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Assessment of sedimentation in Ramganga, Rihand, Tungabhadra, Barna and Somasila reservoirs using digital image processing

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PREFACE

Efficient reservoir management calls for periodic assessment of its capacity. Capacity surveys of reservoirs are important to study patterns and rate of sedimentation for defining appropriate measures for controlling sediment inflow, for managing the available storage in reservoir and for optimum reservoir operation schedule based on realistic assessment of available storage. Data from space platforms can play a significant role in reservoir capacity surveys. In the recent past, satellite remote sensing has emerged as an important tool in carrying out reservoir capacity surveys rapidly, frequently and economically. Multi temporal satellite data provide information on elevation contour areas directly in the form of water spread areas. Any reduction in the water spread area at a specified elevation over a time period is indicative of sediment deposition at this level. When integrated over a range of water stages, it enables computing volume of storage lost due to sedimentation.

Sedimentation rates in five reservoirs, namely Ramganga, Rihand, Tungabhadra, Barna and Somasila reservoirs have been quantified using remote sensing techniques. The scientist and scientific staff of the Institute as given below carried out the study of these reservoirs:

Ramganga reservoir	Dr. S. K. Jain, Sc.'E1' and Mrs. Anju Chaudhry, SRA
Rihand reservoir	Dr. M. K.Goel, Sc.'E1' and Mr. P. K. Agarwal, P.R.A.
Tungabhadra reservoir	Mr. Dilip Durbude, Sc.'B'and Dr. B. Purendara, Sc.'C'
Barna reservoir	Mr. T. R. Nayak, Sc.'C' and Mr. Rahul K. Jaiswal, P.R.A.
Somasila	Mr. V.S.Jeyakanthan, Sc.'C', and Mr. U. V. N.Rao, S.R.A.

The present report describes the results for these reservoirs. The study and report was completed under the supervision of Dr. S. K. Jain, Scientist 'F' and Head Water Resources Systems Division.

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Director

ABSTRACT

Sedimentation in the reservoirs is one of the principal factors, which threaten their longevity. Sedimentation reduces the storage capacity of reservoirs and hence their ability to conserve water for various intended purposes. It is essential to periodically conduct sedimentation surveys to determine the useful life of a reservoir and to assess the sedimentation rate in a reservoir. With the correct knowledge of the sedimentation process going on in a reservoir, remedial measures can be undertaken well in advance and reservoir operation schedules can be planned for optimum utilization of water.

The conventional techniques of sediment quantification in a reservoir, like the hydrographic surveys and inflow-outflow methods, are cumbersome, costly and time consuming. With the advent of remote sensing techniques, it is possible to obtain synoptic, repetitive and timely information regarding the water spread conditions in a reservoir. Due to the deposition of sediments in the reservoir, the water-spread area at an elevation keeps on decreasing. By comparing the decrease in the water-spread area with time, the sediment distribution and deposition pattern in a reservoir can be determined indirectly. This information can be used to quantify the rate of reservoir sedimentation.

Five reservoirs, namely, Ramganga, Rihand, Tungabhadra, Barna and Somasila were selected in the present study for evaluation of sedimentation rate. The results for these reservoirs are summarized in the following table:

Reservoir	Zone of assessment	Period of assessment	Sedimentation rate	
			M m^3/year	ha-m/ 100km^2/ year
Ramganga reservoir	364.40 to 339.05 m	1974-2001	4.23	13.49
Rihand reservoir	267.31 to 258.78 m	1964-01	-	-
Tungbhadra reservoir	477.45 to 494.79 m	1981-2002	16.37	5.81
Barna reservoir	325.00 to 348.55 m	1975-2002	3.89	33.09
Somasila reservoir	94.39 to 83.17 m	1987-2002	1.60	0.764

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1.0 INTRODUCTION

1.1 GENERAL

Soil is eroded due to rainfall and winds, resulting in tremendous sediment movement into the watercourses by floods and storms. Soil erosion, its transportation and subsequent deposition in reservoirs is a universal problem. When sediment flows into a reservoir, due to decrease in flow velocity, the coarser particles deposit first in the upper reach of the reservoir. Subsequently, the finer materials are deposited further into and along the reservoir bed. Sedimentation of the reservoir is, therefore, a natural process resulting from the geologic and geomorphologic process of water borne erosion. Human actions can considerably hasten the natural process and increase the rate of sedimentation.

Sedimentation of reservoirs is a matter of vital concern to all water resources development projects. Sediment deposition into reservoirs meant for hydropower generation has several major detrimental effects, which include:

- Loss of storage capacity,
- Damage or impairment of hydro equipment,
- Bank erosion and instabilities,
- Upstream aggradation,
- Effect on water quality,
- Effect on eutrophication

To determine the useful life of a reservoir, it is essential to periodically assess the sedimentation rate in a reservoir. In addition, for proper allocation and management of water in a reservoir, knowledge about the sediment deposition pattern in various zones of a reservoir is essential. With the up-to-date knowledge of the sedimentation process going on in the reservoir, remedial measures can be undertaken well in advance and reservoir operation schedules can be planned for optimum utilization of water. Hence, systematic capacity surveys of a reservoir are conducted periodically.

Conventional reservoir surveys are carried out using the field equipments, such as theodolites, plane table, sextant, range finders, sounding rods, echo sounders and slow moving boats etc. Most common conventional techniques for sedimentation quantification are: a) direct measurement of sediment deposition by hydrographic surveys, and b) indirect measurement by inflow - outflow method. Both these methods are laborious, time consuming and costly and have their own limitations. Sampling and measurement of suspended sediments is a tedious and expensive program for either in-situ or laboratory work.

With the introduction of remote sensing techniques in the recent past, it has become convenient and far less expensive to quantify sedimentation in a reservoir and to assess its distribution and deposition pattern. Remote sensing techniques, offer data acquisition over a long time period and broad spectral range, are superior to conventional methods for data acquisition. Spatial, spectral and temporal attributes of remote sensing provide invaluable synoptic and timely information regarding the estimated water spread area after the occurrence of sedimentation and sediment distribution pattern in the reservoir. Multi-temporal satellite data are used in determining sedimentation rate in a reservoir. It is highly cost effective, easy to use and it requires less time in analysis as compared to conventional methods.

The advantage of satellite data over conventional sampling procedures include repetitive coverage of a given area every few weeks, availability of a synoptic view which is unobtainable by conventional methods, and almost instantaneous spatial data over the areas of interest. The remote sensing techniques provide synoptic view of a reservoir in spatial form while the surface data collection and sampling gives point information only.

1.2 OBJECTIVES AND SCOPE OF THE REPORT

The objectives of the present study were to assess the sedimentation in five reservoirs, namely Ramganga, Rihand, Tungabhdara, Barna and Somasila reservoirs. The study involved the following steps:

- Assessment of water spread area using remote sensing technique
- Estimation of storage loss due to sedimentation
- Estimation of sedimentation rate in live storage zone
- Updation of Elevation-Area-Capacity curve in live storage zone

Results of sedimentation assessment in these five reservoirs have been described in chapter 2, 3, 4, 5 and 6.

2.0 SEDIMENTATION STUDY OF RAMGANGA RESERVOIR

2.1 THE STUDY AREA AND AVAILABILITY OF SATELLITE DATA

Ramganga reservoir had been created in 1974-75 by constructing a 125 m high and 595 m long dam across Ramganga River. Ramganga dam is located in Uttranachal state (Figure 2.1). The main tributaries of the Ramganga River at dam site are Mandalti and Sona rivers. The catchment area of Ramganga River and its tributaries up to the dam site is 3134 km^2. The reservoir has a spread area of 78.31 km^2 at full reservoir level of elevation 365.3 m. The dam was fully filled for the first time in 1975.

The Ramganga River transports a lot of silt, which is detrimental to the life of reservoir. The silt contribution is largely due to unprecedented deforestation, over-grazing in the pasturelands, unscientific agricultural practices, indifferent contour terrace farming, absence of effective afforestation programs and other development activities undertaken in the catchment area, including mining activities, road construction etc.

In the present case, the historical record of annual maximum and minimum observed levels was available with the dam authorities. In the year 2000, maximum level at 364.4 m was observed on 28th September 2000. The reservoir level fell down gradually to the minimum level of 339.05 m on 2nd May 2001.

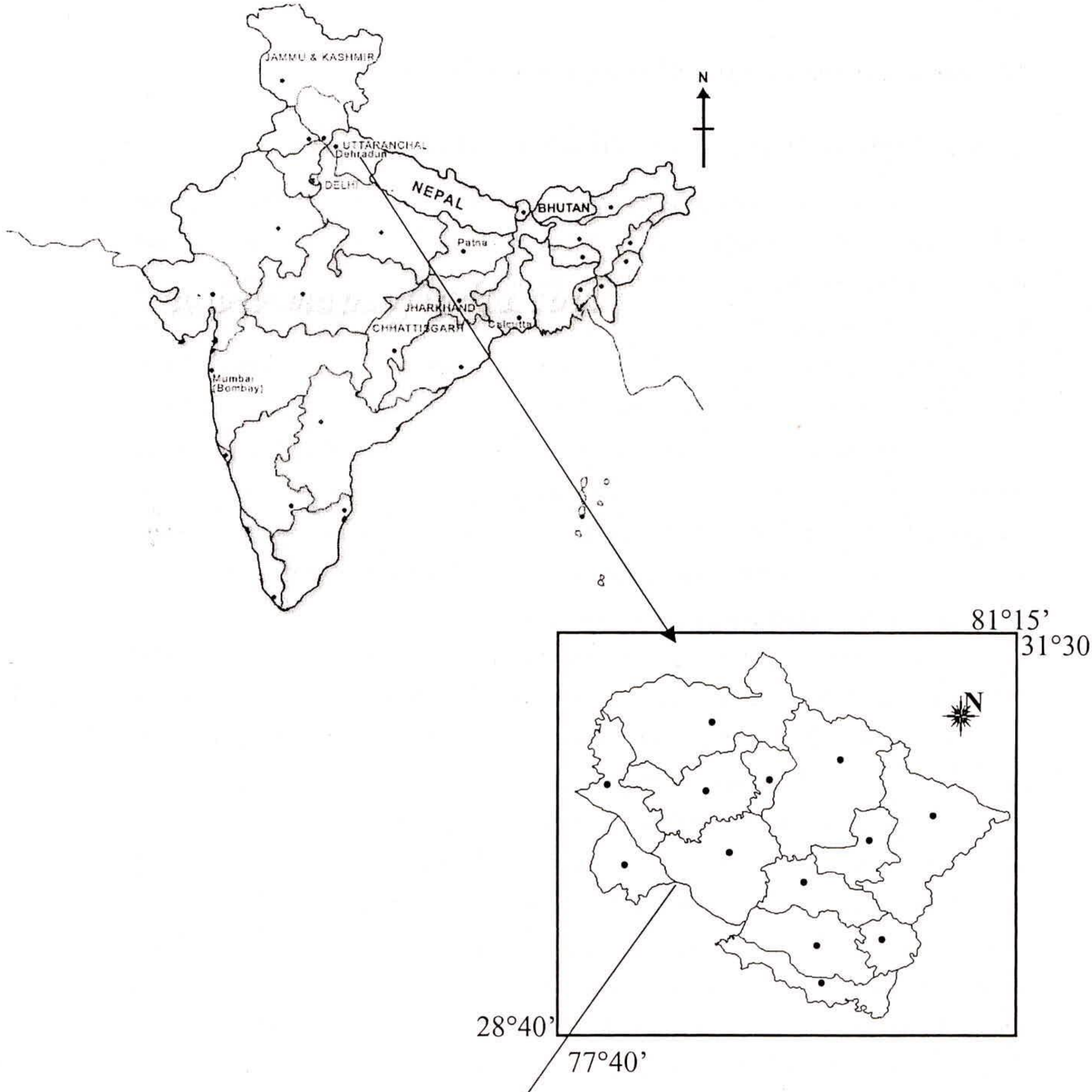
In the present study, the analysis has been carried out for the year 2000-01. The data of LISS-III sensor of IRS-1C satellite, which has a resolution of 23.50 m was used. The multi spectral data are available in four spectral bands, which is very helpful in the identification of water spread area. The reservoir water spread area is covered by A2 quadrant of Path 97 and Row 50 of the satellite. Due to cloud cover, images of some of the dates could not be obtained. The remote sensing data of following dates were procured: 28-09-2000, 15-11-2000, 09-12-2000, 19-02-2001, 08-04-2001 and 02-05-2001.

2.2 METHODOLOGY

The basic output from remote sensing data analysis is the water spread area of the reservoir. Two techniques were used for identification of water pixels:

(i) Normalized Difference Water Index (NDWI)

The Normalized Difference Water Index (NDWI) is selected to give some information about the water. Equation used to compute NDWI is given below:



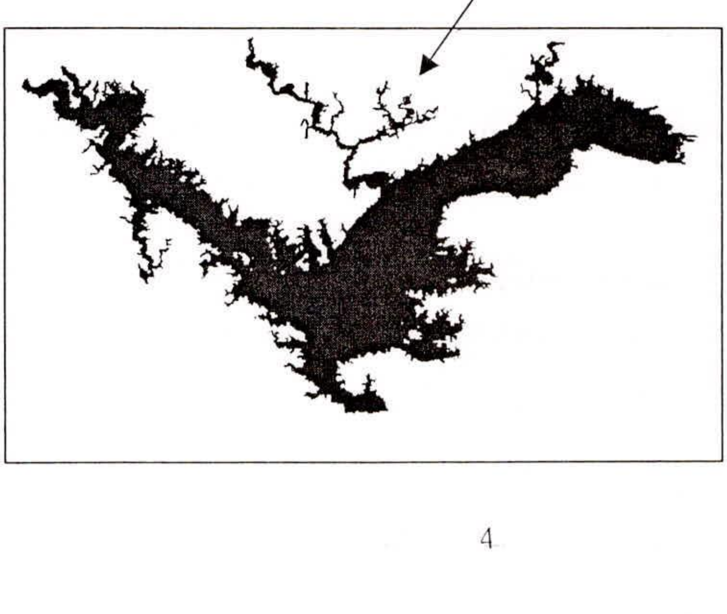


Figure 2.1: Location of Ramganga reservoir

NDWI = (Green - NIR) / (Green + NIR), 2.1

The positive values of NDWI indicate water.

(ii) Tasselled Cap Transformation (TCT)

Tasselled Cap Transformation was applied on all the NDWI images for identifying the water pixels more clearly. After applying the Tasselled Cap Transformation, the value 1 is assigned for water pixel and 0 for the area not covered by water. The coefficients used in this transformation are given below:

0.279	0.474	0.559	0.000
-0.244	-0.544	0.724	0.000
0.197	0.328	0.341	0.000

The images obtained after TCT show only water feature through this technique.

2.2.1 Data Collected Through Hydrographic Survey

Irrigation Research Institute, Roorkee, carried out the hydrographic survey of Ramganga reservoir and its tributaries in the year 1988 and 1997. The capacity of the main portion of the reservoir along with the tributaries is given in Table-2.1. The total capacity at FRL worked out to 2480.25 Mm^3. The average rate of silting in a span of 23 years was 4.80 Mm^3/year. This has been calculated with respect to the original capacity of Ramganga reservoir after making correction for the saddle dam portion.

Table-2.1: Capacities of Ramganga reservoir estimated by hydrographic survey in year 1988 and 1997

S. N.	Elevation (m)	Gross capacity of the reservoir (Mm^3)	
		1988	1997
1.	365.3	2508.01	2480.25
2.	360.0	2121.82	2006.87
3.	355.0	1831.91	1666.54
4.	350.0	1533.05	1359.08
5.	345.0	1195.42	1102.75
6.	340.0	954.64	849.10
7.	335.0	723.21	646.66
8.	330.0	552.40	477.77

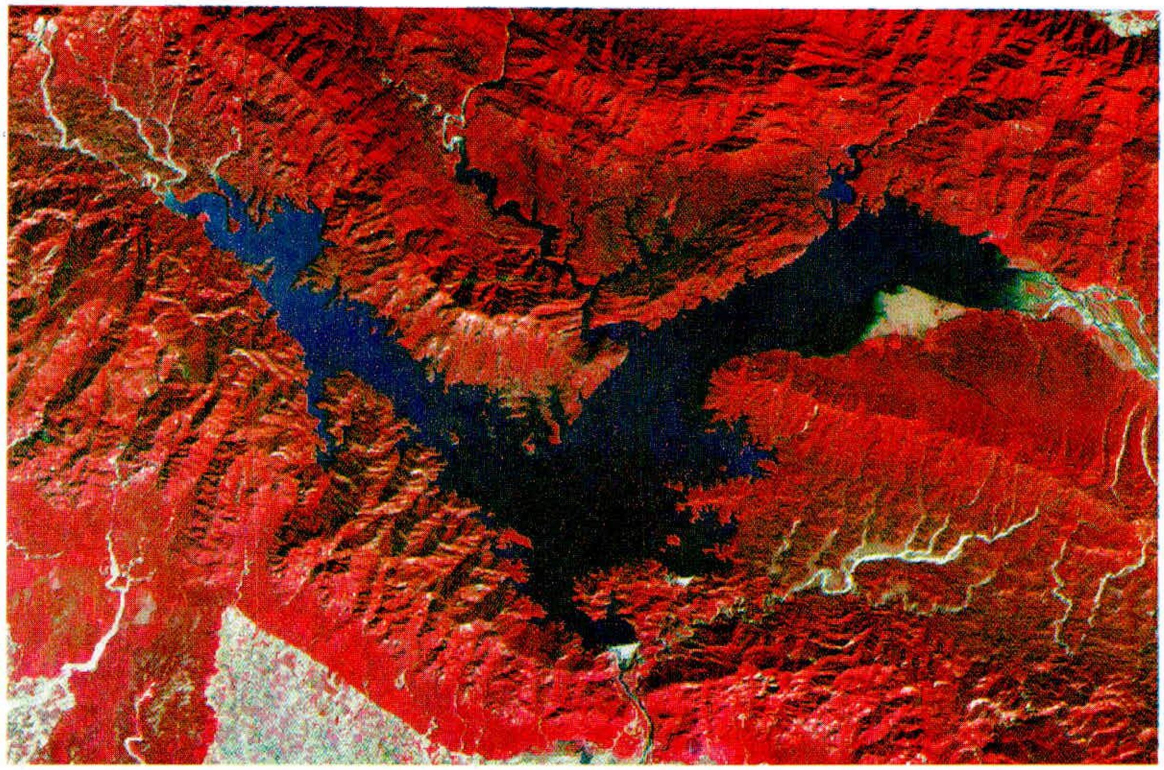
9.	325.0	403.36	350.45
10.	320.0	283.30	251.54
11.	317.0	234.92	210.21
12.	315.0	202.67	182.66
13.	310.0	133.58	124.15
14.	305.0	87.22	79.49
15.	300.0	56.48	44.13
16.	295.0	26.36	21.03
17.	290.0	9.38	6.42
18.	285.0	2.97	1.86

2.2.2 Calculation of waterspread area and sediment deposition

The reservoir elevations at the time of satellite pass were obtained from CWC, New Delhi. The revised areas as computed in the last section and the corresponding elevations are presented in Table – 2.2 for the year 2000-2001. Using the revised areas, revised capacity has been computed and shown in Table 2.2. The imageries of different dates showing the FCC and the final water spread areas are presented in Figure-2.2 to Figure 2.6.

