delta h/3\ (A1 + A2 + \sqrt{A1 * A2})$$

Where,

ΔV_{1-2} = Volume between elevation E2 and E1 (E2>E1)

Δh = E2 - E1

A1, A2 = Water spread areas at elevation E1 and E2

After computing volumes between successive elevations (for which water spread areas are estimated), cumulative volumes at different reservoir levels are computed to develop new Elevation- Area- Capacity relationship (curve).

vii. Estimation of sediment volume deposited at different levels in reservoir

Comparison of newly established Elevation-Area-Capacity curve with the original curve or curve established from previous hydrographic survey indicate reduction in cumulative storage capacity at different elevations. This reduction in cumulative capacity of the reservoir is due to sediment deposition. Hence from the difference in the capacities at different elevations indicated by two curves the cumulative volume of sediment deposited below different elevations could be computed.

Flow chart showing methodology in brief for reservoir sedimentation survey using SRS technique is given vide Annexure – I.

3.12 Study Area, Data Used and Analysis

3.12.1 General

The study area belongs to the Sharavathy/Gerusoppa reservoir on river Sharavathy and is located near Gerusoppa village, Taluka Honnavar District Shimoga of Karnataka state of India. The project was completed in 2002 and aimed to improve irrigation and power generation. Total catchment area of the project is 2148 sq. km.

3.12.2 River Sharavathy

Sharavathy River is a river which originates and flows entirely within the state of Karnataka in India. It is one of the few westward flowing rivers of India and a major part of the river basin lies in the Western Ghats. The famous Jog Falls are formed by this river. The river itself and the region around it are rich in biodiversity and are home to many rare species of flora and fauna. The river originates at a place called Ambutheertha in the Thirthahalli taluk of Shimoga district. According to a legend of the times of Ramayana, this is the place where the Hindu God Rama broke a bow to win the hand of Sita. The total length of the river is around 128 km and it joins the Arabian Sea at Honnavar near Uttara Kannada district. On its way, the Sharavathi forms the Jog Falls where the river falls from a height of 253 meters. The river is dammed at Linganamakki on upstream of Sharavathy Dam. The major tributaries of the river are Nandihole, Haridravathi, Mavinahole, Hilkunji, Yennehole, Hurlihole, and Nagodihole. Sharavathi river basin falls into two districts of Karnataka namely Uttara

Kannada and Shimoga. The upstream river basin is extended to two talukas in Shimoga viz. Hosanagara and Sagara. The entire basin has an area of 2985.66 km^2 with upstream being 1988.99 km^2. and the downstream being 996.67 km^2.

3.12.3 Study Area

As described above the study area for the present study was Sharavathy/ Gersoppa reservoir on river Sharavathy.

3.12.3.1 Location

The Sharavathy/Gerusoppa dam on river Sharavathy is located at latitude 14° 14'30" N and longitude 74° 37'15"E which lies in the Karnataka State. The index plan of the project is shown as Fig.8 The Sharavathy reservoir area falls in the survey of India topographical maps 48J/11 & 47J/12.

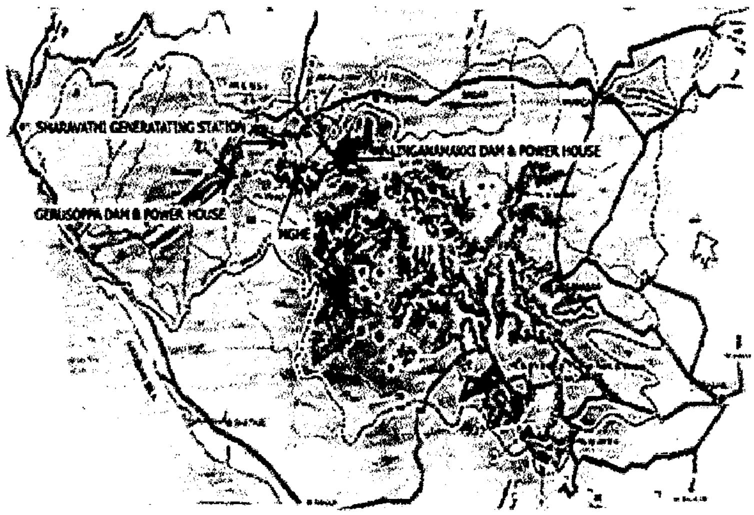


Fig 5: Index plan of Sharavathy Reservoir

3.12.3.2 Geology

The river basin mainly consists of Pre-Cambrian rocks. The two major groups of rocks found in the Sharavathy river basin are the Dharwar system and the peninsular gneiss.

- The Dharwar system: This system contains metamorphic rocks that are considered to be among the oldest in India. These rocks are derived from ancient sediments like conglomerates, ferruginous quartzites, greywackes, schists and limestones. They are rich in iron and manganese.
- Peninsular gneiss: These are crystalline rocks and are made up of granite, granodiorite, granito-gneiss, migmatite etc.

Soils in the Sharavathy basin are mainly lateritic in origin and tend to be acidic and reddish to brownish in colour. The various type of soil found here are clay loamy, clayey, clayey-skeletal, and loamy. Four soil orders are found in the upstream river basin viz. ultisols, alfisols, inceptisols and entisols.

3.12.3.3 Rainfall

With a major part of the river lying in the Western Ghats, the Sharavathi river basin receives a large amount of rainfall. Mean annual rainfall ranges from 6000 mm in the western side to 1700 mm in the eastern side of the basin. About 95% of the rainfall is received during the month of June to September (July being the rainiest) when the southwest monsoon is at its peak. There is some rainfall in the post monsoon season in the form of thundershowers mostly during October and some rainfall also occurs during the summer months of April and May.

3.12.3.4 Temperature

April is usually the hottest month with the mean daily maximum temperature at 35.8°C and the mean daily minimum at 22.2°C.

3.12.3.5 Humidity

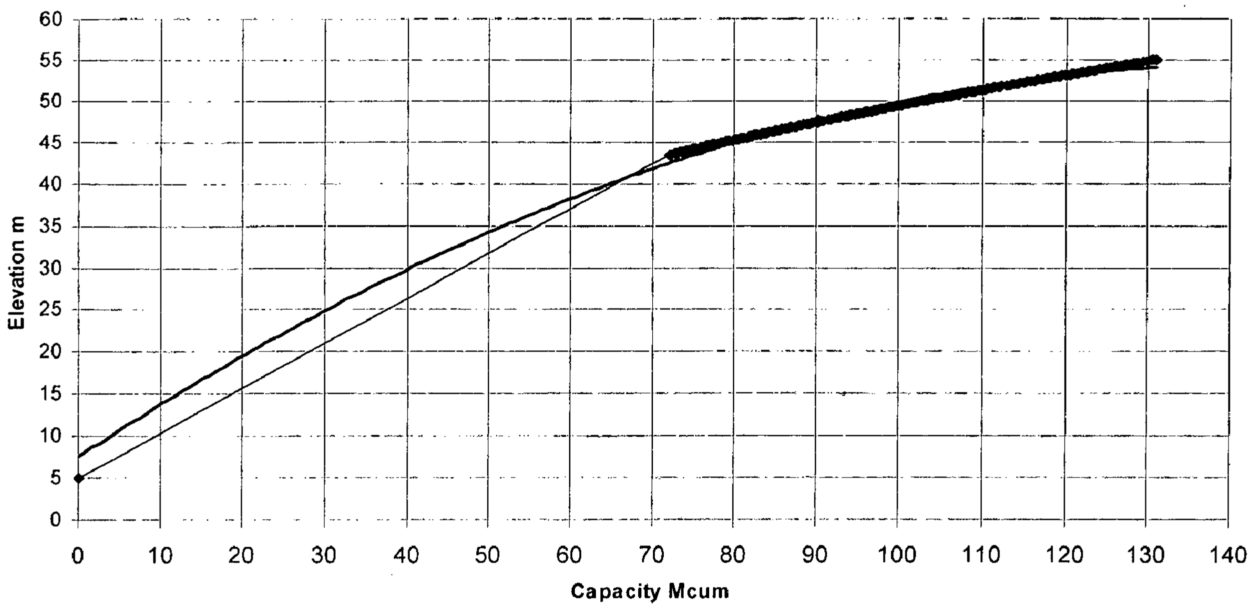
During the morning, the relative humidity exceeds 75% for most times of the year. During the months of monsoon, the relative humidity during the afternoons is approximately 60%. During the driest months (January to March), the relative humidity in the afternoon is less than 35%.

3.12.3.6 Project Details

Sharavathy/Gerusoppa dam was constructed to impound 130.879Mm^3 of water at FRL 55.00 m. The catchment area of reservoir is 2148 km^2 including free catchment of 151.50 km^2. The sailient features of the reservoir are given at Annexure II. The Power House on the right bank of the Gerusoppa dam consists of four Francis-type turbines coupled to the generating units of 60 MW each. The units are configured to operate at a design head of 47.5 m. An outdoor switchyard is located between the toe of the dam and the power house. Power from the outdoor yard is evacuated through a 220 KV double circuit transmission line connected to the state grid at Talaguppa. Photographs (Annexure III) shows details of Dam, Power House and reservoir during site visit.

3.12.3.7 Historic Sedimentation Survey

As reported by the field officers the original survey was carried out before 2002 and impoundment began from the same year. Thus the Elevation Capacity curve (Fig.6) available for year 2002 is taken as base for present study. The Hydrographic survey has not been carried out for this project. The content table of the same is given as Table – I (Annexure IV).The gross capacity of base year was 130.879 Mm^3 (4.622 TMC) at FRL 55.00m. In order to study the sedimentation pattern since the construction of dam, capacity of the reservoir in the year 2010 was estimated using satellite remote sensing data.



Original Elevation Capacity curve for Sharavathy reservoir, Karnataka

Fig.6. Original Elevation Capacity curve of Sharavathy Reservoir for the year 2002

3.13 Data Used

For the quantification of volume of sediment deposited in the reservoir, the basic information extracted from the satellite data is water spread area at different water surface elevations. The data for reservoir water levels are collected from project authorities. The selection of water year for analysis is from consideration of maximum variation in reservoir levels (ideally FRL to MDDL) and availability of cloud free images. In India, more than 80% of the rainfall is received during the four-monsoon months from June – September. During this period, water level in the reservoir rises from minimum in May/June to maximum in Sept/Oct months, depending on the amount of rainfall. But the cloud free data products may not be available during this period. Subsequently the water level of reservoir gradually depletes to lower levels towards the onset of next monsoon (May /June). The satellite data for this period can be efficiently used coupled with field data for analysis purpose.

3.13.1 Topographical data :

The topographical details were taken from Toposheets obtained from Survey of India as detailed below:

i. Toposheet No. 48 J/11 &48 J/12

ii. Scale : 1:50,000

iii. Latitude 14^{0} 14'30" N and Longitude 74^{0} 37'15"E.

3.13.2Field data

The salient features of the reservoir along with original Elevation – Capacity tables, daily water level data, catchment area details and maps were collected from the Karnataka Power Corporation Limited, office of Chief Engineer (C), Sharavathy/ Gerusoppa dam, Karnataka.

