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SEDIMENTATION OF RESERVOIR USING REMOTE SENSING TECHNIQUES (TUNGABHADRA)

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PREFACE

Sedimentation in the reservoir is one of the principal factors which threaten the longevity of the reservoirs. High sediments load is indicative of land degradation upstream in the catchment. Information on distribution patterns of suspended load is prerequisite in determining reservoir life time and is critical for better reservoir management.

Remote sensing has now become an important tool in monitoring of sedimentation in reservoirs. Qualitative assessment of sediment distribution using synoptic view is possible using remote sensing data. In this study sedimentation rate in Tungabhadra reservoir has been quantified and turbidity level mapping has been carried out using multitemporal remotely sensed data. Digital analysis techniques have been carried out using the ILWIS (Integrated Land and Water Information System) system. Sediment distribution patterns have been presented and the resulting conclusions have been discussed. This study has been carried out by shri S.K.Jain and shri A.V.Shetty , Scientist 'B' and assisted by shri Tanvear Ahmad, S.R.A. under the guidance of shri K.S.Ramashatri, Scientist 'F'.

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ABSTRACT

Sedimentation of reservoirs is a natural phenomena. For the operation of any reservoir, it is required to find out the reservoir sedimentation rate going on in the reservoir. The reservoir surveys using conventional methods are time consuming and expensive. With the introduction of remote sensing techniques in the recent past , it has become very cheap and convenient to quantify sedimentation in a reservoir and to assess its distribution pattern.

For the evaluation of sedimentation rate, Tungabhadra reservoir in Krishna basin has been selected for the present study. This study has been carried out using IRS-1A LISS I images. Digital analysis have been performed to obtain the information on the location and extent of sediment distribution in water spread area of the reservoir. ILWIS system has been used for the purpose. Density slicing approach has been employed to obtain various turbidity levels.

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INTRODUCTION

During the last four decades India has constructed several major/medium river valley projects involving construction of dams and creation of reservoirs for flood controls, irrigation and hydropower. As the above storages are subjected to silting, sedimentation of reservoirs is infact a matter of vital concern to all water resources development projects. The surveys conducted in some of the reservoirs have indicated that siltation not only occurs in the dead storage but also enchroaches in the live storages zone which impairs the intended benefits from the reservoir. Sedimentation in many reservoirs is encroaching on the live storage resulting in continuous reduction in its capacity. The decrease in storage capacity impairs the functioning of the reservoir for which it has been designed.

This problem of sedimentation starts with the impounding of water in the reservoir. When the sediment laden flood water enters the reservoir the velocity of the inflowing currents is reduced. Consequently nearly all the coarser particles, including sand/gravel and boulders are deposited in or near the tail end of the impoundment. The silt and clay particles remain in suspension longer and are carried forward into the water body where deposition takes place.

The following factors are responsible for reservoir sedimentation (Rao et al,1990)

(i) Physical and hydrological characters of the catchment

(ii) Trap efficiency of reservoir ,method of reservoir operation.

(iii) Intensity of erosion in the catchment.

(iv) Landuse pattern in catchment.

(v) Quality ,quantity and concentration of the sediment brought down by the river.

(vi) Growth of vegetation at the head of the reservoir.

Presently the reservoir surveys have been carried out using conventional methods.Most common conventional techniques for sedimentation quantification are (1) direct measurement of sediment deposition by hydrographic surveys and (2) indirect measurement of sediment concentration by inflow - outflow method. Both these methods are laborious, time consuming and costly and have their own limitations.The successful management of large reservoirs is possible if cheap ,efficient and accurate means for determining the instantaneous suspended sediments in large water bodies are available.

Remote sensing methods can be effectively used to assess sedimentation in reservoirs. Remote sensing of reflected solar radiation can provide timely and repeated information concerning suspended sediment flow patterns in reservoirs. The sensors aboard various remote sensing missions provide data from various sensors operating in different regions of electromagentic spectrum (EMR). Remotely sensed data from satellites is based on interaction of EMR from sun with various surface features , which interact in different fashions with the incident EMR and hence give rise contrast in the remotely sensed data. The incident EMR on any terrain feature will underabsorption , reflection and transmission ,which will vary from one terrain feature to the other. Remote sensing sensors operating in visible region of EMR record the reflected component from the terrain feature and convert the reflected radiation to electrical signals. These analog signals are sampled on board the platform and are converted to digital numbers (DNs) which are transmitted to receiving station . These DNs have linear relationship with the reflected radiation.Suspended particles tend to increase the total scatter and backscatter and consequently change the spectral distribution of light and reduce the average path length in which suspended silt backscatter light depends on silt concentration (Moore,1978). Thus turbid water is more reflective than clear water and the remote signal from a turbid water represents only near surface conditions . The measured signal at any wavelengths depends on the particle size and concentration. Satellites provide landsurface imageries at regular intervals from which spread area of the reservoir can be identified. The synoptic view provided by remote sensing gives very different data from that which can be obtained with surface data collection and sampling.

