# Assessment of Sedimentation in Ghatprabha, Gandhi Sagar, Vaigai, Tandula and Lingnamakki reservoirs using digital image processing techniques

आपो हि ष्ठा मयोभुवः

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAVAN
ROORKEE - 247 667 (INDIA)
2002-2003

# 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 period of time 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 rate in five reservoirs, namely, Ghatprabha, Gandhi Sagar, Vaigai, Tandula and Lingnamakki have been quantified using remote sensing techniques. The study of different reservoirs was carried out by the scientist and scientific staff of the Institute as given below:

| | |
|---|---|
| Ghatprabha reservoir | Dr. S. K. Jain, Sc.'E1' and Mrs. Anju Chaudhry, SRA |
| Gandhi sagar reservoir | Dr. M. K. Goel, Sc.'E1' and Mr. P.K.Agarwal, P.R.A. |
| Vaigai reservoir | Mr. V.S.Jeyakanthan, Sc.'C', Mr. D.Mohana Rangan and Mr. U.V.N. Rao, S.R.A. |
| Tandula reservoir | Mr. T.R.Nayak, Sc.'C' and Mr. Rahul K. Jaiswal, P.R.A. |
| Lingnamakki reservoir | Mr. Dilip Durbude, Sc.'B'and Dr. B.Purendra, Sc.'C' |

The present report describes the results of assessment of sedimentation rate using remote sensing techniques for these reservoirs. The study and report was completed under the supervision and guidance of Dr. S.K. Jain, Scientist 'F' and Head, Water Resources Systems Division.

8.4.05

(K.D.Sharma)
Director

## CONTENTS

## LIST OF TABLES

Page No.

# LIST OF FIGURES

# 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, Ghatprabha, Gandhisagar, Vaigai, Tandula, and Lingnamakki 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 |
| Ghatprabha reservoir | 658.6 to 631.1m | 1974-2001 | 4.45 | 31.65 |
| Gandhi sagar reservoir | 398.58 to 380.57m | 1960-61 | 3.58 | 1.557 |
| Vaigai reservoir | 168.61to 152.78 m | 1983-1999 | 0.99 | 1.42 |
| Tandula reservoir | 1089.93 to 1053.03m | 1922-2001 | 0.28 | 3.392 |
| Lingnamakki reservoir | 548.78 to 532.20 m | 1957-2001 | 1.70 | 8.57 |

## 1.0 INTRODUCTION

### 1.1 GENERAL

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. Soil is eroded due to rainfall and winds, resulting in tremendous sediment movement into the watercourses by floods and storms. 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 in fact 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 equipments, e.g. 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.

## 1.2 SEDIMENTATION ASSESSMENT USING REMOTE SENSING

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.

## 1.3 SEDIMENTATION IN INDIAN RESERVOIRS

During the last five decades, India has constructed many major /medium river valley projects involving construction of dams and creation of reservoirs for flood controls, irrigation and hydropower. Although the sedimentation survey of reservoirs in India dates back as early as 1870, the systematic surveys started only in 1958 when the Central Board of Irrigation and Power undertook a co-ordinated scheme of reservoir sedimentation and entrusted this task to several research stations in the country. The analysis of capacity survey data of 46 reservoirs shows a wide variability in sedimentation rate of reservoirs. The sedimentation rate is affected by multiple factors like hydrometerology, physiography, climate etc. Considering these factors, the whole country has been classified into seven regions (Morris, 1995). The sedimentation rate in reservoirs in India is given region wise in Table-1.1:

**Table - 1.1 Reservoir Sedimentation Rates in India (Moris, 1995)**

| Reservoir | Year of Construction | Catchment Area ($km^2$) | Reservoir Volume (mm) | Sedimen-tation Rate (mm/year) | 50% Capacity Loss (year) | Life of Reservoir (Year) |
|---|---|---|---|---|---|---|
| Sriramsagar | 1970 | 91750 | 35 | 0.62 | 1998 | 56 |
| Nizamsagar | 1930 | 21694 | 39 | 0.64 | 1960 | 61 |
| Matatila | 1956 | 20720 | 55 | 0.44 | 2018 | 124 |
| Hirakud | 1956 | 83395 | 97 | 0.66 | 2030 | 147 |
| Girna | 1965 | 4729 | 129 | 0.80 | 2045 | 161 |
| Tungabhadra | 1953 | 28179 | 133 | 1.01 | 2019 | 132 |
| Bhakra | 1958 | 56980 | 172 | 0.60 | 2101 | 287 |
| Maithon | 1955 | 6294 | 218 | 1.43 | 2031 | 152 |
| Lower Bhawani | 1953 | 4200 | 222 | 0.44 | 2205 | 504 |
| Mayurakshi | 1954 | 1860 | 327 | 1.63 | 2054 | 201 |
| Gandhisagar | 1960 | 23025 | 336 | 0.96 | 2135 | 350 |
| Koyna | 1961 | 776 | 3851 | 1.52 | 3228 | 2533 |

## 1.4 OBJECTIVES AND SCOPE OF THE REPORT

The objectives of the study are as follows:

- 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

The chapter-2 briefly describes the methodology. Results of sedimentation assessment in five reservoirs have been described in chapter 3,4,5, 6 and 7.

## 2.0 METHODOLOGY

In this study, digital analysis was carried out for identifying the water pixels and for determining the water spread area. The various steps followed in general in the analysis are described below. There might be some deviations in case of few reservoirs and these have been described at appropriate places.

## 2.1 IMPORT AND VISUALISATION

The satellite data were procured from NRSA, Hyderabad on the CD media. The data were loaded on the computer from the CD-ROM and was imported in the image processing software. Each scene was having 2500 rows, 2520 columns and the information of different spectral bands. There were no header bytes in the data. Imageries of all the dates were imported and stored in the hard disk.

## 2.2 GEO-REFERENCING

While using the temporal satellite data of the same area, it is required to geo-reference the imageries of different time periods. Using geo-referenced imageries, overlaying of different scenes and detection of land use/land cover changes can be made. Using the geo-referenced data, it was possible to overlay the remote sensing data of different dates, to compare the change in the water spread area and to observe the shrinkage in the water spread with time, particularly the tail end of the reservoir. Using the geographic water spread information, revised contours (as prevailing in the present condition after sedimentation) can also be prepared by vectorization of the raster water-spread data and the DEM of the gorge can be generated. Using the revised and the original DEM, the depth of sediment deposited at any point can be determined.

The satellite data of one date or Survey of India toposheets was considered as the base (master). The data of other dates were considered slaves and geo-referenced with the master. In the ERDAS/IMAGINE, a number of viewer windows can be opened at the same time and in the present case, two such windows were opened. In these windows, one master image and one slave image was displayed. Some clearly identifiable features like crossing of rivers, canals, sharp turns in the rivers, dam, bridges etc. were located on both the images and were selected as control points. After completing this process, different images were displayed one over the other and the superimposition was compared for checking the accuracy of geo-referencing.

## 2.3 SEPARATION OF AREA OF INTEREST (AOI)

Since the size of each full scene was very large and our area of interest was only the reservoir spread area, the reservoir area and its surrounding was separated out from the full scene in all the data. This was done through a utility named area of interest (AOI). A polygon was constructed which covered the reservoir spread area and some area adjacent to it. Now the data corresponding to this AOI polygon was saved in a new file and similar procedure was repeated for all the imageries by using the same AOI. Separation of the area of interest from the full scene resulted in less consumption of computer space, easy handling of files and appreciable reduction in the analysis time. This also reduced the efforts for editing the files at the later stage.

## 2.4 IDENTIFICATION OF WATER PIXELS

Though spectral signatures of water are quite distinct from other land uses like vegetation, built-up area and soil surface, yet identification of water pixels at the water/soil interface is very difficult and depends on the interpretative ability of the analyst. Deep water bodies have quite distinct and clear representation in the imagery. However, very shallow water can be mistaken for soil while saturated soil can be mistaken for water pixels, especially along the periphery of the spread area. Secondly, it is also possible that a pixel, only at the soil/water interface, may represent mixed conditions (some part as water and other part as soil). Just by looking at the tone and colour of a pixel it is difficult to tell the difference between suspended sediment and shallow water. After all, it is basically the same material with the same reflection properties. Therefore, very shallow water will have the same colour and brightness as very turbid (high concentration of suspended sediment) water. To try to separate the two features, we must examine the shape as well as the change in the spatial distribution of the feature over time. If the feature has the wispy shape of water in motion and the pattern changes with time, then there is a strong likelihood that the feature is suspended sediment.

In the visible region of the electromagnetic spectrum (0.4 - 0.7 μm), the transmittance of water is quite significant while the absorptance and reflectance are low. The absorption of water rises rapidly in the near-infrared band while the reflectance and transmittance decrease appreciably. The transmittance of visible radiation through water causes the bottom of the water body to reflect appreciably, transmitted back through the water and detected by the sensor. In such cases, it may not be clear from the visible bands whether the detected surface is above or below the water surface. For resolving this issue, the image in the near-infrared portion of the spectrum is inspected as a submerged surface will not be detected in this portion of the spectrum. At near-infrared wavelengths, water apparently acts as a black body absorber and the boundary between the water and other surface features becomes quite prominent. However, along the periphery of the water spread area, the reflectance from the wetland may be quite similar to the reflectance from the adjacent shallow water. For differentiating pixels in such situations, comparative analysis of the digital numbers in different bands needs to be carried out. The signatures of the water and soil/vegetation show opposite trends from the Green band (0.53 - 0.59 μm) onwards. Beyond Green band 2, with increase in wavelength, water reflectance curves show downward trend while soil/vegetation curves show upward trend. This characteristic was mainly used to differentiate the exclusive water pixels from other pixels in all the data.

In the study for estimation of water-spread area three techniques have been applied, they are unsupervised classification, classification of NDVI and NDWI images.

### 2.4.1 UNSUPERVISED CLASSIFICATION

Multi-spectral classification is an information extraction process that analyses the spectral signature and then assigns pixels to classes based on similar signatures. Classification procedures attempt to group together such similar pixels so that a GIS layer can be generated with each land cover type represented by a different class. The detail of the class depends on the spectral and spatial resolution characteristics of the imaging system. Unsupervised classification is a method in which the computer searches for natural groupings of similar pixels called clusters (Jensen, 2000). In ERDAS, unsupervised classification is performed using an algorithm; the analyst input the number of clusters desired and a confidence threshold. The computer then builds clusters iteratively .and the clusters become more and more refined with each iteration. The iterations stop when the confidence level (or a maximum number of iterations specified by the user) is reached. After the clusters are built, the analyst must select the land cover classes (water, vegetation etc.) and then assign each cluster to the appropriate class. For this, it is important that the user have a good knowledge of the region being mapped, since he or she must decide what land cover the pixels of each cluster represent. Once all the clusters have been assigned to a class, the image of clusters can be recoded into a GIS layer, which displays each land cover class with a different colour.

### 2.4.2 Band

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 generalized condition is stated as, "*If the DN value of* *near-IR band of the pixel is less than the DN value of the Band 2 and Band 3, then it must be classified as water otherwise not*". The condition was applied in the form of a model in the ERDAS/IMAGINE software and the model runs were taken.