Table-2.2 : Calculation of Sediment Deposition in Reservoir Using Remote Sensing for the year 2000-2001

Date of satellite pass	Elevation of water level in meters	Number of Water Pixels	Surface area using remote sensing	Incremental capacity using remote sensing (Mm^3)	Capacity using hydrographic survey (Mm^3) (1974)	Capacity using remote sensing (Mm^3)
28-09-2000	364.40	141476	78.13	48.05	2442.43	2391.63
15-11-2000	363.78	139231	76.89	107.72	2398.00	2343.62
09-12-2000	362.35	133599	73.78	676.18	2292.06	2235.91
19-02-2001	352.14	106745	58.95	496.51	1660.90	1559.72
08-04-2001	342.51	80761	44.60	115.49	1075.52	1063.20
02-05-2001	339.05	76686	42.35		947.7	947.7



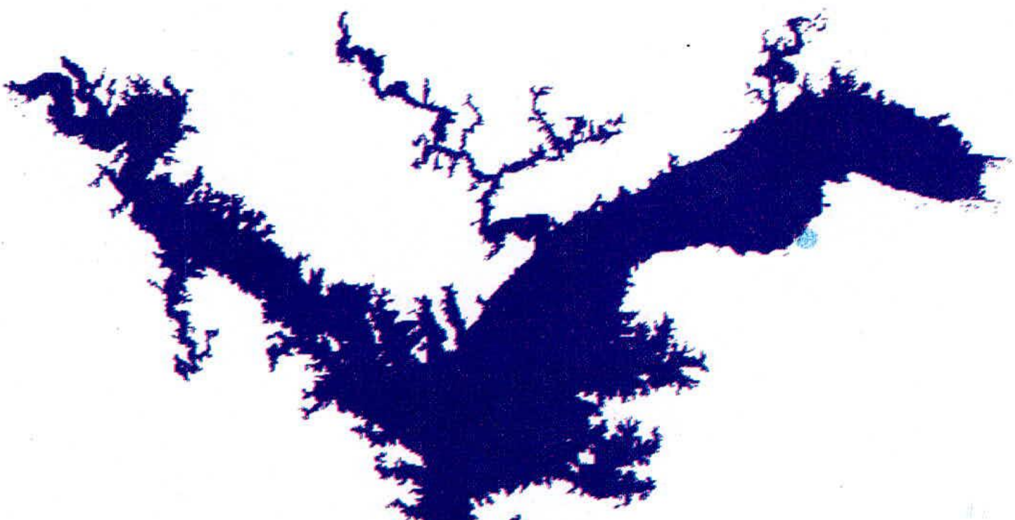


Fig. 2.2 FCC AND RESERVOIR AREA IN NOV 2000

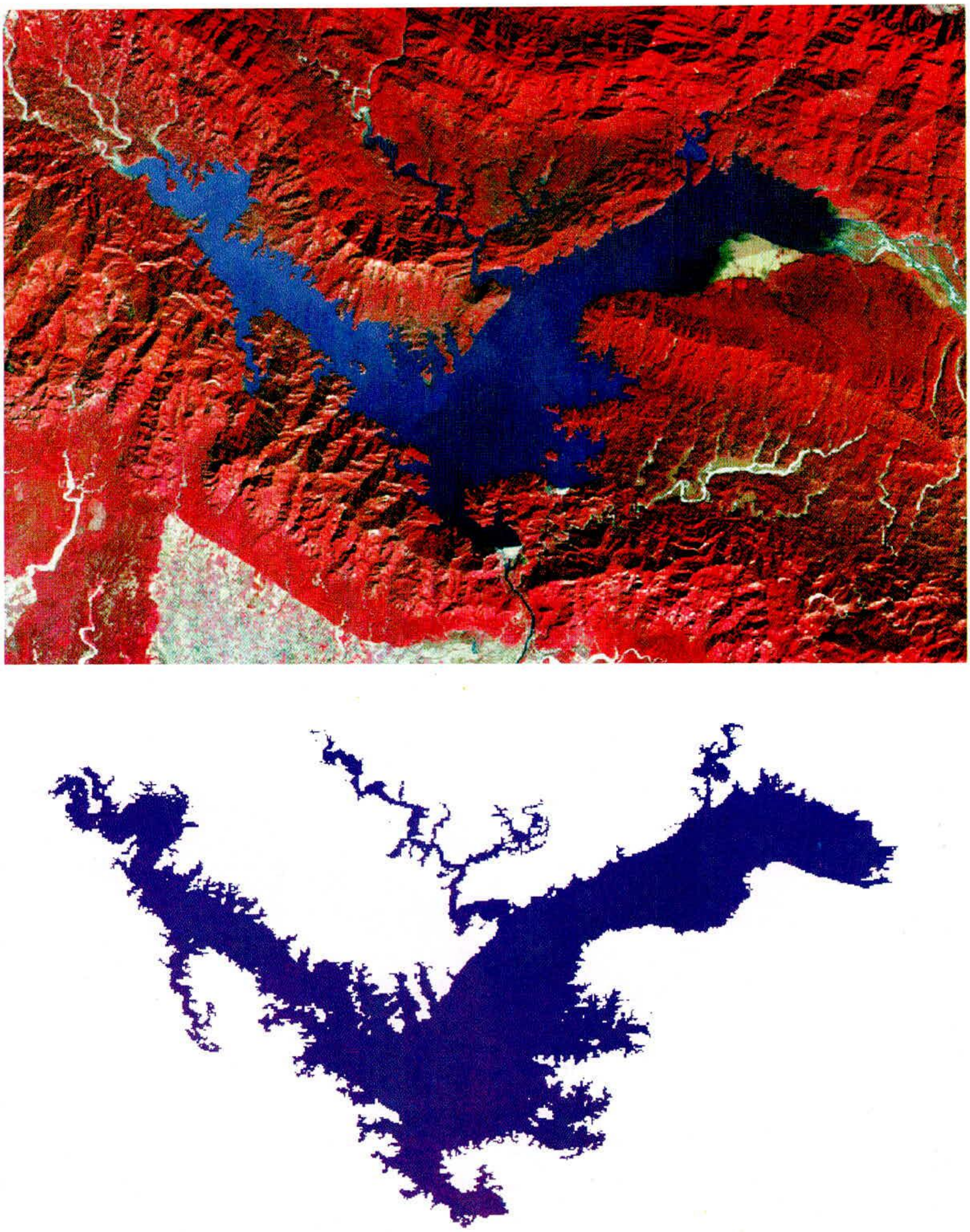
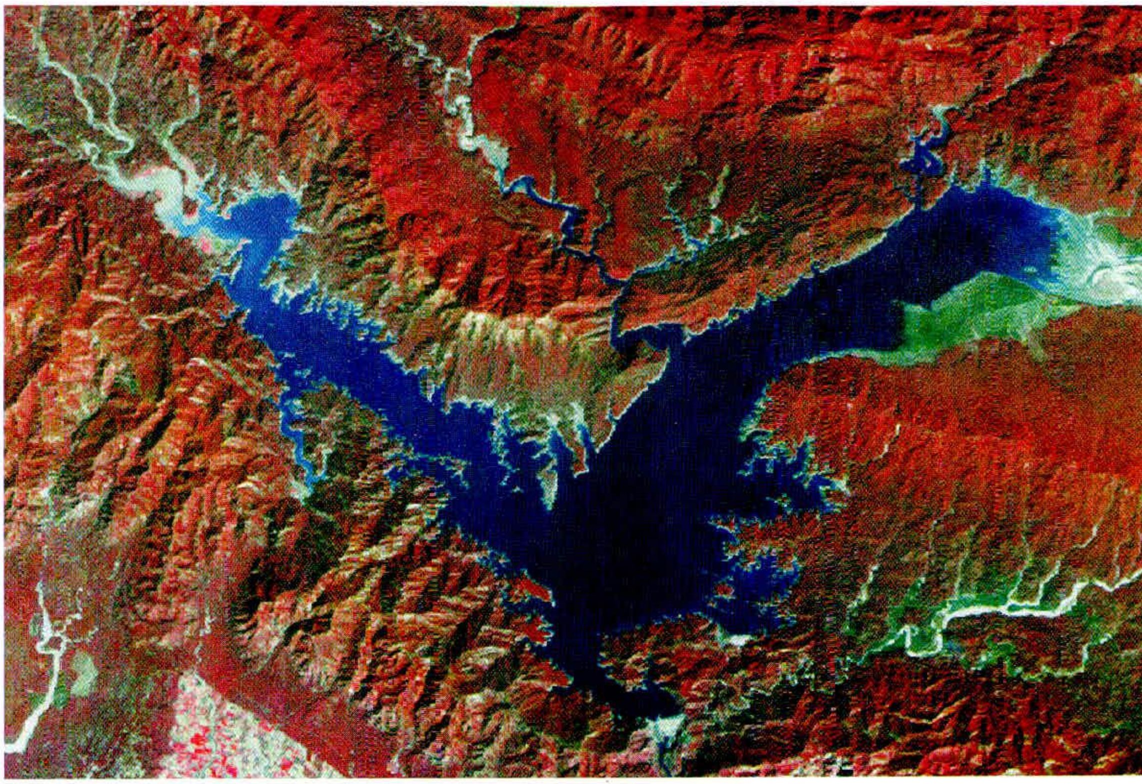


Fig. 2.3 FCC AND RESERVOIR AREA IN DEC 2000



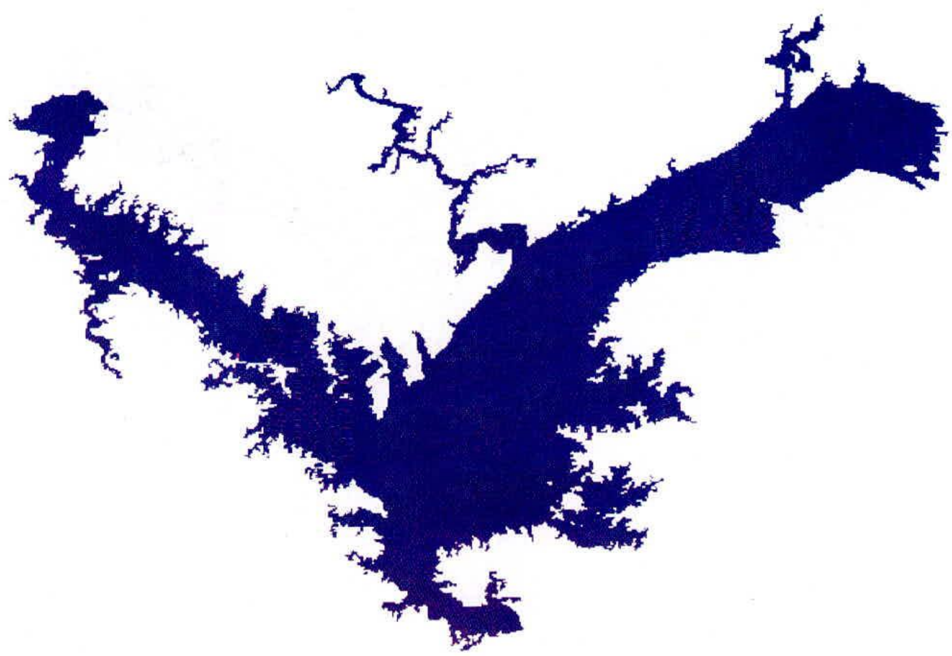
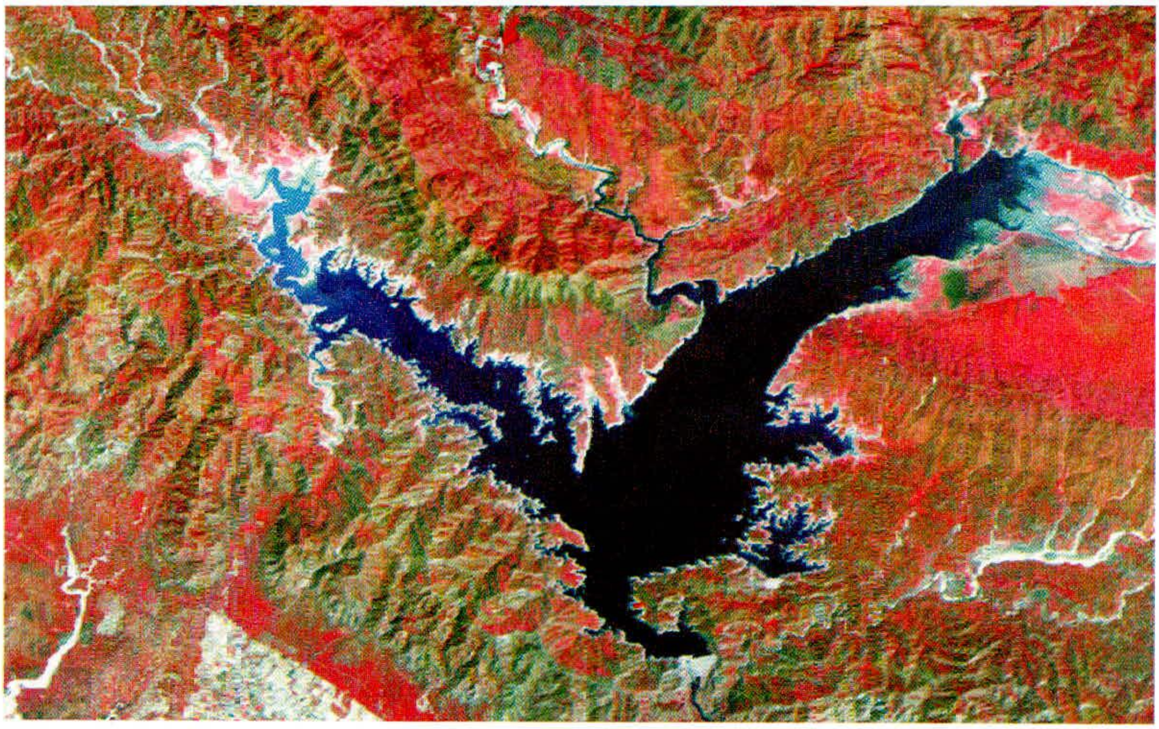


Fig. 2.4 FCC AND RESERVOIR AREA IN FEB 2001



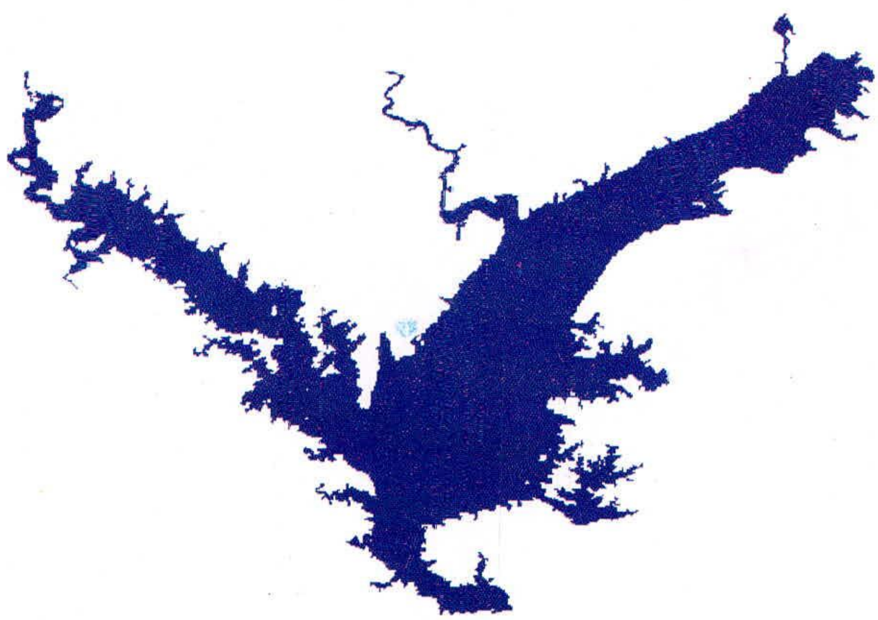


Fig. 2.5 FCC AND RESERVOIR AREA IN APR 2001

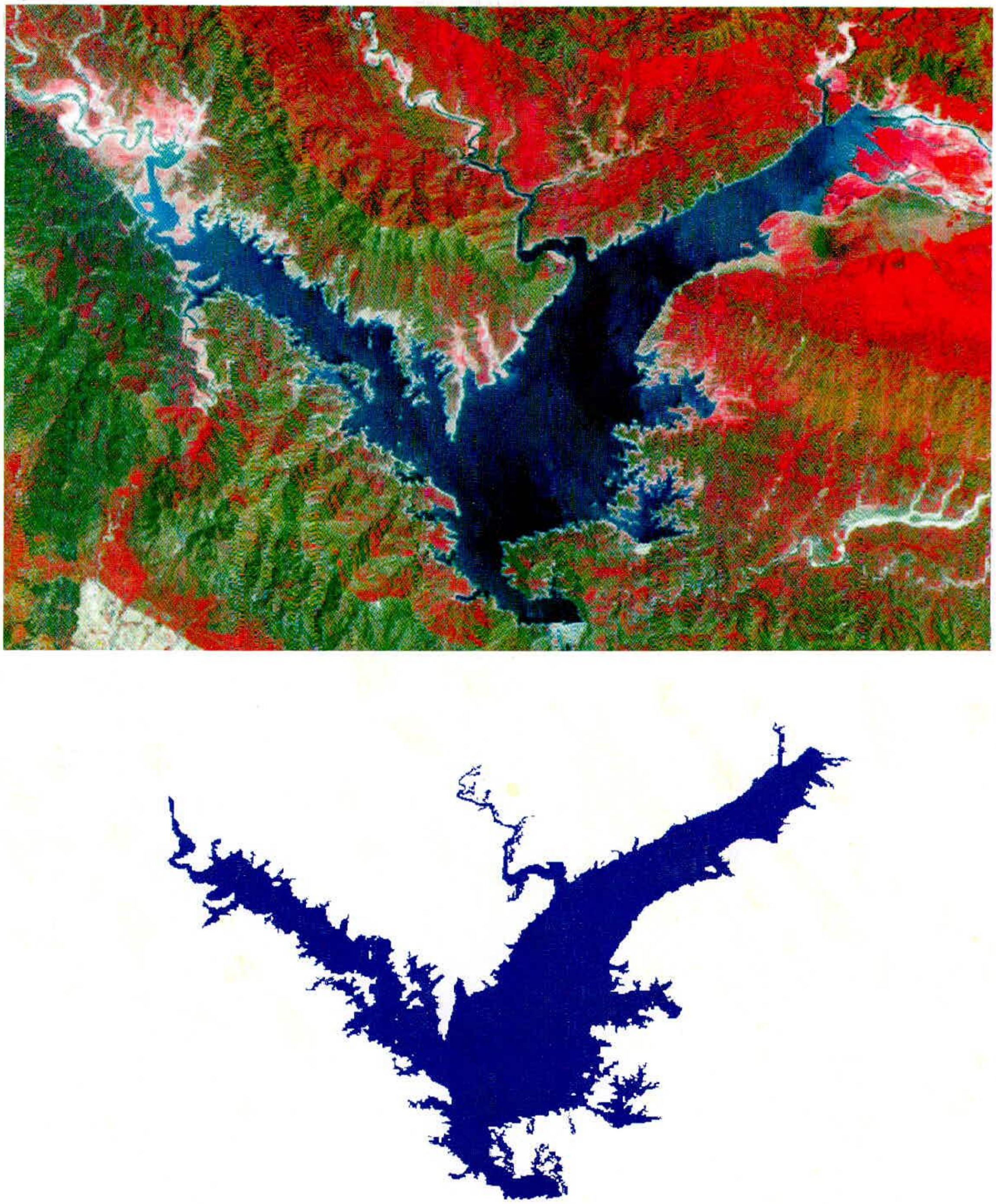


Fig. 2.6 FCC AND RESERVOIR AREA IN MAY 2001

The reservoir capacity between two consecutive reservoir elevations was computed using the trapezoidal formula.

2.3 COMPARISON OF RESULTS OF REMOTE SENSING AND HYDROGRAPHIC SURVEY

The results show that the volume of sediment deposition during 1988 to 2000-2001 (12 years) between the maximum and minimum observed levels (364.4 m and 339.05 m) is 50.8 Mm^3. If the uniform rate of sedimentation is assumed, then as per the satellite data analysis for the year 2000-2001, the sedimentation rate in the zone (364.4 m and 339.05 m) is 1.95 M m^3 per year. The plot of original and estimated cumulative capacity as derived using remote sensing technique is shown in Fig-2.7 for the year 2000-2001.

As per the IRI report, the results are as follows.

Capacity of reservoir in Mm^3				Sedimentation Rate (Mm^3/year)		
1974	1988	1997	2000	(1974-1997)	(1988-1997)	(1988-2000)
2590.72	2508.01	2480.25	2463.64	4.80	3.08	3.70

The dead storage of the reservoir was 210.11 Mm^3 and the live storage was 2270.14 Mm^3 the year 1997. At the gross sedimentation rate of 4.23 Mm^3/year, it will take approximately 500 years for this live storage to completely fill up if the sedimentation continues at the current rate.

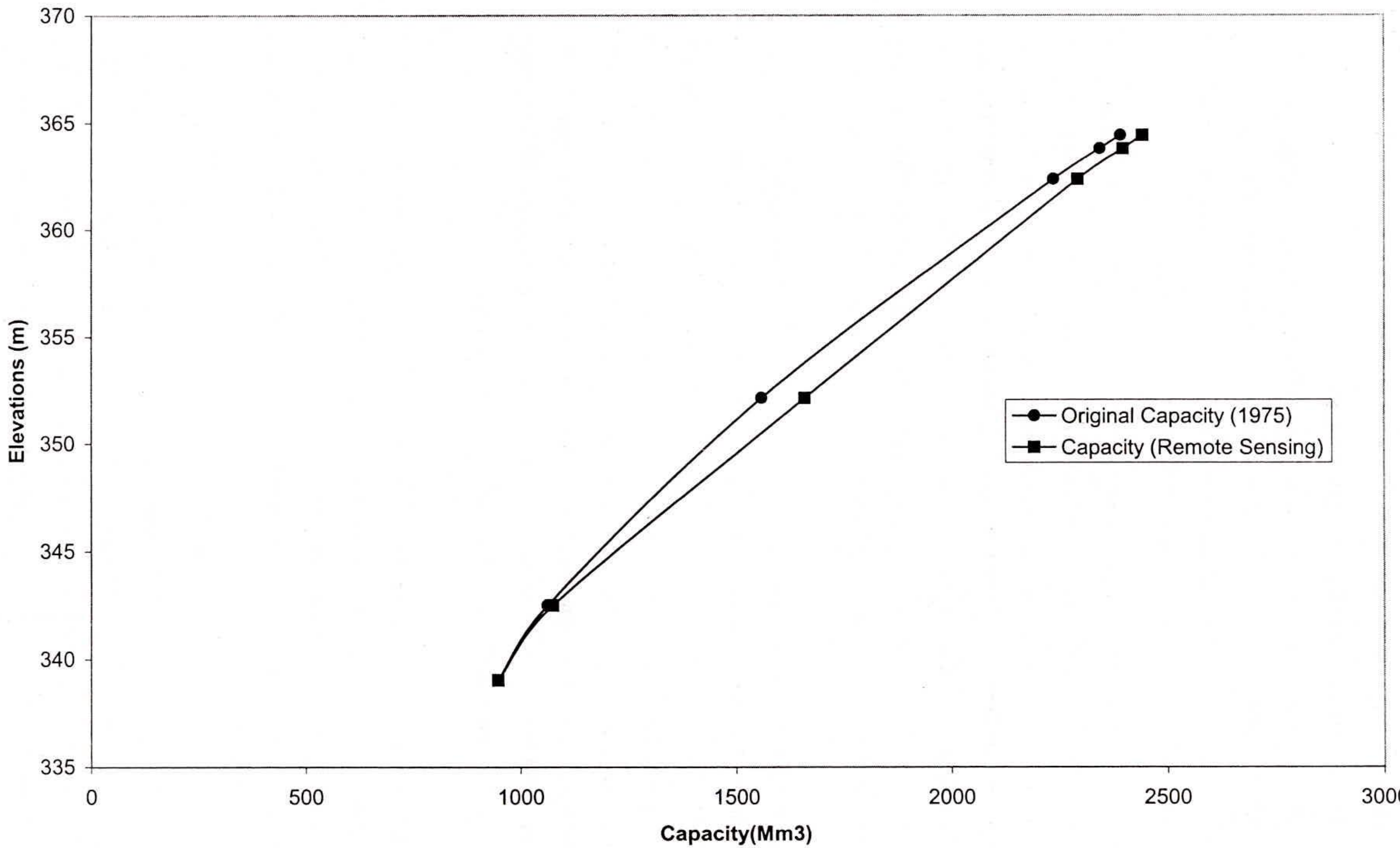


Figure 2.7 : Elevation Capacity curves for Ramganga reserovir

3.0 RIHAND RESERVOIR

3.1 THE STUDY AREA AND DATA AVAILABILTY

Rihand Dam was constructed on Rihand River in Distt. Sonbhadra of Uttar Pradesh in the year 1962. The objective of the project was to provide water mainly for generation of hydro-power necessary for speedy development of agriculture and industry in the backward areas of Eastern and South- Eastern parts of the State of Uttar Pradesh.