3.13.3 Satellite data

The multi-spectral data of IRS 1A/1C/1D and P6 Satellites for LISS-III Sensor were available for period of analysis and same were used for this study. The specifications of these satellites are given in the following table II :

Table II : Specifications of IRS satellites

Satellite	Sensor	Resolution (m)	Number of Spectral Bands	Revisit (days)	Coverage (km x km)
IRS-1A IRS-1B	LISS-I	72.5	4	22	148 x 174
	LISS-II	36.25			074 x 087
IRS-1C	LISS-III	23.5	3	24	148 x 141
IRS-1D	LISS-III	23.5	3	25	141 x 142
IRS-P6	LISS-III	23.5	4	24	142 x 141

The Sharavathy/Gerusoppa reservoir water spread was covered in one scene of path 97 row 63 of IRS P6 (LISS – III) satellites. An FCC image of Reservoir is ahown as Fig 7

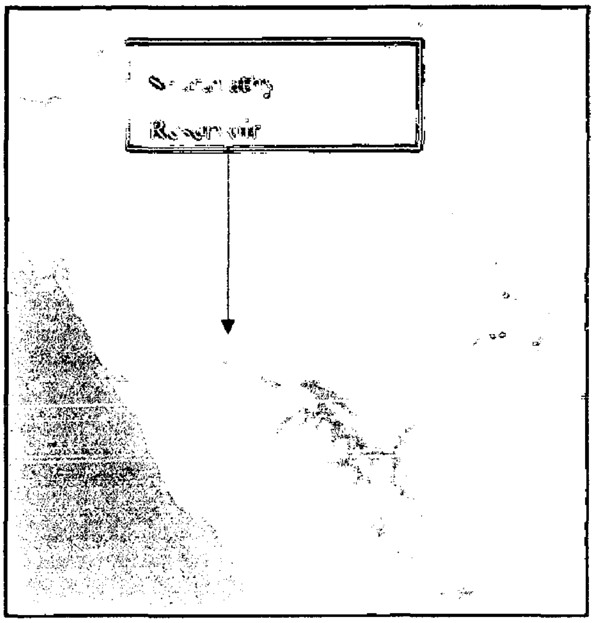


Fig 7: FCC image of Sharavathy Reservoir

3.14 Analysis of Data

The useful information extracted from the remote sensing data is the water spread area at different dates of pass of the satellite over the reservoir area. Hence every care was taken right from the selection of study period to image interpretation to correctly assess the water spread area. Field and Satellite data analysis was carried out in order to calculate loss in capacity of Sharavathy reservoir using SRS technique.

3.14.1 Browsing of Satellite imageries

This is the most important and initial part of analysis which is simultaneously done along with the Reservoir water level analysis. As it was tentatively decided to carry out sedimentation survey of Sharavathy reservoir for the year 2010 therefore all the imageries available through IRS P6 satellite with LISS III sensor were first browsed. In each year near about 10 imageries were available. The images were then categorised with respect to their quality after visual interpretation of imageries in image search module of NRSC web site www.nrsc.gov.in as follows:

A. Cloudy image
B. Hazy image
C. Good image
D. Very good image

The images which are cloudy can not be used for digital analysis hence outright discarded. But some times clouds may be there on whole image but our area of interest might be free from clouds then such images may be chosen because at near FRL level it is very difficult to get cloud free images. Hazy images are also some times chosen for the same reason. For the purpose of present study 'good' and 'very good' images were chosen. . Based on the status and availability of remote sensing satellite data, scenes shown in Table III were first browsed for five to six years.

Table III : Browsed data for cloud free imageries

Sr. no.	Date	Satellite / Sensor / Scene	Path	Row
a) Period : 2006- 07				
1	15-Oct-06	IRS P6 / LISS - III	97	63
2	08-Nov-06	IRS P6 / LISS - III	97	63
3	02-Dec-06	IRS P6 / LISS - III	97	63
4	26-Dec-06	IRS P6 / LISS - III	97	63
5	19-Jan-07	IRS P6 / LISS - III	97	63
6	08-Mar-07	IRS P6 / LISS - III	97	63
7	01-Apr-07	IRS P6 / LISS - III	97	63
8	25-Apr-07	IRS P6 / LISS - III	97	63
9	19-May-07	IRS P6 / LISS - III	97	63
b) Period : 2007 - 2008				
1	10-Oct-07	IRS P6 / LISS - III	97	63
2	03-Nov-07	IRS P6 / LISS - III	97	63
3	27-Nov-07	IRS P6 / LISS - III	97	63
4	21-Dec-07	IRS P6 / LISS - III	97	63
5	14-Jan-08	IRS P6 / LISS - III	97	63
6	07-Feb-08	IRS P6 / LISS - III	97	63
7	02-Mar-08	IRS P6 / LISS - III	97	63
8	26-Mar-08	IRS P6 / LISS - III	97	63
9	19-Apr-08	IRS P6 / LISS - III	97	63
10	13-May-08	IRS P6 / LISS - III	97	63
c) Period : 2008 - 2009				
1	04-Oct-08	IRS P6 / LISS - III	97	63
2	28-Oct-08	IRS P6 / LISS - III	97	63
3	21-Nov-08	IRS P6 / LISS - III	97	63
4	08-Jan-09	IRS P6 / LISS - III	97	63

5	01-Feb-09	IRS P6 / LISS - III	97	63
6	25-Feb-09	IRS P6 / LISS - III	97	63
7	21-Mar-09	IRS P6 / LISS - III	97	63
8	14-Apr-09	IRS P6 / LISS - III	97	63
9	08-May-09	IRS P6 / LISS - III	97	63
d) Period : 2009 - 2010				
1	23-Oct-09	IRS P6 / LISS - III	97	63
2	16-Nov-09	IRS P6 / LISS - III	97	63
3	10-Dec-09	IRS P6 / LISS - III	97	63
4	03-Jan-10	IRS P6 / LISS - III	97	63
5	27-Jan-10	IRS P6 / LISS - III	97	63
6	20-Feb-10	IRS P6 / LISS - III	97	63
7	16-Mar-10	IRS P6 / LISS - III	97	63
8	09-Apr-10	IRS P6 / LISS - III	97	63
9	03-May-10	IRS P6 / LISS - III	97	63
10	27-May-10	IRS P6 / LISS - III	97	63

3.14.2 Analysis of Daily Reservoir Water Levels and Other Field Data

Study of original area capacity table for the year 2002 (Table I) collected from the KPCIL project authority, Sharavathy, revealed that the capacities and areas at important levels were as given below in Table IV :

Table IV : Capacities and Areas at important levels of Sharavathy reservoir

SN	Level	Elevation (m)	Area (Mm^2)	Capacity (Mm^3)	Remark
1	River Bed Level	5.00	0.00	0.00	Zero content level
2	MDDL	43.50	4.115	72.19	Dead Storage
3	FRL	55.00	6.00	130.879	Gross Storage (Dead + Live)
4	MWL	55.40	6.20	131.00	Gross + Flood storage

Water level data for cloud free dates for the year 2006 to 2011 selected for analysis is shown in Table V. After comparing the availability of cloud free imageries for different date of pass with water level variation for different dates collected from the dam site, it was seen that there was very few imageries for one single year which could show the maximum fluctuation (FRL to MDDL) in reservoir water levels. Therefore, the imageries for the period from 2007 to 2010 were collected for cloud free dates in order to show variation from near FRL to MDDL. It was observed that the satellite dates near to FRL (55.00 m) was 25 Apr 2007 and close to MDDL (43.50 m) was 02 March 2008.

Table - V

Selected Satellite Data for different dates of pass for Sharavathy reservoir water levels

Sr. no.	Date	Satellite / Sensor / Scene	Path	Row	Water Levels (m)
1	2-Mar-08	IRS P6 / LISS - III	97	63	46.460
2	23-Oct-09	IRS P6 / LISS - III	97	63	47.400
3	14-Jan-08	IRS P6 / LISS - III	97	63	49.140
4	27-Jan-10	IRS P6 / LISS - III	97	63	50.000
5	21-Nov-08	IRS P6 / LISS - III	97	63	50.600
6	25-Feb-09	IRS P6 / LISS - III	97	63	50.650
8	10-Dec-09	IRS P6 / LISS - III	97	63	50.970
9	8-Mar-07	IRS P6 / LISS - III	97	63	51.240
10	20-Feb-10	IRS P6 / LISS - III	97	63	52.980
11	3-Jan-10	IRS P6 / LISS - III	97	63	53.560
12	22-Jan-11	IRS P6 / LISS - III	97	63	49.630
13	25-Apr-07	IRS P6 / LISS - III	97	63	54.350

3.14.3 Geo-coding of Satellite Imageries

The raw data obtained from NRSA was first geo-coded as given below:

Import and visualization

The satellite data was received from NRSC Hyderabad on the CD-ROM media. The data was then loaded on the CWPRS computer from the CD-ROM and imported in the available software system EASI-PACE. The raw IRS imageries are supplied in binary format. The EASI / PACE software directly reads the IRS –1C and IRS -1D imageries. While importing, the file it was saved in 'pix' format for further processing of imageries using EASI PACE software. The visual interpretation of the data gave an idea of the reservoir water spread. As the raw data covers a swath of 141 km, number of reservoirs in this reach were seen in the imagery. It was essential to identity Sharavathy reservoir and concentrate on study area.

Initially False Colour Composite (FCC) image of 3, 2 and 1 bands combination for IRS P6 for LISS – III sensor were generated and visualized. The pixel representing water spread area (except at the periphery) of the reservoir was quite distinct and clear in the FCC. All the imageries were cloud free.

Separation of area of interest (sub-setting)

Image sub setting is primarily done to create imagery covering small area known as Area of Interest (AOI) from much larger image. This reduces the processing time and increases the accuracy of analysis. The reservoir area and its surroundings were separated out from the full scenes from all the images. This was done through a utility named 'sub-setting', the four corners were selected covering entire reservoir with some of the area around the reservoir. The data corresponding to this area of interest was saved in a new file and similar procedure was repeated for all the imageries.

Base Map Creation

A digital base map of study area is created from 1:50000 scale SOI Toposheets 48 J/11 and 48 J/12. Toposheet was first scanned in A-0 size scanner and then imported to the available system in '.pix' format. Using the utility tool / module 'Xpace' in the software, the raw image of Toposheet was Geo-referenced by giving co-ordinates of each corner as well as middle points. This is termed as correcting an image having known geo-referenced points by choosing an option called Ground Control Points (GCP). RMS error of less than 0.5 is ensured. As this is the first step in geo coding, it needs to be precisely done, as the accuracy of result is totally dependent on the accuracy of the base map.

Geo referencing

All images must be geometrically corrected and transformed into the standard cartographic projection and scale so that any measurement made on the image will be accurate with those made on the base map and ground. The geometric corrections enable the images to be represented in their latitudinal and longitudinal coverage. This is achieved by correcting the image using geo-referenced base map (topo sheet). In present study, imagery of 3rd January 2010 was first geo-referenced, since this was very sharp, clear, noise free and cloud free and it was considered as the base imagery. The imageries of other dates were considered slaves and geo - referenced with this base imagery.

Some clearly identifiable features like crossings on Sharavathy river, confluence with Tail race channel from Talakalale dam, crossings with highway, sharp bends in the rivers, drains, bridges etc. were selected as GCP's to geo reference the images. About 10 to15 points around the reservoir were selected for geo referencing. Looking at the statistics, some points, which generated large errors, were either deleted or fine adjustments were made so as to obtain the precise geo referencing. In this manner topo sheet to image and image to another image geo referencing was completed keeping the same criteria of RMS error. In most of the imageries the geo referencing was so good that RMS error was even brought to 0.01m to achieve accuracy. After completing this process, two different imageries were displayed one over the other and linking was done to ensure that the geo referencing is done satisfactorily.

Digital Image Processing for Delineation of Water and Land Boundary

Water is one of the most easily delineable features on the satellite data due to high contrast between land and water body in NIR band, wherein water absorbs almost entire incident energy depending on nature and status of water body while land absorbs less depending on cover type, roughness, composition etc. Although spectral signatures of water are quite distinct from other land features such as vegetation, barren land and man made developments, yet identification of water pixels at the water / land interface is very difficult and depends on the visual interpretation ability of the analyst. Therefore, digital image processing technique, which includes vector generation and modeling for water land boundary delineation was required in addition to visual interpretation. It was observed in all images of Sharavathy reservoir that the deep water was quite distinct. However, if we magnify the image at tail portion or periphery of reservoir the colours of pixels changes from dark blue to light blue to greenish blue to bluish green and finally to dark green, mustered, reddish and brown colour. Hence, it created a lot of difficulties in deciding exact line to delineate water from land. Though the statistics of histogram gave an idea about the ranges of values of NIR band for land / water boundary demarcation, pixel by pixel identification was difficult by visual interpretation. The digital image processing technique adopted was useful to overcome these difficulties.