2.0 REVIEW :

Moore (1980) suggested that remote sensing techniques can be used gainfully to obtain either qualitative or quantitative estimates of water turbidity. The relative turbidity appear on images can be summarised and is given in table 1 :

Table 1: Relative turbidity appear on imagery

Relative turbidity	Tone of image				Hue of color composite
	Bands				
	4	5	6	7	
None	Dark Medium	Dark	Black	Black	Black
slight	Medium	dark	Black	Black	Dark Blue
Moderate	light	medium	Dark	black	Medium blue
Heavy	light	light	Medium	dark	light blue
very heavy	light	light	light	medium	white

Nayak and Sahai (1981) prepared semi quantitative maps of different concentration levels in gulf of khambhat using density slicing technique.The seasonal variations in suspended sediments were studied. Sediments which were brought in suspension by strong monsoon currents started settling after the sediments.

Muralikrishan (1983) analyzed a Landsat scene around Gulf of Cambay. The Landsat MSS band4/band5 values were evaluated. This ratio has been taken as basis and corresponding sediments were evaluated by making use of the sea truth information. The scene was analyzed in an interactive computer and six level delineation represented by various colour shades was carried out The concentration of suspended matter in the surface water ranged from 0.5 to 3.5 mg/l.

Dubey and Bhatia (1985) attempted the multi variate analysis after evaluating geological, morphological, pediological and botanical parameters from remote sensing data. Study has been carried out for evaluating erosion rate using remote sensing data for proposed Tehri reservoir. The descriptive classifications were compiled and possible estimated sediment production was evaluated. High and low sediment production area have been identified.

Simoda et al. (1986) correlated various water quality parameters measured at ground with the machine processed landsat data characteristics for lake Balaton in Hungary. System correlated Landsat MSS image covering the study area acquired on 2nd July, 1981 was used. Fourteen items of water qualities were measured at thirty points.

Sahai et al (1987) investigated suspended sediment distribution pattern in the Ukai reservoir. They analysed suspended sediment distribution in the summer monsoon and post monsoon seasons. They concluded that sediment concentration is high along the fringe and the tail end.

Abiodum (1976) identified five distinct water masses in lake Kainji on the river Niger. Later work by Abiodum and Adeniji (1978) demonstrated how spectral classification of the lake water with sequential Landsat data could be used to chart the movement of different masses

Jonna et al (1985) carried out digital image processing of remote sensing data for water quality studies . Some of the image processing techniques such as image enhancement , band ratioing , principal component analysis and unsupervised classification have been applied on 'IMAVISION' system for analysing digital data of Jayakwadi reservoir.

Rao et.al (1990) predicted rate of sedimentation of Tungabhadra reservoir. In this study, Miraki's mathematical model was used. First the model was verified by comparing with the available data to do this sedimentation rate for thirteen years (1973-85), the computed rate was 7.862 ha-m/100 sq.km/year while observed rate was 7.148 ha-m/100 sq. km/year. After that average rate of sedimentation for 53 years (1986-2038) was predicted as 8.0741 ha-m/100 sq. km/ year or 22.75 Mcm/year i.e. reservoir losses its capacity by .6065 percent of its original capacity every year.

Manavalan et al (1991) carried out capacity evaluation of Ghataprabha reservoir using digital analysis of IRS LISS-II data. Reductions is six contour areas of the Ghataprabha reservoir between the RLS 835.24 m and 662.94 m were studied and the change in capacity of the reservoir storage between these levels was computed.

Schiebe et al (1992) used Landsat MSS satellite data and corresponding water quality measurements of suspended sediments concentration for lake chicok ,Asaknsas to evaluate several possible mode;s for the relation between these two data types. Satellite data were converted to physical values of radiance and reflectance using both the NASA standard curves and the spectrum recommended by the world radiation center.Results of the analyses

, which involved 310 observations suggest that a theoretically derived exponential curve best characterizes the relation between exo-atmospheric reflectance and suspended sediment concentration. Based on the strength of the model relations and the range of data tested , it is concluded that temporal and spatial variability in the concentration of suspended sediments within lake and reservoirs can be inventoried and monitored from space based sensor system .

Choubey et al (1992) used IRS -1A ,LISS I data in combination with field measurement for the estimation of suspended solids concentration in Tawa reservoir of the Narmada basin .The relation between LISS I digital data and measured values of suspended solids were quantified using simple linear regression equations. An optimum equation was chosen based on higher coefficient of determination ,lowest standard error and F value . The results indicates that in the concentration range 10-15 ppm ,functional relations exists between suspended solids concentration and visible wavelength band 1,2 and 3.

3.0 DESCRIPTION OF THE STUDY AREA:

For the present study Tungabhadra reservoir in Krishna basin has been selected. The dam has been constructed on river Tungabhadra, 69 kms upstream of Ballary city, in Karnataka state. The river Tungabhadra derives its name from two tributaries Tunga and Bhadra both of which take origin in Varahagiri in the western ghats. The two rivers confluence at a village called Kudali near Shimoga. Tungabhadra river flows for a distance of 768 kms before it joins the river Krishna at Sangameswaram in Kurnool district of Andhra Pradesh. The Tungabhadra reservoir is quite wide with as much as 15.3 kms very near the dam and has a stretch of 85.34 kms. It is multipurpose reservoir ,water being used for hydroelectric power and irrigation in Karnataka and Andhra Pradesh states. The Tungabhadra project was completed in 1953. The total catchment of the Tungabhadra river upto confluence with Krishna river is 69,557 sq.km. and at the dam site is 28180 sq. kms. and the annual rainfall varied from 70 cm to 750 cms. The storage capacity of the reservoir is 3751 m. cu. m. The location of the Tungabhadra project is shown in Fig. 1.