Rihand River is a tributary of the Sone River. The river and its tributaries arise in the hills in Madhya Pradesh and flow in the northern direction through this state and also through the district of Sonbhadra in Uttar Pradesh. At Chopan in Sonbhadra district, the Rihand River joins the Sone River. The river above the dam site drains an area of 13,333 sq. km and has a length of 257.50 km. The stream slopes down from an elevation of about 915.50 m in the upper valley to 190.5 m at the dam site. The region is hilly and is covered with vegetation. The catchment of Rihand River along with the location of the project is shown in Figure 3.1.

The Rihand Dam is located at latitude 24° 12' 30" N and longitude 83° 03' E. It comprises about 90 m high and 934.2 m long concrete gravity dam on Rihand River near village Pipri, 46.2 km south of its confluence with the Sone River. The dam impounds 10608.32 million cubic meter (Mm^3) of water at full reservoir level (FRL) of 268.22 m. A powerhouse with 6 units of 50 MW each is also constructed at the toe of the dam on right bank of the river to provide a firm power of 105 MW with total annual power output of 912 million units. The Rihand Power Station is connected to the common grid of Uttar Pradesh Madhya Pradesh and also to Damodar Valley Corporation System in Bihar.

The reservoir can attain a maximum level of 271.52 m during the passage of PMF of 13,339 cumec. The reservoir has a designed dead storage of 1628.38 Mm^3 below R.L. 236.22 m and a live storage of 8979.94 Mm^3 between R.L. 236.22 m and the FRL. Its water spread is 469.45 sq. km at FRL. The water spread area lies in both Uttar Pradesh (347 sq. km) and Madhya Pradesh (122 sq. km).

The basin falls under the influence of South-West monsoon. The average annual rainfall in the drainage basin is 1422 mm while the average annual runoff is 475 mm. The Rihand River experiences heavy floods during the monsoon season and has little discharge during the remaining part of the year. The maximum and minimum runoffs have been estimated to be 8993 Mm^3 and 3503 Mm^3 respectively, the average annual runoff being 6328.47 Mm^3.

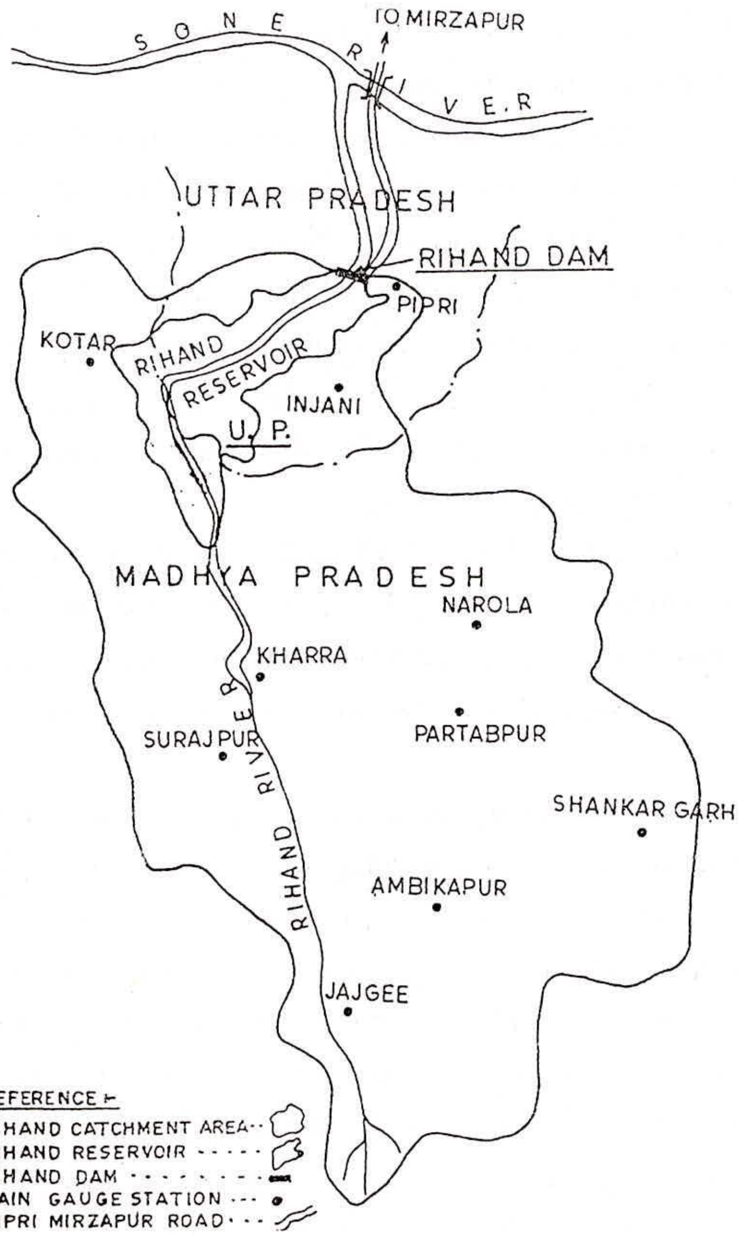


Figure – 3.1 Catchment of Rihand Project (Source: UPIRI 1996).

Although the original project envisaged generation of only hydroelectric power, Rihand reservoir has been used mainly for generation of thermal power as coal is available in the adjacent areas. The following thermal power stations have been installed at the periphery of the reservoir.

a. Anpara Super Thermal Power House of 2000 MW at Anpara in U.P. under the control of UPSEB.

b. Renu Sagar Power Station of 600 MW at Renu Sagar in U.P. under the control of Birla Group.

c. Shakti Nagar Super Thermal Power Station of 2000 MW at Shakti Nagar under the control of National Thermal Power Corporation.

d. Vindhya Nagar Super Thermal Power Station of 2000 MW at Vindhya Nagar in M.P. under the control of National Thermal Power Corporation.

e. Rihand Nagar Super Thermal Power Station of 1000 MW at Rihand Nagar in U.P. under the control of National Thermal Power Corporation.

The reservoir is encroached upon by construction of several ash dykes and other structures near its periphery. The capacity of the reservoir has consequently been reduced by 44.7 Mm^3. Thus, the net capacity of 10,563.62 Mm^3 and the net live storage capacity of 8979.94 Mm^3 is available for storage of water.

The reservoir could be filled up to FRL of 268.22 m only in the years 1964, 1971 and 1995 and it was well below FRL during rest of the years. Consequent upon installation of several thermal power stations around the periphery, the reservoir level is now not allowed to fall below 252.98 m. Therefore, the dead storage level is deemed to have shifted from 236.22 m to 252.98 m.

The provision of dead storage in the reservoir is made considering the sedimentation in 140 years of its operation. During this period, the live storage was expected to reduce from 8979.94 Mm^3 to 8185.49 Mm^3. However, the capacity survey of the reservoir carried out before the monsoon of 1995 indicates that sediment deposition has reduced live storage to 8009.94 Mm^3 in only 33 years of operation. This gives sedimentation rate of 2918 m^3/sq. km/year against the assumed value of 904-m3/sq. km/year. These values of capacity loss are based on the original reservoir capacity worked out from the aerial survey by the Survey of India at the planning stage. The large difference in the assumed and the estimated rate is partly attributed to the inaccuracies in original capacity surveys.

3.2 METHODOLOGY

3.2.1 Previous Capacity Surveys of Rihand Reservoir

At the project planning stage, the original capacity of the reservoir was worked out from the contoured map by aerial survey. The capacities of the reservoir for different water elevations were calculated from the plan of the area with contours 20 feet apart. The error in capacity computations was stated to be under 5%. The original elevation-area-capacity table of the reservoir is given in Table – 3.1.

Table – 3.1 Original Elevation-Area-Capacity Table for Rihand Reservoir

Elevation (m)	Area (Mm^2)	Capacity (Mm^3)
268.224	469.45	10600.32
262.128	381.84	7968.58
256.032	316.60	5743.30
249.936	242.13	4112.57

Subsequently, a hydrographic survey of the reservoir was carried during November 1994 to May 1995 in which the reservoir level varied from 267.02 m to 256.95 m. The survey was carried using the range lines and echo-sounding equipment. The details of the method are provided in the UPIRI Research Report (1996). The elevation-area-capacity table estimated with the hydrographic survey of 1995 is given in Table – 3.2.

Table – 3.2 Revised Elevation-Area-Capacity Table for Rihand based on the Hydrographic Survey (1995).

Elevation (m)	Area (Mm^2)	Capacity (Mm^3)
268.224	395.65	9324.81
268.00	394.44	9235.62
267.00	389.02	8842.37
266.00	384.09	8452.08
265.00	377.80	8073.06
264.00	371.26	7697.27
263.00	361.80	7329.28
262.00	352.59	6971.05
261.00	342.29	6622.76
260.00	333.94	6284.64
259.00	322.42	5956.48
258.00	312.03	5939.63
257.00	301.27	5332.83
256.00	289.56	5037.17
255.00	279.85	4752.55
254.00	269.70	4477.61
253.00	258.00	4213.59
252.00	245.04	3962.21
251.00	231.56	3722.60
250.00	220.29	3496.67

For the Rihand reservoir, the daily reservoir level data from August 1996 to March 2002 were obtained from the Water Management Directorate, CWC, New Delhi. The variation of water level in the reservoir is shown in Figure – 3.2. The maximum and minimum reservoir levels observed during this period were 268.26 m (11 September 1997) and 255.33 m (23 June 1997) respectively.

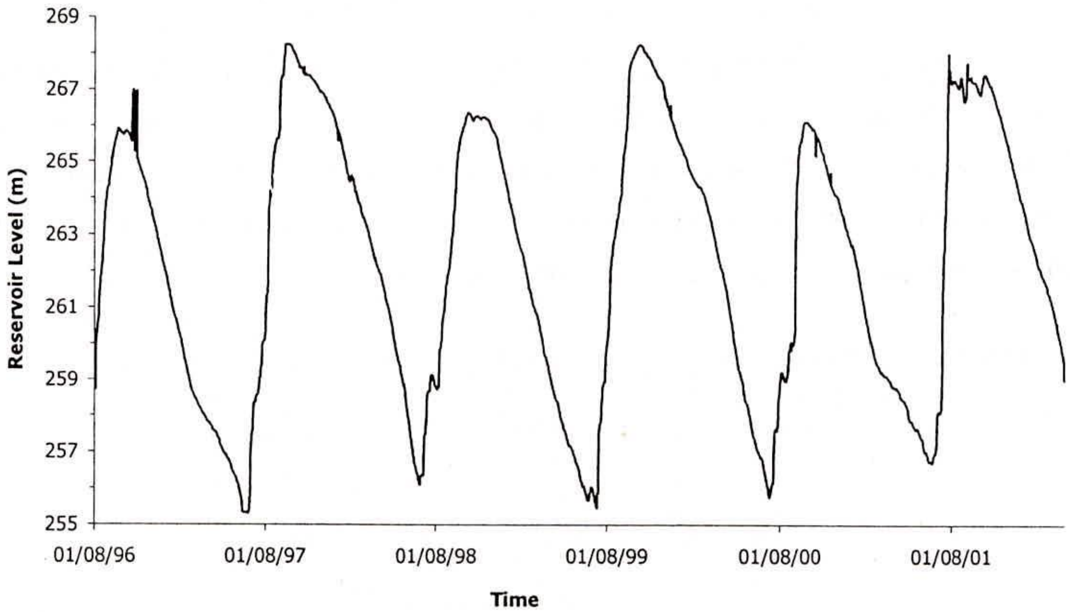


Figure – 3.2 Water Level Variation in Rihand Reservoir during 1996-2001.

Since the water level hardly goes below 255 m in the reservoir (as can be seen from Figure 3.2), it was desired to cover most of the range from 268 m to 255 m. However, cloud free satellite data were not available for the months (May-June) when the reservoir level generally falls around 255 m. Looking at the water level variation and the availability of satellite data, the period from October 1999 to April 2001 was considered for analysis. Reservoir level varied from 268.25 m to 258.78 m during this period.

The Rihand reservoir water spread is covered in Row 55 of the satellite. The full water spread area of the reservoir is covered either in one Path 102 or in two Paths 102/103 of IRS 1C satellites. Based on the status and availability of cloud free remote sensing data and the variation in reservoir level in-between the dates of satellite pass, six dates of pass were selected for acquiring remote sensing data. The dates of pass and the corresponding reservoir levels are given in Table – 3.3.

In the satellite image of Path 102 on 20.11.1999, the full water spread of the reservoir was not covered. To cover the entire spread of reservoir at higher elevation (around 268 m), the image of Path 103 was also acquired and the water spread of image dated 20.11.1999 was merged with the water spread of image dated 10.10.1999. So, effectively five dates of satellite data were used to find the water spread conditions corresponding to five different reservoir levels. Table 3.3 gives reservoir elevation and capacities using remote sensing.

Table – 3.3 Reservoir area and capacity at different elevations using remote sensing

Date of Pass	Number of Water Pixels	Reservoir Elevation (m)	Revised Area Using R.S. (M Sq. m)	Revised Capacity using R.S. (M. Cum)
20.11.1999	603786	267.31	347.78	8537.993
29.09.2000	580389	266.09	334.30	8122.003
16.11.2000	550170	264.45	316.90	7588.083
18.01.2001	504359	261.73	290.51	6762.266
03.04.2001	448981	258.78	258.61	5952.77

3.2.2 Calculation of water spread area

For identifying the water pixels in the Rihand reservoir, first the digital numbers in remote sensing images were converted to radiance values by using the radiometric characteristics of different sensors. Using radiance values, it is possible to make a relative comparison of values in different bands. For each band represented by wavelength λ, the digital radiance numbers, Q_{cal} on the satellite image is converted to radiance, $L(\lambda)$ by:

$$L(\lambda) = L_{min}(\lambda) + [L_{max}(\lambda) - L_{min}(\lambda)] * (Q_{cal}/Q_{cal,max}) \quad \text{... (3.1)}$$

The minimum $[L_{min}(\lambda)]$ and maximum $[L_{max}(\lambda)]$ radiance values of a sensor can be obtained from its radiometric characteristics. Radiometric characteristics of LANDSAT TM, IRS-1C LISS-III and IRS-1D LISS-III sensor are presented in Table – 3.4.

For identifying the water pixels in Rihand reservoir, a number of models were tried. These included the density slicing of near-infrared band, comparison of radiance of NIR band with the Red band and Green band, and the thresholding of normalized difference water index. However, none of these models gave satisfactory results for all the images. So, in addition to the NDWI, Normalized Difference Vegetation Index [NDVI = ((Red - NIR)/(Red + NIR))] was also used to identify water pixels. Images corresponding to NDWI and NDVI were prepared for each radiance image and four windows of images (corresponding to FCC, NIR band, NDWI, and NDVI) were visualized for finding the threshold values of NIR band, NDWI, and NDVI for water pixels. For various images, the threshold values used for separation of water pixels are given in Table – 3.5.

To differentiate water pixels in different images, different threshold values were applied on images in the form of models in the ERDAS/IMAGINE software and the model runs were taken. The resulting images of water pixels were compared with the corresponding near-IR band image and the standard FCC. The near-IR image of November 16, 2000 and the corresponding water image are shown in Figure – 3.3. The images of water pixels, as obtained from the interpretation, were edited to remove the isolated water pixels, extension of tail and joining of rivers around the waterspread.

Table – 3.4 Radiometric Characteristics of LANDSAT TM and IRS-1C/1D LISS-III

Band	Wavelength (um)		Satellite radiance (W m^{-2} mm^{-1} sr^{-1})					
	Landsat TM	IRS-1C/ 1D LISS-III	TM		1C LISS-III		1D LISS-III	
			L_{min}	L_{max}	L_{min}	L_{max}	L_{min}	L_{max}
1	0.45 - 0.52	-	-1.5	152.1	-	-	-	-
2	0.53 - 0.61	0.52 - 0.59	-2.8	296.8	1.76	14.45	-2.8	296.8
3	0.62 - 0.69	0.62 - 0.68	-1.2	204.3	1.54	17.03	-1.2	204.3
4	0.78 - 0.90	0.77 - 0.86	-1.5	206.2	1.09	17.19	-1.5	206.2
5	1.57 - 1.78	1.55 - 1.70	-0.37	27.19	0.00	2.42	-0.37	27.19
7	2.10 - 2.35	-	-0.15	14.38	-	-	-	-

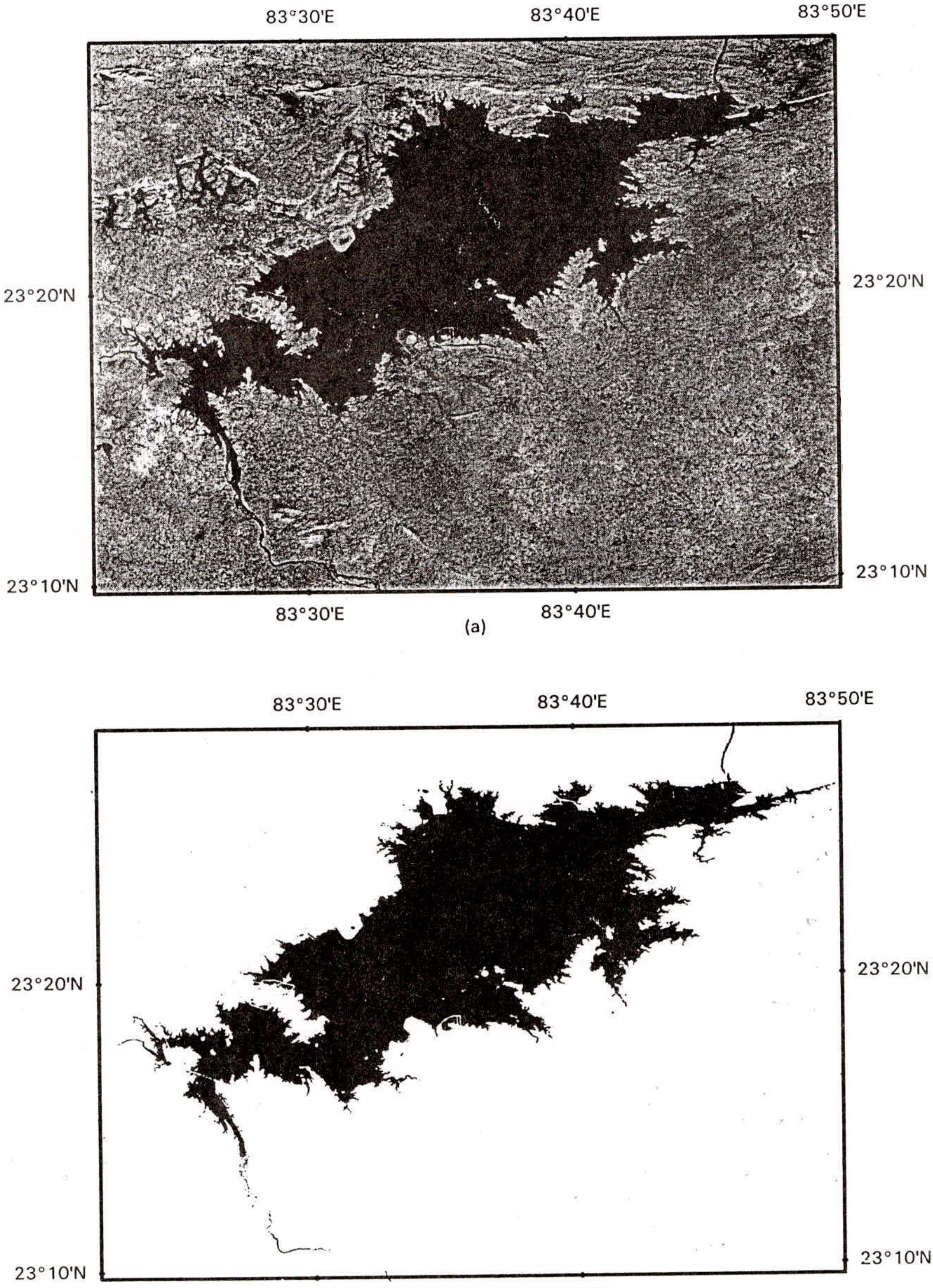


Figure 3.3 (a) Near-infrared image of Rihand reservoir on November 16, 2000
(b) Corresponding water pixels derived from digital analysis

Table – 3.5 Various Thresholds Used for Water Identification in Remote Sensing Images

Date of Remote Sensing Image	NDWI	Radiance in NIR band	NDVI	Radiance in Red Band
10.10.1999	> 0.24	< 7	< 0.16	-
20.11.1999 (Head portion)	> 0.22	< 7	-	> 8.7
20.11.1999 (Tail portion)	> 0.22	< 7	< 0.16	-
29.09.2000 (Head portion)	> 0.22	< 7	-	> 8.7
29.09.2000 (Tail portion)	> 0.13	< 7	< 0.11	-
16.11.2000	> 0.18	< 6.5	-	-
18.01.2001	> 0.18	< 5	< 0.04	-
03.04.2001	> 0.11	< 5	< 0.0	-

3.2.3 Removal of discontinuous water pixels and extended tail

As the water level falls, small islands appear within the reservoir area. The size of these islands keeps on increasing as the water level goes down. Due to the presence of local depressions within the islands and around the periphery of the reservoir, a few pixels within the depressions and around the periphery of the reservoir may appear as water pixels. The main objective of calculating the water-spread area is to determine the revised contour area at the elevation of the water surface. Since the contour area represents the continuous area, it is required that the isolated water pixels, surrounding the water-spread area and/or located within the islands be removed from the interpreted water image.