Delineating the Land and Water Pixels

Various methods adopted for delineating the land and Water pixels for a better accuracy are as follows:

a) Generation of contours:

Contours of equal intensity (lines of equal digital numbers) can be generated along the water – land boundary using EASI/PACE software. Any correction for noises or otherwise can be edited manually in the vector contour using vector editing facilities. For the generation of contours, the contour interval was given by using the XPACE module. The contours were then generated at these intervals, which indicated probable delineation of the land and water pixels. The 2-3 probable contours were selected, which could give correct land- water delineation. From these contours DN values in NIR band were checked at various locations and a single contour was selected which gave the actual water spread area at that elevation. The area of that particular contour was noted down. The islands present in that water spread were also demarcated and the total area of all islands subtracted from the area of contour to obtain net water spread area for that particular elevation. Similar process was carried out for all the images to find water spread areas.

b) Thresholding technique

After analyzing the histogram of the image, the ranges of values (NIR band) for land/water boundary demarcation were identified. The NIR image was thresholded into two to three ranges in increasing order by roaming the cursor on FCC image with numeric display of image on. First range contained all confirmed water pixels and a mask was created, second and third range contained pixels at the island/water boundary and at the tail portions of the water-spread extending in to river course and other masks were created. These range masks were evaluated for the correctness of range limits by consulting FCC In most of the cases the criterion for thresholding the image could not give satisfactory results in identifying the correct water pixels due to shallow depth of water at some of the locations along the periphery and at the tail portion of the reservoir. Hence, actual water pixels in these two range masks were estimated by including thresholding of RED band data and further applying the condition of reflectivity property of water for NIR and RED band. (The reflectivity of water in NIR band is smaller than RED band and hence the DN values of NIR band will be smaller than DN values of RED band for water). The total reservoir water spread area was estimated by adding the water spread masks under the different range masks.

For delineation of water and land boundary by Thresholding Technique, following two criteria were adopted

i). WATER INDEX (WI) METHOD

The water pixels are identified by taking band ratio of Green/Near Infrared. Since the maximum absorptance of electromagnetic radiation by water is in the Near infrared spectral region, the DN value of water pixel in NIR band is appreciably less than the DN values of Green spectral region, which is having high reflectance value. This ratio separates the water body from soil/vegetation quite distinctly.

ii). MODIFIED NORMALIZED DIFFERENCE WATER INDEX (NDWI) METHOD

The condition used to separate the water pixels from the other pixels is as follows:

$$NDWI = \frac{DN(G) - DN(NIR)}{DN(G) + DN(NIR)}$$

"If NDWI is positive and if the DN value of NIR band is less than the DN value of Red band and the Green band (NIR < Red < Green), only then the pixel must be classified as water".

Chapter

Estimation of Water Spread Areas and Capaciti

4.1 General

After delineation of water land interface by EASI / PACE, the vector editor displays direct the area of selected closed vector contour. These water spread areas after following corrections we utilized to calculate capacities between two elevations. The original water spread areas at differe levels were not supplied by project authority. However it was observed through salient features of tl project that the submergence area was 6.00 Km^2 which was corresponding to FRL area. Assumir the water spread area at River bed level as zero and knowing capacities at equal elevation differenc the primordial formula was used to solve simultaneous equations. The original areas thus obtaine were then compared with the latest area obtained through Remote Sensing Method after applyir following corrections:

4.2 Corrections in Vector Contours and masks

The area indicated by the vector contour after fine tuning by modelling needs to be furth refined by applying corrections to account for the effect of clouds, islands, vegetation, pix discontinuity, cut-off in extended tail of back water etc. while dealing with the calculation of tl water spread area of the reservoir. In the masks, the isolated water patches within the reservoi which do not have any hydraulic connectivity with continuous water-spread area were eliminated.

4.2.1 Elimination of Cloud Effect

All the imageries were cloud free. Hence no correction was needed for cloud effect.

4.2.2 Removal of Island Areas

The areas of islands present in the reservoir were deducted from the total water spread area from a the imageries.

4.2.3 Removal of Discontinuous Pixels

Isolated water pixels surrounding the water spread area were not found, however some water pixe seen near the boundary of reservoir, which have shown no hydraulic connectivity were remove Similarly, water pixels downstream of reservoir were not a part of reservoir, hence were removed.

4.2.4 Removal of Extended Tail and Channel

Water in tail channels of Sharavathy river appears as a part of reservoir in the imagery, however, th elevation of the water surface in these river channels remains higher than the water surface elevatio of the reservoir. This extended tail of channels with higher water surface elevation were cut at th point of termination of reservoir water spread at corresponding levels taking help of base ma (contour map). The longitudinal section of main river and tributaries proved to be useful in order to decide cut-off points. Removal of extended tail is very much necessary as this could generate errors.

4.2.5 Correction for vegetation on the periphery of reservoir

There was no distinct vegetation found either on the periphery or floating in the reservoir. Hence this correction was also not applied.

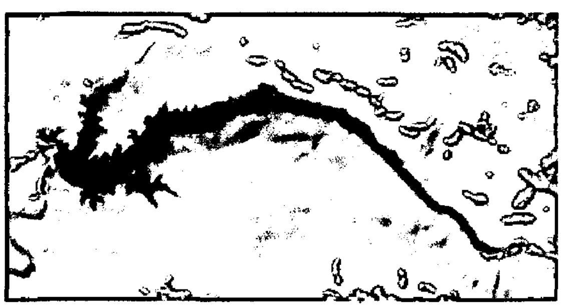
4.3 Water Spraed Area Extraction

The water spread areas for different dates extracted from FCC image of Sharavathy/Gerusoppa reservoir are shown in Fig.8 a , 8 b and 8 c for period 2007 – 2011. The superimposed water spread areas of the reservoir for the same period at different elevations is shown in Fig.9.

Fig 8a . Water Spread Areas of different dates for Sharavathy Reservoir

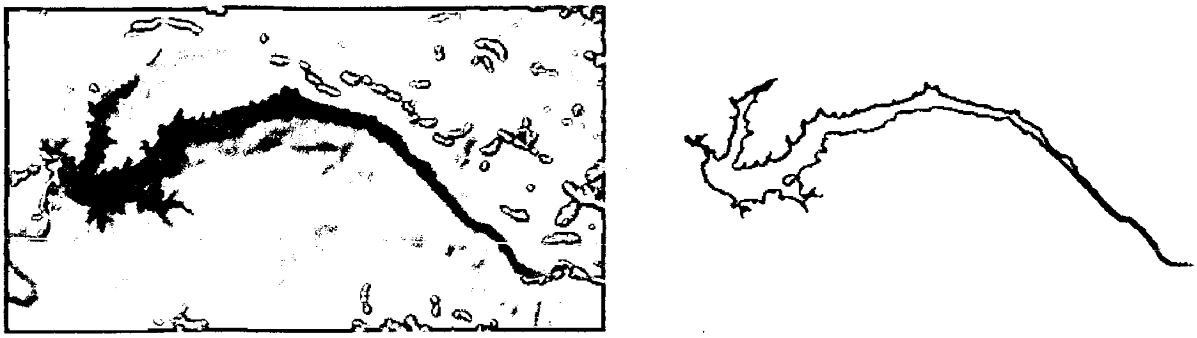
Satellite Imagery **Extracted Water Spread Area**

Date of Pass: 25 Apr 2007 Water Level: 54.35 m Area:5.369 M m^2

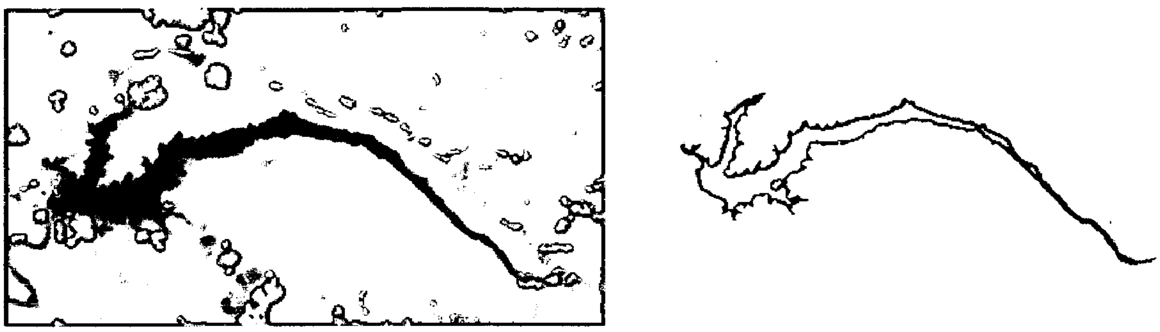


Date of Pass: 3 Jan 2010 Water Level: 53.56 m Area:4.985 M m^2

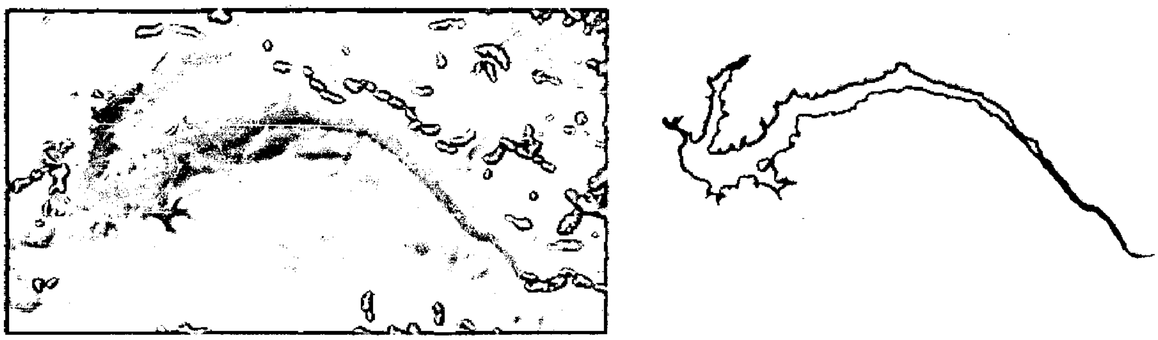
Fig 8b . Water Spread Areas of different dates for Sharavathy Reservoir



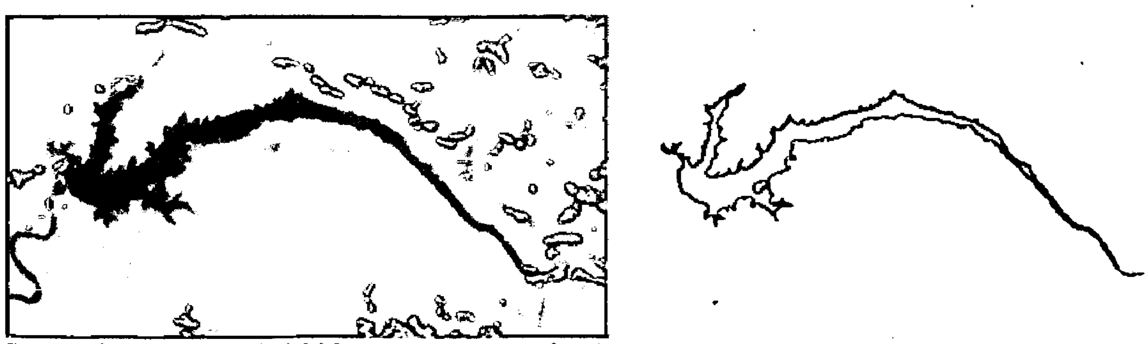
Date of Pass: 20 Feb 2010 Water Level: 53.980 m Area:4.917 M m^2