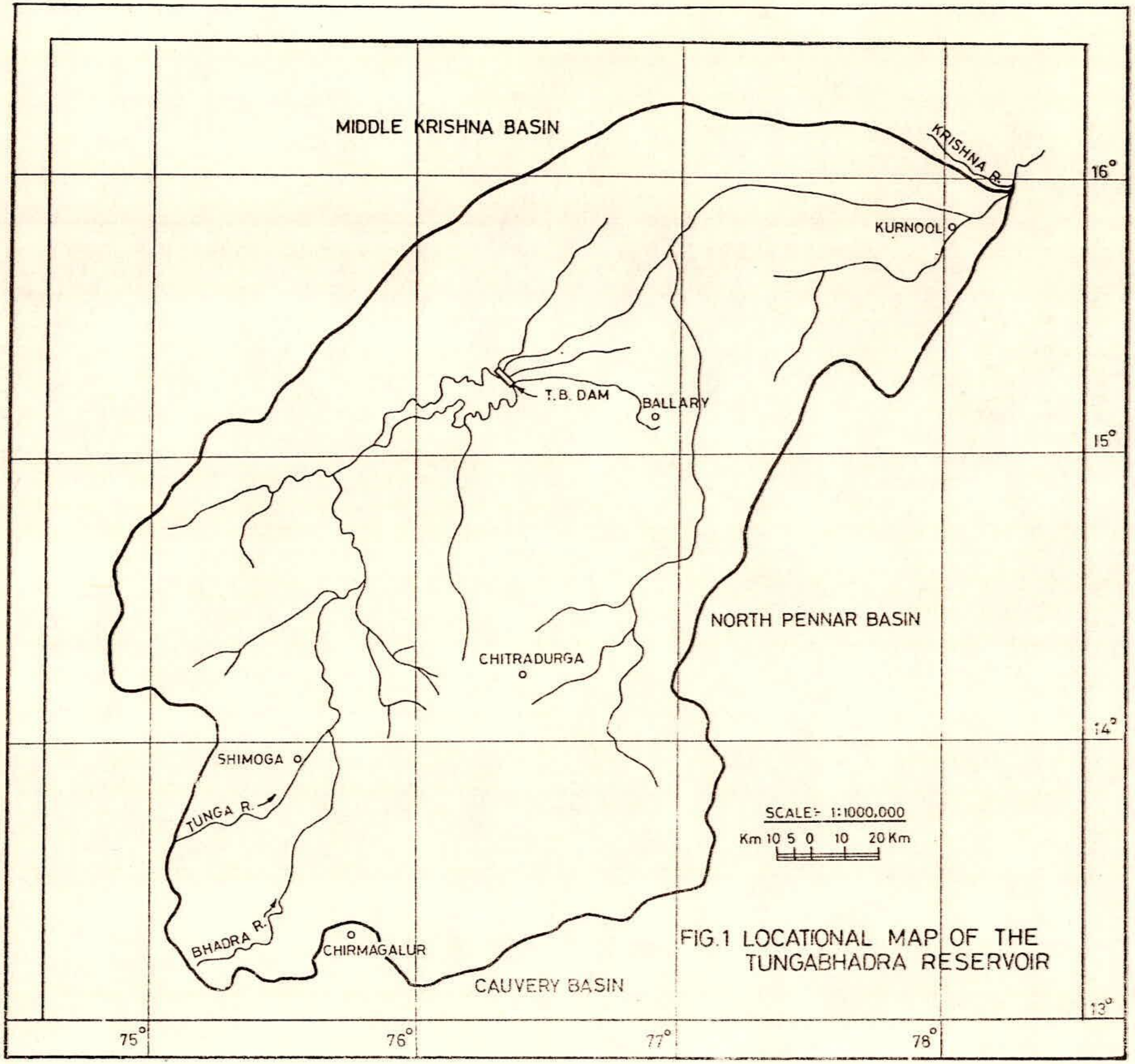


FIG.1 LOCATIONAL MAP OF THE TUNGABHADRA RESERVOIR

4.0 DATA AVAILABILITY :

Multitemporal data of IRS-1, LISS-I sensor has been used in the study. The IRS - A satellite path/Row number of the area is 27-58. Different dates are given the table - 2 below.