Around the Rihand reservoir, a number of ash dykes have been constructed (within the water-spread area) and water is preserved in ponds for thermal power stations. All such ponds do not contribute towards the storage capacity of Rihand reservoir. Hence, their water pixels were excluded from the calculation of total water-spread area of the reservoir. Further, towards the tail end of the reservoir, Rihand bridge crosses the reservoir tail and bifurcates the water-spread in two parts. Using the EDIT facility of ERDAS, the bridge pixels were converted to water pixels.

For removing unwanted discontinuous water pixels, a GIS utility known as "CLUMP" was used. An 8-connected clump image was formed for all the water images. This utility created a clump around each discontinuous group of pixels and assigned a unique value to each clump. The clump value of the reservoir water-spread was read from the clumped image. Using the "MODELER" option, the reservoir water-spread was separated out from the water image.

Further, main River at the tail end of a reservoir and numerous small channels join the reservoir from different directions around its periphery. The water in these channels is classified as water. However, the elevation of water in these channels and rivers may remain higher than the reservoir level and must be excluded from the calculation of water-spread area. In the case of Rihand reservoir, for the images of April 3, 2001 and January 18, 2001, the discontinuity in water pixels at the tail-end was obvious and there was no need of subjective curtailment. For the other three images (dated 20.11.1999, 29.09.2000, and 16.11.2000), the tails were curtailed from the point of termination of water-spread area. There were no extended channels around the periphery of the reservoir that needed curtailment. The final reservoir water-spread of September 29, 2000 overlaid with water spread area of April 3, 2001 image is presented in Figure – 3.4.

3.2.4 Derivation of contours

After finalising the water spread area for a particular image, the periphery of the reservoir was derived. First, the islands within the spread area and the diagonally connected pixels were removed, using the CLUMP utility in ERDAS. Then, the three different kinds of filters, namely Edge Detection, Horizontal and Vertical were convoluted with the total water spread image. After obtaining the peripheral pixels, the elevation values were assigned to them using the MODELER.

The revised contours were developed for all the imageries individually and the same were overlaid in one image after assigning the elevation values. The revised contours of the submergence area are presented in Figure – 3.5.

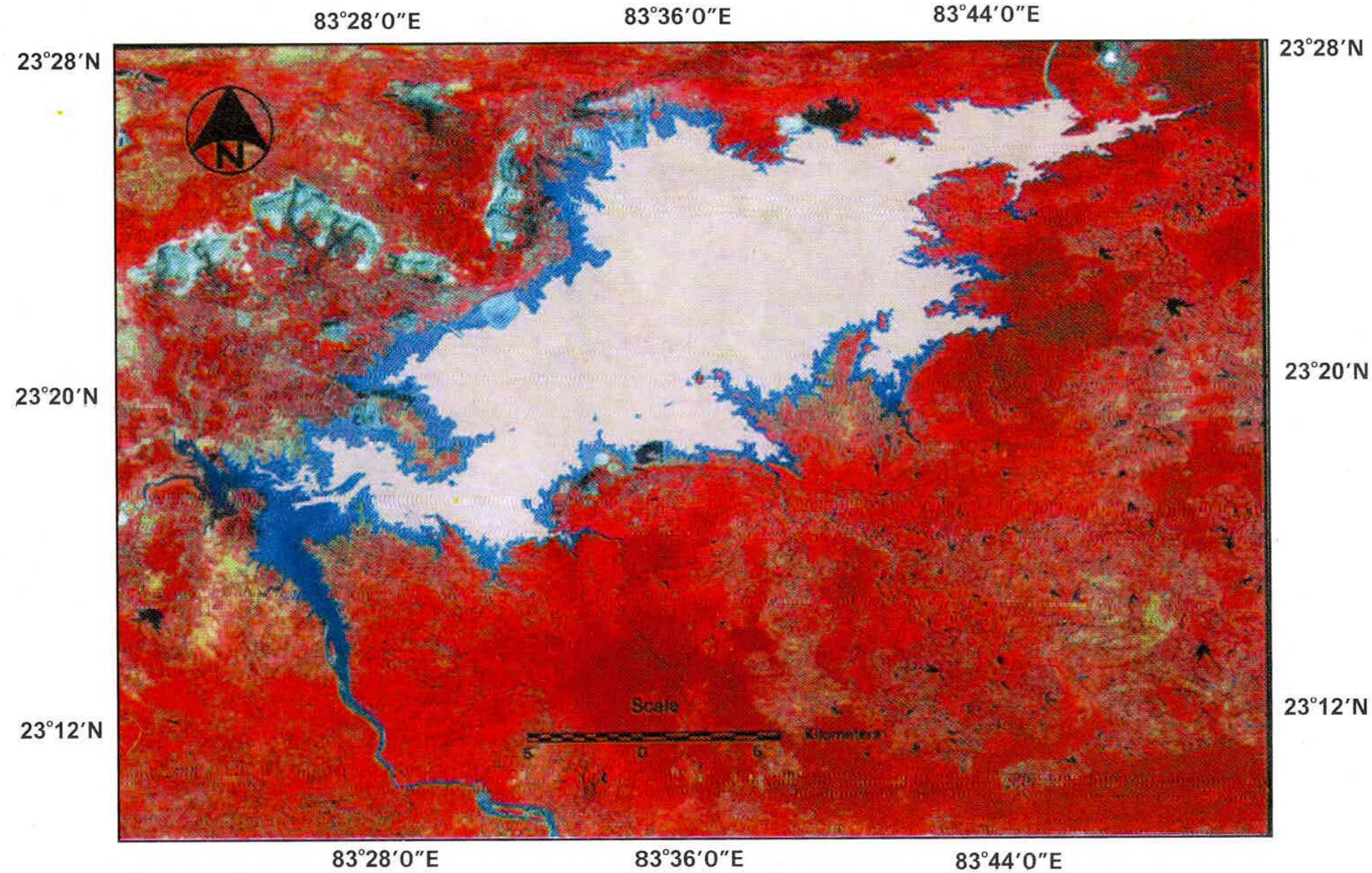


Figure 3.4 : FCC of geo-referenced image of Sept. 29, 2000 overlaid with water spread area of April 3, 2001

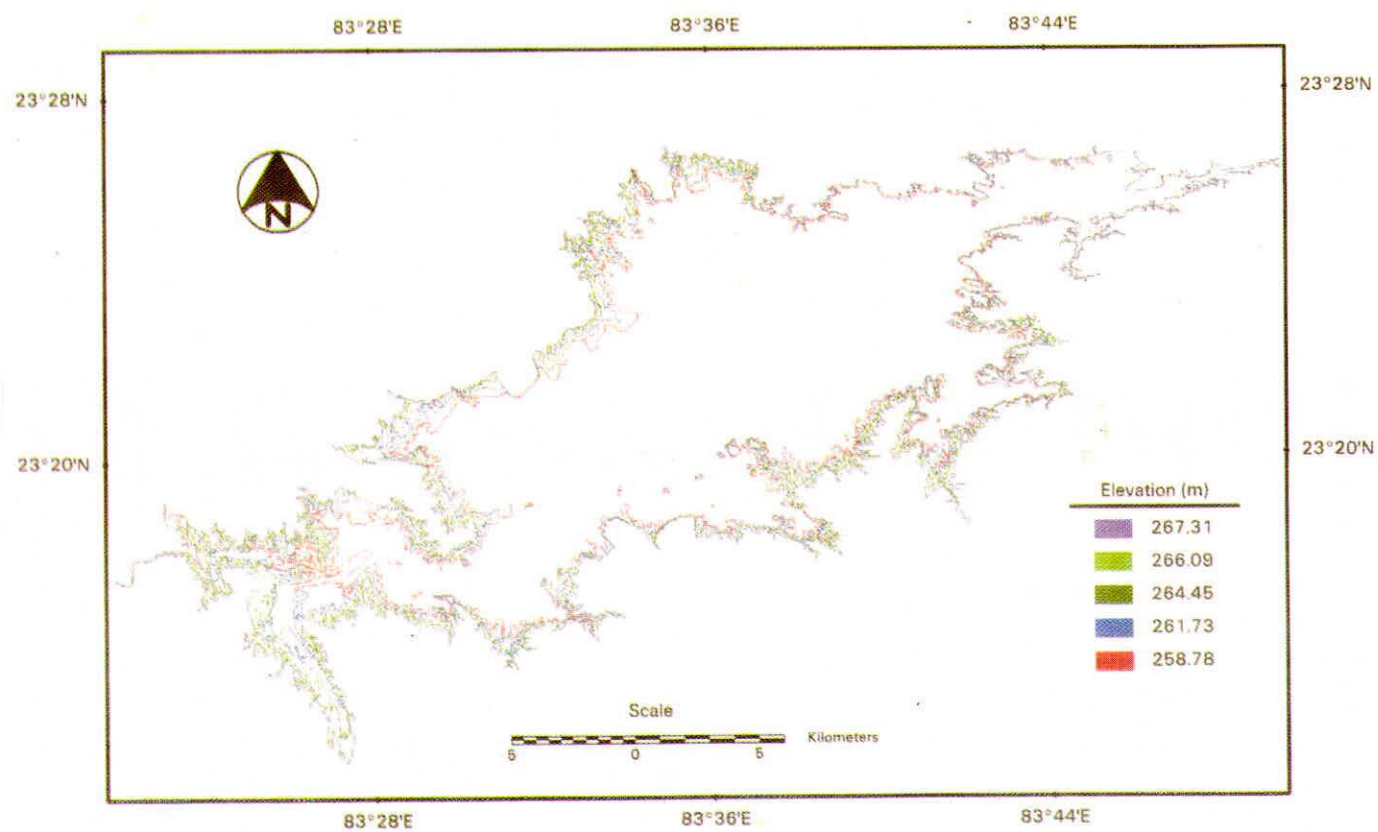


Figure 3.5 : Revised contours of Rihand reservoir from remote sensing analysis.

3.3 RESULTS AND DISCUSSION

After finalising the water spread areas of all the five date imageries, the histograms of the imageries were analysed and the number of water pixels in each was recorded. It is important to mention here that before recording the number of pixels from the histogram, the skip factor for the statistics calculation was set equal to 1.

Revised areas at different elevations in the reservoir (obtained from the remote sensing analysis) were calculated by multiplying the number of pixels in the water spread area by the size of one pixel (24m x 24m). The reservoir capacity between two consecutive reservoir elevations was computed using the trapezoidal formula.

From the estimated values of revised areas at different elevations, the corresponding revised capacities in various intermediate zones were worked out using the trapezoidal formula as mentioned above. The cumulative capacity of the reservoir at the lowest observed level (258.78 m) was assumed to be the same as the cumulative capacity at this elevation obtained from the hydrographic survey analysis in the year 1995. By linear interpolation, it was found to be 5952.77 Mm^3. Above this lowest observed level, the cumulative capacities between the consecutive levels were added up so as to arrive at the cumulative revised capacity at the maximum observed level (267.31 m). The calculations of revised capacity estimation are presented in Table – 3.3.

Based on the availability of satellite data and the water level variation in the Rihand reservoir during the period 1999-2001, the study was carried out for the zone of the reservoir lying in-between the elevations 258.78 m and 267.31 m. The revised areas at five different elevations were calculated by determining the continuous water spread areas from the remote sensing data and multiplying the number of pixels by the size of each pixel. The available capacity in the reservoir in-between 258.78 m and 267.31 m comes out to be 2585.223 Mm^3. This capacity excludes the capacity of ash dykes and water pools created around the reservoir for various thermal power plants.

In comparison to the results of original survey or the hydrographic survey, the estimates of waterspread areas at different elevations by the remote sensing technique comes out to be very less. Probably, the most important reason for the same is the consideration of waterspread areas of the surrounding ash dykes and water pools. In the present analysis, these have not been taken into account because of the fact that, though constructed within the water spread of the reservoir, their capacities no longer contribute to the capacity of the reservoir. Further there may not be much deposition of silt in these ponds. As a consequence, the capacity of the reservoir in the zone of study comes out to be 3011.507 Mm^3 by the hydrographic survey method while the same from the original survey is estimated to be 3466.1 Mm^3.

Since the details of hydrographic survey concerning the consideration of capacity of surrounding water pools is not known, the sediment deposition in the zone of study can not be estimated. Similarly, the original survey included the capacities of surrounding water pools. Hence, it is not advisable to compare the results of remote sensing with the original survey either. However, the remote sensing analysis provides an estimate of the available capacity in the reservoir in the year 2001 and five different contours in the zone of study.

4.0 SEDIMENTATION STUDY OF TUNGABHADRA RESERVOIR

4.1 THE STUDY AREA AND DATA AVAILABILTY

The Tungabhadra River, an important tributary of the Krishna River, derives its name from two tributaries: Tunga and Bhadra, both of which originate in Varahaagiri in the Western Ghats of Karnataka State at an elevation of about 1,196 m. These two rivers confluence at a village called Kudali near Shimoga. Tungabhadra River flows for a distance of 768 km before joining the Krishna River at Sangameswaram in Kurnool District of Andhra Pradesh at an elevation of about 264 m. The Varada and the Hagari are the two important tributaries of the Tungabhadra. The Varada drains a large area of the Western Ghats and falls into the Tungabhadra at an elevation of about 509 m and 156 km below the confluence of the Tunga and the Bhadra. The Hagari joins the Tungabhadra about 169 km upstream of its confluence with the Krishna. The total drainage area of Tungabhadra is 71,417 km^2. The figure 4.1 shows the location of Tungabhadra River in the Krishna basin.

The Karnataka State Irrigation Department has constructed a composite dam across the Tungabhadra River near Mallapur village in Hospet taluka of Bellary district of Karnataka State. Located at about 15^0 15' 0'' N latitude and 76^0 21' 0" E longitude, the dam is about 69.25 km from Bellary city. The Tungabhadra dam was completed in 1953 and its catchment area is 28,180 sq. km. The total length of the dam is 2.4 km. The water-spread area of the reservoir is 378 km^2 having maximum width of 15.30 km near dam and a fetch of 85.34 km. The storage capacity of the reservoir is 3751 M cum. The pictorial view of the reservoir is shown in the Figure 4.2. The salient features of Tungabhadra Reservoir are given in Appendix 4.1.

Satellite data corresponding to various water elevations procured from NRSA Data Center for the year 2002-2003, are described in Table 4.1. Based on the status and availability of remote sensing data and the time spacing in-between the satellite data, eight scenes were ordered. It was found that the reservoir level varied from 494.79 m on 22.09.2002 to 477.45 m on 30.05.2003 and the reservoir elevations corresponding to each scene were collected from Irrigation Branch, Tungabhadra Board, TB Dam. The capacity evaluation was restricted to this zone of reservoir only. The selected dates of pass of satellites has covered a wide range of reservoir levels in the operational (live) zone of reservoir between minimum draw down level (MDDL) as 477.01 m and Full Reservoir level (FRL) as 497.74 m. Under normal conditions, such situation rarely occurs. The design sedimentation rate was also collected from Tungabhadra Board to compare the result. It is 4.29 ha-m/100sq.km/year.

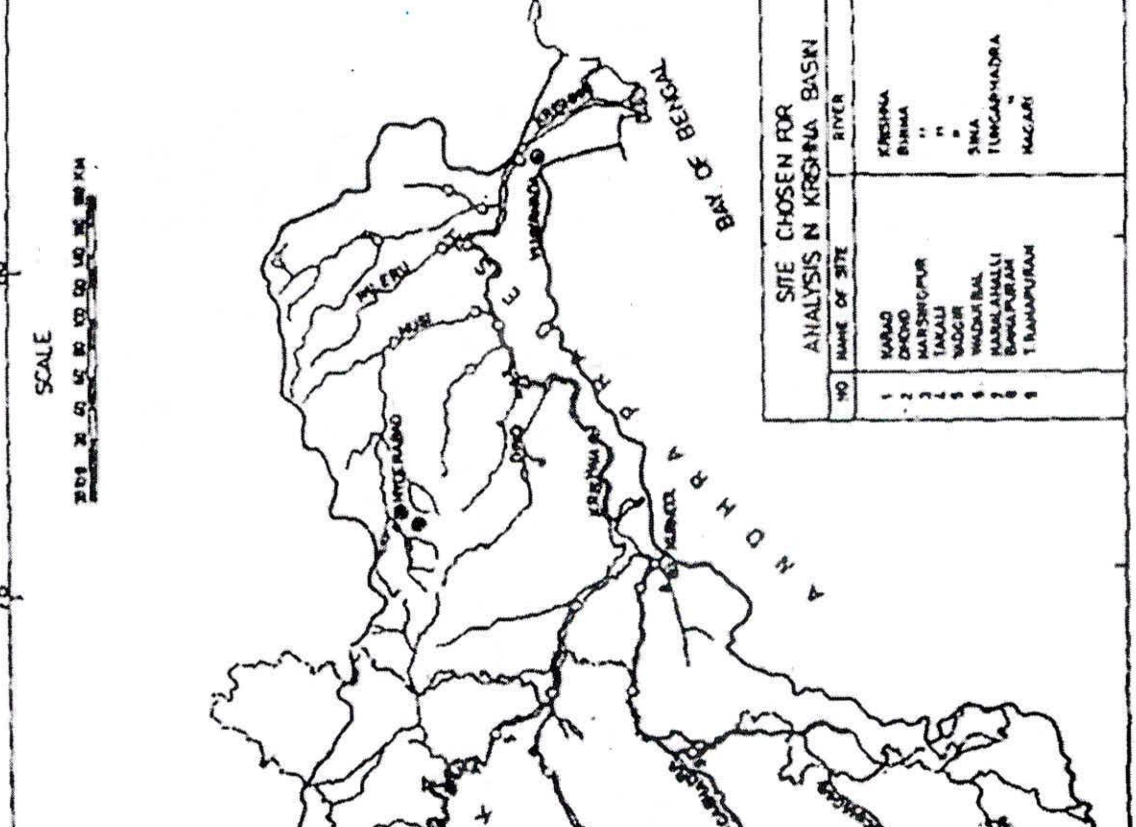


Figure 4.1. Location Map of Tungabhadra Sub-basin

Figure 4. 2 Pictorial View of Tungabhadra Reservoir

Table 4.1 Details of IRS 1D LISS-III Satellite Data used for Tungabhadra study

Sr. No.	Date of Pass of satellite	Path/Row
1.	22nd September 2002	98/62
2.	6th December 2002	98/62
3.	31st December 2002	98/62
4.	25th January 2003	98/62
5.	19th February 2003	98/62
6.	10th April 2003	98/62
7.	5th May 2003	98/62
8.	30th May 2003	98/62

The elevation-capacity table during the year 1981 was obtained from Tungabhadra Dam Authority. It is presented in the Table 4.2.

Table 4.2 Original Elevation-Area-Capacity Table for Tungabhadra Reservoir

Sr. No.	Reservoir elevation (m)	Water Spread Area (km^2)	Total capacity (M. cum)
1.	477.45	12.28	36.38
2.	479.05	22.80	64.01
3.	481.64	44.81	149.98
4.	482.19	52.32	166.12
5.	483.11	65.82	220.01
6.	484.02	79.62	286.41
7.	485.24	101.08	396.01
8.	486.05	117.57	495.37
9.	487.07	130.69	611.27
10.	488.29	150.67	751.30
11.	489.20	170.23	927.92
12.	490.20	192.79	1122.06
13.	491.03	214.50	1280.14
14.	492.25	240.94	1557.62
15.	493.17	266.06	1789.32
16.	494.08	290.57	2044.28
17.	495.3	319.72	2416.17
18.	496.21	344.01	2719.56
19.	497.13	369.06	3045.54
20.	497.74	386.06	3275.68

4.2. METHODOLOGY

The image processing capabilities of Integrated Land and Information System (ILWIS) GIS software were used to extract the water spread area of the reservoir. The pixel size of the processed data was 23.5 m. A false colour composite (FCC) of 3, 2, and 1 bands combination was prepared which corresponds to the standard FCC. The waterspread area was quite distinct and clear in the FCC. The images were analysed and waterspread area was calculated against the respective elevations

Band slicing, band ratioing as well as normalised difference water index (NDWI) was computed to identify water pixels. The near-IR image of September 22, 2002 and the corresponding NDWI image are shown in Figure 4.3. The image of water spreads, as obtained from the interpretation were edited to remove the effect of noise, isolated water pixels, extension of tail and joining or rivers around the water spread (Figure 4.4). After finalising the waterspreads of all the eight imageries, the histograms of the imageries were analysed and the number of water pixels in each was recorded. The imageries of different dates showing the near-IR image and the corresponding water spread area are shown in Figure 4.5 to Figure 4.8. Water Spread area has been calculated by multiplying number of pixels with the area of each pixel (for LISS III data - 23.5m X 23.5m).