Date of Pass: 8 Mar 2007 Water Level: 51.240 m Area:4.910 M m^2

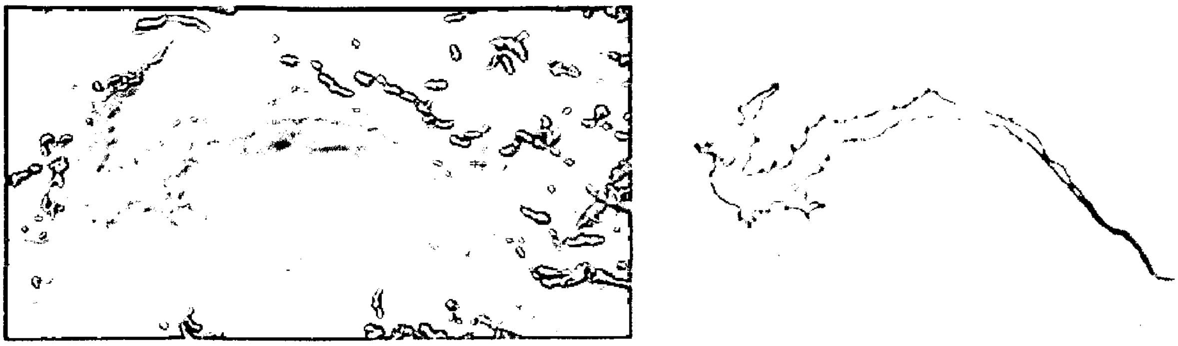


Date of Pass: 10 Dec 2009 Water Level: 50.970 m Area:4.838 M m^2

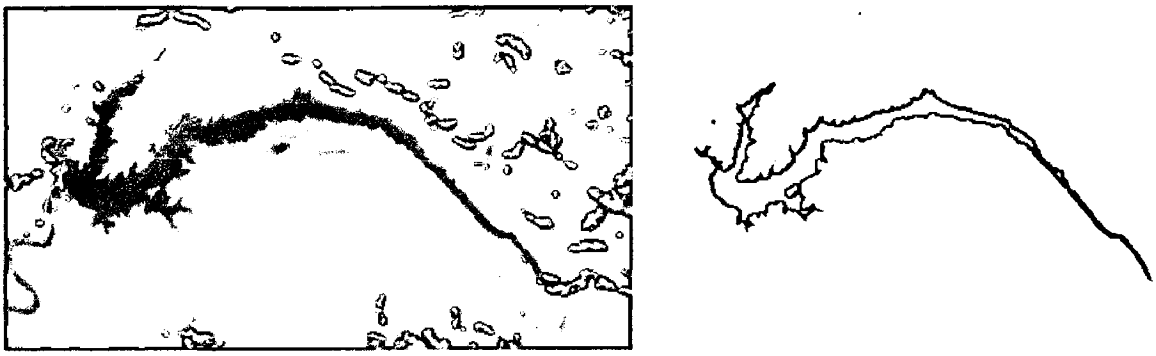


Date of Pass: 25 Feb 2009 Water Level: 50.650 m Area:4.792 M m2

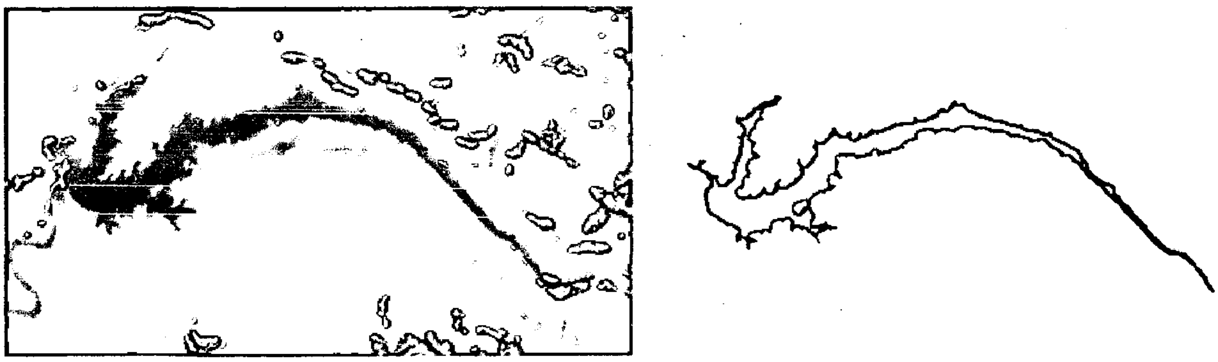
Fig 8c. Water Spread Areas of different dates for Sharavathy Reservoir



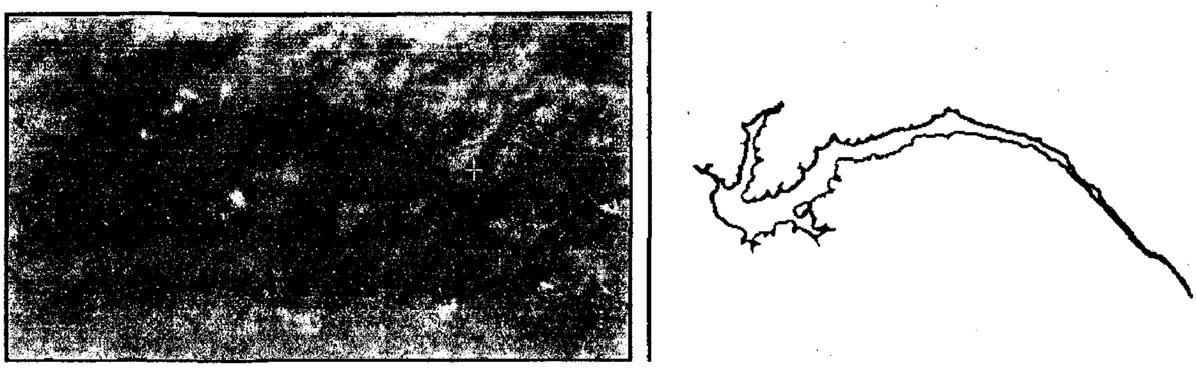
Date of Pass: 21 Nov 2008 Water Level: 50.600 m Area:4.708 M m^2



Date of Pass: 27 Jan 2010 Water Level: 50.000 m Area:4.620 M m^2

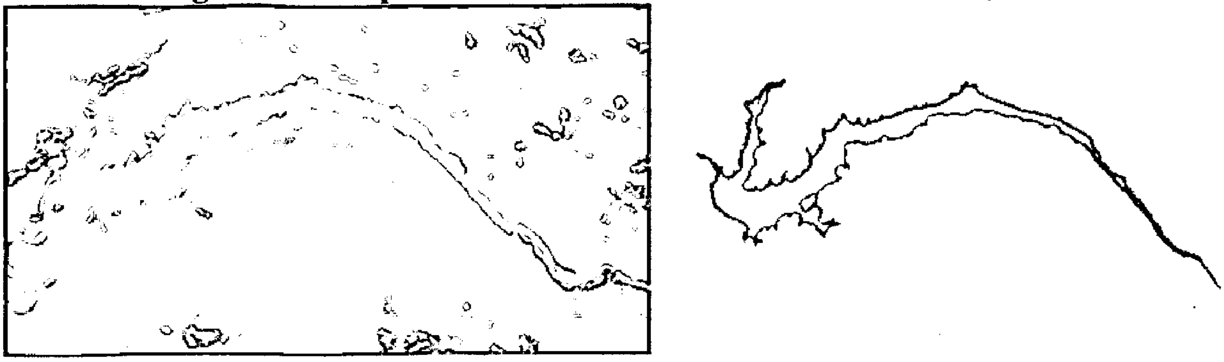


Date of Pass: 22 Jan 2011 Water Level: 49.630 m Area:4.550 M m2

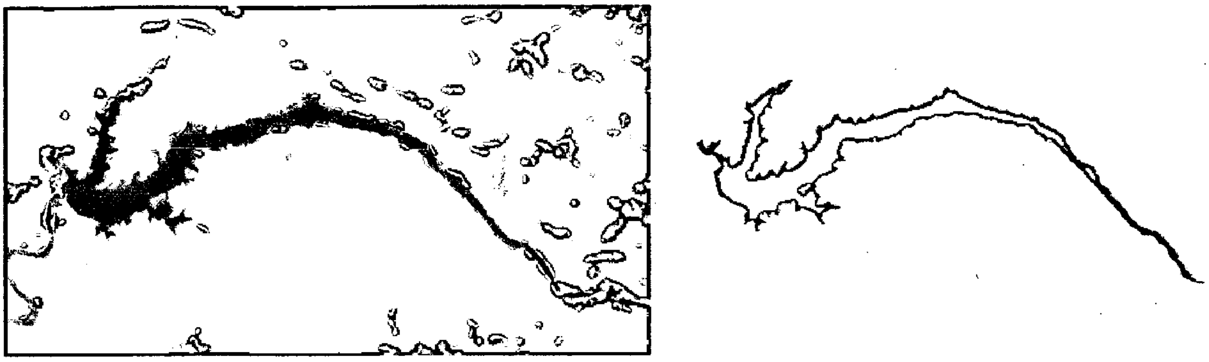


Date of Pass: 14 Jan 2008 Water Level: 49.140 m Area:4.490 M m2

Fig 8d. Water Spread Areas of different dates for Sharavathy Reservoir



Date of Pass: 23 Oct 2009 Water Level: 47.400 m Area:4.467 M m^2



Date of Pass: 2 Mar 2008 Water Level: 46.46 m Area:4.445 M m^2

Fig 9. Superimposed Water Spread Areas of Sharavathy Reservoir

	03-Jan-10
	20-Feb-10
	08-Mar-07
	25-Feb-09
	14-Jan-08

4.4 Generation of Latest Elevation – Curve

After applying above corrections the actual water spread area was obtained as detailed in Table VI Estimated water spread areas for different dates (dates of satellite over pass) obtained by digit analysis of satellite data corresponding to different elevations were plotted to generate area-elevatic curve. As remote-sensing technique is limited to give water spread area mostly in live storage zor and in the present case also the fluctuation of water level was from 43.5 m to 55.00 m, therefore tl water spread area below MDDL and at FRL were not available. Linear interpolation / extrapolatic technique was used to assess these areas. The area elevation graph for the period 2010 is presented a Fig 13a.

4.5 Estimation of Cumulative Volume of Reservoir at Different Elevations

The reservoir capacity between two elevations was then computed by prismoidal formula using wat spread areas obtained above :

$$\Delta V_{1\text{-}2} = \Delta h \ (A1 + A2 + \sqrt{A1 * A2}) \ / \ 3$$

Where,

$\Delta V_{1\text{-}2}$ = Volume between elevation E2 and E1 (E2>E1)

Δh = E2-E1

A1, A2 = Water spread areas at elevation E1 and E2 respectively.