TABLE 2: Data availability

Path/Row	Satellite/Sensor	Date	Type of data
27-58	IRS-1/LISSI	11.10.88	CCT
		20.10.89	
		16.03.92	
		27.12.92	

5.0 METHODOLOGY :

Concentration of suspended sediment is an important parameter for monitoring sedimentation in the reservoir. Digital image processing techniques have been used to obtain the information on the location and extent of sediment distribution pattern in the water spread area of the reservoir. Seasonal fluctuation on the water spread area have been monitored and corresponding fluctuations in the volume of water and changes in the sediment distribution have been measured. The rate of reservoir sedimentation can be found out by dividing the total sediment volume with the time of deposition of sediments. Turbidity mapping of the reservoir has also been performed. Only synoptic view of the distribution of various sediments levels is possible. Quantitative assessment could have been possible had there been the ground truth data with regard to sediment concentration in the reservoir at different location and at different depths on the data when the satellite passed over the reservoir.

In this study ILWIS (Integrated Land and Water Information System) system has been used for carrying out analysis. This system has been developed by the international Institute of Aero Space Survey and Earth Sciences (ITC). The main characteristics of the system are:

- PC based system
- a tabular, vector and raster data base integrated in one system
- remote sensing capabilities, fully integrated into the GIS and full data format compatibility.

Remote sensing data can be entered into the raster data base from either computer compatible tapes (CCT) or high density floppy disks. Complex modelling procedures can be easily executed through the MAPCALCULATOR, which integrates tabular databases with spatial databases; it includes an easy to use modelling language and the possibilities of using functions and macros. Tabular and spatial databases can be used both independently and on an integrated basis. A versatile program TABLECALCULATOR, provides direct communication between the ILWIS kernel and outside models, statistical packages, raw data files, databases and other systems. Image processing capabilities integrated with cartographic modellling and relational databases constitute a powerful tool that allows the analysis of data. ILWIS incorporates conventional image processing capabilities. Pre processing and processing of data are possible. Data processing includes several basic image analysis capabilities, such as histogram manipulation, automatic stretch display, user defined filters, transfer function manipulations and other standard functions. The system provides black and white or color hard-copy output products in either vector or raster format. It supports standard peripherals such as EPSON, IBM, Tektronix and HP printers and plotters.

6.0 INTERPRETATION AND ANALYSIS :

Digital analysis has been performed for calculating the waterspread area and mapping various turbidity levels.The basic data extracted from the satellite data were the waterspread areas at different elevations levels. At greater wavelengths, water apparently acts as a black body absorber and reflected solar energy is very low. In the band 4 (0.77um-0.86um), the spectrum of reflection of water approaches the status of being completely absorbed and the boundary between water and the other surface features is very clear. Thus band 4 was used in the waterspread area calculation for different dates data. For differentiating water pixels from the adjacent wet land pixels, comparative analysis of digital numbers in different bands, was carried out. The behaviour of the reflectance curves of water and soil or vegetation is different from the second band onwards. Beyond band 2, with increase in wavelength water reflectance curves show downward trend while soil or vegetation reflectance curves show upward trend. While differentiating water pixels from the peripheral wet land pixels, the above principle was used.

The reservoir spread area is isolated by density slicing of band 4 data because in band 4 maximum absorption is there. Using classify table in TABCALC module, two classes were made for band 4 data. The classes made were 0-20 value 1 and class 21-255 value 0. Now with the help of MAPCALC module the band 4 map was classified using the above table and water spread area was isolated. The water pixels were then calculated using Histogram module. Statistics of the above output was done and number of water pixels obtained. These pixels were then multiplied by their area (pixel size 72.5m for LISS-I data) for determining water spread area. Thus we got water spread area or in other words the contour area at that particular waterlevel or elevation. The water spread area of different dates are shown in Fig. 2. Table 3 provides the number of water pixels and area for different dates.

TABLE 3 : Water spread area for different dates

S.No.	Date	No. of water of pixels	Area (km)
1.	11.10.88	57406	301.74
2.	20.20.89	57263	300.98
3.	16.03.92	15681	82.42
4.	27.12.92	63434	333.42

Presence of sediments in water changes the backscattering characteristics of the water. Suspended particles tend to increase the total scatter and backscatter, reduce the average path length and consequently change the spectral distribution of light. Thus, a turbid water is more reflective than clear water. The measured signal at any wavelength depends on the particle size and concentration. Band 1 (0.45um-0.52um) and band 2 of IRS LISS-II sensor gives maximum information about the suspended sediments in water. Band 3 and 4, because of their limited penetration capacity does not show clear pattern of suspended sediments.

For identifying turbidity levels, reflectance values within the water areas have been observed in band 1 and various levels have been identified. Density slicing technique is used to delineate the sediment concentration levels as sub classes within reservoir spread area. A maximum of five levels of