Since the absorptions 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 absorptions in the Band 4 will cause the DN value to be less than Band 3 and Band 2. 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.

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.

### 2.4.2 NDVI approach

Numerous vegetation indices have been developed to estimate vegetation cover with the remotely sensed imagery. A vegetation index is a number that is generated by some combination of remote sensing bands. The most common spectral index used to evaluate vegetation cover is the Normalized Difference Vegetation Index (NDVI). The basic algebraic structure of a spectral index takes for form of a ratio between two spectral bands Red and near infrared (NIR). This index is calculated by subtracting Red reflectance from NIR reflectance, and dividing by the sum of the two. For instance, in vegetation areas, the NIR portion of the spectrum is reflected by leaf tissue, and the sensor records the reflectance.

The index is calculated as follows:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \qquad (2.1)$$

The value of NDVI index can range from -1 to +1. Vegetated surfaces tend to have positive values, bare soil may have near zero, and open water features have negative values. Now from the output we have to select different values as the limits pertaining to be water required in NDVI. In addition to NDVI values, we have to apply one algorithm, which is discussed below.

### 2.4.3 NDWI Approach

McFeeters (1996) developed an index similar to the NDVI, which is called the NDWI. This stands for the Normalized Difference Water Index. Any instrument having a green band and a near infrared band can apply this index. The NDWI was derived using principles similar to those that were used to derive the NDVI. The NDWI is calculated as follows:

$$NDWI = \frac{(GREEN - NIR)}{(GREEN + NIR)} \tag{2.2}$$

where GREEN is a band that encompasses reflected green light and NIR represents reflected near-infrared radiation. The selection of these wavelengths was done to: (1) maximize the typical reflectance of water features by using green light wavelengths; (2) minimize the low reflectance of NIR by water features; and (3) take advantage of the high reflectance of NIR by terrestrial vegetation and soil features. When equation (2.2) is used to process a multi-spectral satellite image that contains a reflected visible green band and an NIR band, water features have positive values; while soil and terrestrial vegetation features have zero or negative values, owing to their typically higher reflectance of NIR than green light. Image processing software can easily be configured to delete negative values. This effectively eliminates the terrestrial vegetation and soil information and retains the open water information for analysis. The range of NDWI is then from zero to one. Multiplying equation (2.2) by a scale factor (e.g. 255) enhances the resultant image for visual interpretation.

## 2.5 REMOVAL OF DISCONTINUOUS WATER PIXLES 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 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 required that the isolated water pixels, surrounding the water-spread area and/or located within the islands, be removed from the interpreted water image.

For removing unwanted discontinuous water pixels around the reservoir, 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 clump of reservoir water spread was separated out from other water clumps.

## 2.6 STORAGE CAPACITY OF A RESERVOIR

The capacity of a reservoir on dam site is determined from the contour map of the water spread area. A topographic survey of the dam site is carried out before the dam construction starts, and a contour map is drawn. The area enclosed within each contour is measured using planimeter. The contour elevations and the areas enclosed at respective elevations can be plotted in the form of a curve called Area Elevation Curve. The volume of water that can be stored by the reservoir at a certain water surface elevation can be computed after determining the increment of storage between two elevations (Δ s). The increment of storage (Δ s) between two elevations is usually computed by multiplying the average of the areas at the two elevations $\left[\frac{A_1 + A_2}{2}\right]$, by the elevation difference (Δ h). The summation of these increments below any elevation is the storage volume below that level. Thus, the capacity of a reservoir can be calculated either by using trapezoidal formula, prismoidal formula or by cone formula as given below:

i) Trapezoidal formula

$$\text{Volume (V)} = h\left[\frac{A_1 + A_n}{3} + A_2 + A_3 + A_4 \ldots\ldots\ldots + A_{n-1}\right] \qquad \ldots(2.3)$$

ii) Prismoidal formula

$$\text{Volume (V)} = \frac{h}{3}\left[(A_1 + A_n) + 4(A_2 + A_4 + \ldots\ldots) + 2(A_3 + A_5 + \ldots\ldots)\right] \qquad \ldots(2.4)$$

iii) Cone formula

$$\text{Volume (V)} = \sum \frac{h}{3}\left\lfloor A_1 + A_2 + \sqrt{A_1 * A_2}\right\rfloor \qquad \ldots(2.5)$$

Where, $A_1$, $A_2$, ... $A_n$, are the areas enclosed between successive elevation lines having a height interval of h.

# 3.0 SEDIMENTATION STUDY OF GHATPRABHA RESERVOIR

## 3.1 THE STUDY AREA

The Ghatprabha (Hidkal) reservoir is located on Ghatprabha River (Figure 3.1). The details of the reservoir including river and catchment characteristics are given below.

### 3.1.1 The Ghatprabha River

The Ghatprabha River with its main tributaries viz., the Hiranyakeshi, the Taamraparani, and the Markandeya, is one of the principal rivers of the Northern part of the Karnataka State. It is one of the major inter-state tributaries of the Krishna River. The total catchment area of Ghataprabha and its tributaries is 8829 sq. km (3.41 percent of the area of the Krishna basin).

The river rises from an elevation of 884 m above m. s. l. in the Western Sahyadri range near Amboli to flow in the eastern direction for a distance of 283 km before joining the Krishna River at Kudalasangama in Bijapur district, about 35 km north-east of Kaladgi, at an elevation of 500m. The river flows for about 60 km in the Ratnagiri and Kolhapur districts of Maharashtra before entering Karnataka. Two of its tributaries, the Hiranyakeshi and Markandeya, also rise in the Western Ghats and flow through Maharashtra and Karnataka. In its flow, the river drops 53 m at the famous Gokak falls at the 192nd km of its journey.

### 3.1.3 Climatic and Hydro-Meteorological Characteristics

#### Climate

The Ghatprabha basin lies in the Western Ghats where the mean annual temperature is $26^{0}$ C. During January which may be taken as representative of the winter months, the mean annual daily temperature is $15^{0}$ C, the mean daily maximum temperature generally exceeds $30^{0}$ C. During April which may be taken as representative of summer months, preceding the monsoon, the mean annual daily temperature is $22^{0}$ C and the mean maximum daily temperature is about $35^{0}$ C. During July, which may be taken as representative of monsoon months, the mean daily minimum temperature is about $20^{0}$ C and the daily mean maximum is about $27^{0}$ C. During October, which may be taken as representative of the post-monsoon months, the mean daily minimum temperature is about $23^{0}$ C and the mean daily maximum is about $39^{0}$ C.

#### Reservoir Submergence

The reservoir extending over an area of 78.03 sq. km (7803 ha) and falling entirely within the State of Karnataka, caused submergence of 22 villages necessitating rehabilitation of 15,660 project affected people in 26 rehabilitation centers.

## 3.2 AVAILABILITY OF SATELLITE DATA

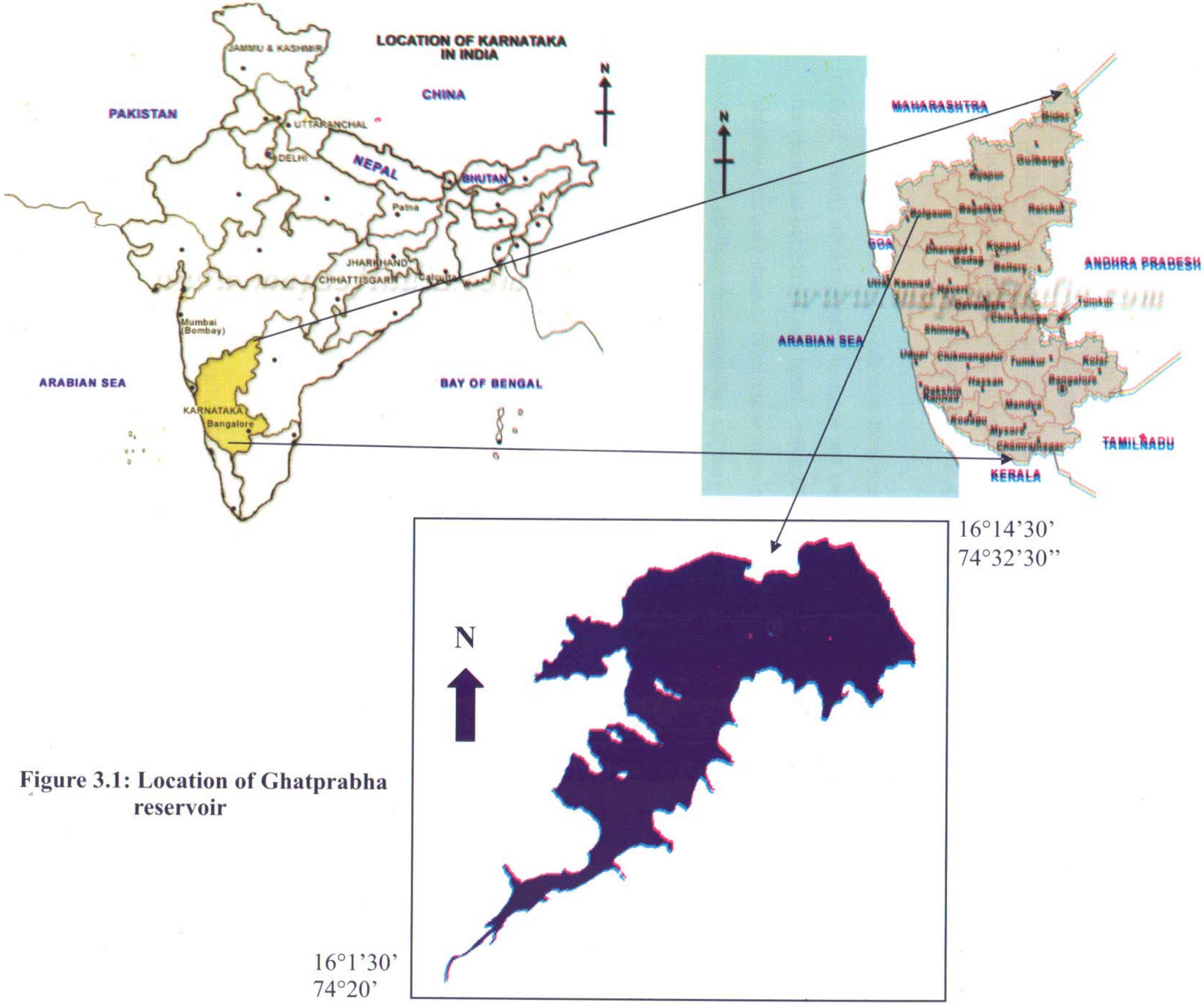


Figure 3.1: Location of Ghatprabha reservoir

Selection of appropriate period for analysis is an important step in the study of reservoir sedimentation assessment using remote sensing data. The only useful information extracted from the remote sensing data is the water spread area at different dates of pass of the satellite over the reservoir area. Though in the wavelength region 0.45 - 0.52 μm, the information within 1 - 2 m depth below the water surface (like sediment concentration, shallow water depth etc.) can be obtained but it cannot be used to quantify the amount of sediment deposition in the reservoir. Therefore, it is imperative to use the remote sensing data of such a period when there is maximum variation in the elevation of the reservoir water surface and consequently, the water spread area.