4.3 RESULTS AND DISCUSSIONS

To calculate the prevailing water spread area, ten different elevations have been selected which vary from minimum draw down level (MDDL) at 477.01m to full reservoir level (FRL) at 497.74 m. The revised areas and corresponding elevations are presented in Table 4.3.

Table 4.3. Reservoir Elevation and Revised Waterspread Area on the Selected Dates of Satellite Pass

Sr. No.	Date of Pass of satellite	Number of Water Pixels	Reservoir elevation (m)	Revised Area using R. S. (km^2)
1.	22.09.2002	494189	494.79	272.92
2.	06.12.2002	297934	490.20	164.53

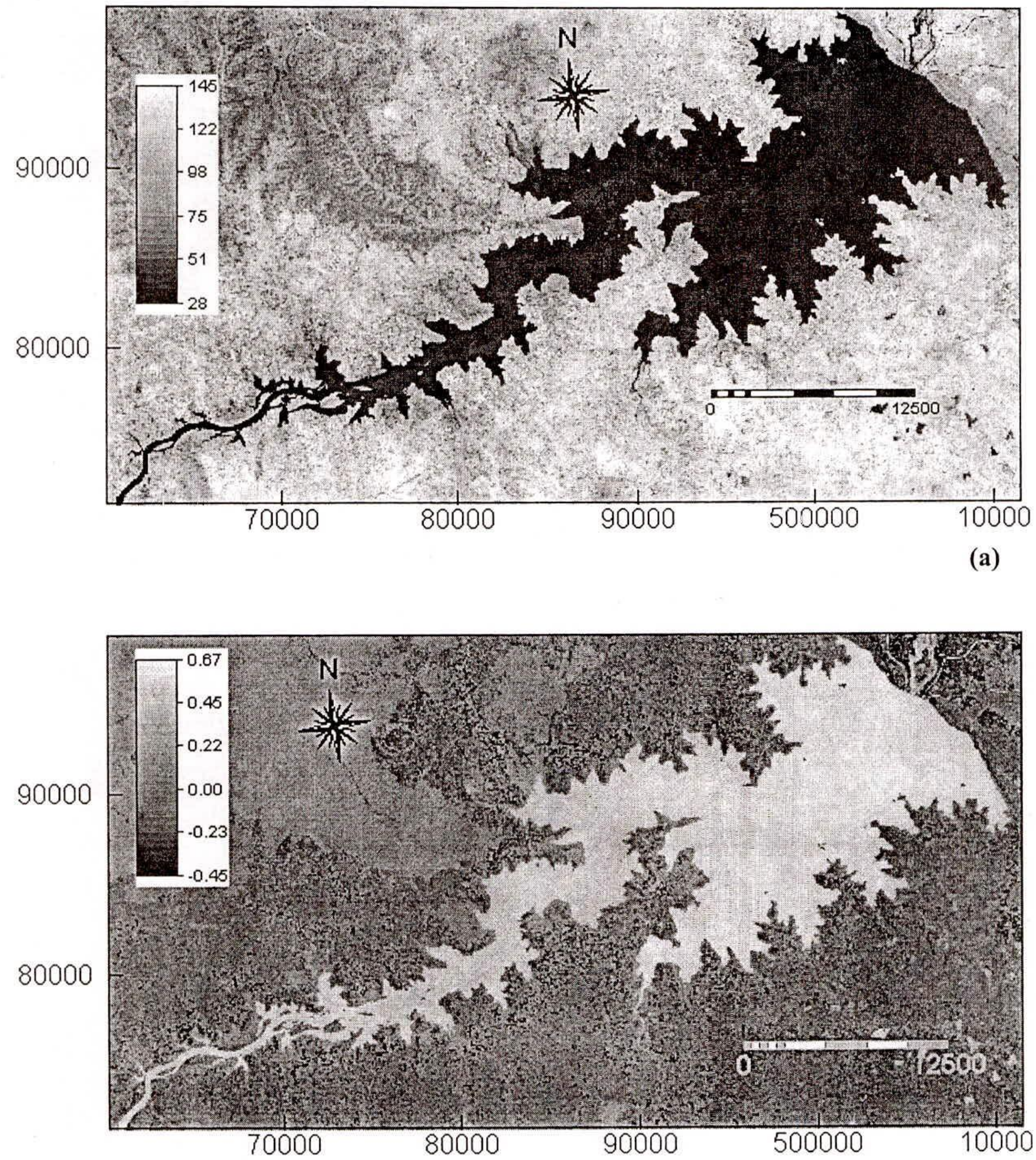


Figure 4.3 a. Near-Infrared (NIR) of Tungabhadra Reservoir on September 22, 2002
b. Corresponding Normalised Difference Water Index Image (NDWI)

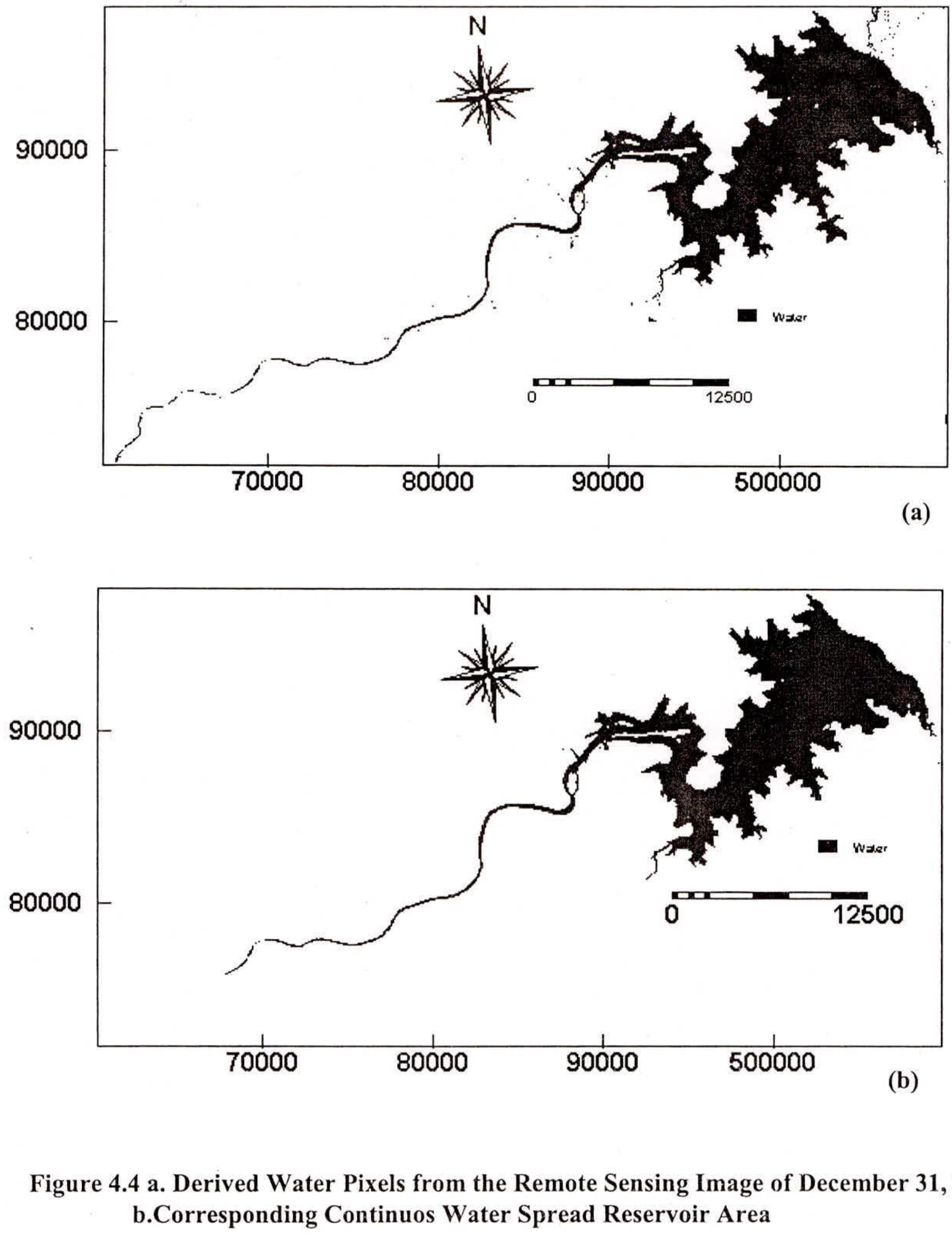
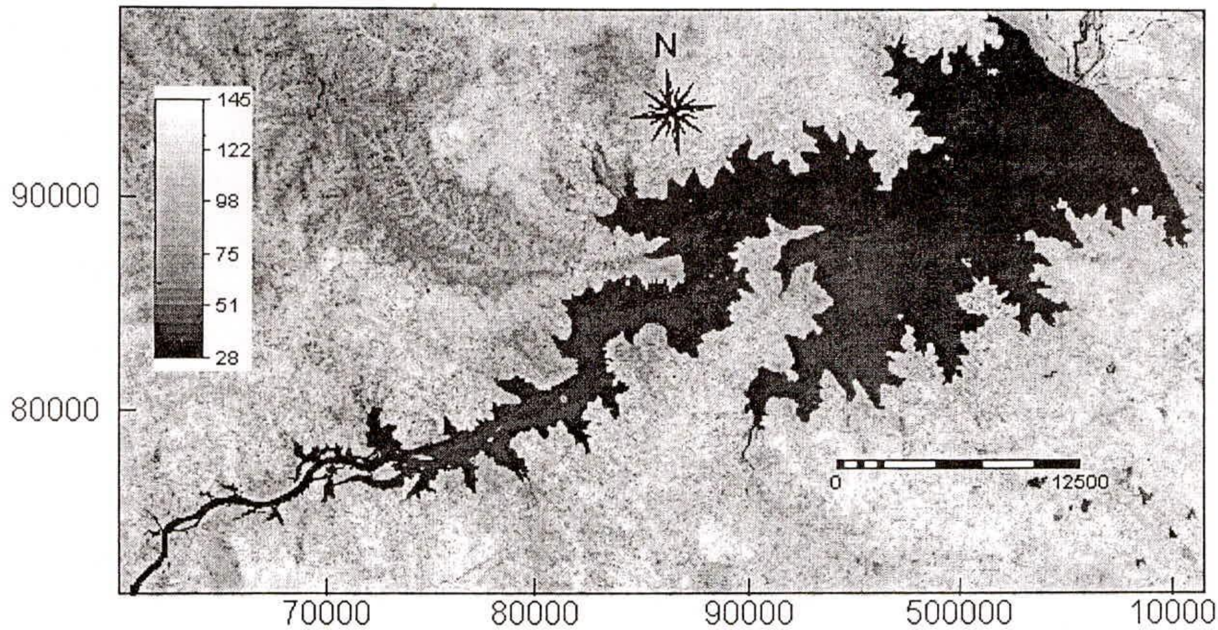
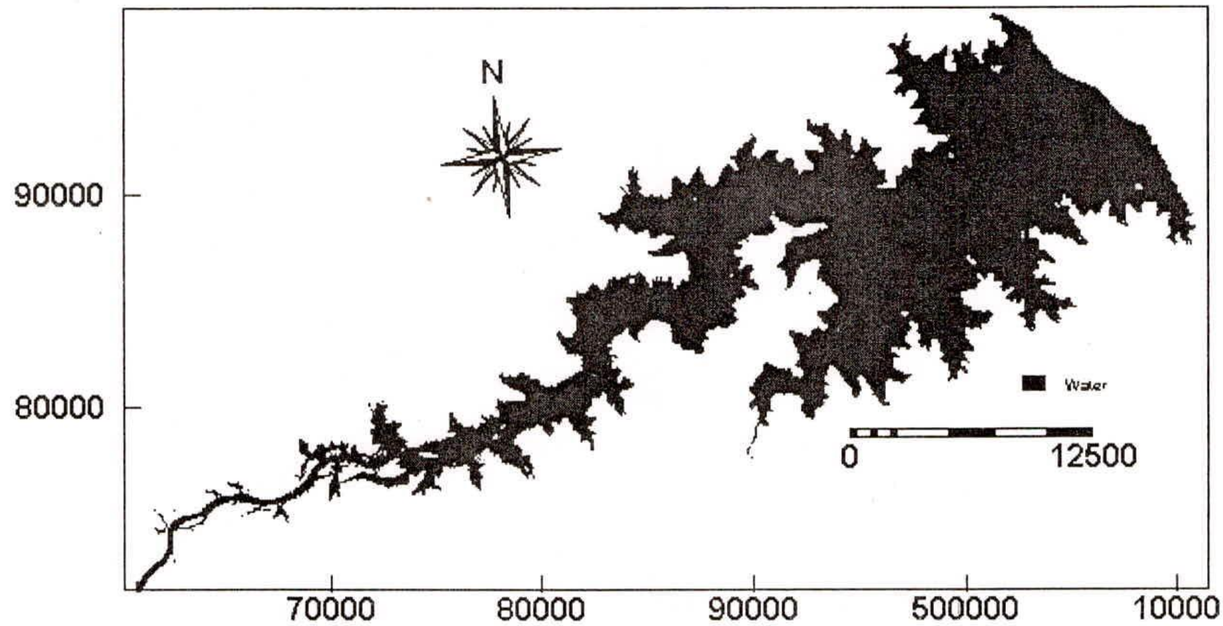


Figure 4.4 a. Derived Water Pixels from the Remote Sensing Image of December 31, 2002
b.Corresponding Continuos Water Spread Reservoir Area



(a)



(b)

Figure 4.5 a. Near-Infrared (NIR) Image of Tungabhadra Reservoir on September 22, 2002
b. Corresponding Extracted Continuous Waterspread Area

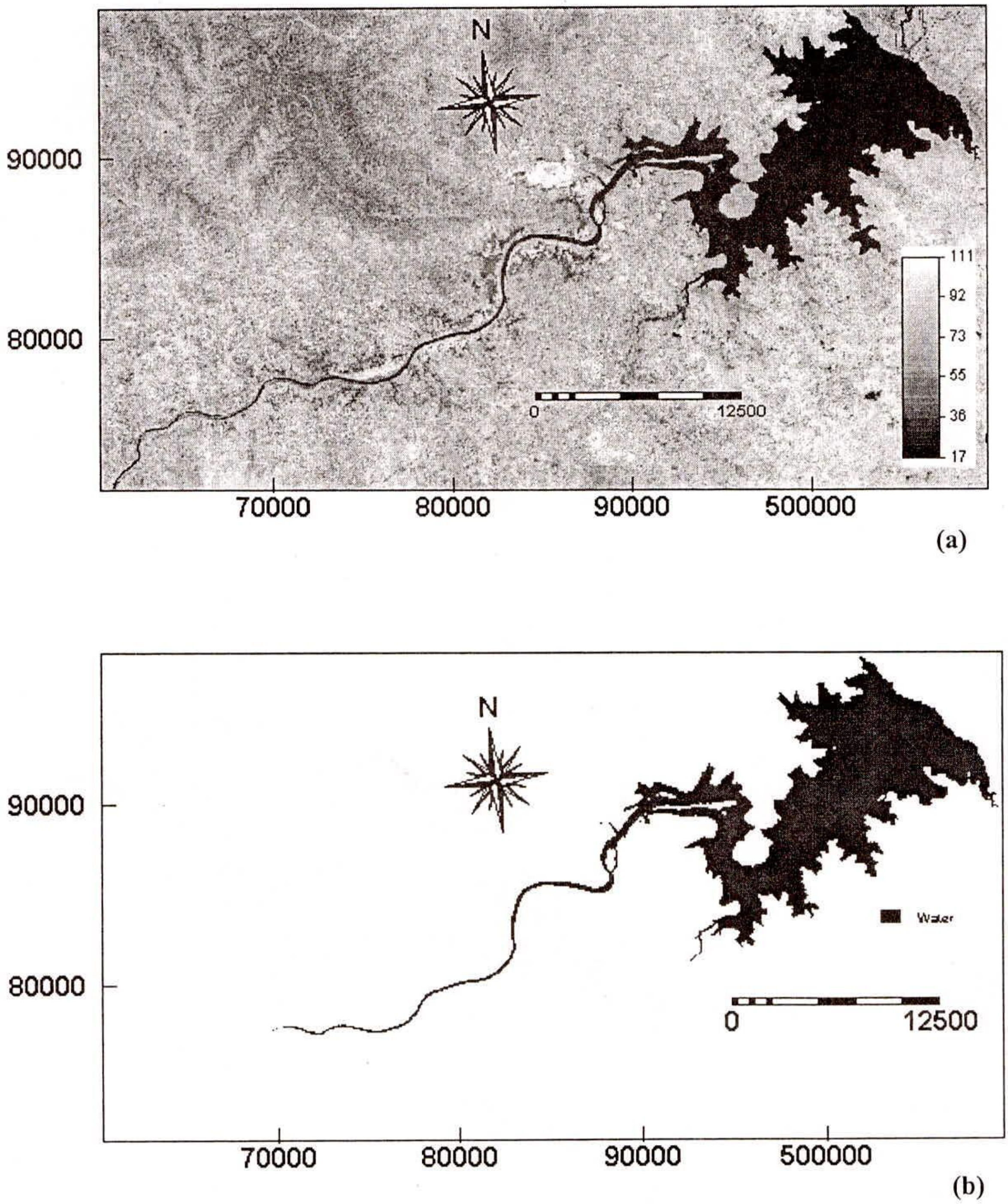


Figure 4.6 a. Near-Infrared (NIR) Image of Tungabhadra Reservoir on December 31, 2002
b.Corresponding Extracted Continuous Waterspread Area

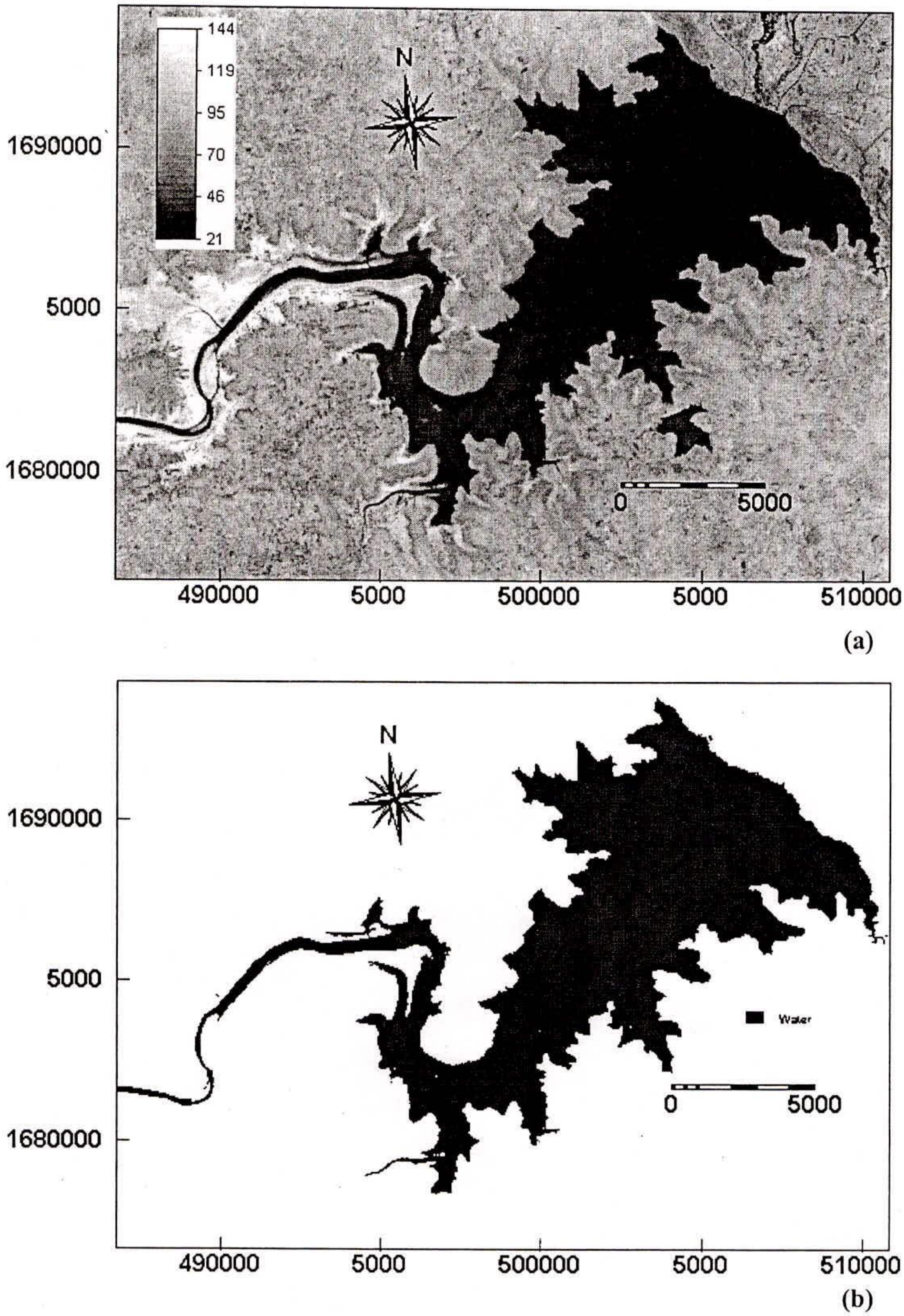


Figure 4.7 a. Near-Infrared (NIR) Image of Tungabhadra Reservoir on February 19, 2003
b.Corresponding Extracted Continuous Waterspread Area