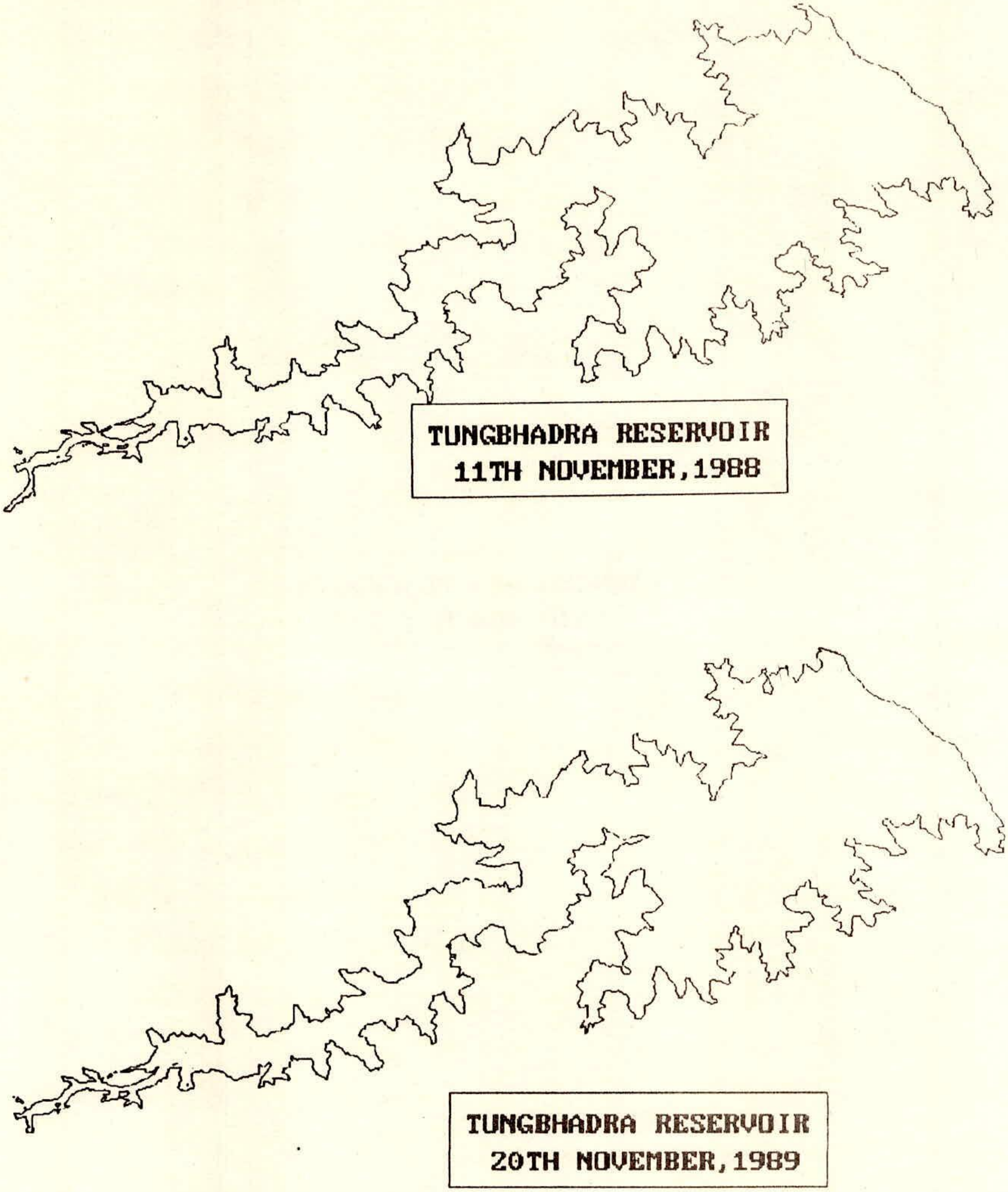
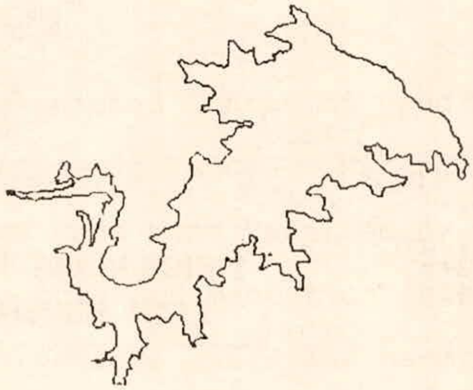
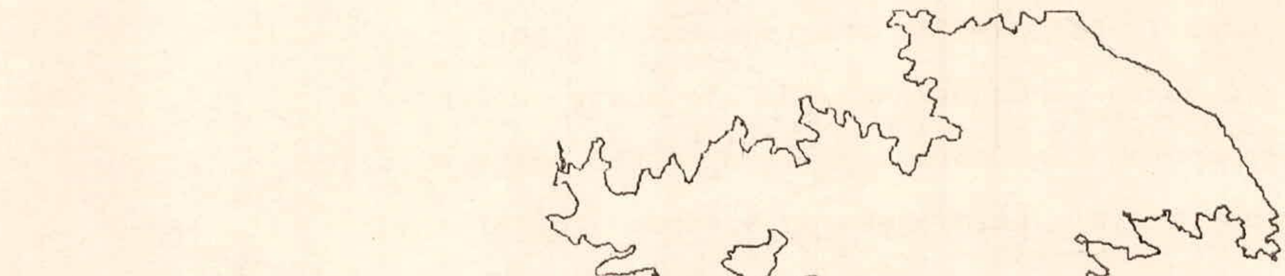


Fig. 2 WATERSPREAD AREA OF TUNGABHADRA RESERVOIR PREPARED FROM MULTI DATE IMAGERY



TUNGBHADRA RESERVOIR
16TH MARCH , 1992



TUNGBHADRA RESERVOIR
27TH DECEMBER,1992

FIG. 2 (CONTD.)

concentrations could be tried with significant variation, with two to three grey levels for each subclass. The analysis using ILWIS system is described below:

First of all using the band 4 data and MAPCALC module, the reservoir area was isolated for band 1. For this following formula was applied.