4.5.1 Sample Capacity Calculation

Estimation of the capacity between 43.5m and 46.460m

V = {(46.460-43.5/3)* (4.115+4.445+ SQRT(4.115*4.445)}=12.726 Mm3

Assuming capacity at MDDL 43.5m as zero, cumulative capacity at 46.460m is 12.726Mm3

Estimation of capacity at 54.35 m and FRL 55.00m

V=(55-54.35)/3*(5.369+5.900+SQRT(5.369*5.900)=3.661Mm3

Cumulative capcity at FRL 55.00m is (50.021+3.661)=53.682Mm3

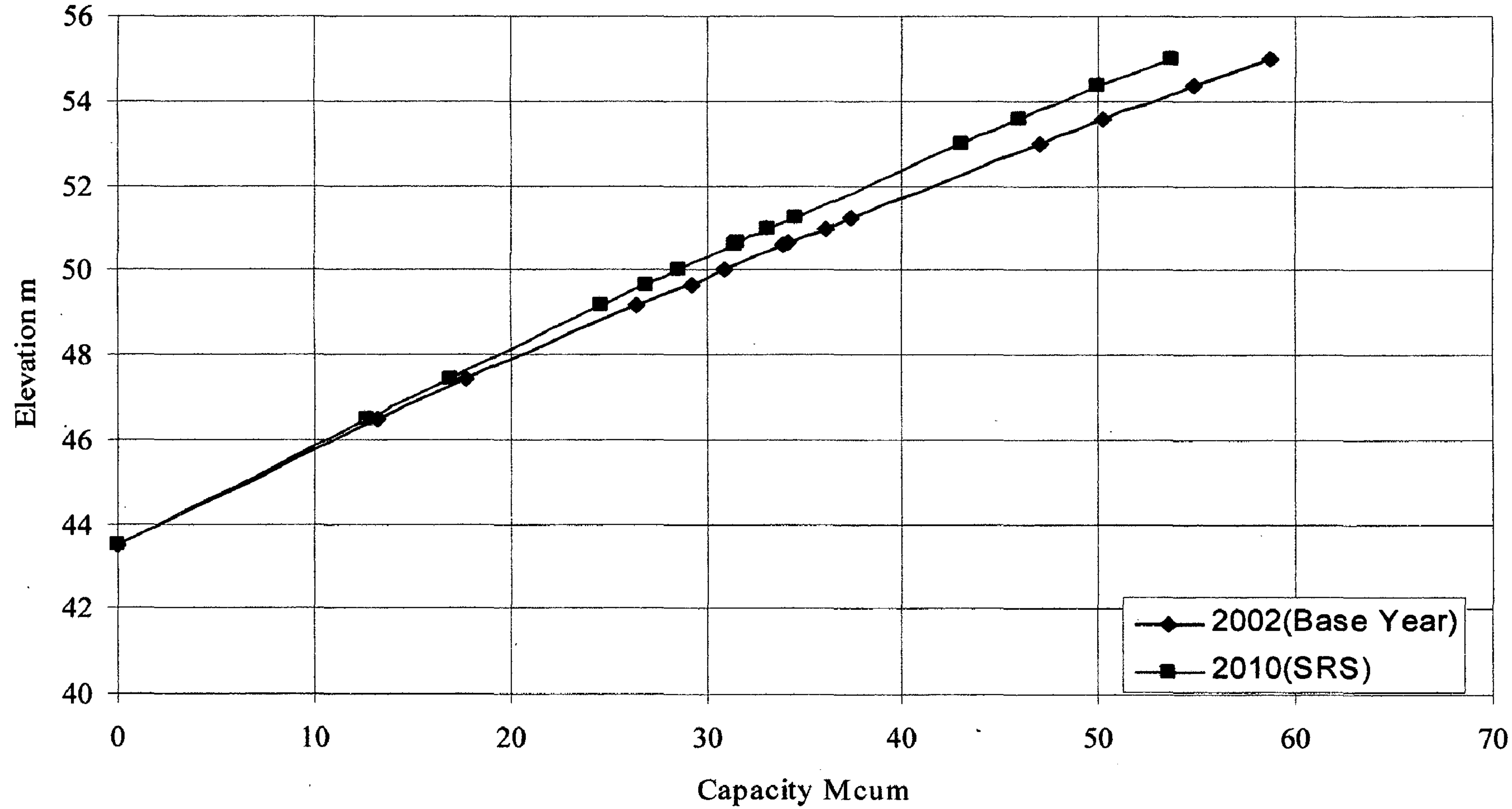
Table VI gives the cumulative live storage capacity at different elevation.

Sediment deposition in Mm3 (Original – Revised)= 5.007 Mm3

Table - VI
Sharavathy reservoir capacity loss estimation due to sedimentation

Sr. no.	Reservoir Levels	Date of Satellite Pass	Elevation (m)	Elevation Difference (m)	WS Area (Mm^2)		Capacity (Mm^3)		Cumulative Capacity (Mm^3)		Sediment deposition (Mm^3)
					2002	**2010**	**2002**	**2010**	**2002**	**RS2010**	**RS 2010**
1	**MDDL**	**MDDL**	**43.500**	**0.000**	**4.155**	**4.155**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
2		2-Mar-08	46.460	2.960	4.795	4.445	13.252	12.726	13.252	12.726	0.526
3		23-Oct-09	47.400	0.940	4.850	4.467	4.530	4.189	17.782	16.914	0.868
4		14-Jan-08	49.140	1.740	5.080	4.490	8.660	7.793	26.442	24.707	1.735
5		22-Jan-11	49.630	0.490	5.100	4.550	2.848	2.215	29.290	26.922	2.368
6		27-Jan-10	50.000	0.370	5.150	4.620	1.702	1.696	30.992	28.618	2.374
7		21-Nov-08	50.600	0.600	5.300	4.708	2.939	2.798	33.931	31.416	2.515
8		25-Feb-09	50.650	0.050	5.310	4.792	0.265	0.238	34.196	31.654	2.542
10		10-Dec-09	50.970	0.320	5.517	4.838	1.855	1.541	36.051	33.195	2.856
11		8-Mar-07	51.240	0.270	5.638	4.910	1.345	1.316	37.396	34.511	2.885
12		20-Feb-10	52.980	1.740	5.789	4.917	9.654	8.550	47.050	43.061	3.989
13		3-Jan-10	53.560	0.580	5.811	4.985	3.139	2.872	50.189	45.932	4.257
14		25-Apr-07	54.350	0.790	5.842	5.369	4.651	4.089	54.840	50.021	4.819
15	**FRL**	**FRL**	**55.000**	**0.650**	**6.00**	**5.900**	**3.849**	**3.661**	**58.689**	**53.682**	**5.007**

MDDL: Minimum Draw down level FRL : Full Reservoir level



Elevation capaciy curve of Sharavathy reservoir, Karnatka

4.6 Estimation Of Sediment Deposition

As mentioned earlier, the Sharavathy reservoir was constructed in the year 2002. As per tl records available, the first impoundment of reservoir was done in the same year. The gross storaş capacity of the reservoir in 2002 was 130.879 Mm^3 at FRL 55.00 m. The original elevation capaci table of 2002 is given as Table I in Annexure 4. In order to calculate loss in storage and to kno sedimentation rate, capacity survey by remote sensing technique was carried out under the prese study for the periods 2007 – 10 for the zone of fluctuation between 43.50 m to 55.00 m.. Tl difference between the cumulative capacities of original (2002) and latest (2010) surveys gave lo in storage in live storage zone as shown in Table VII . The comparative capacity elevation curves f the above periods are shown as Fig.10. Following Table VII gives the status of loss in Live storag of Sharavathy reservoir during above survey along with loss in capacity, annual rate of siltation ar percentage loss in capacity since 2002 to latest survey by SRS technique in 2010.

Table VII :Loss of Live Storage

Year	*Reservoir capacity* **Mm^3**	*Loss of Capacity* **Mm^3**	*Period (years)*	*Rate of siltation* **Mm^3/yr**	*% loss of capacity from 2002*	*% annual loss*
		From 2002	*From 2002*	*From 2002*		
2002	58.689	0.000	0	0.000	0.000	0.000
2010	53.682	5.007	9	0.556	8.53	0.95

From the above table showing loss of live storage it can be seen that there is a capacity loss of 5.0C Mm^3 during 2002 to 2010 (9 years) respectively. The rate of siltation was 0.556 Mm^3 / year up t 2010. The result of analysis of satellite imageries for Sharavathy reservoir for the year 2010 indicat that the reservoir capacity in the year 2010 was 53.682 Mm^3. The percentage loss of capacity fro 2002 was 8.53%. Percentage average annual loss of capacity was 0.95%. Considering tot catchment of 2148 km^2 the rate of sedimentation comes to about 0.000259 Mm^3/km^2/year which equivalent to 311 tonnes/ km^2/Year .Also taking free catchment of 151.50 km^2 the rate c sedimentation will be 0.00367 Mm^3/km^2/year which corresponds to 4407 tonnes/ km^2/Year.

4.7 Uncertainty in Remote Sensing

4.7.1 General

Uncertainty, a complex and multi-faceted issue that is at the core of spatial statistics, is widely recognized in geographical information science and is of increasing importance in remote sensing. It is fundamentally important to agree terms and their definitions to facilitate the communication of desired meanings.

The goal of remote sensing is to give information about objects from measurements made from a remote location from space. The digital data is represented in the form of electromagnetic radiation of a pixel. The interpretive ability of the user and limitations of the methodology of SRS leads to uncertainty in prediction. The inference process is always less than perfect and thus there is an element of uncertainty regarding the results produced using remote sensing. When viewed from this perspective, the problem of uncertainty is central to remote sensing. It does not mean that the methodology or analysis is wrong. The author want to through light upon the facts and dark corners in analysis which may be kept in mind while forecasting the critical parameters like sedimentation index.. These facts are based on the observations during the course of applying SRS method for sedimentation analysis of reservoir. However, the topic of uncertainty in remote sensing gets a relatively modest amount of attention. The reasons for this can be debated, but it is somewhat natural for people involved with remote sensing to focus on what can be done well with remote sensing rather than what cannot be done well. However, as a matter of the natural growth and maturity of the field of remote sensing, it is essential that the topic of uncertainty begins to demand more attention.

4.7.2 What is Uncertainty?

Uncertainty arises from many sources ranging from ignorance (e.g. in understanding), through measurement to prediction. The Oxford English Dictionary gives the following definition of the word uncertain: 'not known or not knowing certainly; not to be depended on; changeable'. Uncertainty (the noun)is, thus, a general concept and one that actually conveys little information. For example, if someone is uncertain, we know that they are not 100% sure, but we do not know more than that, for example, how uncertain they are or should be. If uncertainty is our general interest then clearly we shall need a vocabulary that provides greater information and meaning, and facilitates greater communication of that information.

Uncertainty is a term used in different ways in a number of fields, including physics, statistics, economics, finance, engineering. It applies to predictions of future events, to physical measurements already made, or to the unknown.

The word uncertainty has resisted a narrow definition, possibly because unlike related words such as bias, precision, error and accuracy, the generic meaning of uncertainty deals with the subjective. That is, while two individuals may arrive at the same answer to a question, one individual may be more certain than the other about that answer. The definition of uncertainty to be used in this chapter is the simple 'quantitative statement about the probability of error'. A reasonable extrapolation of this definition is that accurately measured, estimated or predicted values will have small uncertainty; inaccurate measurements, estimates or predictions.

4.7.3 Uncertainty in remote sensing applications to reservoir sedimentation estimation

Various factors which affects results in reservoir sedimentation due to uncertainty in Remote Sensing include the data, Analysis part and interpretation ability of analyst. As we have already discussed the methodology of present study i.e. satellite remote sensing based sedimentation study, then the fundamental question will arise where the uncertainty term comes in picture, How can we (explicitly) estimate and propagate all sources of uncertainty in analysis? What are the Sources of uncertainty in estimating the areas?

The Uncertainty analysis, deals with assessing the uncertainty in a measurement. It is an experiment designed to determine an effect, or estimate the numerical value of a physical variable will be affected by errors due to instrumentation, methodology, and so on. Experimental uncertainty estimates are needed to assess the confidence in the results. Error and uncertainty in remotely sensed data come from several sources, and can be increased or mitigated by the processing to which that data is subjected (e.g. resampling, atmospheric correction). The main objective is to identify the uncertainty from the satellite data and to improve the image processing techniques for estimation of areas with uncertainty information raised by *spatial, spectral, positional accuracy* of GPS data. Uncertainty deals with various factors in the present study i.e . in the estimation of Water Spread Areas and Capacities namely in corrections in Vector Contours and masks, in Elimination of Cloud Effect, in Removal of Discontinuous Pixels and in Removal of Extended Tail and Channel etc.

4.7.3.1 Uncertainty in Spectral resolution

As in the Spatial approach, the term uncertainty is used in various ways; one being that the resolution of the data does not allow a user to make an assured decision about the content of the data. For example, pixels in remotely sensed images might contain uncertain information because of sub- pixel mixing or sensor sampling bias (Bastin et al., 2002). The increase of image clarity or quality always depends on the number of pixel covered per sq.km. The pixel breakage is not only makes uncertainty but also pixel overlap is one of the causes to identifying the objects differences. Poor spatial resolution makes high uncertainty at the overlap region. With the concept of these, reservoir does not create sharp boundary or edges. Sometimes it is very difficult to identify the land and water interface.