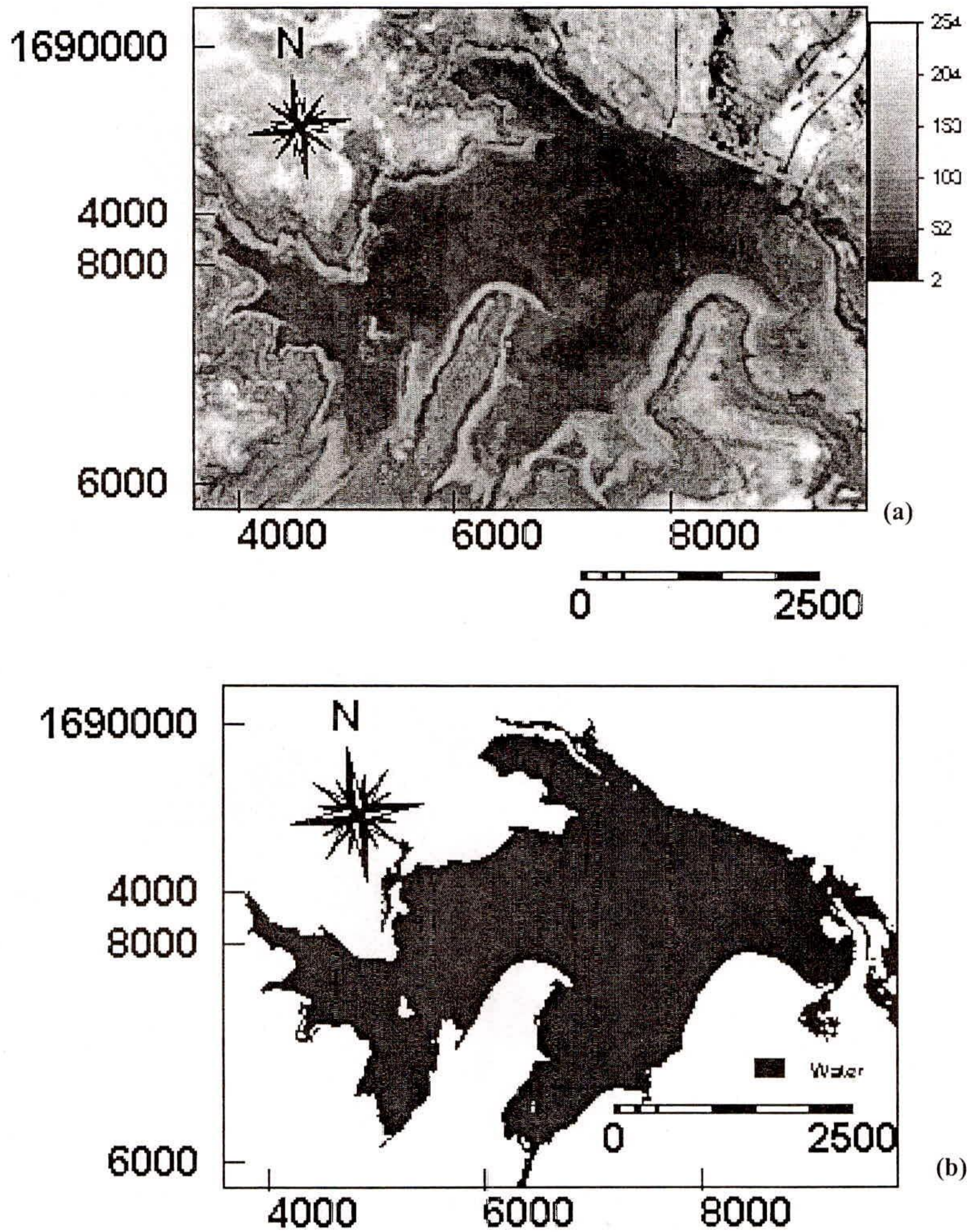


Figure 4.8 a. Near-Infrared (NIR) Image of Tungabhadra Reservoir on May 30, 2003
b. Corresponding Extracted Continuous Waterspread Area

3.	31.12.2002	203815	487.54	112.56
4.	25.01.2003	180167	486.81	99.99
5.	19.02.2003	155262	486.05	85.74
6.	10.04.2003	71844	481.64	39.68
7.	05.05.2003	38294	479.05	21.15
8.	30.05.2003	17499	477.45	9.66

From the known values of previous and revised areas at different elevations the corresponding previous and revised capacities were worked out using trapezoidal formula. The cumulative revised capacity of the reservoir at the lowest observed level (477. 45 m) was assumed to be the same as that of previous cumulative capacity (36.38M cum) as on 1981. Cumulative capacities between the consecutive levels were added up so as to reach at the cumulative previous and revised capacity at the maximum observed level of 494.79 m. The comparison between previous and revised water spread area curves is shown in Figure 4.9.

The difference between the previous and revised cumulative capacity represents the loss of capacity due to sedimentation in the zone under study. The calculations of cumulative capacity of the reservoir are presented in Table 4.4.

Table 4.4. Assessment of Sediment Deposition in Tungabhadra Reservoir using Remote Sensing (RS) for the years 2002/2003

Date of Pass of Satellite	Reservoir elevation (m)	Original Area (km^2)	Revised area using RS data (km^2)	Incremental Volume Original (M cum)	Incremental Volume Revised (M cum)	Cumulative Volume Original (M cum)	Cumulative Volume Revised (M cum)
30.05.2003	477.45	12.28	9.66			36.38	36.38
05.05.2003	479.05	22.80	21.15	27.63	24.06	64.01	60.44
10.04.2003	481.64	44.81	39.68	85.97	77.52	149.98	137.96
19.02.2003	486.05	117.57	85.74	345.97	270.11	495.37	408.06
25.01.2003	486.81	128.21	99.99	93.37	70.51	588.74	478.57
31.12.2002	487.54	137.01	112.56	96.79	77.54	685.53	556.11
06.12.2002	490.20	192.79	164.53	436.53	366.35	1122.06	922.46
22.09.2002	494.79	307.41	272.92	1137.78	993.51	2259.83	1915.97

Figure 4.10 shows the comparison between original and revised capacity of the reservoir. The results show that the revised capacity in the zone under consideration (up to 494.79m) is 1915.97 M. cum, while the original capacity was 2259.83 M. cum. Thus, it can be inferred that the volume of sediment deposition in the zone under study for the period 1981 to 2002 is (2256.85 M. cum – 1915.97 M. cum) 343.86 M. cum. If a uniform rate of sedimentation is assumed in 21 years up to 2002, then the reservoir sedimentation rate is 5.81 ha-m/100 km^2/year. The estimated rate of sedimentation is found higher than the design rate of sedimentation (4.29 ha-m/100 km^2/year). It calls for urgent precautionary and remedial measures to prevent the further siltation of reservoir.

The revised contours were developed for all the imageries individually using the GIS capability of ILWIS software. To represent the overall variation of water spread area, these were overlaid in one image after assigning the elevation values. The revised contours of the submergence area are presented in Figure 4.11.

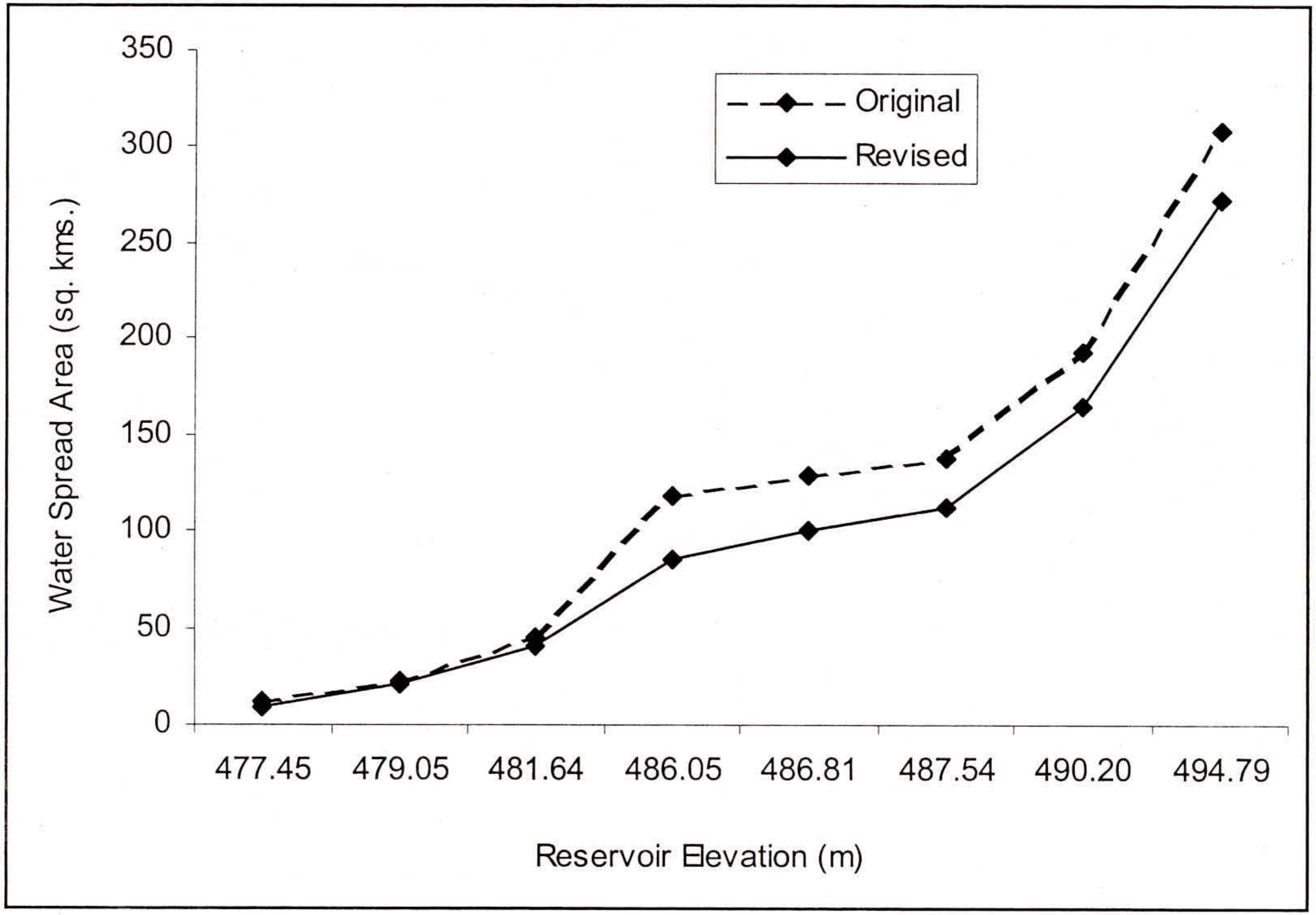


Figure 4.9. Original and Revised Water spread Area Curves for Tungabhadra Reservoir

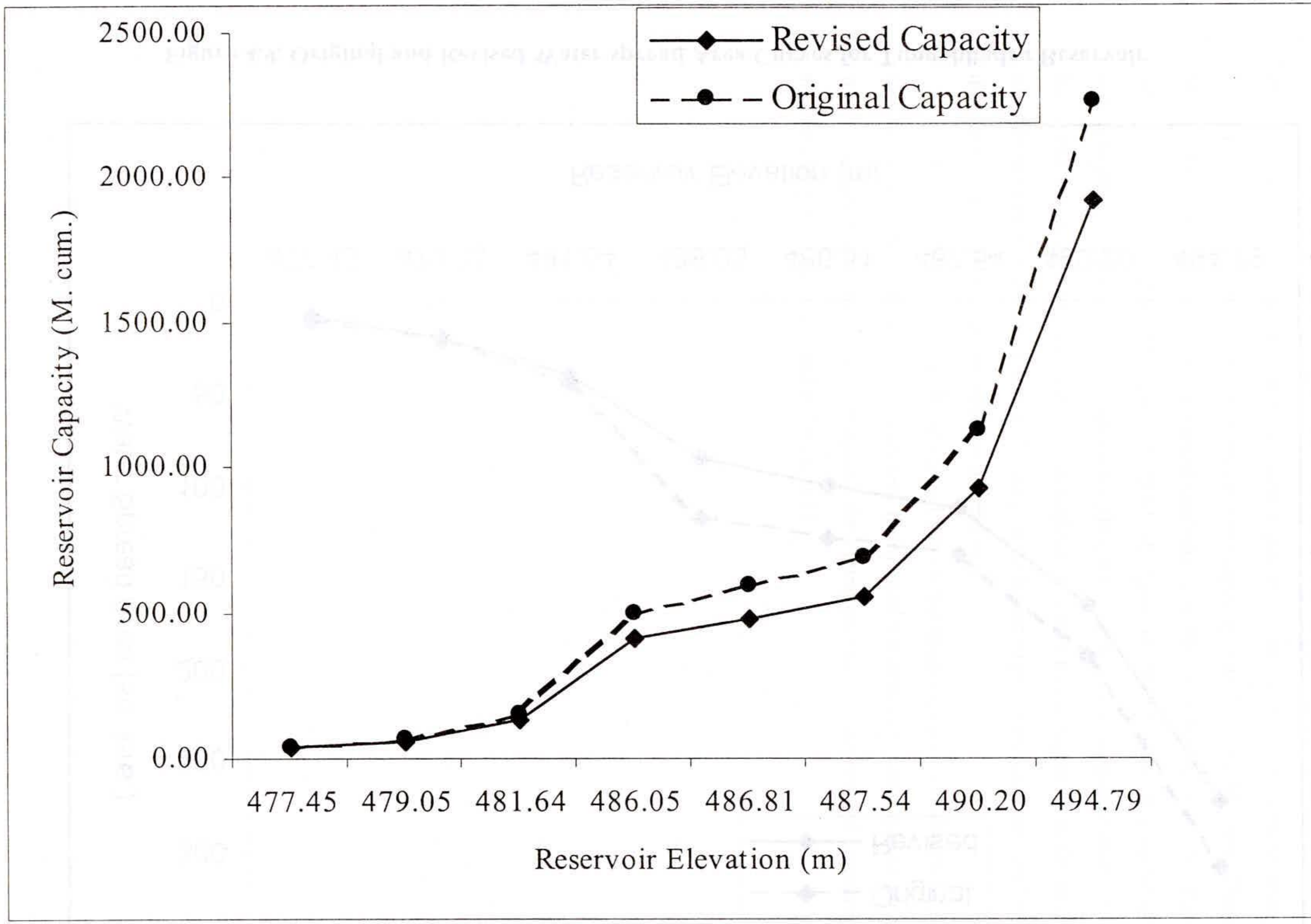


Figure 4.10. Original and Revised Elevation-Capacity Curves for Tungabhadra Reservoir

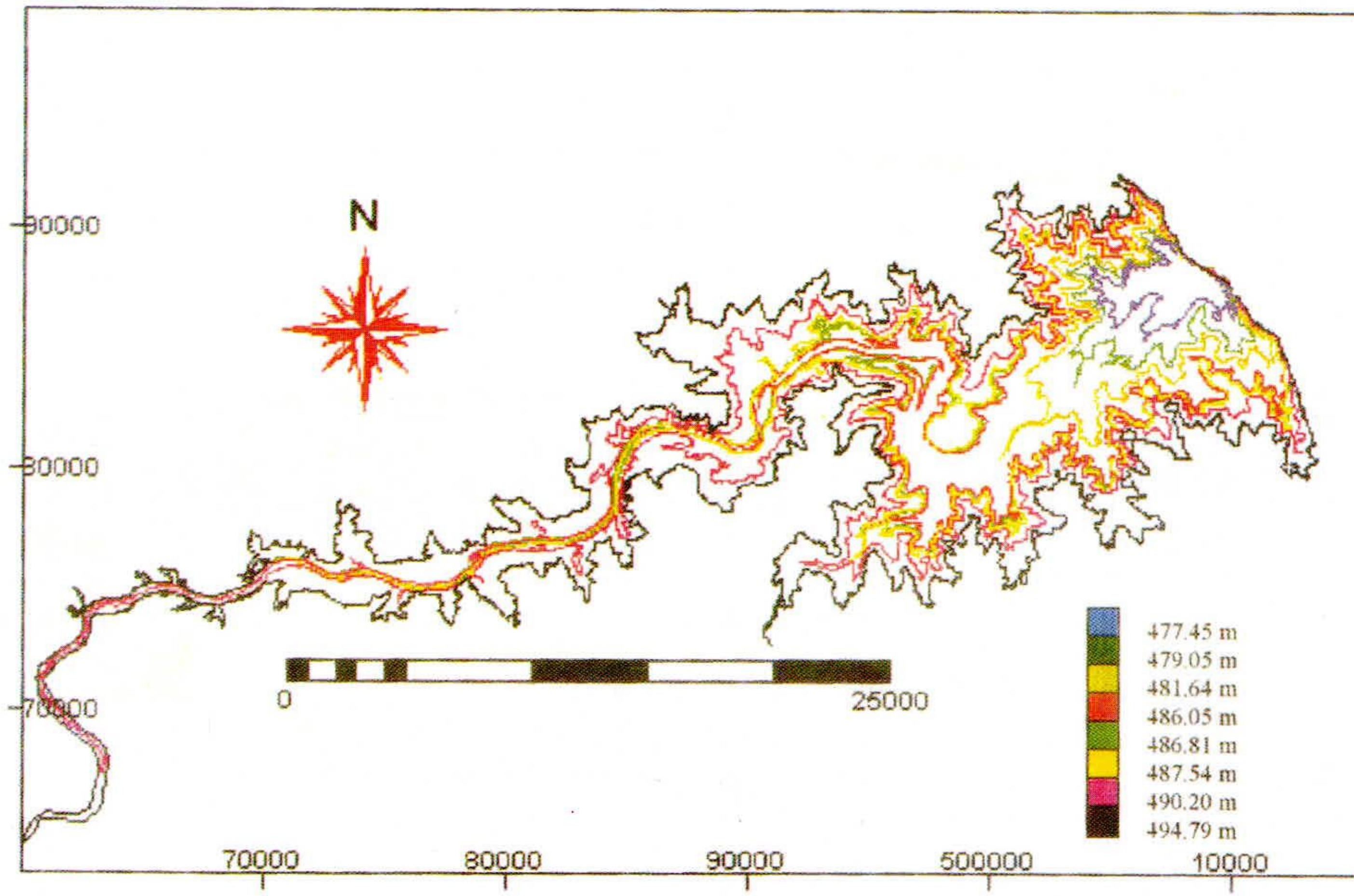


Figure 4.11 : Revised Contours in Submergence Area of Tungabhadra Reservoir

5.0 BARNA RESERVOIR

5.1 THE STUDY AREA AND DATA AVAILABILITY

Barna dam has been constructed on a tributary with the same name in the Narmada basin. The main dam is a 432 meters long masonry structure with maximum height of 48 meters above foundation. The spillway is 115 meters long with crest 35 meters above foundation level. Over the crest, there are eight radial gates. The lake formed behind the dam has a live storage of 45,560 ha-m with submergence area of 7,700 ha.

With a view to ensure progressive utilization of irrigation water, the project has been constructed in two stages. The first stage comprises construction of dam up to crest level of spillway along with dam head regulator and part of Right Bank canal system to irrigate 12,000 ha of Rabi crops. The second stage comprises of work above crest level of spillway, i.e., erection of 6.86 meters high crest gates along with road bridge and construction of the remaining canal system.

The data used in this study are given in Table-5.1.

Table-5.1: Satellite data of IRS 1D LISS III used for sedimentation study of Barna reservoir

Sl. No.	Date of Pass	Elevation (m)
1	20-May-2002	338.69
2	06-Mar-2002	339.47
3	30-Jan-2001	341.42
4	05-Jan-2001	343.03
5	21-Dec-2001	344.20
6	26-Nov-2001	345.90
7	01-Nov-2001	347.05

The original Elevation-Capacity table was used to compare the present capacity at selected elevations. The difference in the capacity is assumed as sediment deposition in the reservoir.

Table 5.2: The original elevation-area-capacity of Barna reservoir

Sl. No.	Reservoir level (m)	Area (Ha)	Capacity (M m^3)	Remark
1.	325.0			River Bed
2.	326.0	130.0	0.980	
3.	328.0	259.0	2.460	
4.	330.0	389.0	8.630	
5.	332.0	583.0	12.840	
6.	334.0	907.0	33.920	
7.	335.0	1114.0	44.410	
8.	335.6	1231.0	55.200	Crest level
9.	336.0	1321.0	53.660	
10	337.0	1555.0	64.760	
11.	338.0	1853.0	80.180	
12.	338.1	1878.0	83.200	MDDL
13.	339.0	2176.0	103.620	
14.	340.0	2526.0	123.290	
15.	341.0	2915.0	156.670	
16.	342.0	3420.0	188.740	
17.	343.0	4081.0	222.050	
18.	344.0	4638.0	264.000	
19.	345.0	5234.0	317.660	
20.	346.0	5830.0	373.790	
21.	347.0	6542.0	437.940	
22.	348.0	7255.0	499.620	
23.	348.55	7708.0	539.000	FRL

5.2 METHODOLOGY

The IRS 1D LISS-3 digital data of eight selected dates were obtained and image processing carried out using ILWIS 3.0. All the images were cut down to cover the Barna reservoir and surroundings.