Output Map b1 (say) := If (Map (Band 4) = 1, Map (Band 1),0); -------> (1)

After that range of pixels for different dates have been identified using PIXEL INFO module. Then the entire range is classified in 4 to 5 classes using Tabcalc module. The classes for different dates have been given in table No. 4 :-

TABLE 4 : Range of pixel of different turbidity levels (class)

S.No.	Date	Range of pixels	Class
1.	11.10.88	38-41	1
		42-44	2
		45-47	3
		48-50	4
		51-54	5
2.	20.10.89	35-36	1
		37-38	2
		39-40	3
		41-44	4
3.	16.03.92	49-50	1
		51-52	2
		53-54	3
		55-57	4
4.	27.12.92	33-35	1
		36-38	2
		39-41	3
		42-44	4
		45-47	5

After preparing the classification table for each data, the band 1 map was classified using the following relationship in

Mapcalc module and using b1 map as obtained from equation no. 1.

Final output Map := Clfy (b1, Classification table);
--------- (2)

In this way four or five classes have been identified for each date. The number of pixels for each class were computed using Histogram module. Different colours have been assigned to these ranges so that synoptic view of various turbidity levels in the reservoir can be made. For different dates numbers of pixels, corresponding area in sq.km. (after multiplying by pixel area) have been shown in table 5 :-

In all five concentration levels were identified viz., very high, high, moderate, slight to moderate and slight. Finally before taking output of the classified data, annotation was done using Annotation module.

TABLE 5 : Class with area for different dates

S.No.	Date	class	Number of Pixels	Area
1.	11.10.88	1	6082	31.87
		2	7865	41.34
		3	3827	20.11
		4	13362	70.23
		5	26270	138.08
2.	20.10.89	1	3749	19.71
		2	17237	90.61
		3	19272	101.29
		4	17005	89.38
3.	16.03.92	1	753	3.95
		2	2829	14.87
		3	5819	30.58
		4	6289	33.05
4.	27.12.92	1	10669	56.07
		2	8300	43.63
		3	3073	16.15
		4	13539	71.16
		5	27856	146.41

7.0 RESULTS AND DISCUSSIONS :

Fig. 3. shows the suspended sediments distribution pattern for different dates . Irrespective of the season sedimentation concentration is generally high along the fringe and at the tail end. The area near the dam, which is deeper remains relatively free from the suspended sediments. The central part of the reservoir , right from the dam to the tail end generally has medium level of sediment concentration.

The post monsoon data i.e. November and December scenes shows very high concentration along the fringe and at the tail end. At the extreme tail end the sedimentation level is less than at the just above the tail end. This is because at the extreme tail end some portion of the river course is included. At the tail end sedimentation is high because of the arrival of the new sediments brought by the flood water through the main channel. In all five concentration levels were identified viz. very high, high, moderate, slight to moderate and slight.

In premonsoon period i.e. in the month of March only four concentration levels namely moderate to high, moderate, slight to moderate and slight are present. The silting rates of the sediments in the water i.e. settling velocity is dependent on the viscosity of the reservoir water. During summer month , as the temperature rises, the viscosity reduces and consequently more amount of suspended sediments settles in the month of March. The reservoir was completed in 1953 and after that in 1963, 1972 and 1981 and 1985 hydrographic surveys were made. The data for above two levels for 1953,1963 and 1972 have been taken from technical report no. 20 of Central Board of Irrigation and Power ,Jan.,1981 and for 1981 and 1985 the data has been collected from