In India, the reservoirs generally attain the highest level near the end of the monsoon period (October - November) and then deplete gradually before the onset of next monsoon (June - July). Thus, temporal remote sensing data for any water year (October - June) can be selected and analysed. However, if the historical records of maximum and minimum water level in each year are available, the water year of maximum variation will be the best year for sedimentation analysis. A wet year followed by a dry year is the best period for such type of study since for such sequence, the reservoir water level is likely to fluctuate from the maximum to the minimum level which is generally attained during the operation of the reservoir. It is also desirable to select the remote sensing data series of the same water year in sequence to the extent possible, and preferably, the imageries at the fortnightly intervals be used. Besides technical, there might be some administrative reasons to select the period of analysis.

In the present case, the historical record of annual maximum and minimum observed levels was available with the CWC. In the year 2000-2001, maximum level at 661.02 m was observed on 25th. October 2000. The reservoir level fell gradually till the minimum level of 629.26 m was observed on 13th. June 2001.

The data of LISS-III sensor of IRS - 1D satellite, which is having good resolution of 23.5 m, was used. This multi-spectral data was having information of four bands, which were very helpful in the identification of water-spread area. The reservoir water spread area was covered in Path 96 and Row 61 of the satellite. The National Remote Sensing Agency (NRSA), Hyderabad, was contacted for enquiring about the availability of the remote sensing data for the period selected above. Due to cloud cover, data of some of the dates could not be obtained. The availability of remote sensing data is given in the Table 3.3.

Table 3.3 Specifications of the satellite data

| Satellite | Sensor | Path/Row | Date |
|---|---|---|---|
| IRS 1 D | LISSIII | 96-61 | 28 Oct., 2000 |
| IRS 1 D | LISSIII | 96-61 | 22 Nov., 2000 |
| IRS 1 D | LISSIII | 96-61 | 11, Jan., 2001 |
| IRS 1 D | LISSIII | 96-61 | 05, Feb. 2001 |
| IRS 1 D | LISSIII | 96-61 | 02, Mar, 2001 |
| IRS 1 D | LISSIII | 96-61 | 21, Apr, 2001 |

It needs to be mentioned here that for the year 2000-2001, the sedimentation assessment was restricted to 668.99 m (on 28.10.2000) to 631.1 m (on 21/04/2001) zone of reservoir only. It is worth mentioning here that under normal circumstances, the reservoir level varies within or around this range and our main concern is to quantify the sedimentation rate and assess the sediment deposition pattern in the zone of operation (live storage).

## 3.3 METHODOLOGY

In the study for estimation of water-spread area three techniques have been applied, they are unsupervised classification, classification of NDVI and NDWI images. These three techniques are applied on the data of November 2000. Then the classified output was compared with the original image. It was found that the output obtained using NDVI approach is matching best with the original data. Therefore for other dates this approach was applied. All the three approaches are discussed in chapter 2.

All the three approaches as discussed above have been applied on the scene of November 2000. Water-spread area for this data has been estimated and given in table given below.

| November 2000 | Number of Water Pixels | Reservoir Elevation (m) | Water spread Area Using Remote Sensing (M $m^2$) |
|---|---|---|---|
| NDVI approach | 109872 | 658.6 | 60.68 |
| NDWI approach | 108000 | 658.6 | 59.64 |
| Unsupervised | 106366 | 658.6 | 58.74 |

From the table it is seen that using NDVI approach the water spread area matches best with the spread area as seen in satellite. This was confirmed by overlaying all the three outputs over raw data one by one. Also the area obtained using NDVI approach is more close to the area reported in the CWC report (CWC, 2002). Therefore, for other dates, only NDVI approach has been applied.

## 3.4 ANALYSIS AND RESULTS

### 3.4.1 CALCULATION OF SEDIMENT DEPOSITION

Central Water Commission (CWC) has taken up the task of conducting capacity survey of some important reservoirs in the country. The results of survey carried out in 1974 and 2000 are given in Table 3.4.

**Table 3.4 Elevation - Capacity - Area Curves**

| 1974 – SURVEY | | | 2000 - SURVEY | | |
|---|---|---|---|---|---|
| | | | AREA | CAPACITY | |
| ELEV. | AREA | CAPACITY | | DTM | CONE |
| ( m ) | ( M sqm ) | ( M cum ) | ( M sqm ) | ( M cum ) | ( M cum ) |
| 613.000 | 0.018 | 0.002 | 0.000 | 0.000 | 0.000 |
| 614.000 | 0.066 | 0.043 | 0.000 | 0.000 | 0.000 |
| 615.000 | 0.228 | 0.159 | 0.000 | 0.000 | 0.000 |
| 616.000 | 0.656 | 0.597 | 0.048 | 0.043 | 0.040 |
| 617.000 | 1.084 | 1.464 | 0.218 | 0.169 | 0.164 |
| 618.000 | 1.511 | 2.760 | 0.400 | 0.467 | 0.467 |
| 619.000 | 1.939 | 4.484 | 0.658 | 0.992 | 0.992 |
| 620.000 | 2.573 | 6.736 | 0.943 | 1.784 | 1.791 |
| 621.000 | 3.217 | 9.629 | 1.330 | 2.909 | 2.921 |
| 622.000 | 3.933 | 13.184 | 1.973 | 4.526 | 4.542 |
| 623.000 | 4.920 | 17.608 | 2.743 | 6.910 | 6.917 |
| 624.000 | 5.908 | 23.021 | 3.663 | 10.105 | 10.118 |
| 625.000 | 6.936 | 29.431 | 0.600 | 14.247 | 14.259 |
| 626.000 | 8.171 | 36.982 | 5.645 | 19.366 | 19.383 |
| 627.000 | 9.405 | 45.768 | 6.640 | 25.501 | 25.520 |
| 628.000 | 10.625 | 55.785 | 7.673 | 32.655 | 32.665 |
| 629.000 | 11.723 | 66.958 | 8.675 | 40.821 | 40.830 |
| 630.000 | 12.821 | 79.229 | 9.748 | 50.033 | 50.049 |
| 631.000 | 13.931 | 92.600 | 11.168 | 60.495 | 60.516 |
| 632.000 | 15.227 | 107.178 | 12.578 | 72.341 | 72.365 |
| 633.000 | 16.523 | 123.051 | 14.030 | 85.641 | 85.674 |

| | | | | | |
|---|---|---|---|---|---|
| 634.000 | 18.038 | 140.308 | 15.518 | 100.396 | 100.435 |
| 635.000 | 19.645 | 159.148 | 17.038 | 116.660 | 116.694 |
| 636.000 | 21.493 | 179.654 | 18.633 | 134.513 | 134.542 |
| 637.000 | 23.717 | 202.257 | 20.105 | 153.894 | 153.910 |
| 638.000 | 25.942 | 227.084 | 21.650 | 174.780 | 174.806 |
| 639.000 | 28.215 | 254.148 | 23.323 | 197.272 | 197.297 |
| 640.000 | 30.068 | 283.278 | 24.950 | 221.397 | 221.424 |
| 641.000 | 31.875 | 314.270 | 26.695 | 247.218 | 247.238 |
| 642.000 | 33.117 | 346.766 | 28.638 | 274.844 | 274.884 |
| 643.000 | 34.358 | 380.503 | 30.420 | 304.384 | 304.414 |
| 644.000 | 36.119 | 415.682 | 32.365 | 335.757 | 335.792 |
| 645.000 | 38.115 | 452.798 | 34.285 | 369.046 | 369.083 |
| 646.000 | 40.076 | 491.901 | 36.158 | 404.266 | 404.303 |
| 647.000 | 41.791 | 532.834 | 38.225 | 441.467 | 441.512 |
| 648.000 | 43.507 | 575.483 | 40.098 | 480.633 | 480.670 |
| 649.000 | 45.228 | 619.849 | 42.180 | 521.752 | 521.807 |
| 650.000 | 46.954 | 665.939 | 44.050 | 564.855 | 564.924 |
| 651.000 | 48.467 | 713.669 | 46.135 | 609.963 | 610.011 |
| 652.000 | 49.900 | 762.852 | 48.268 | 657.159 | 657.210 |
| 653.000 | 51.676 | 813.554 | 50.398 | 706.474 | 706.536 |
| 654.000 | 53.830 | 866.306 | 52.623 | 758.010 | 758.078 |
| 655.000 | 55.985 | 921.212 | 54.832 | 811.720 | 811.793 |
| 656.000 | 58.140 | 978.274 | 57.005 | 867.635 | 867.709 |
| 657.000 | 60.198 | 1037.453 | 59.515 | 925.875 | 925.953 |
| 658.000 | 62.148 | 1098.625 | 61.828 | 986.550 | 986.633 |
| 659.000 | 65.202 | 1162.022 | 64.180 | 1049.509 | 1049.616 |
| 660.000 | 67.285 | 1228.276 | 66.273 | 1114.715 | 1114.817 |
| 661.000 | 69.211 | 1296.532 | 68.495 | 1182.084 | 1182.193 |
| 662.000 | 71.005 | 1366.647 | 70.663 | 1251.716 | 1251.806 |
| 662.940 | 72.588 | 1434.136 | 72.588 | 1318.513 | 1318.612 |

The reservoir elevations at the time of satellite pass were obtained from CWC, New Delhi. The revised areas and the corresponding elevations are presented in Table - 3.5 for the year i.e. 2000-2001. The imageries of different dates showing the FCC and the final water spread area are presented in Figures 3.2 to 3.7.

**Table 3.5 : Reservoir elevation & revised area on the date of satellite pass**

| Date of Pass | Number of Water Pixels | Reservoir Elevation (m) | Water spread Area Using Remote Sensing (M $m^2$) |
|---|---|---|---|
| 28/10/2000 | 116332 | 660.99 | 64.24 |
| 22/11/2000 | 109872 | 658.6 | 60.68 |
| 11/1/2001 | 79876 | 650.84 | 44.11 |
| 05/2/2001 | 62400 | 645.8 | 34.46 |
| 02/3/2001 | 41220 | 638.84 | 22.76 |
| 21/4/2001 | 22113 | 631.1 | 12.21 |

The reservoir capacity between two consecutive reservoir elevations was computed using the trapezoidal formula. From the original elevation-area table, the original areas at the intermediate elevations (reservoir elevations on the dates of satellite pass) were obtained by linear interpolation. As seen from this that level difference varies form approx. 3 to 7 m. To compute the water spread area at a closer interval, a curve between elevation and water spread area has been drawn. In this curve a best-fit line has been drawn and from this best fit curve the area corresponding to closer interval have been computed (Figure 3.8). From the known values of original and estimated areas at different elevations, the corresponding original and estimated capacities were worked out using above formula. Above the lowest observed level, the cumulative capacities between the consecutive levels were added up so as to reach at the cumulative original and estimated capacities at the maximum observed level. It is to be noted that the while calculating the capacities, the volume at the lowest level has been taken as zero. The difference between the original and estimated cumulative capacity represents the loss of capacity due to sedimentation in the zone under study. The calculations of sediment deposition are given in the Table 3.6.