The images were first geo-referenced using the SOI topographical maps as base map, so that all the images can be overlaid and change in the water spread can be detected. The geo-referencing also gives the geographical area directly in square meters (using metric coordinate system in ILWIS) of any polygon masked from the image. The Normalised Difference Water Index (NDWI) images were created and water spread areas of the reservoir were masked out from all the scenes. The false colour composite image and masked out water spread area from the images of some selected dates have been presented in Figure- 5.1 to Figure- 5.6.

The revised volume between two consecutive elevations of the reservoir has been calculated using waterspread area obtained from satellite data and respective elevations by applying the cone formula. The live storage of the reservoir falls between RL 338.10 m and 348.55 m. The satellite data available for the present study cover the reservoir elevations from 338.69 m to 348.32 m. The revised cumulative capacities at various elevations have been obtained by adding the revised volume between consecutive elevations.

5.3 RESULTS

The computation of revised area and capacities at different elevations have been given in the Table 5.3. The difference between the original and revised cumulative capacity represents the loss in capacity due to sedimentation. Satellite data for FRL, i.e. 348.55 m elevation could not be obtained therefore, for computation purpose, the percentage loss in capacity between elevations 348.32 and 347.05 m has been assumed the same as loss between elevations 348.32 and 348.55 m, i.e. 6.24 %.

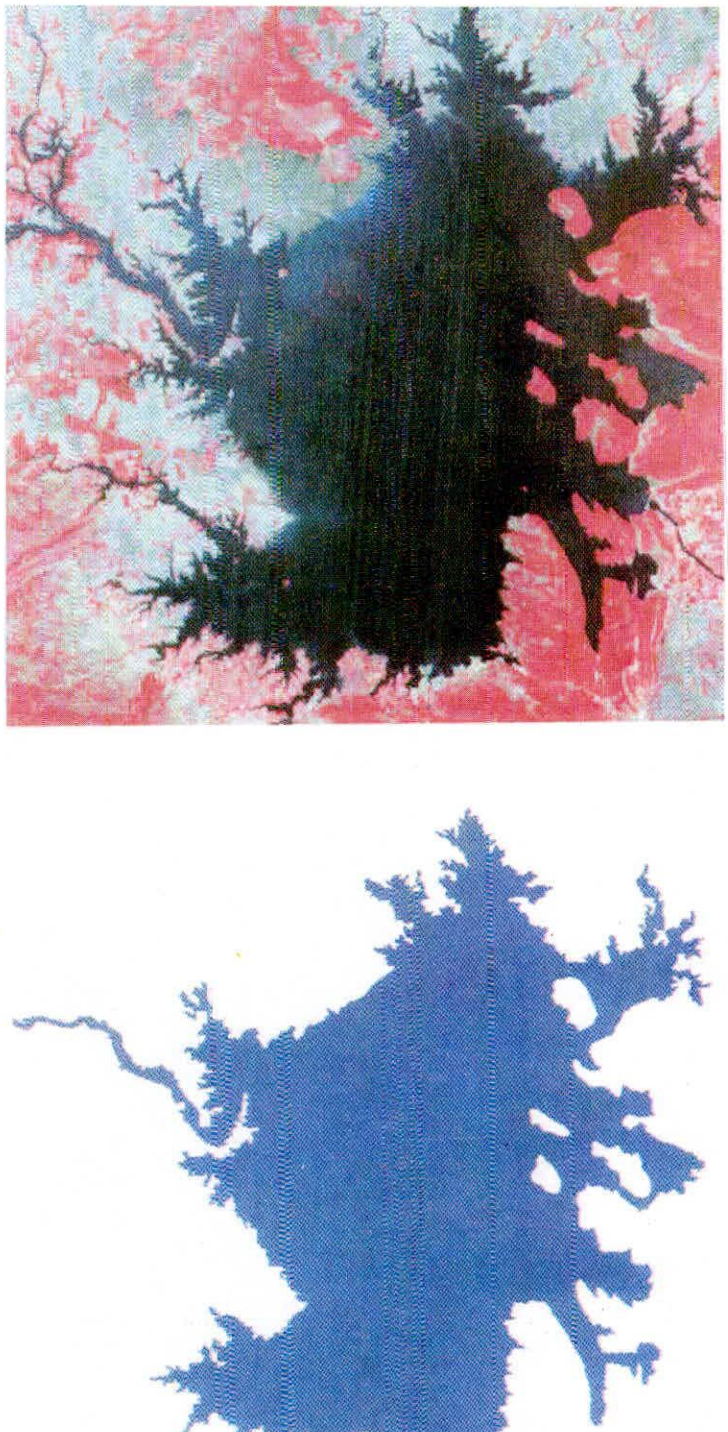


Fig. 5.1 Standard FCC and extracted water spread area of 22 Sept. 2002

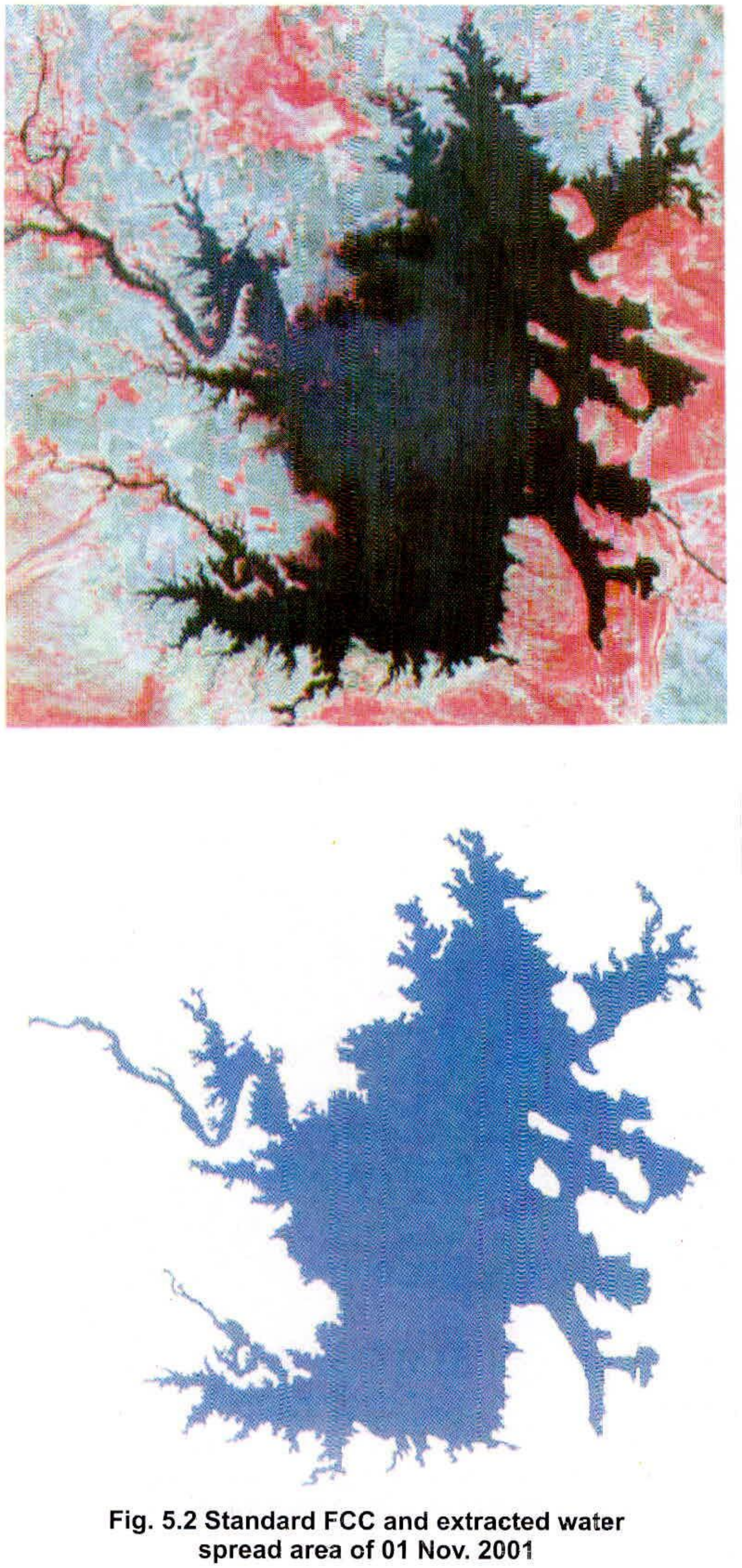


Fig. 5.2 Standard FCC and extracted water spread area of 01 Nov. 2001

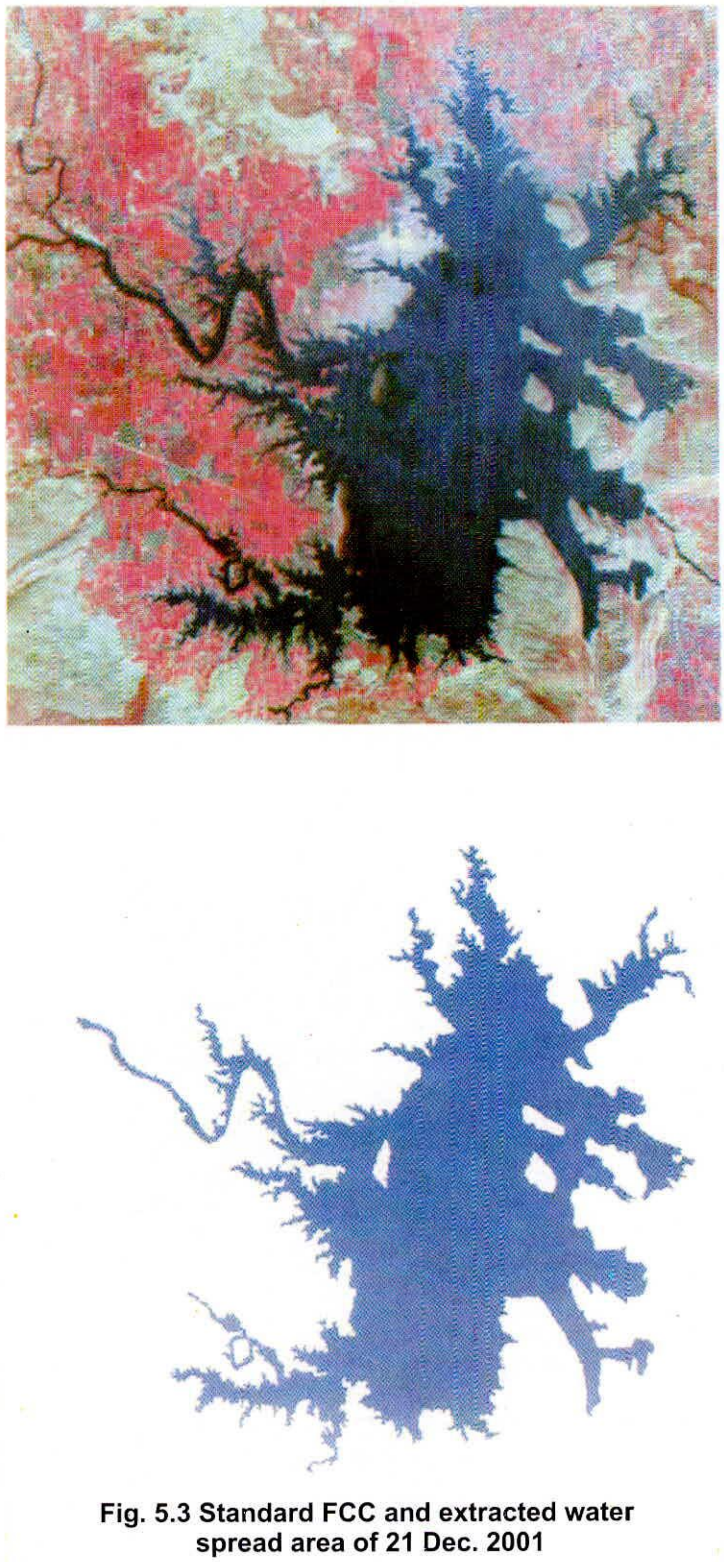


Fig. 5.3 Standard FCC and extracted water spread area of 21 Dec. 2001

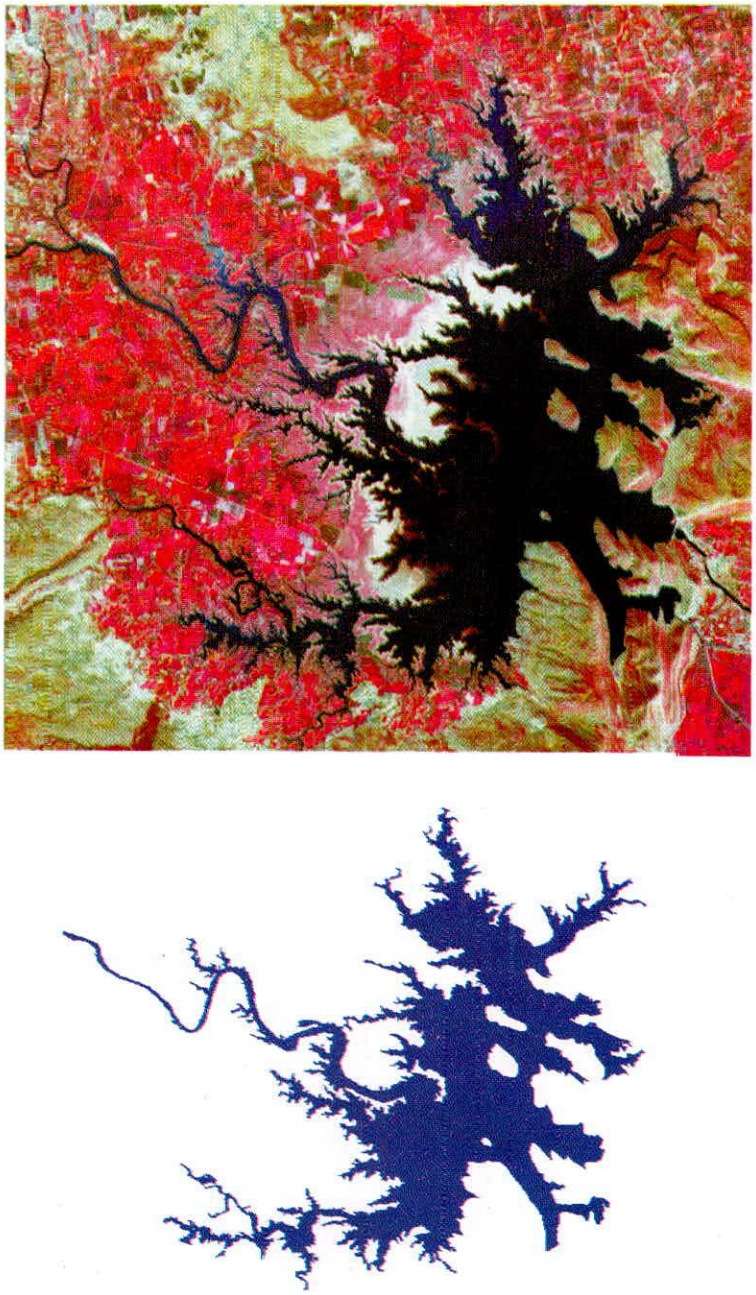


Figure 5.4: Standard FCC and extracted water spread area of 05 Jan. 2001

Figure 5.5: Standard FCC and extracted water spread area of 06 Mar. 2002

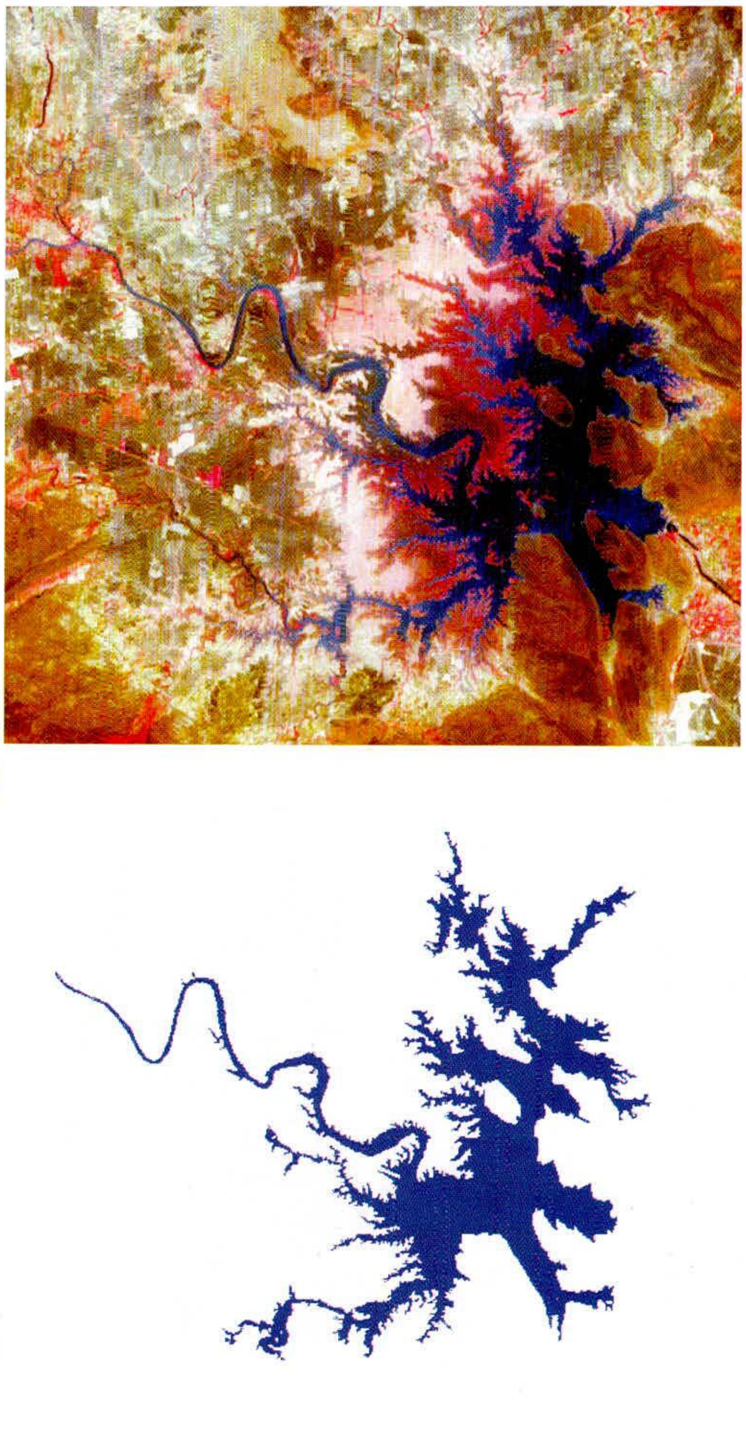


Figure 5.6: Standard FCC and extracted water spread area of 20 May. 2002

Table 5.3: Revised elevation-area-capacity table for Barna reservoir

* Revised volume extrapolated from RL 348.32 m.

S. No.	Date of Pass	Reservoir Elevation (meter)	Number of Water Pixel	Revised Area (hectare)	Revised incremental Volume (M.cu.m)
1.	MDDL	338.10		N.A.	
2.	20-May-02	338.69	28391	1635.3	
					13.616
3.	6-Mar-02	339.47	32263	1858.3	
					39.764
4.	30-Jan-01	341.42	38637	2225.5	
					41.216
5.	5-Jan-01	343.03	50517	2909.8	
					41.224
6.	21-Dec-01	344.20	72482	4175.0	
					77.249
7.	26-Nov-01	345.90	85476	4923.4	
					61.069
8.	1-Nov-01	347.05	99079	5707.0	
					76.453
9.	22-Sep-02	348.32	110041	6338.4	
					15.730 *
10.	FRL *	348.55		N.A.	

The estimated percentage loss in the cumulative storage capacity at eleven different elevations has been presented in the table 5.4. The loss in the live storage capacity (455.8 M.cu.m) of Barna reservoir has been estimated to be 79.766 M.cum i.e., 17.5 % of the live storage. Further, by extrapolating the revised elevation-capacity curve, silting in the dead storage capacity (83.200 M.cu.m.) comes out to be 25.311 M.cu.m. Hence total loss in the gross storage capacity (539.000 M.cu.m.) has been estimated to be 105.077 M.cu.m. in last 27 years.

Table 5.4 Estimation of loss in storage of Barna reservoir

Elevation (meter)	Original Capacity (M.cu.m.)		Revised Capacity (M.cu.m.)		Loss in Cum. Capacity (M.cu.m.)	% Loss in Cumulative Capacity
	Volume	Cumulative Capacity	Volume	Cumulative Capacity		
325.00	55.200	55.200	35.785	35.785	19.415	35.17
335.60	28.000	83.200	22.104	57.889	25.311	30.42
338.10	13.305	96.505	9.713	67.602	28.903	29.95
338.69	18.604	115.109	13.616	81.218	33.891	29.44
339.47	53.991	169.100	39.764	120.982	48.118	28.46
341.42	54.057	223.157	41.216	162.198	60.959	27.32
343.03	51.363	274.520	41.224	203.422	71.098	25.90
344.20	93.370	367.890	77.249	280.671	87.219	23.71
345.90	72.795	440.685	61.069	341.740	98.945	22.45
347.05	81.538	522.223	76.453	418.193	104.030	19.92
348.32	16.877	539.000	15.730	433.923	105.077	19.49
348.55*						

* Extrapolated values

The graph shown in Figure-5.8 gives the elevation vs. original and revised cumulative capacities of Barna reservoir. Further, an equation representing the revised elevation-capacity graph has been obtained and the revised capacities at one-meter interval have been estimated using the same equation. The estimated percentage losses in the cumulative storage capacity at elevations at one-meter interval have been presented in the following Table 5.5.