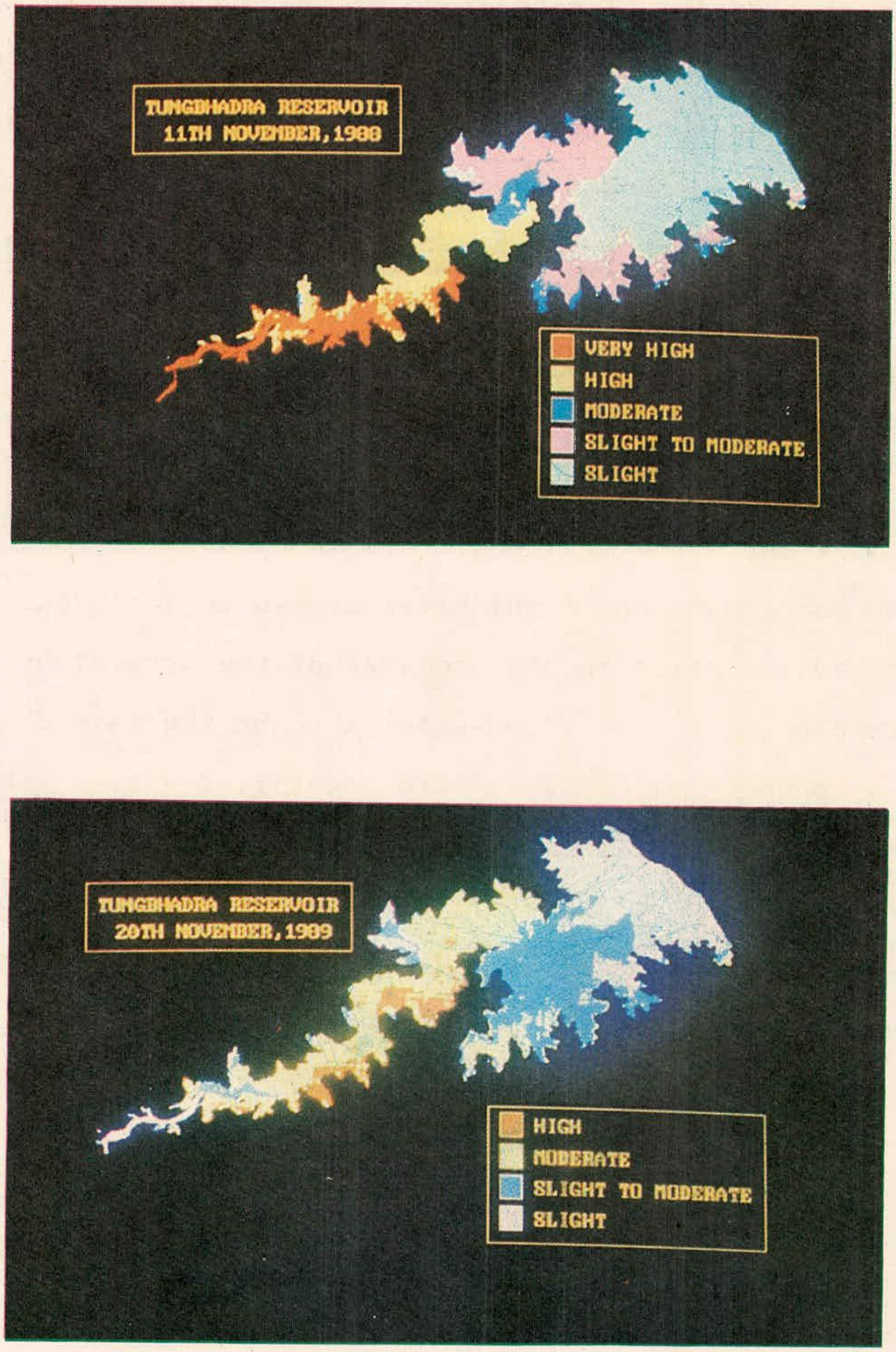
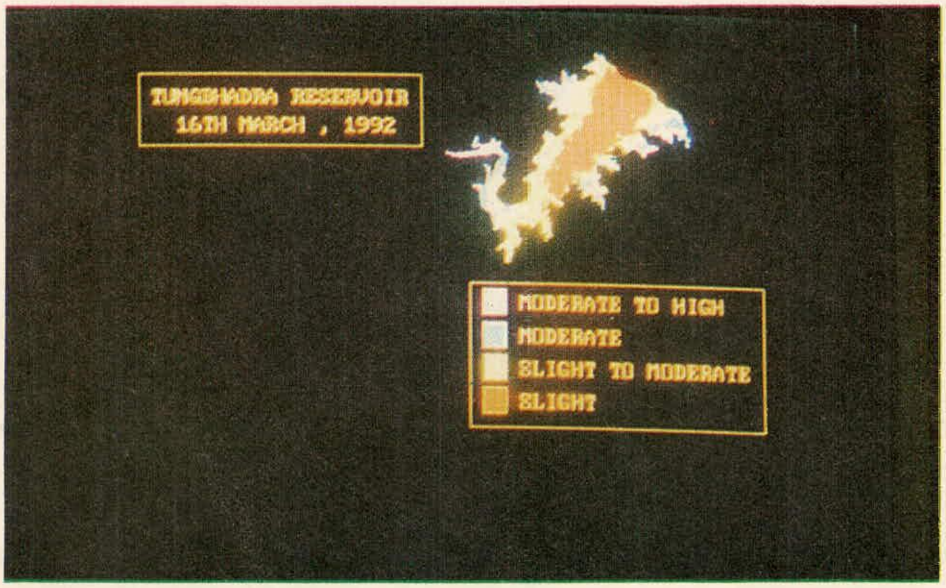


Fig. 3 SEDIMENT DISTRIBUTION PATTERN IN TUNGABHADRA RESERVOIR.