**Table - 3.6: Sediment Deposition in Reservoir Using Remote Sensing for the year 2000-2001**

| Date of Satellite Pass | Reservoir Elevation (m) | Original Area (Mm$^2$) 1974 | Estimated Area (RS) (Mm$^2$) | Original Volume (Mm$^3$) 1974 | Estimated Volume (RS) (Mm$^3$) | Original Cumulative Volume (Mm$^3$) | Estimated Cumulative Vol. (RS) (Mm$^3$) |
|---|---|---|---|---|---|---|---|
| 28/10/2000 | 660.99 | 69.17 | 64.24 | | | | |
| 22/11/2000 | 658.6 | 64.68 | 60.68 | 159.92 | 149.25 | 1230.22 | 1114.3 |
| | 654.7 | 54.71 | 52.1 | 232.54 | 219.70 | 1070.29 | 965.05 |
| 11/01/2001 | 650.84 | 48.15 | 44.11 | 198.39 | 185.47 | 837.75 | 745.35 |
| | 648.00 | 43.51 | 40.09 | 130.10 | 119.52 | 639.36 | 559.88 |
| 05/02/2001 | 645.8 | 39.85 | 34.46 | 91.67 | 81.92 | 509.26 | 440.36 |
| | 642.0 | 33.11 | 29.93 | 138.44 | 122.24 | 417.60 | 358.43 |
| 02/03/2001 | 638.84 | 27.77 | 22.76 | 96.08 | 82.99 | 279.16 | 236.19 |
| | 635.00 | 20.45 | 17.6 | 92.22 | 77.28 | 183.08 | 153.19 |
| 21/04/2001 | 631.11 | 14.07 | 12.21 | 66.93 | 57.81 | 90.85 | 75.90 |
| | 629.26 | 11.97 | 7.63 | 23.93 | 180.09 | 23.93 | 18.09 |

The results show that the volume of sediment deposition during 1974 to 2000-2001 (26 years) in-between the maximum and minimum observed levels (660.99 m and 629.26 m) is 115.90 Mm$^{3}$. If the uniform rate of sedimentation is assumed, then as per the 2000-2001 analysis, the sedimentation rate in the zone (660.99 m to 629.26.1 m) is 4.457 M m$^3$ per year.

## 3.6 COMPARISON OF RESULTS WITH HYDROGRAPHIC SURVEY

As given earlier CWC has carried out hydrographic survey for the year 2000. Comparison of remote sensing results with hydrographic survey is given in table 3.7.

**Table - 3.7: Comparison of Results of Hydrographic Survey with Remote Sensing for the year 2000-2001**

| Date of Satellite Pass | Reservoir Elevation (m) | Original Area ($Mm^2$) 2000 | Estimated Area (RS) ($Mm^2$) | Original Volume ($Mm^3$) 1974 | Estimated Volume (RS) ($Mm^3$) | Original Cumulative Volume ($Mm^3$) | Estimated Cumulative Vol. (RS) ($Mm^3$) |
|---|---|---|---|---|---|---|---|
| 28/10/2000 | 660.99 | 68.49 | 64.24 | | | | |
| 22/11/2000 | 658.6 | 63.68 | 60.68 | 157.91 | 149.25 | 1140.6 | 1114.3 |
| | 654.7 | 54.5 | 52.1 | 230.22 | 219.70 | 982.74 | 965.05 |
| 11/01/2001 | 650.84 | 45.72 | 44.11 | 193.18 | 185.47 | 752.52 | 745.35 |
| | 648.00 | 40.09 | 40.09 | 121.76 | 119.52 | 559.35 | 559.88 |
| 05/02/2001 | 645.8 | 35.9 | 34.46 | 83.54 | 81.92 | 437.58 | 440.36 |
| | 642.0 | 28.64 | 29.93 | 122.37 | 122.24 | 354.04 | 358.43 |
| 02/03/2001 | 638.84 | 23.04 | 22.76 | 81.49 | 82.99 | 231.67 | 236.19 |
| | 635.00 | 17.04 | 17.6 | 76.66 | 77.28 | 150.18 | 153.19 |
| 21/04/2001 | 631.11 | 11.33 | 12.21 | 54.94 | 57.81 | 73.51 | 75.90 |
| | 629.26 | 8.9 | 7.63 | 18.56 | 18.09 | 18.56 | 18.09 |

The plot of original and estimated cumulative capacity as derived using remote sensing technique is shown in Figures 3.9 for the year 2000-2001. The plot of the estimated cumulative capacity as per the hydrographic study and as per the remote sensing analysis for the year 2000 is presented in Figure 3.10. As per the CWC report, the results of hydrographic survey are as follows.

| Annual Sedimentation Rate | Satellite Imageries Study | | Hydrographic Survey |
|---|---|---|---|
| | 1974-90 | 1974-97 | 1974-2000 |
| Ham / 100 sq km / year | 40.113 | 32.809 | 31.478 |
| M cum / year | 5.662 | 4.631 | 4.443 |

As calculated above the results obtained from this study shows that the sedimentation rate (1974-

2000) is 4.45 $Mm^3$/year.

### 3.7 CONCLUSION

The sedimentation rate and volume was determined in the Ghatprabha reservoir using the remote sensing data. Remote sensing data of IRS-1D satellite and LISS-III sensor was acquired for the year 2000-2001 and the estimated water spread area was extracted. The original elevation-area-capacity curve and the reservoir levels on these years for the dates of pass of satellite were obtained from CWC. Using the trapezoidal formula, the estimated capacity in between the maximum and minimum observed levels was obtained. For the year 2000-2001, the estimated capacity (1114.3 M $m^3$) was subtracted from the original capacity (1230.22 M $m^3$) and the loss in capacity (115.90 M $m^3$) was attributed to the sediment deposition in the zone of study (660.99 m to 629.26 m) of the reservoir. Thus, the average rate of loss of capacity in this zone came out to be 4.45 M $m^3$ per year.

The hydrographic survey of the reservoir was carried out in the year 2000. As per the results of this survey, annual sedimentation rate for the period 1974-2000 comes out to be 4.443 M $m^3$. Also in the report of CWC, using satellite imagery, the results shows that the sedimentation rate was 5.662 M $m^3$ and 4.631 M $m^3$ for the period 1974-90 and 1974-97 respectively. In this study the sedimentation rate comes out to be 4.45 M $m^3$ per year, which is comparable with the above rates. However it should be noted that in our case the rate is only for live zone and the rate given in CWC report are for the total storage.

# SALIENT FEATURES - GHATAPRABHA RESERVOIR PROJECT

| | |
|---|---|
| Location | : Near Hidkal Village in Hukkeri Taluk of Belgaum district |
| Latitude | : 16° 05 ' to 16° 10 ' |
| Longitude | : 74° 28 ' to 74° 32 ' |
| Nearest City/Town | : Hukkeri |
| Village | : Hidkal |
| Purpose | : Irrigation, water supply & hydropower |
| District | : Belgaum |
| River | : Ghataprabha |
| Year of Impoundment | : 1974 |
| Year of Completion | : 1977 |
| Hydrology | |
| Catchment Area | : 1411.55 sq. km (545 sq. miles) |
| Average yield | : 1971 M cum. |
| Temperature | : Highest 39° C |
| | : Lowest 15° C |
| F.R.L | : 662.94 m (2175 ft.) |
| L.B.L | : 612.64m (2010 ft) |
| Minimum Draw down level | : 633.292 m (2078 ft) |
| M.W.L | : 662.94 m (2175 ft.) |
| Water spread area at FRL | : 72.588 M. Sq. m |
| Gross Capacity at FRL | : 1434.136 M.cum. |
| Dead Storage Level | : 629.07 m (2064 ft) |
| Storage Capacity at DSL | : 68.00 M. cum. |

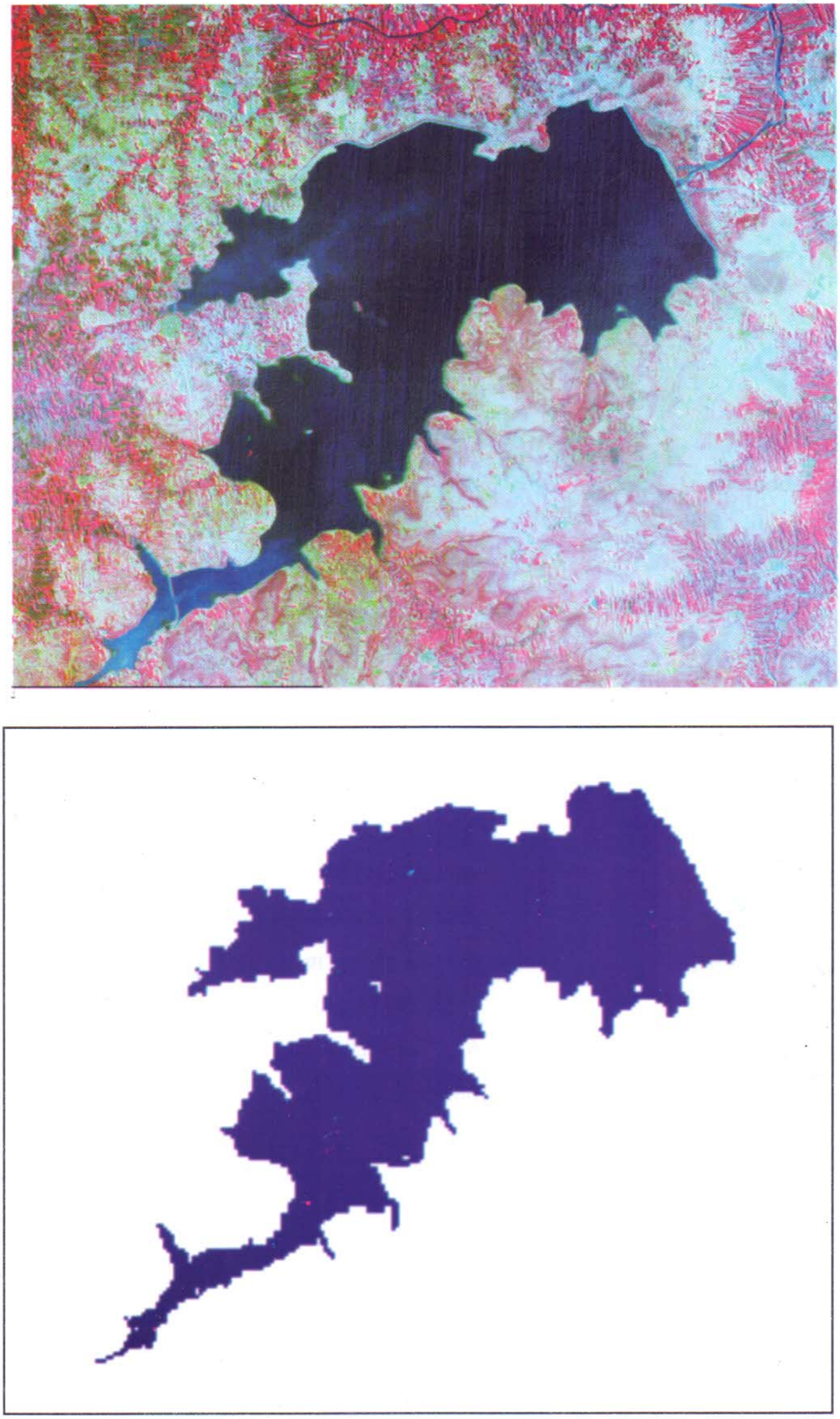


Figure 3.2 FCC of IRS 1 D LISS III data of October, 2000 and water spread area of the Ghatprabha reservoir