4.7.3.2 Uncertainty in number of Pixels in Water spread area.

As the data are received they are translated into a digital image that can be displayed on a computer screen. Just like the pictures on a television set, satellite imagery is made up of tiny squares, each of a different gray shade or colour. These squares are called pixels, short form of picture elements, and represent the relative reflected light energy recorded for that part of the image. Each pixel represents a square area on an image that is a measure of the sensor's ability to resolve (see) objects of different sizes. For example, the Indian Remote Sensing P6 with LISS III sensors has a maximum resolution of 24 meters; therefore, each pixel represents an area 24 m x 24 m, or 576 m^2. Higher resolution (smaller pixel area) means that the sensor is able to discern smaller objects. By adding up the number of pixels in an image, the area of a scene can be calculated. For example, by counting the number of pixels in NIR band a false colour image, the total area covered with water can be calculated. Sometimes it is very difficult to identify the water and land pixel, and if this counting of water pixel is not accurate then the calculation of area produces the huge error.

Following are some more areas where uncertainty lies while estimating sedimentation in reservoir.

4.7.3.3 Uncertainty in import and visualization

4.7.3.4 Uncertainty in base Map Creation

4.7.3.5 Uncertainty in Geo referencing

4.7.3.6 Uncertainty in Digital Image Processing for Delineation of Water and Land Boundary

4.7.3.7 Uncertainty in Delineating the Land and Water Pixels

4.7.3.8 Uncertainty in adopting Catchments area for computation of sedimentation index.

The uncertainty analysis is therefore utmost important before predicting sedimentation rate of a region. Although such analysis is beyond the scope of present study yet it was an important aspect which was pointed out for future analysis.

Chapter 5
Validation of Results and Discussions

5.1 General

Each reservoir has its own deposition pattern which is governed by a number of parameters related to water flow, reservoir operation, sediment characteristics, sediment inflows and reservoir topography. Therefore, its deposition pattern may not exactly match with standard types suggested by Borland and Miller as described in chapter 3. The assessment of sedimentation rates has great impact on its distribution pattern. Hence, it is necessary to know the characteristics of catchment of the river across which the dams are proposed. Moreover, in absence of any sedimentation survey carried out in past for a reservoir it will be appropriate to validate the results with respect to the topography, catchment characteristics, standard erosion rates of the region or with the trend of sedimentation in the surrounding catchments as discussed below.

5.2 Discussions on Topography and Catchment Characteristic

The river Sharavathy originates at a height of 730m near Ambuthirtha, in Shimoga district. It flows in a north-west direction, in its long, 132-km journey. The Sharavathy is joined by several tributaries. It traverses through hilly terrain and dense forests. After a stretch of 80 km along its course, the river drops down a steep mountain face of 293m – a visually delightful spectacle known as the Jog Falls (Photo1).

Photo 1 : Fall at Jog on Sharavathy river upstream of Sharavathy reservoir

From this breathtaking leap, the river continues its journey till it flows into the Arabian Sea near Honnavar (Dist : Uttar Kannada, Karnataka). The total catchment area of the river up to its confluence with the Arabian Sea is 2,774 Km^2. The basin receives a rainfall ranging between 5000-7500 mm. The catchment is covered with steep sloped scattered forest (Photo 2) which leads to high velocity of excess rainfall.

Photo 2 : Catchment of Sharavthy reservoir showing steep slopes and thick forest.

More over rock outcrops on the banks of the river reach as seen from Photo 3 indicates the high erosive nature of the river . The type of the sediment also include disintegrated rocks , boulders of various size and sand . As seen from the geological data of the catchment the crystalline rocks and metamorphic rocks contributes to the sediment generation along with the lateritic brown soil.

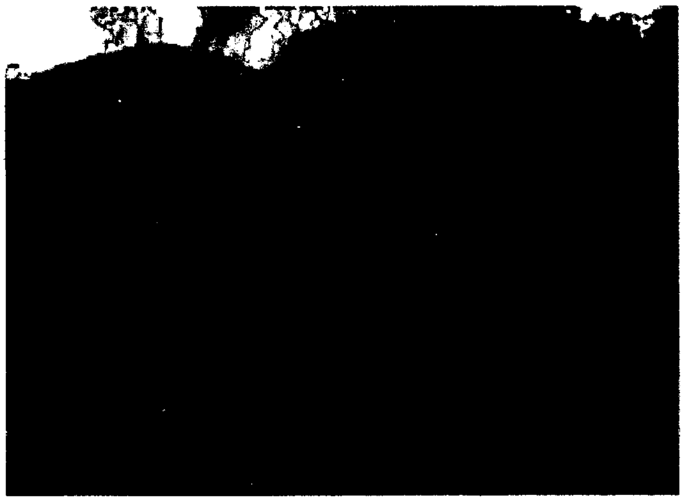


Photo 3 : catchment of Sharavathy river showing rock outcrops and type of sediment

The study of rainfall pattern also suggest that the primary force for generation of sediment in the catchment is raindrop impact, whose erosive potential depends on raindrop size, distribution, fall velocities and total mass of impact. The steep slopes cause intensive soil movement and carry runoff from interrill areas. The topography of the Sharavathy catchment shows that sheet and interrill erosion are major mode of sediment removal and transport. Also the part of sediment composed of the relatively coarser material due to fragmented rocks and boulders which moves along the stream bed which is executed by rolling, sliding along the bed or saltation of bed particles by the action of moving water due to heavy rainfall.

It was also observed during site visit that most of the sediment is being trapped in Linganmakki reservoir having an cathcment area of 1991.7 km^2 which is about 93 % of total catchment upto Sharavathy reservoir i.e. 2,774 km^2. Moreover two power generating stations discharges clear water in Sheravathy reservoir. Thus Sharavathy reservoir seems to receive relatively silt free water from atleast 50% volume from 93 % catchment. Whatever sediment reaches the reservoir is from the small catchment area of 151.50 km^2 area which is having steep slopes. Surplus water from Linganmakki reservoir also contributes in transporting sediment from free catchment of Sharavathy reservoir. As the Jog falls is continuous throught the year and is to the downstream of Linganmakki Dam , it would be appropriate to consider more impact free catchment of Sharavathy reservoir as compared to whole catchment , for want of estimation of sedimentation rate.

The study of topography and catchment characteristics reveals that the zone of Sharavathy reservoirs is having higher sedimentation rates due to steep slope and impact of rainfall all over the catchment . Thus Sedimentation rate of 0 .003367 Mm^3/ km^2 / yr seems to be in order. But the lower rate of .000259 Mm^3/ km^2 / yr has also some significance in sedmentation.

5.3 Iso Erosion Maps

The erosion rates vary considerably from one region to the other, from one reservoir to other and also within the reservoir and its catchment. In India erosion has been studied by Garde and Kothyari (1987) after analyzing the data on reservoir sedimentation and characteristics of the catchments. Fig 11 shows Iso – erosion rate line map for India. It can be seen that annual erosion rates vary from 1000 to 2000 tonnes/km^2/year in the study area . The sedimentation rate of 4406 tonnes/ km^2 / yr is on the high side. This may be because iso sedimentation lines are not available near the study area due to paucity of data of South Indian west flowing rivers. But the increasing trend of iso sedimentation lines towards west , supports the higher sedimentation rates near Sharavathy reservoir. Although, the lower sedimentation rate of 311 tonnes/ km^2 / yr is far below the minimum contour the same should be accounted to calculate rate of sedimentation.

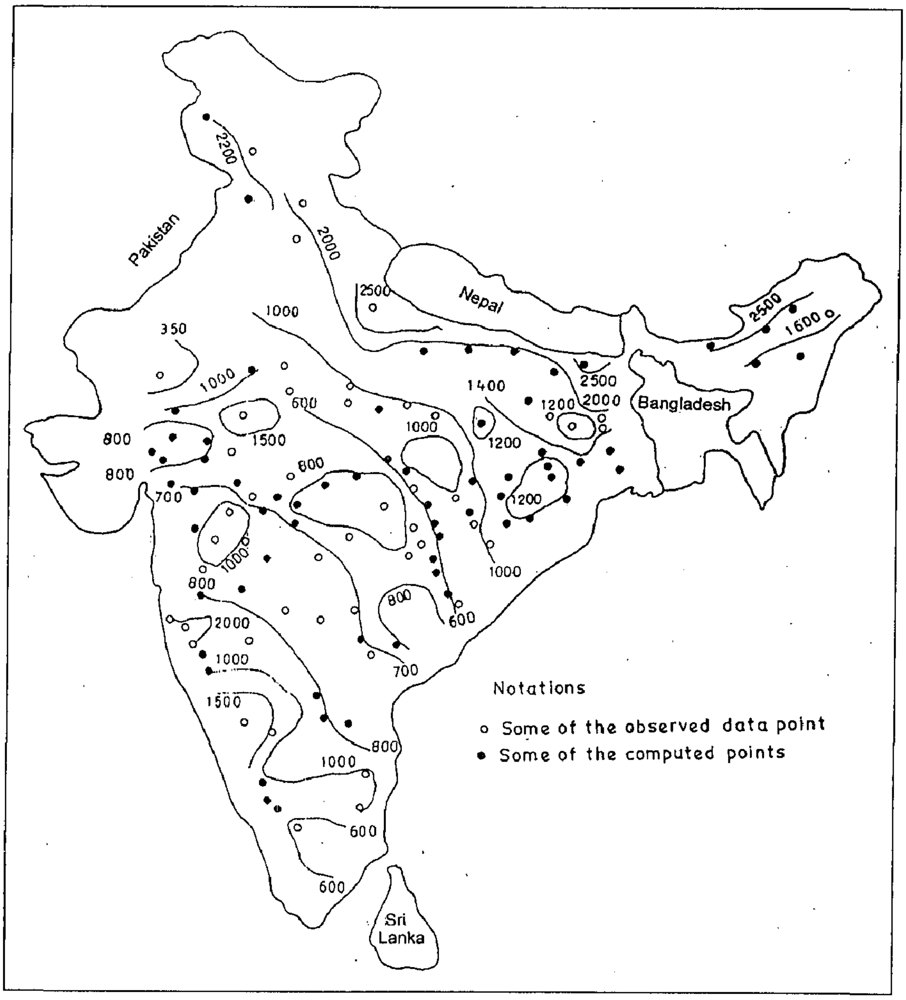


Fig 11 : Iso-erosion rate lines by Garde and Kothiyari

5.4 Annual percentage loss in capacity

Annual percentage rate loss as per sedimentation analysis of 44 reservoirs by Central Water Commission has shown annual loss of capacity between 0.5% to 1.0% in many of the Indian reservoirs. The above annual percentage loss was also suggested by Central Board of Irrigation and Power (CBIP) in their publication " Life of Reservoir" , 1977. Some reservoirs indicate annual loss above 1% also. Now considering the Live storage capacity of Sharavathy reservoir as 58.696 MCM, the annual loss of capacity comes to about 0.95 % which is near the upper limit of annual sedimentation rate, Hence validate the higher sedimentation rate arrived above.