TUNGBHADRA RESERVOIR
16TH MARCH , 1992
MODERATE TO HIGH
MODERATE
SLIGHT TO MODERATE
SLIGHT

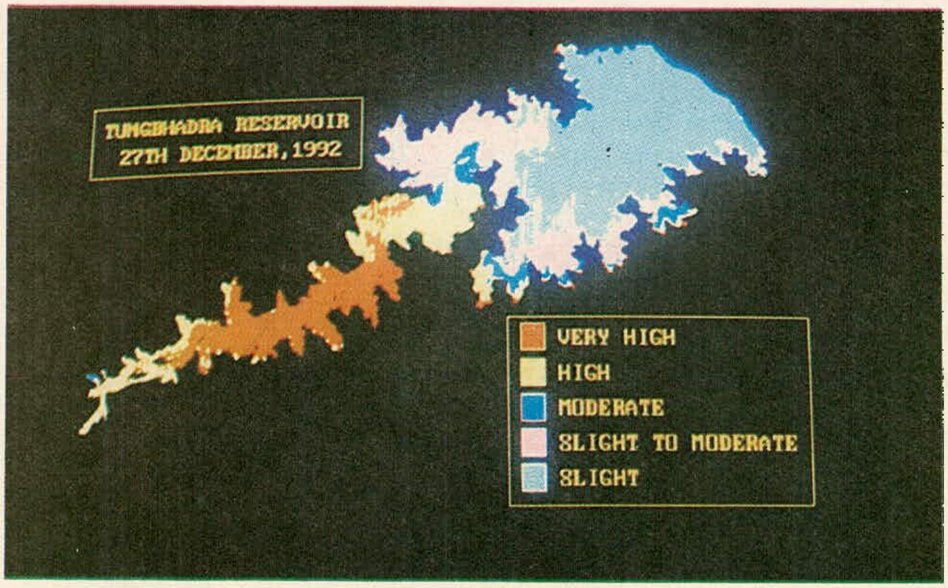

TUNGBHADRA RESERVOIR
27TH DECEMBER, 1992
VERY HIGH
HIGH
MODERATE
SLIGHT TO MODERATE
SLIGHT

Fig. 3 (CONTD.)

Project Authority. As per the data given by Project authority the water level on 16.3.92 and 27.12.92 were 486.36 m and 497.13 m above msl respectively. These data are given below:

Elevation	Capacity(mcm)				
(m)	1953	1963	1972	1981	1985
486.36	870.21	524.86	572.77	524.83	-
497.13	3483.79	2994.8	3173.64	3032.14	-
497.74	3751.79	3246.79	3435.00	3275.68	3166.74

For December 1992 i.e. at an elevation of 497.13 m the capacity was calculated using the waterspread area as computed from satellite data and the following Prisomidal formula :

$$V = \frac{H (A_1 + A_2 + A_1 * A_2)}{3} \qquad ----(3)$$

where,

V = Volume between two consecutive levels

A_1 = Water surface area at elevation 1

A_2 = Water surface area at elevation 2

H = Difference in elevation 1 and elevation 2

The capacity in Dec. 1992 with respect to 1953,1963,1972 and 1981 comes out to be as given in table below:

Capacity (mcm) in 1992 w.r.t			
1953	1963	1972	1981
2958.2	2612.85	2660.70	2612.82

From the above table the sedimentation rate for 1953-92,63-92,72-92 and 81-92 comes to be 13.47 ,13.17 ,25.14 and 38.12 mcm per year respectively.

As per the CBIP report the sedimentation rate for 1953-63 comes to 50.46 mcm per year and for 1953-72 comes to 16.99 mcm per year. It means that sedimentation rate as arrived from the survey of 1963 is nearly three times computed to that of the rate arrived from the survey of 1972. This spectacular decrease can not be attributed to any change in the catchment in the characteristics of the catchment in the short period of nine years from 1963 to 1972. In CBIP report some of the aspects which might have caused discrepancies in the conduct of 1963 survey were described. As per the observed data of 1981 rate for 1972-81 comes to be 15.72 mcm per year and for 1981-85 comes to 27.24 mcm per year. According to Rao et al (1990) the sedimentation rate is 0.5 to 1.2 % on the total capacity i.e approx. 18 to 45 mcm per year. The rate as computed using satellite data is well within this limit.

8.0 CONCLUDING REMARKS:

Multitemporal and multiband satellite data are extremely useful in determining sedimentation rate in a reservoir and mapping different concentration levels of sediment load. Advantages of using remote sensing data is that it is highly cost effective, very easy to use and takes very little time in analysis as compared to conventional methods. Spatial, spectral and temporal attributes of remote sensing provide invaluable synoptic and timely information regarding the waterspread and sediment distribution pattern in the water body. Qualitative analysis of the satellite data help in the selection of sampling points for quantitative estimation of the sediment in the reservoir. After a relationship between the reflectance and the sediment concentration is established , high resolution satellites can be more useful for the quantitative assessment of suspended load.

On the basis of this study ,it is concluded that the sediment concentration is very high at the tail end of reservoir, moderate to high at fringes and low at the dam site. Total capacity was computed with the help of satellite data and sedimentation rate has been measured in Dec.,92. The sedimentation rate comes to be slightly more than the rate computed by observed data of the last hydrographic surveys. Inspite of some advantages of remotely sensed data there are some limitations also, Remote Sensing is pretty much limited to sensing of turbidity and sediment level at surface etc. Remote Sensing can only measure reflected or emitted energy from the surface or near surface. Also turbidity is not a uniform parameter, either spatially or temporally. It will change with changes in inflowing discharge and with internal currents, thermal layering and the life cycles in the water. Remote Sensing provides an excellent method for tracking their spatial and temporal changes.

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