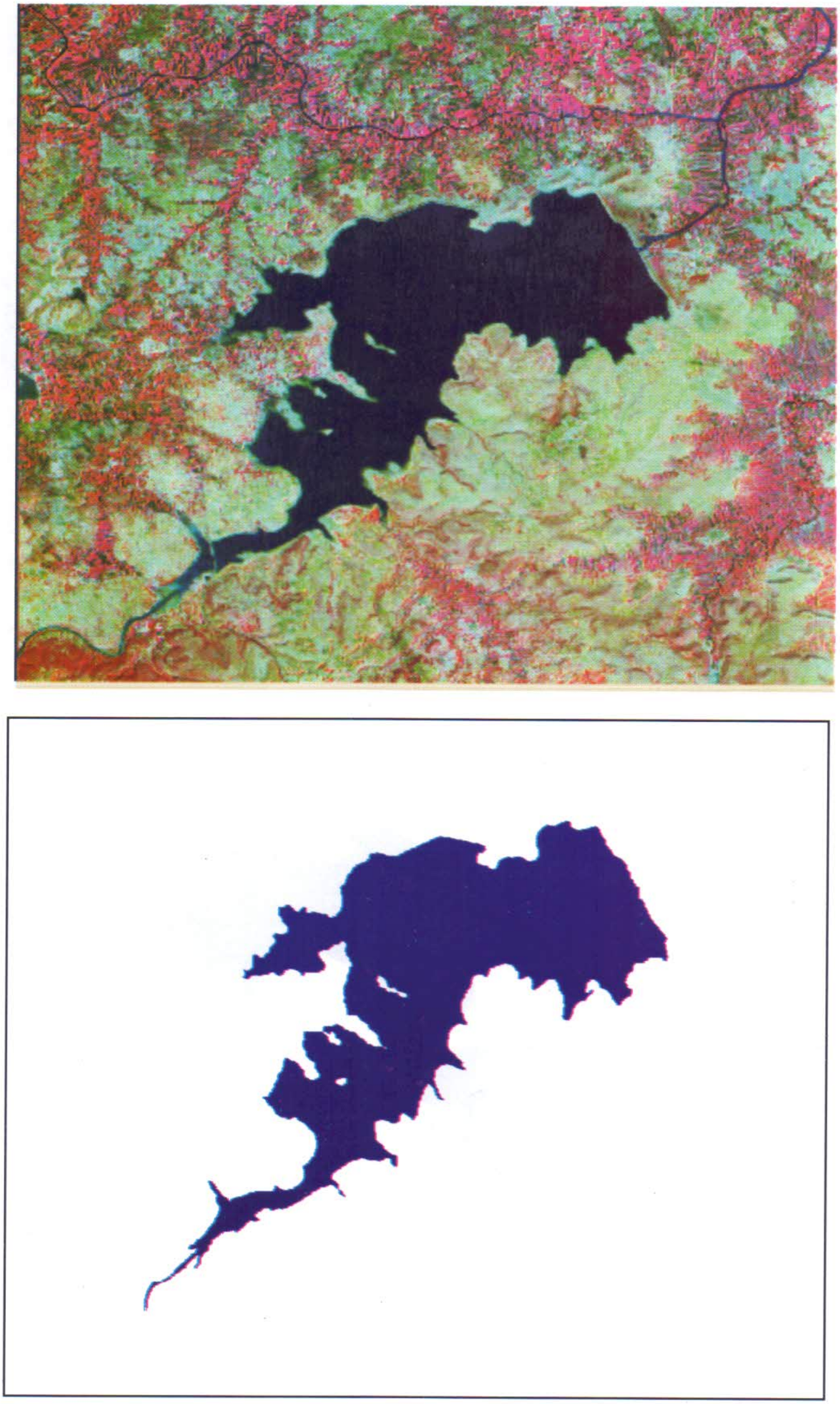


**Figure 3.3: FCC of IRS 1 D LISS III data of November, 2000 and water spread area of the Ghatprabha reservoir**

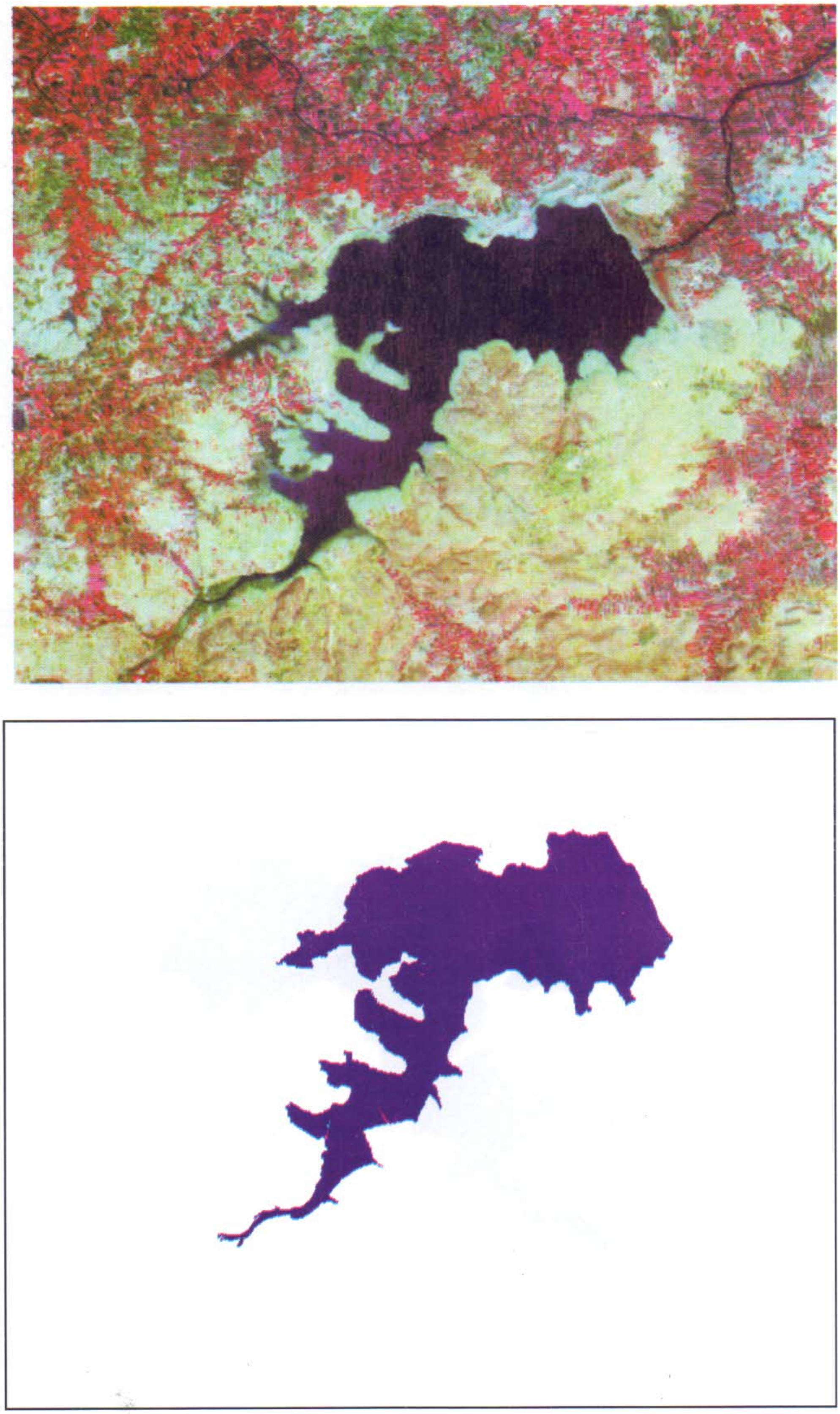


**Figure 3.4: FCC of IRS 1 D LISS III data of January, 2001 and water spread area of the Ghatprabha reservoir**

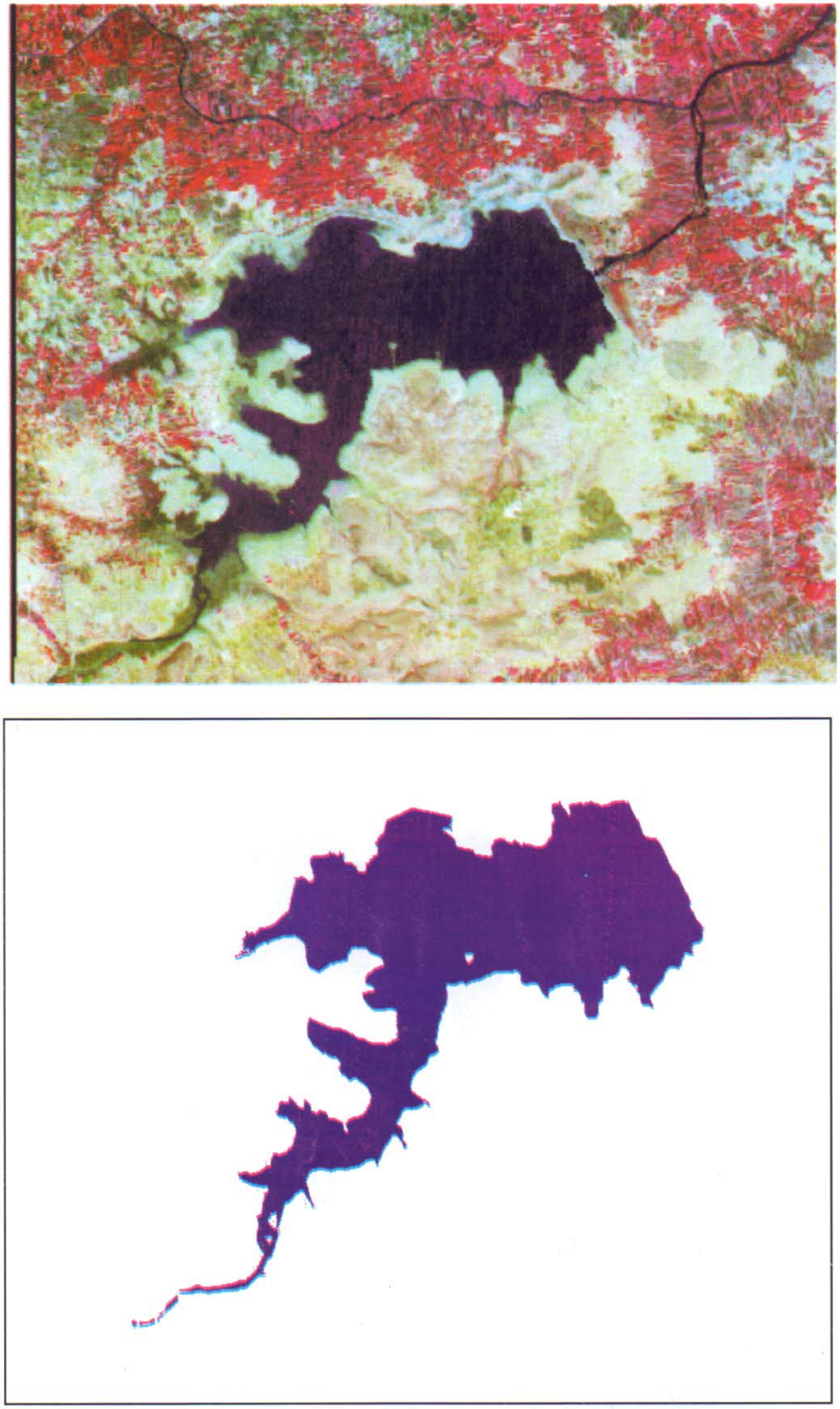


Figure 3.5: FCC of IRS 1 D LISS III data of Feburary, 2001 and water spread area of the Ghatprabha reservoir