5.5 Region-wise Sedimentation Rates

Based on the data of 144 reservoirs the annual percentage loss in storage has been worked out as the weighted average by Central Water Commission. The analysis of capacity survey data of 144 reservoirs showed a wide variation in sedimentation rate of reservoirs. The sedimentation rate is affected by multiple factors like hydrometeorology, physiography and climate etc. Considering these factors the whole country had been classified into 7 regions. The region-wise sedimentation rates are presented in table VIII :

Table VIII Region wise sedimentation rate as per CWC survey of 144 reservoirs

SN	Region	No. of reservoirs	Median values of rate of siltation	
			Mm^3 / sq. km / year	Ha.m / 100 sq. km / year
1.	Himalayan Region (Indus, Ganga and Brahmaputra basins)	5	0.00211	21.10
2.	Indo - Gangestic Plains	9	0.00089	8.90
3.	East flowing rivers upto Godavari (Excluding Ganga)	1	0.00064	6.35
4.	Deccan Peninsular East flowing rivers including Godavari and south Indian rivers	62	0.00046	4.65
5.	West flowing river upto Narmada	45	0.00084	8.40
6.	Narmada and Tapi basins	3	0.00075	7.50
7.	West flowing rivers beyond Tapi and south Indian rivers	19	0.00179	17.90
	All regions	144	0.00081	8.10

It may be observed that highest rate of siltation is for Himalayan region (Zone 1) followed by the region of west flowing rivers beyond Tapi (Zone 7) . As the reservoirs under study falls under zone 7, the siltation rate should have been 0.00179 Mm^3/ Km^2/ yr. The estimated rate of sedimentation 0.00367 Mm^3/ Km^2/ yr is higher than the standard sedimentation rate of zone 7 but seems to be realistic as it could not be as less as .000259 Mm^3/ Km^2/ yr which is estimated considering whole catchment.

5.6 Rate of sedimentation for gross storage

The rate of sedimentation discussed above is only for live storage zone which is 8.53 % in 9 years . If same pattern is assumed for dead storage zone of 72.19 Mm^3 the total loss in 9 years will be 6.16 Mm^3. Thus the total loss in gross storage zone may be roughly estimated. Table: IX gives the sedimentation rate for all storage zones based on the pattern found in live storage zone by Satellite remote sensing method.

Table IX :Loss of Gross Storage considering 8.53% loss in storage in 9 years

Year	Storage Zone	Resr. Cap. Mm^3	Loss of Cap. Mm^3	Period (years)	Rate of siltation Mm^3/yr	Rate in $Mm^3/km^2/yr$ (CA 2148 km^2)	Rate in $T/km^2/yr$ (CA 2148 km^2)	Rate in $Mm^3/km^2/yr$ (CA 151.50 km^2)	Rate in $T/km^2/yr$ (CA 151.50 km^2)
2002	Dead	72.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010			**6.158**	**9**	**0.684**	**.000318**	**382**	**0.00452**	**5420**
2002	Live	58.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010			**5.007**	**9**	**0.556**	**.000259**	**311**	**0.00367**	**4406**
2002	**Gross**	130.879	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010			**11.165**	**9**	**1.24**	**.000576**	**693**	**0.00818**	**9862**

5.7 Discussions

It is seen from above table that the rate of sedimentation in all the three storage zones shows extremely higher results considering free catchment only and very low values if whole catchment is considered. The catchment of Sharavathy reservoir receives its discharges from surplus water of Linganmmakki dam continuously as seen from perennial Jog falls and also from its free catchment. Therefore it has impact of both the catchments. But at the same time most of the water from Linganmakki dam is circulated from Power Houses and discharges silt free water in Sharvathy reservoir. Therefore to arrive at the realistic figure of Sedimentation rate a percent weightage may be given to the larger catchment as well as free catchment which contribute sediment to Sharavathy reservoir. The study of daily discharges from Linganmakki dam suggests a contribution of 40% of whole catchment to be adopted for assessment of sedimentation rate which reveals that 60% weightage could be given to the values obtained by considering free catchment. Table X below gives the value of .00367 $Mm^3/km^2/yr$. These values are more close to standard sedimentation rate and hence may be recommended. The corresponding sedimentation rate for Dead and Live storage zone is given in Table X.

Table X Rate of Sedimentation in Sharavathy Reservoir

considering different combinations of sediment contribution from catchments

Sl. No.	% of Total Catchment	Rate of Sedimentation $Mm^3/km^2/yr$	% of free Catchment	Rate of Sedimentation $Mm^3/km^2/yr$	Rate of Sedimentation $Mm^3/km^2/yr$	% of Total Catchment	Rate of Sedimentation $T/km^2/yr$	% of free Catchment	Rate of Sedimentation $T/km^2/yr$	Rate of Sedimentation $T/km^2/yr$
1	0.00	0.000259	1.00	0.00367	0.00367	0.00	311	1.00	4406	4406
2	0.05	0.000259	0.95	0.00367	0.00350	0.05	311	0.95	4406	4201
3	0.10	0.000259	0.90	0.00367	0.00333	0.10	311	0.90	4406	3997
4	0.30	0.000259	0.85	0.00367	0.00320	0.30	311	0.85	4406	3838
5	0.20	0.000259	0.80	0.00367	0.00299	0.20	311	0.80	4406	3587
6	0.25	0.000259	0.75	0.00367	0.00282	0.25	311	0.75	4406	3382
7	0.30	0.000259	0.70	0.00367	0.00265	0.30	311	0.70	4406	3178
8	0.35	0.000259	0.65	0.00367	0.00248	0.35	311	0.65	4406	2973
9	0.40	0.000259	0.60	0.00367	0.00231	0.40	311	0.60	4406	2768
10	0.45	0.000259	0.55	0.00367	0.00214	0.45	311	0.55	4406	2563
11	0.50	0.000259	0.50	0.00367	0.00196	0.50	311	0.50	4406	2359
12	0.55	0.000259	0.45	0.00367	0.00179	0.55	311	0.45	4406	2154
13	0.60	0.000259	0.40	0.00367	0.00162	0.60	311	0.40	4406	1949
14	0.65	0.000259	0.35	0.00367	0.00145	0.65	311	0.35	4406	1744
15	0.70	0.000259	0.30	0.00367	0.00128	0.70	311	0.30	4406	1540
16	0.75	0.000259	0.30	0.00367	0.00130	0.75	311	0.30	4406	1555
17	0.80	0.000259	0.25	0.00367	0.00112	0.80	311	0.25	4406	1350
18	0.85	0.000259	0.20	0.00367	0.00095	0.85	311	0.20	4406	1146
19	0.90	0.000259	0.10	0.00367	0.00060	0.90	311	0.10	4406	721
20	0.95	0.000259	0.05	0.00367	0.00043	0.95	311	0.05	4406	516
21	1.00	0.000259	0.00	0.00367	0.00026	1.00	311	0.00	4406	311

Rate of Sedimentatin in Sharavathy Reservoir										
considering 40% of total catchment and 60% contribution from free catchment										
Dead	0.40	0.000318	0.60	0.00452	0.00284	0.40	382	0.60	5420	3405
Live	0.40	0.000259	0.60	0.00367	0.00231	0.40	311	0.60	4406	2768
Gross	0.40	0.000576	0.60	0.00818	0.00514	0.40	693	0.60	9862	6194

Further, Satellite Remote Sensing survey could be done for the available imageries of Live storage zone only which covers only 45 % part of Gross storage while 55% part remained unassessed. Thus giving sedimentation rate for whole storage on the basis of analysis of 45 % volume will not be appropriate, Therefore it is recommended to carry out Hydrographic survey for dead storage zone and SRS survey for Live storage zone so as to give more accurate sedimentation depositing volume and rate with integrated system

Chapter 6

Conclusion

6.1 General

The Satellite Remote Sensing (SRS) method of assessment of reservoir uses the fact, that the water spread area of reservoir at various elevations keeps on decreasing due to sedimentation. The water spread areas of the Sharavathy reservoir at different levels between FRL and MDDL in different month of the year are computed from .satellite imageries. Knowing the reservoir levels(as ground truth) at the time of imageries new elevation capacity curve was established and compared with that at the time of dam construction in 2002. Shift in the capacity curve indicated extent of loss in reservoir capacity. Following are the conclusions drawn from the study.

6.2 Conclusion and recommendation

i. The gross, dead and live storage capacities of Sharvathy reservoir for the year 2002 were 130.879 Mm^3, 72.19 Mm^3 and 58.689 Mm^3 respectively.

ii. The loss in live storage capacity since 2002 to recent remote sensing survey in 2010 was 5.007 Mm^3 which was 8.53% of original live storage capacity.

iii. The original live storage capacity of 58.689 Mm^3 reduced to 53.682 Mm^3 i.e. by 8.53% in 9 years. Thus, the average annual rate of loss of live storage capacity was 0.95%.

iv. The sediment index computed considering sediment deposition in Live storage zone since 2002 upto 2010 (9 years) was about .000259 Mm^3/km^2/year which was equivalent to 311 T/ km^2/year with respect to total catchment of 2148 km^2.

v. The sediment index computed considering sediment deposition in live storage zone since 2002 upto 2010 (9 years) was about 0.00367 Mm^3/km^2/year which was equivalent to 4406 T/ km^2/year with respect to free catchment of 151.50 km^2.

vi. Considering 40% contribution of total catchment to be adopted for assessment of sedimentation rate which reveals that 60% weightage could be given to the values obtained by considering free catchment., suggests the rate of 0.00231 Mm^3/km^2/yr . These values are more close to standard sedimentation rate and hence recommended for future allocations from reservoir.

vii. The rate of sedimentation discussed above is only for live storage zone which is 8.53 % in 9 years . If same pattern is assumed for dead storage zone of 72.19 Mm^3 the total loss in 9 years will be 6.16 Mm^3 . Thus the total loss in gross storage zone may be roughly estimated as 11.165 Mm^3.

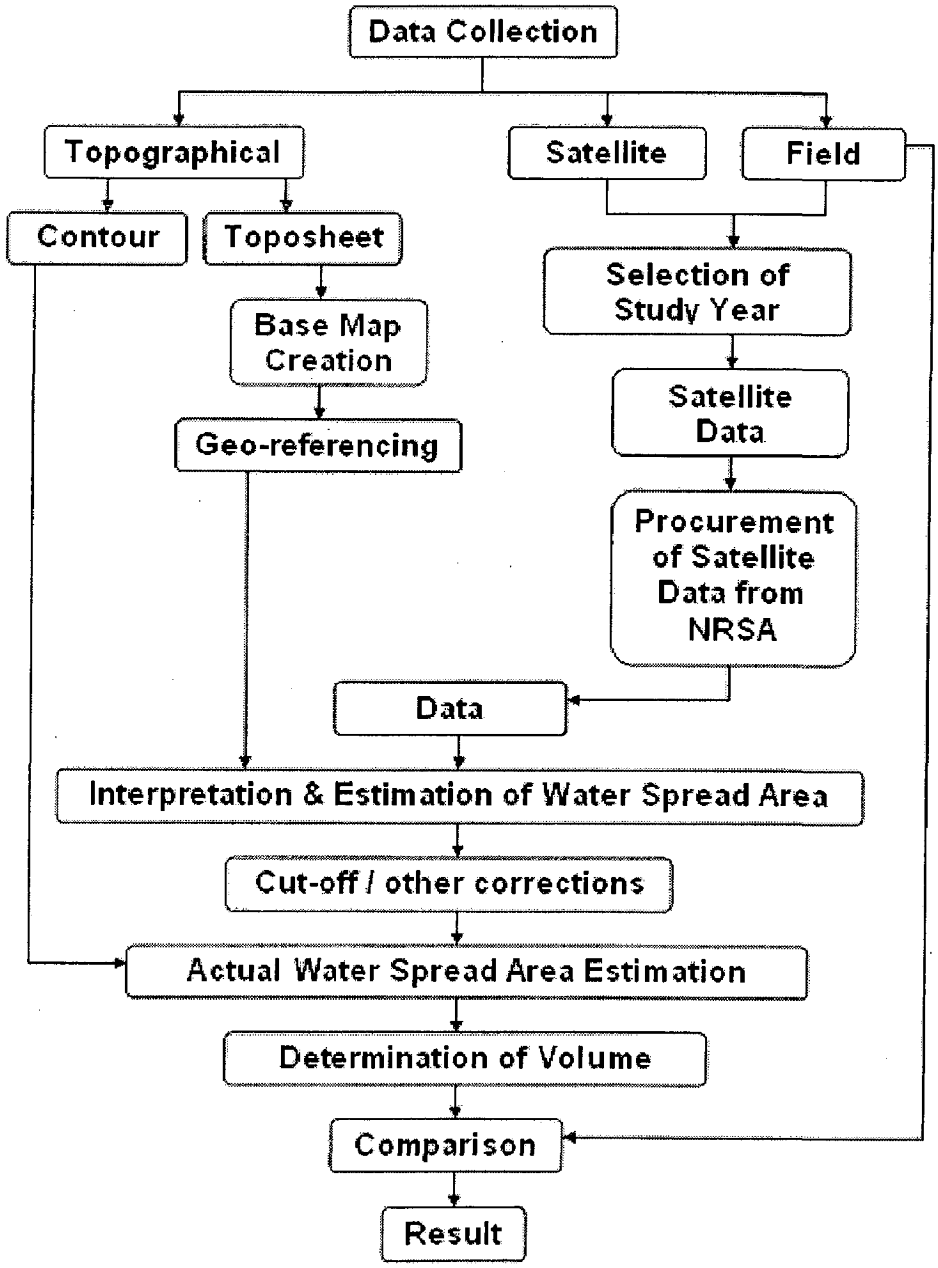
viii. Sedimentation index computed based on above assumption gives very high results. Hence taking 40% weightage to Total area and 60% weightage to free catchment the rate of sedimentation in Gross storage may be roughly 0.00514 $Mm^3/km^2/yr$ which is equivalent to 6194 $T/km^2/yr$ and seems to be realistic.