Table 5.5 Comparison of live storage capacity of Barna reservoir (M cu.m.)

Sl. No.	Elevation (m)	Original (1975)	Satellite Remote Sensing (2002)	Percentage loss
1.	325.00	0.000	0.000	--
2.	335.60	55.200	35.785	35.17
3.	338.10	83.200	57.889	30.42
4.	339.00	103.620	74.855	27.76
5.	340.00	123.290	92.019	25.36
6.	341.00	156.670	112.618	28.12
7.	342.00	188.740	137.200	27.30
8.	343.00	222.050	162.007	27.04
9.	344.00	264.000	200.518	24.05
10.	345.00	317.660	240.351	24.33
11.	346.00	373.790	286.368	15.22
12.	347.00	437.940	339.117	22.55
13.	348.00	499.620	399.149	20.11
14.	348.55	539.000	433.923	19.49

Based on the analysis, it has been observed that 105.077 M.cu.m. of gross storage capacity has been lost due to sedimentation in a period of 27 years (1975 – 2002). If we assume a constant rate of sedimentation over the period of 27 years, it comes out to be 3.891 M.cu.m/year or 389.1 ha-m. The catchment area of Barna reservoir being 1176 sq. km, the silting rate in more common unit is computed to be 33.09 ha-m/100sq. km/year.

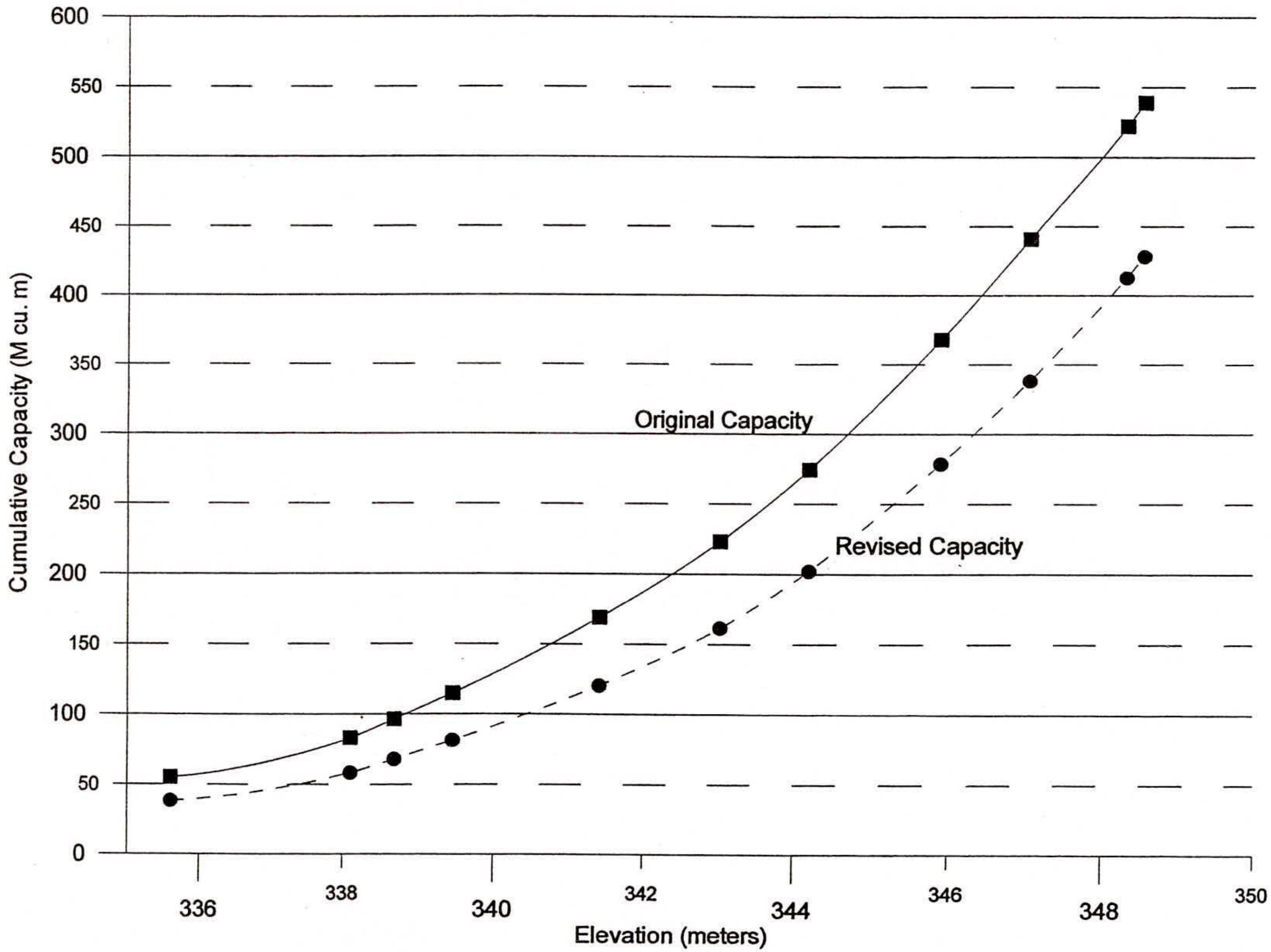


Figure-5.7: Elevation vs. original and revised cumulative capacities of Barna reservoir

6.0 SOMASILA RESERVOIR

6.1 THE STUDY AREA AND DATA AVAILABILITY

Somasila reservoir is located (Fig 6.1) on the river Pennar that flows through the Nellore district in Andhra Pradesh. The reservoir is at a distance of about 80 km from the Nellore town, which is also the district capital. Location of the dam site is 79^0 18' 25" E and 14^0 29' 15" N and it is covered in the SOI toposheet No. 57N/7. The designed FRL of the reservoir is 94.488 m and the storage capacity of this level is 77.988 tmcft respectively. Riverbed level is at 67.056 m. MDDL & dead storage of the reservoir is 82.296 m and the dead storage capacity is 7.567 tmcft.

Since cloud cover is reported for the overall scene, it is recommended that the intending user access the internet website (www.nrsa.gov.in) to browse the data for cloud cover specifically over the reservoir area. This on many occasions yields more cloud free coverage than selected solely from the catalogue. NRSA Data Centre has archived satellite data of past years enabling reservoir surveys even for historic periods.

6.2 PROCESSING OF REMOTE SENSING DATA

Different techniques were tried to distinguish and separate out the water pixels. Density slicing of the near – IR band was carried out and compared with the standard FCC. Though most of the water pixels could be accounted by this technique, it was not considered to give exclusive water pixels in a satisfactory way. To extract only water pixels, a new algorithm was developed using the information of different bands.

Using the spectral information, the algorithm matches the signatures of the pixel with the standard signatures of water and then identifies whether a pixel represents water or not. The algorithm checks for one condition for each pixel and if a pixel satisfies the conditions, then it is recorded as a water pixel, otherwise not. The condition states that "If the DN value of near – IR band of the pixel is less than the DN value of the blue (0.52-0.59 micrometer) and green (0.62-0.68 micrometer), then it must be classified as water otherwise not". Since the absorptance of electromagnetic radiation by water is maximum in the near – IR spectral region, the DN value of water pixels is appreciably less than those of other land uses. Even if the water depth is very shallow, the increased absorptance in the red band will cause the DN value to be less than blue band and green band. If the soil is exposed (may be it is saturated) at the surface, the reflectance will be as per the signatures of the soil, which increases with wavelength in this spectral range. So, this condition differentiates the water pixels exclusively from other pixels.

The condition was applied in the form of a model in the ERDAS /IMAGINE software and the model runs were taken. This condition was employed to differentiate the water pixels in all the imageries. The resulting imagery of water pixels from this method was compared with the near – IR imagery and the standard FCC. The results were found to be satisfactory in all the cases. The biggest advantage of using this method was that it avoided the necessity of selecting different limits as is required in NDVI or density slicing.

Some problems like, cloud cover and presence of noise, were encountered in the process of interpretation. The images of waterspread, as obtained from the interpretation, were edited to remove the effect of clouds, noise, isolated water pixels, extension of tail and joining of rivers around the water spread. Waterspread area that existed during the study period at different elevations is shown in Figure 6.2.

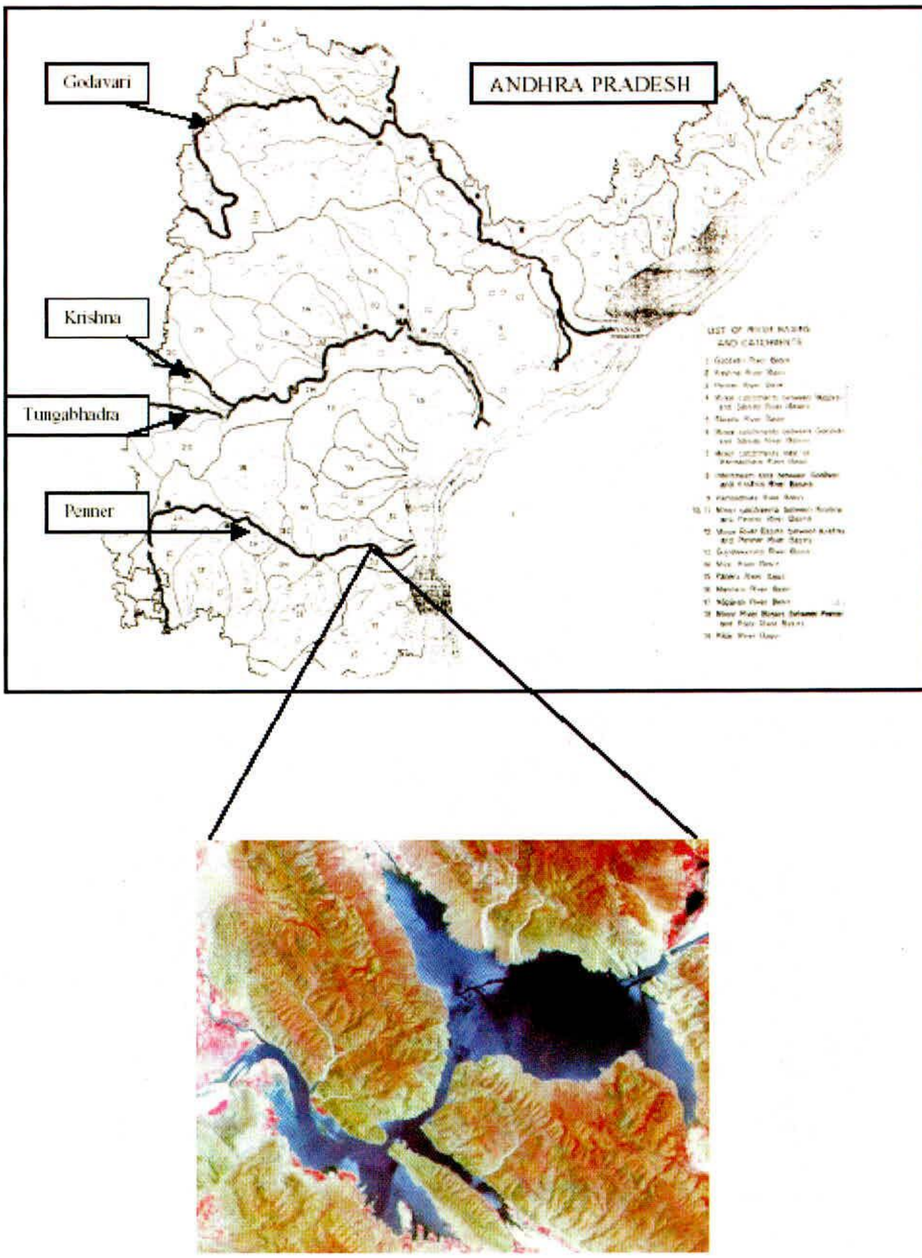
6.3 RESULTS AND DISCUSSION

To calculate the prevailing water spread area of 2002, seven different elevations have been selected (Table.6.1) which vary from 82.3 m (MDDL) to 94.488 m. The dam has been constructed up to the designed FRL 100.584 m but reservoir level is being maintained at 94.488 m due to non-completion of land acquisition in the foreshore submersible area). The satellite data pertaining to these water levels or elevations were procured and revised water spread areas were calculated.

Table-6.1. Selected Water Levels and their corresponding date of satellite pass over the Reservoir.

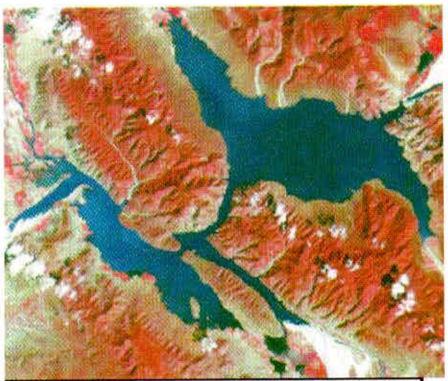
Sl. No.	Date of Satellite Pass	Reservoir elevation (m)
1.	17.01.2002	94.39
2.	22.03.2002	93.47
3.	16.04.2002	92.10
4.	11.05.2002	90.14
5.	05.06.2002	88.30
6.	27.11.2002	85.69
7.	13.09.2002	83.17

Water spread areas of 1987 (henceforth 1987 elevation-area-capacity data will be called as original data) against the selected elevations were drawn from the elevation area

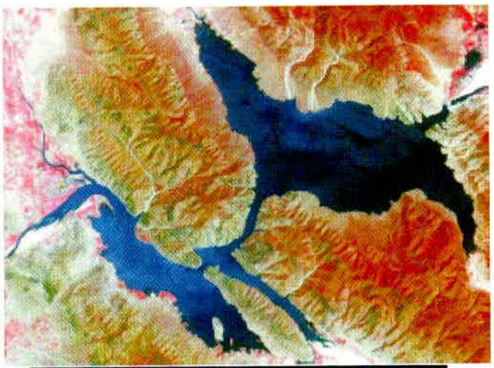


Study Area – Somasila Reservoir.

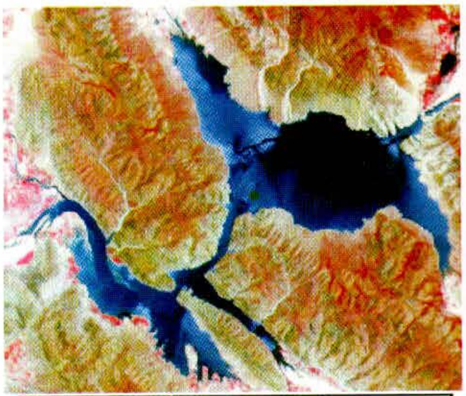
Fig. 61



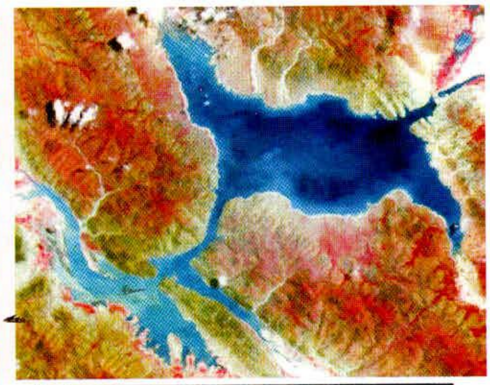
1. At 94.39 m on 17th January 2002



2. At 93.47 m on 22nd March 2002

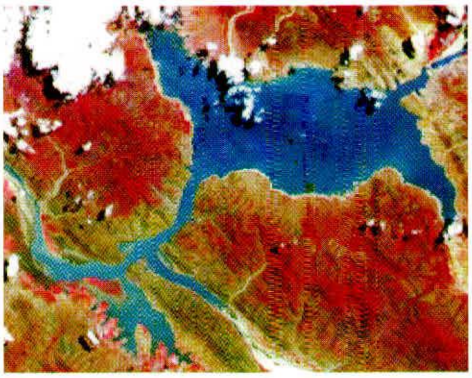


3. At 92.1 m on 16th April 2002

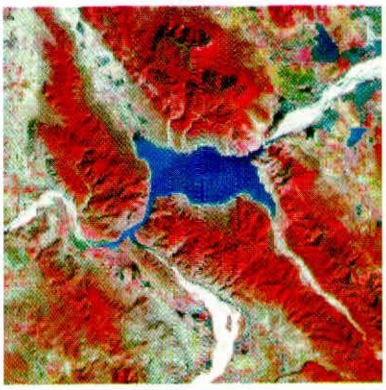


4. At 90.14 m on 11 May 2002

Fig. 6.2



5. At 88.30 m on 5th June 2002



6. At 85.69 m on 27th November 2002

7. At 83.17 m on 13th September 2002

Fig. 6.2

table obtained from the dam authority. Fig 6.3 shows the original and revised water spread area of the reservoir.

From the known values of original and revised areas at different elevations the corresponding original and revised capacities were worked out using trapezoidal formula. The cumulative revised capacity of the reservoir at the lowest observed level (83.17 m) was drawn from the capacity area table (255.35 Mm^3). The calculations of cumulative capacity of the reservoir are presented in the Table 5.2. Above the lowest observed level the cumulative capacities between the consecutive levels were added up so as to reach at the cumulative original and revised at the maximum observed level. The difference between the original (1975) and revised cumulative capacity (2002) represents the loss of capacity due to sedimentation. Fig 6.3 shows the comparison between original and revised capacity of the reservoir. The results show that the volume of sediment deposition is 23.96 M cum (1158.12 – 1134.16) for the period 1987 to 2002. If a uniform rate of sedimentation is assumed in 15 years of occurrence of the reservoir then the sedimentation rate is 1.597 M cum per year.

Table-6.2 Calculation of Sediment Deposition in Somasila Reservoir Using Remote Sensing.

Date of Satellite Pass	Reservoir Elevation (m)	Original Area - 1987 (Mm^2)	Revised Area – 2002 (RS) (Mm^2)	Original Volume (Mm^3)	Revised Volume (Mm^3)	Original Cumulative Volume 1987 (Mm^3)	Revised Cumulative Vol.2002 (RS) (Mm^3)
17.01.2002	94.39	118.73	118.18	107.43	106.19	1158.12	1134.16
22.03.2002	93.47	114.82	112.69			1050.69	1027.94
				150.11	147.43		
16.04.2002	92.10	104.39	102.62			900.59	880.54
				186.41	184.53		
11.05.2002	90.14	86.11	85.92			714.18	696.01
				149.40	144.93		
05.06.2002	88.30	76.38	71.82			564.78	551.09
				175.49	166.90		
27.11.2002	85.69	58.49	56.39			389.29	384.18
				133.94	128.84		
13.09.2002	83.17	47.98	46.04			255.35	255.35

No hydrographic survey has been carried out for this reservoir and hence the results could not be compared.

Note: Somasila project was initiated during 1975. The gauge was erected during 1987 prior to this for few years water was stored up to spillway crest level (86.868 m), hence the deposition of sedimentation was considered from the year 1987 onwards.

7.0 CONCLUSIONS

In the present study, sedimentation rate of five reservoirs, namely, Ramganga, Rihand, Tungabhadra, Barna and Somasila have been computed using remote sensing and the results for these reservoirs are as follows.

As per the results of hydrographic survey of Ramganga reservoir, annual gross sedimentation rate for the period 1974-2000 came out to be 4.89 M m^3. Also in the report of CWC, using satellite imagery, the results show that the sedimentation rate is 4.80 M m^3 and 3.08 M m^3 for the period 1974-97 and 1988-97 respectively. In the present study, the sedimentation rate came out to be 4.23 M m^3 per year in elevations 364.4 –339.05 m.

The hydrographic survey results for Rihand reservoir could not be obtained. The capacity of the reservoir using remote sensing have been carried out for the year 1999-2001 between elevation 267.31 to 258.78 m. The capacity comes out to be 2585.223 $Mm^{3.}$ In comparison to the results of original survey, the estimates of water spread area at different elevations by remote sensing techniques comes out be very less. Probably, the most important reason for the same is the consideration of water spread areas of the surrounding ash dykes and water pools. Therefore, the capacity of the reservoir in the zone of the study comes out to be 3011.507 Mm^3 by the hydrographic survey method while the same form the original survey is estimated to be 3466.1 Mm^3.

The revised capacity in Tungabhadra reservoir up to 494.79m for the year 2002-2003 is 1915.97 M. cum, while the capacity was 2252.83 M. cum as reported during the survey in the year 1981. Based on these results, the sedimentation come out to be 5.81 ha-m/100 km^2/year. The total sediment deposition during the period 1981 to 2002 comes out to be 343.86 M. cum. The estimated rate of sedimentation is found higher than the design rate of sedimentation (4.29 ha-m/100 sq. km/year).

The sedimentation rate for Barna reservoir was carried out for the year 1975-2002 for the elevation zone of 325.0 to 348.55 m. Based on the analysis, it has been observed that 105.077 M.cu.m. of gross storage capacity has been lost due to sedimentation in a period of 27 years (1975 – 2002). If we assume a constant rate of sedimentation over the period of 27 years, it comes out to be 3.891 M.cu.m/year. The catchment area of Barna reservoir being 1176 sq. km, the silting rate in more common unit is computed to be 33.09 ha-m/100sq. km/year.

The sedimentation analysis for the Somasila reservoir has been carried out for the year 1987-2002. The result reveals that the volume of sediment deposition is 23.96 M cum (in elevations (83.17-94.39m) during the period 1987 to 2002. If a uniform rate of sedimentation is assumed in 15 years of the life of the reservoir, the sedimentation rate is 1.6 M cum per year. It is also estimated that the loss in capacity in 15 years and annual loss of storage in percentage is 2.07 and 0.13 respectively. The average annual rate of siltation per 100 sq km of catchment is 7642.74 cubic meters.