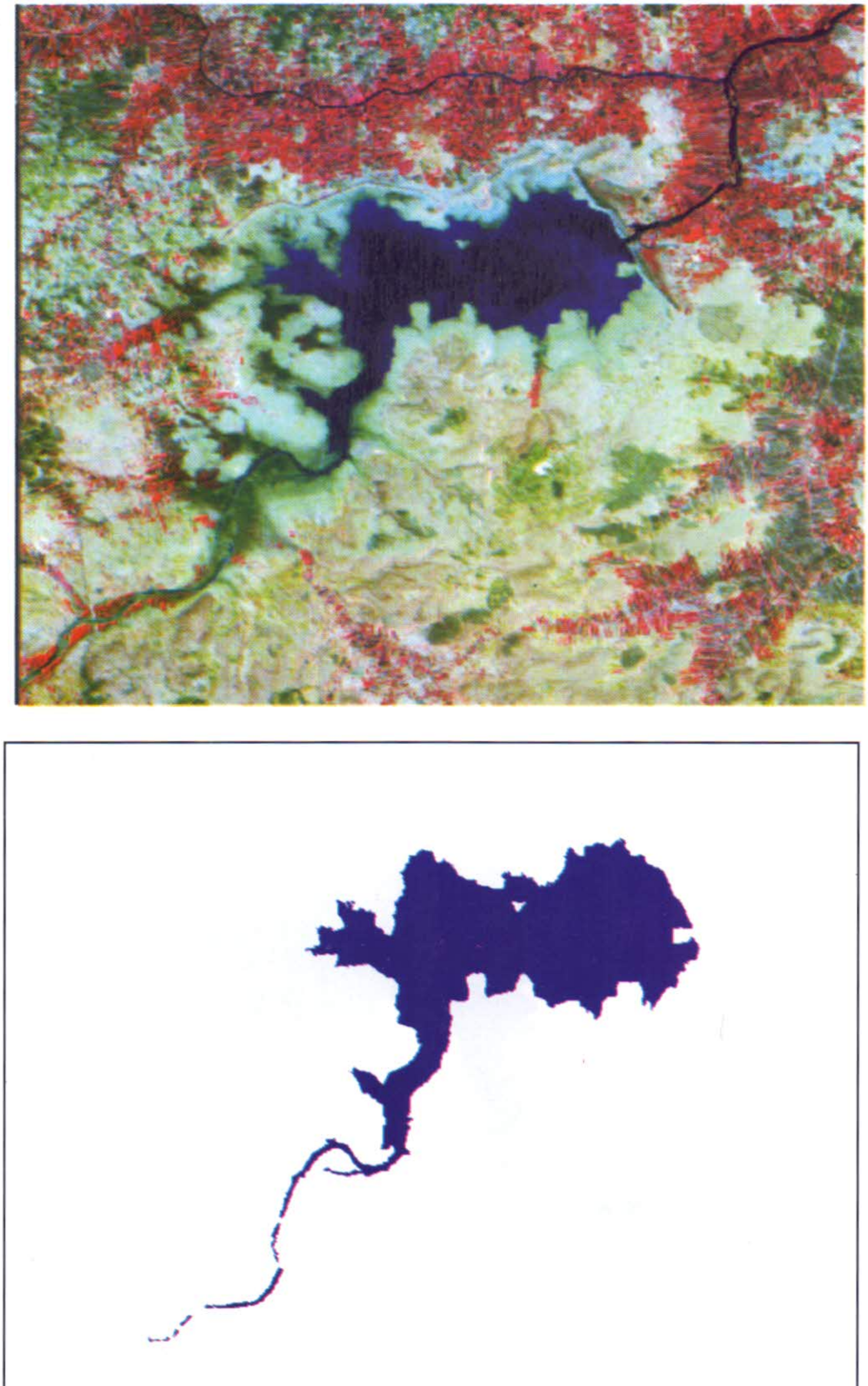


**Figure 3.6: FCC of IRS 1 D LISS III data of March 2001 and water spread area of the Ghatprabha reservoir**

**Figure 3.7: FCC of IRS 1 D LISS III data of April 2001 and water spread area of the Ghatprabha reservoir**

**Figure 3.7: FCC of IRS 1 D LISS III data of April 2001 and water spread area of the Ghatprabha reservoir**

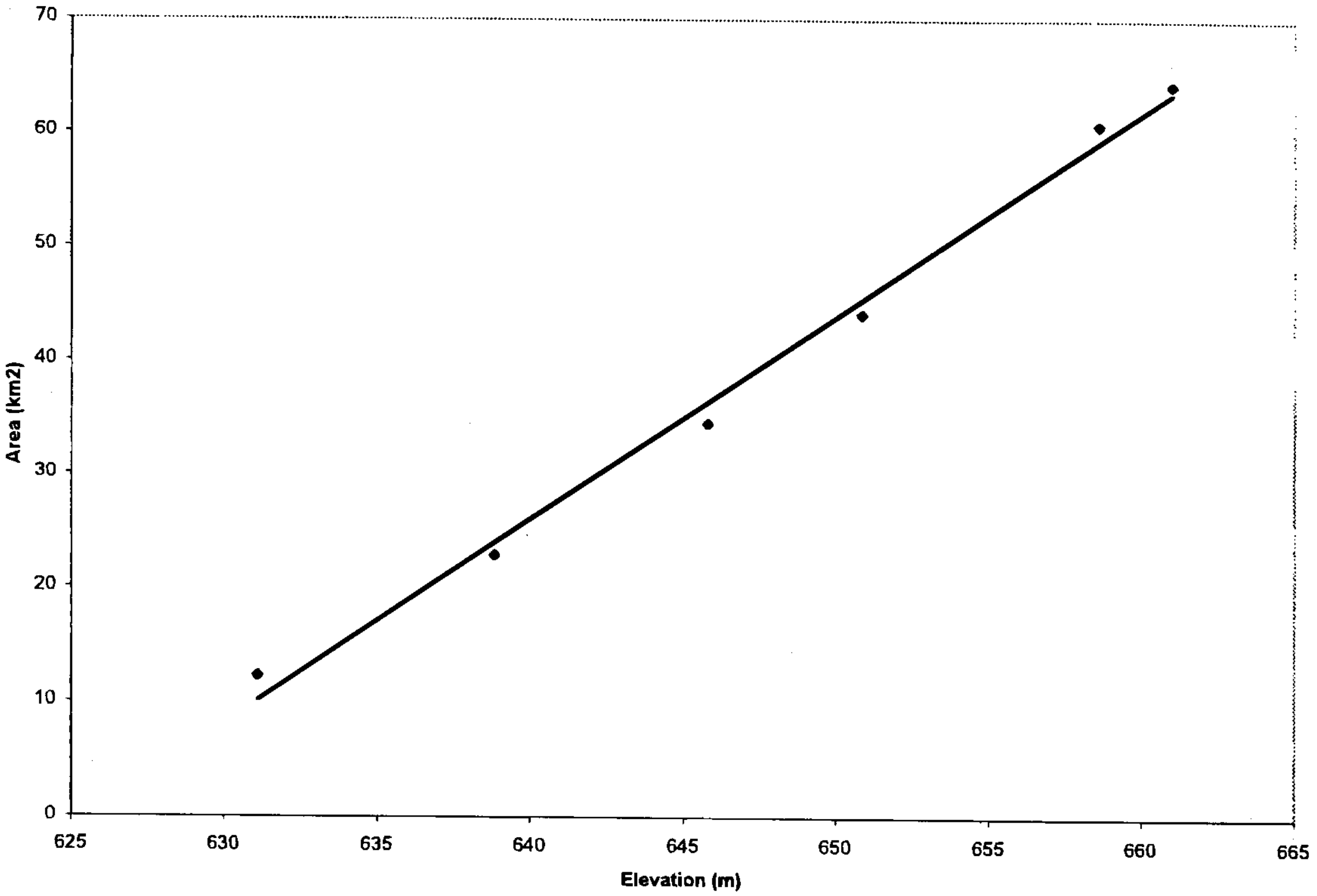


Figure 3.8 : Best Fit curve between elevation and water spread area

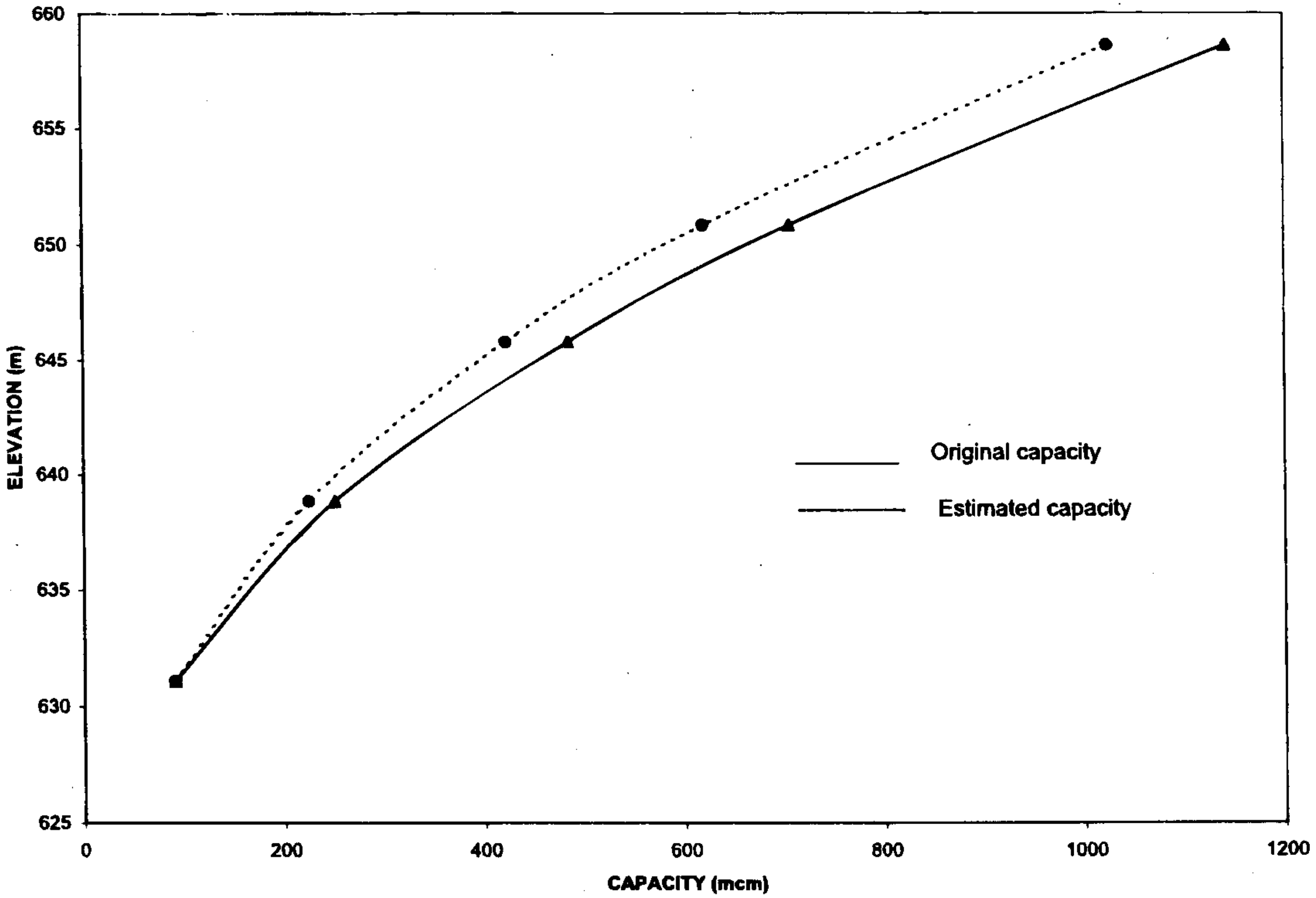


Fig 3.9 : Elevation-Capacity curves for Ghatprabha reservoir, India (2000-01)