ix. Satellite Remote Sensing survey could be done for the available imageries of Live storage zone only which covers only 45 % part of Gross storage while 55% part remained unassessed. Thus giving sedimentation rate for whole storage on the basis of analysis of 45 % volume will not be appropriate,

Therefore it is recommended to carry out Hydrographic survey for dead storage zone and SRS survey for Live storage zone so as to give more accurate sedimentation deposition volume and rate with integrated system

ANNEXURE I

METHODOLOGY OF RESERVOIR SEDIMENTATION ANALYSIS

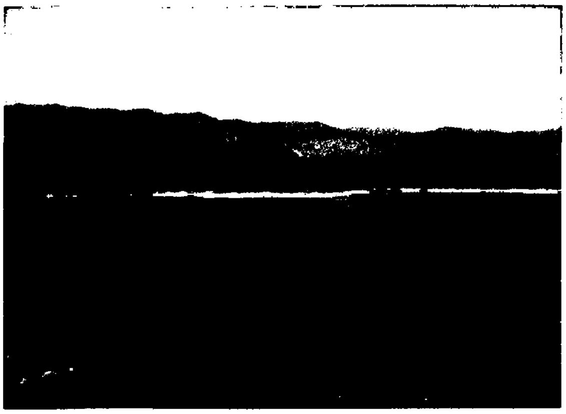


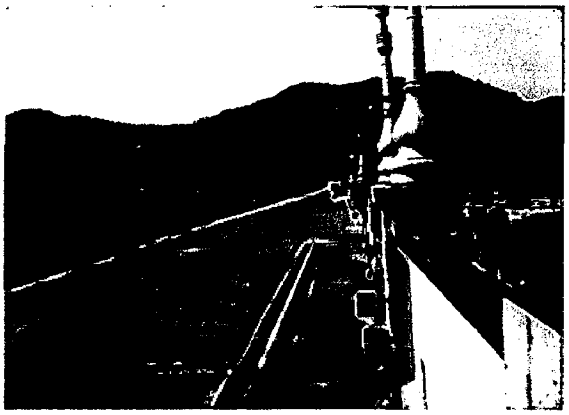
ANNEXURE II
SALIENT FEATURES OF SHARAVATHY RESERVOIR

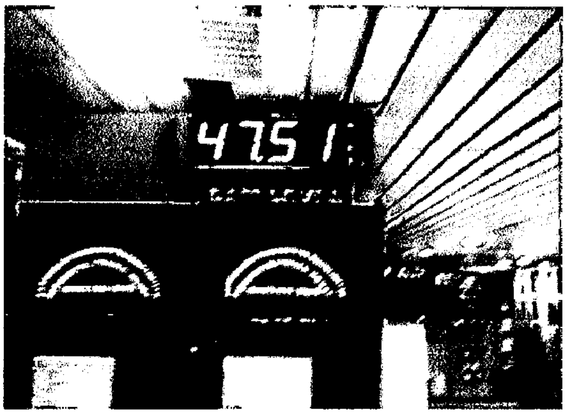
Sr.No.	Particulars		Description
1	**Project Details**	:	
a.	Name of Project		Sharavathy dam
b.	Name of Reservoir		Sharavathy
c.	Year of Completion		2002
d.	Project Authority		KPCL, Gerusoppa HEP
e	River		Sharavathy
2	**Location**	:	
a.	Village		Gerusoppa
b.	Taluka		Honnavar
c.	District		Shimoga
d.	State		Karnataka
e.	Lat & Longi		14^0-14'-30" N & 74^0-37'-15"E
f.	Toposheet No.		48-J/11, 48-J/12
g	Nearest City		Sagar
h.	Catchments area(independebt)		151.50 sq. km.
3	**Purpose**	:	
a.	Electric gerneration		240 MW
4	**Annual Yield from**	:	
a	Free catchments		524 M cum
b	Total		5660 M cum
5	**Reservoir**	:	
a.	Gross storage		130.59 Mm^3
b.	Dead Storage		72.19 Mm^3
c.	Live Storage		58.40 Mm^3
6	**Controlling Levels**		
a.	River bed level		5 m
b.	MDDL		43.5 m
c.	FRL		55.0 m
d.	MWL		55.40 m
7	**Submergence**	:	

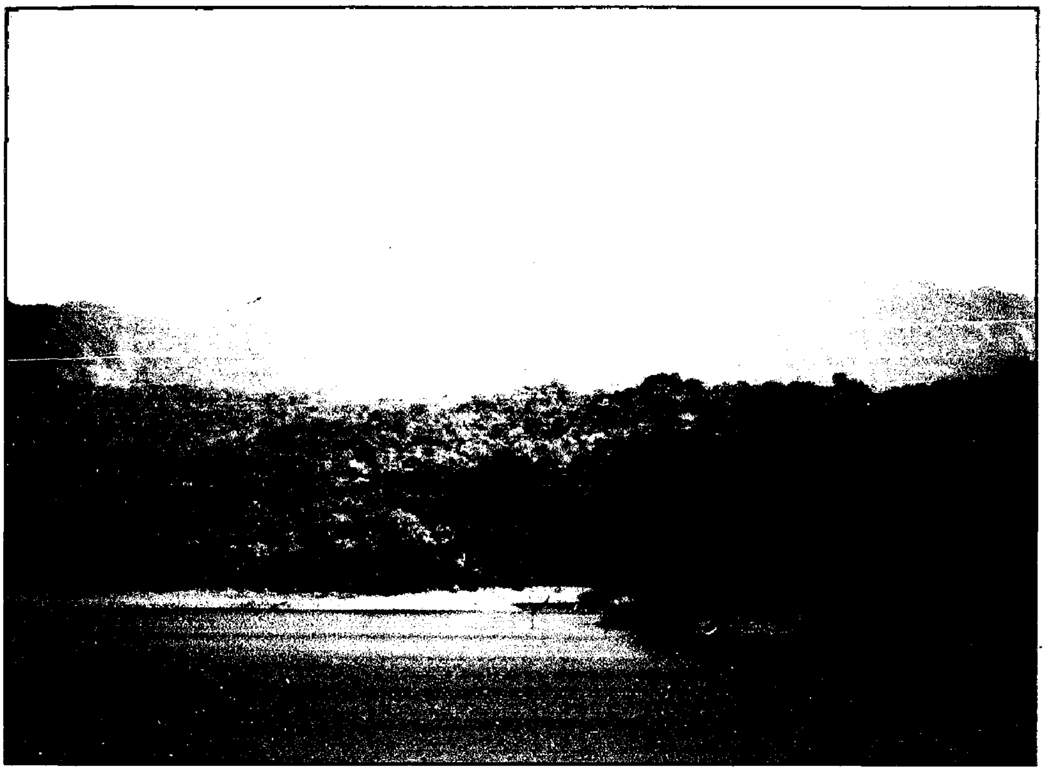
a.	Waterspread Area		6 sq km
8	**Dam**	:	
a.	Type		GravityDam
b.	Length		421 m
c.	Height		64 m
9	**Spillway**	:	
a.	Type		Ogee shaped (gated)
b.	Size & No. of gates		12m x 12m - 5 Nos
c.	Length		93 m
10	**Power House**	:	
a.	Location		Right bank near the toe of the dam
b.	Installed capacity		240 MW
c.	No. of units		4 nos. (60 MW each)
d	Penstock diameter		5.60 m
e	Net rated head		47.50
g	Design discharge		
i)	At rated head	:	155.40 cumecs
ii)	At Max. head	:	149.40 cumecs
g	Minimum reservoir level for operation		43.50 m
h	Type of turbine	:	Francis

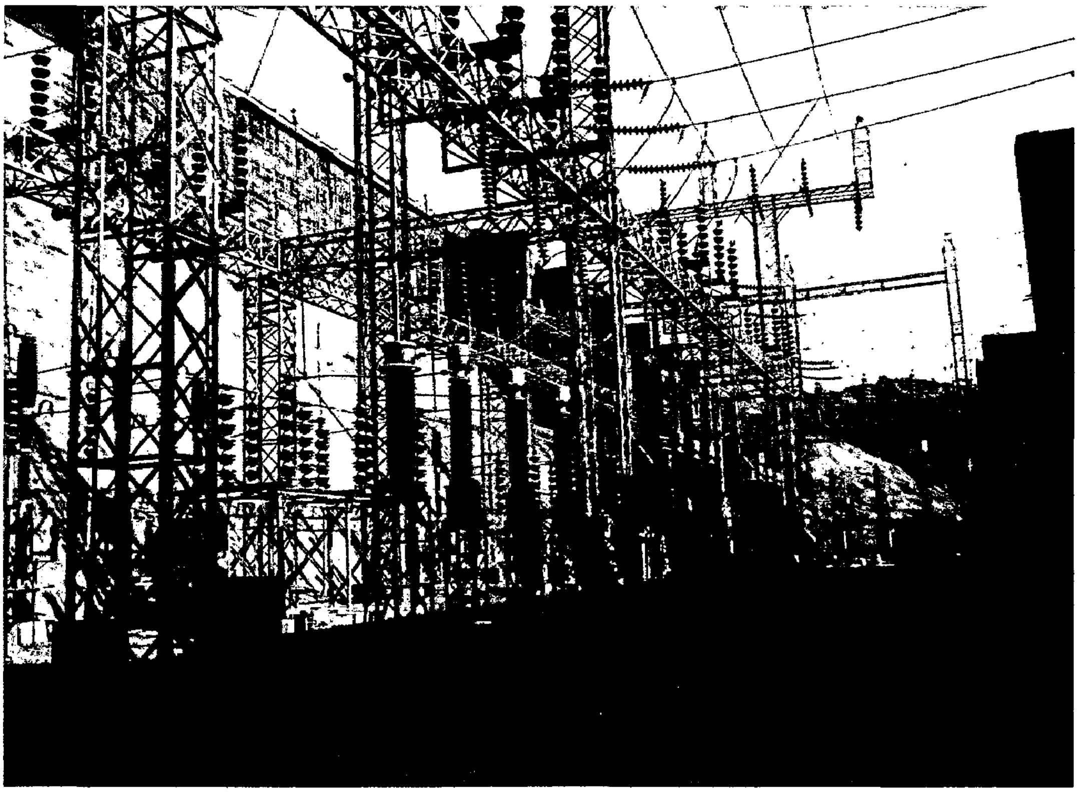
ANNEXURE III PHOTOGRAPHS











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