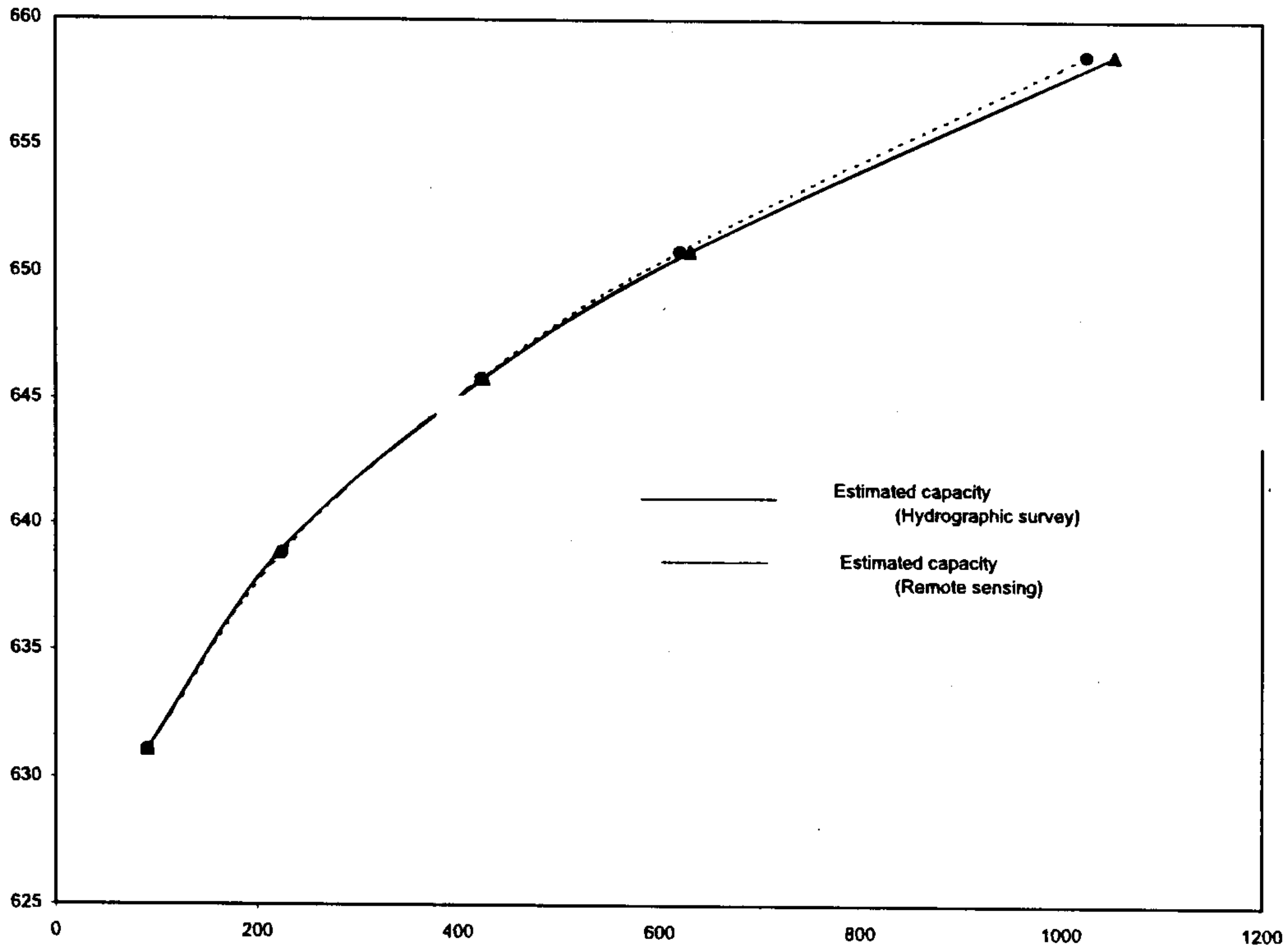


Fig 3.10 : A comparision of the results obtained through remote sensing technique and hydrographic survey (2000)

## 4.0 GANDHISAGAR RESERVOIR

### 4.1 Salient Features of Gandhisagar Reservoir

The Gandhisagar reservoir, one of the first major reservoirs of the State of Madhya Pradesh (M.P.), is the uppermost dam in a series of three dams (Gandhi Sagar, Rana Pratap Sagar, and Jawahar Sagar) and a barrage (Kota barrage) of Chambal Valley Project. The dam was a joint venture of the States of M.P. and Rajasthan and was completed in the year 1960. It is the main storage dam constructed across river Chambal, intercepting a catchment area of about 23025 $km^2$ The dam serves as a backup storage for power generation in the three dams and irrigation through canal systems taking off from Kota Barrage.

The Chambal River, called Charmanvati in the ancient times, is the largest of the rivers flowing through the M.P. and Rajasthan States. The river rises in northern slopes of Vindhya Mountains about 14 km west south west of Mhow in M.P. State at an elevation of about 853 m above mean sea level. The river flows first in northerly direction in M.P. State for a length of about 346 km and after passing the historic fort of Chaurasigarh, it flows in generally north-easterly direction for a length of around 225 km through Rajasthan, for another 217 km between M.P. and Rajasthan, and further 145 km between M.P. & U.P., and finally for 32 km in U.P. before its confluence with the Yamuna, south-east of Etawah, at an elevation of about 122 m. The total area drained by the Chambal up to its confluence with the Yamuna is 143219 sq. km out of which 76854 sq. km lies in the M.P. State, 65264 sq. km in Rajasthan State and 1101 sq. km in U.P. State.

In the reach of 96 km from 344 km to 440 km from its source, the Chambal flows through a deep gorge, ideally suited for dam locations. The Gandhisagar Dam is located at about the middle of this reach. As the country opens out immediately upstream of the gorge, the reservoir has a high capacity for its comparatively low height. The river flows for next 48 km through Kundal Plateau where the left bank of the river clings to steeply rising hill range while on its right bank the ground rises gently. The Rana Pratap Sagar dam is constructed at lower end of this reach. The terrain permits fairly good storage upstream of the dam. Further down, Jawahar Sagar dam is located in the middle of Kota gorge. The Kota barrage is located close to Kota town, where the river emerges from the gorge section into the plateau.

The Gandhisagar dam is located 8 km north-east of Bhanpura and 8 km downstream of mouth of gorge on the boundary of M.P. and Rajasthan States at Latitude $24^0$ 44' N and Longitude $75^o$ 33' E. The full reservoir level (FRL) and the maximum water level (MWL) have been kept at elevation of 400 m while the dead storage level has been kept at an elevation of 381 m. The live and dead storages provided for the reservoir at planning stage were 6910 Million cubic meter (M

Cum) and 836 M Cum respectively. The original reservoir submergence area at FRL was 680 sq. km Gandhisagar dam was constructed as a 64.63 m high straight gravity masonry dam 514 m in length with 182.93 m central spillway and five power blocks on its right along with non-overflow blocks at both flanks. The spillway section consists of 10 spans each of length 18.3 m and 9 sluice piers 7.927 m wide accommodating 9 sluices of size 3.05 m x 7.62 m and steel crest gates of size 18.3 m x 8.54 m with discharging capacity of 13705 cumec at MWL. Immediately at the foot of the power intake portion is the powerhouse accommodating 5 turbines with generating units. Installed capacity of powerhouse is 115 MW while the irrigation potential of the project is 7.57 lakh ha. The Index map and Vicinity map of Gandhisagar reservoir are shown in Figure – 4.1 and Figure – 4.2 respectively.

The Chambal is a rainfed catchment. The annual rainfall up to the Gandhisagar dam site varies from a maximum of 1300 mm (1973) to minimum of 430 mm (1957) with average rainfall of 860 mm on the basis of data of 60 years. The area is located in central part of India and experiences extremes of climate. The temperature in the hottest part of the year occasionally goes up to 40°C in summer and falls to a minimum of 2°C during winter. The relative humidity ranges between 30 to 90 percent during the year.

### 4.2 Previous Capacity Surveys of Gandhisagar Reservoir

At the planning stage, the gross storage capacity of the reservoir was originally assessed to be 8450 M Cum from the toposheets. However, based on the aerial photography and the contour survey at the time of first impoundment by the Survey of India (SOI), the gross capacity was revised to 7746 M Cum.

Subsequently, sedimentation surveys were attempted in the reservoir area in the years 1975 and 1989. Surveys conducted in 1975 indicated reduction of gross capacity by 333 M Cum over a period of 15 years. Hydrographic surveys conducted in the year 1989 by the range line method indicated reduction of 419 M Cum in gross storage. The advanced HI-TECH hydrographic surveys were conducted during March-October, 2001 up to maximum water level, using Global Positioning System in Differential Mode and topographic surveys were carried out above the water level. The outputs from hydrographic & topographic surveys were integrated and merged for griding and contouring operations. Bathymetric surveys were carried out in grids of 100 m x 100 m up to the water level and topographic surveys in grids of 100 m x 200 m in the area above the water level up to MWL. The gross, live, and dead storage capacities as determined from various surveys are reported in Table – 4.1.

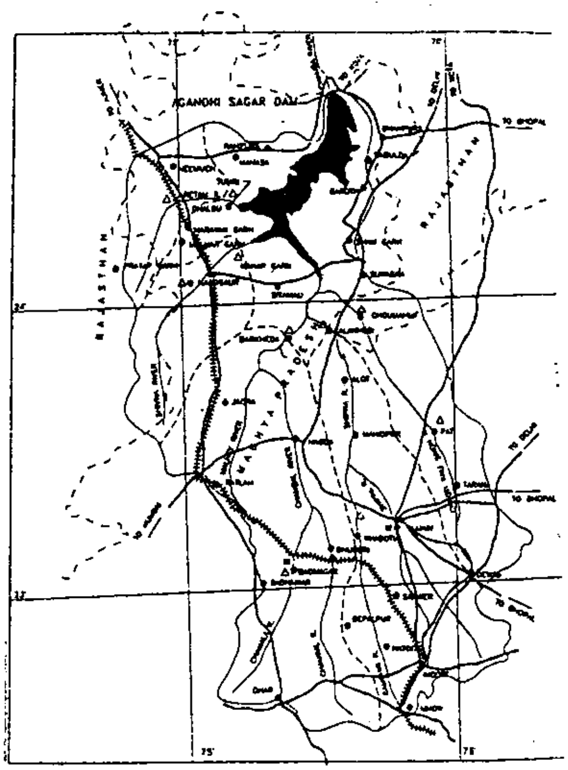


Figure 4.1 : Index map of the catchment of Gandhisagar reservoir

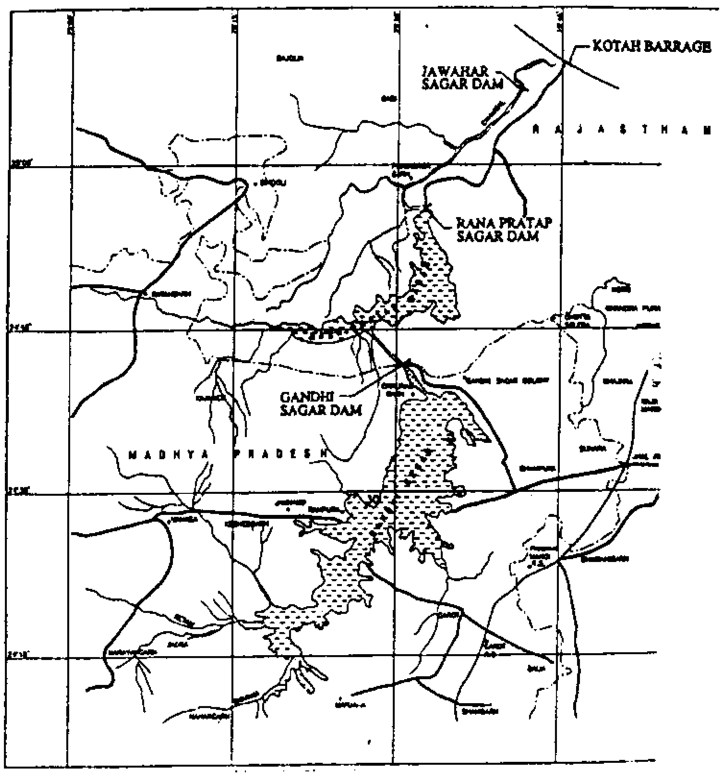


Figure 4.2 : Vicinity map of Gandhisahar reservoir

Table – 4.1 Capacities of Gandhisagar Reservoir in Various Surveys

| | Project Planning Stage | 1960-61 Reassessment | 1975 Survey | 1989 Hydrographic Survey | 2001 Hydrographic Survey |
|---|---|---|---|---|---|
| Gross Storage at FRL | 8450 | 7746 | 7413 | 7323 | 7226 |
| Live Storage | 7620 | 6910 | 6827 | 6798 | 6669 |
| Dead Storage | 830 | 836 | 586 | 525 | 557 |

The rate of sedimentation adopted at the project planning stage was 3.6308 ham/100 sq. km/year. However, the average rate of sedimentation during the first 41 years, on the basis of 2001 surveys, works out to 5.508 ham/100 sq. km/year. The original and revised elevation-area-capacity table for the reservoir is given in Table – 4.2.

Table – 4.2 Original and Revised Elevation-Area-Capacity Table for Gandhisagar Dam

| Elevation (m) | Original Area (sq. km) | Revised (2001) Area (sq. km) | Original Capacity (M Cum) | Revised (2001) Capacity (M Cum) |
|---|---|---|---|---|
| 373.00 | 33.415 | 16.540 | 255.024 | 28.500 |
| 374.50 | 40.038 | 28.859 | 300.061 | 62.550 |
| 376.00 | 55.199 | 46.382 | 368.070 | 118.980 |
| 377.50 | 78.195 | 69.431 | 461.560 | 205.840 |
| 379.00 | 100.342 | 95.869 | 601.033 | 329.820 |
| 380.50 | 125.700 | 121.093 | 768.019 | 492.540 |
| 381.00 | 138.000 | 130.634 | 836.000 | 557.411 |
| 382.00 | 155.000 | 149.717 | 980.019 | 695.650 |
| 383.50 | 188.907 | 182.327 | 1268.018 | 960.000 |
| 385.00 | 217.642 | 211.740 | 1556.773 | 1240.230 |
| 386.50 | 247.897 | 241.585 | 1914.363 | 1580.220 |
| 388.00 | 281.431 | 268.453 | 2316.061 | 1962.750 |
| 389.50 | 316.504 | 301.560 | 2758.678 | 2390.260 |
| 391.00 | 356.019 | 333.154 | 3253.403 | 2866.300 |
| 392.50 | 398.480 | 385.540 | 3811.046 | 3405.320 |

| | | | | |
|---|---|---|---|---|
| 394.00 | 446.016 | 432.290 | 4468.585 | 4018.960 |
| 395.50 | 495.632 | 484.190 | 5186.990 | 4706.430 |
| 397.00 | 548.551 | 528.022 | 5976.211 | 5465.590 |
| 398.50 | 605.070 | 589.000 | 6847.410 | 6330.000 |
| 400.00 | 680.000 | 675.687 | 7746.000 | 7226.150 |

## 4.3. Remote Sensing Analysis for Gandhisagar Reservoir

### 4.3.1 Selection of period of analysis

This is the first and important step in carrying out the analysis using remote sensing data. For the Gandhisagar reservoir, daily water level data from October 1997 to June 2001 were obtained from the Water Management Directorate, CWC, New Delhi. The maximum and minimum reservoir levels observed during this period were 398.82 m (October 1997) and 379.51 m (June 2001) respectively. The variation of water level in the reservoir from October 1997 to June 2001 is shown in Figure – 4.3.

It is seen from the figure that the reservoir level steadily falls from near FRL to near DSL in the span of four years. To the extent possible, continuous time series of water level variation is considered for remote sensing based analysis. Further, the availability of remote sensing data needs to be ensured for selecting the period of analysis. Looking at the water level variation and the availability of satellite data, eight dates were selected for the present analysis. Because of the wide variation in reservoir level in four years, it was possible to cover most of the live storage zone of the reservoir.

Multi-spectral data of LISS-III sensor of IRS-1C/1D satellite were used in this study. The Gandhisagar water spread is covered in Path 95 and Row 54 of the IRS-1C/1D satellites. The dates of pass selected for the analysis and the corresponding reservoir levels are given in Table – 4.3.

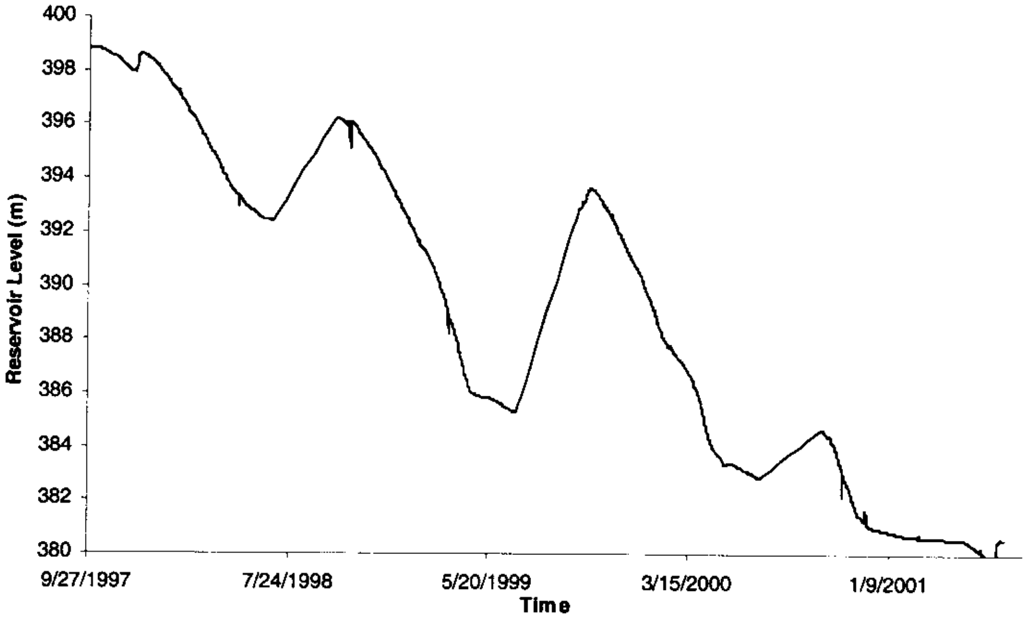


Figure – 4.3 Water Level Variation in Gandhisagar Reservoir during 1997-2001.

In this study, digital analysis was carried out for identifying the water pixels and for determining the water spread area. The analysis was performed using the ERDAS/IMAGINE image processing software. The various steps followed in the analysis are as follows.

Table – 4.3: Dates of Satellite Pass and Reservoir Level

| Date of Pass | Satellite | Reservoir Level (m) |
|---|---|---|
| 15.12.1997 | IRS-1C | 398.58 |
| 12.10.1998 | IRS-1D | 396.12 |
| 16.11.1999 | IRS-1D | 392.73 |
| 05.01.2000 | IRS-1D | 390.25 |
| 20.03.2000 | IRS-1D | 386.47 |
| 12.10.2000 | IRS-1C | 384.45 |
| 05.11.2000 | IRS-1C | 382.76 |
| 22.04.2001 | IRS-1C | 380.57 |

### 4.3.2 Identification of water pixels

For identifying the water pixels in Gandhisagar reservoir, a number of models were tried. These included the density slicing of near-infrared (NIR) band, comparison of radiance in NIR band with Red and Green bands, and the thresholding of Normalized Difference Water Index. However, none of these models gave satisfactory results for all the images. To account for the information in the Red band along with the NDWI, a Water Index (WI) was formulated as follows:

$$\text{Water Index} = \frac{(\text{Green} - \text{NIR})}{(\text{Green} + \text{NIR}} * \frac{\text{Red}}{\text{NIR}} * 100 \qquad (4.2)$$

Simple thresholding of the WI did not yield satisfactory results of water identification in an image. However, thresholding of the WI together with the thresholding of the NIR band provided satisfactory estimation of the water pixels. Further, one set of threshold of WI and NIR for an image did not give good results for the whole of the reservoir. The threshold that worked satisfactorily in the head reach of the reservoir over-estimated the water pixels towards the tail-end. The reason was that due to the lowering of water spread area in the tail-reach, the saturated soil appeared very close to the water pixels in the NIR band. However, the differentiation between the wet soil and water pixels was quite distinct in the FCC. So, for most of the images, different thresholds for WI and NIR band were specified separately for the head-reach (almost upper half of the water spread area) and the tail-reach (lower half of the water spread area) and the results from the two analysis were combined together to get the water spread area for an image.

After preparing the WI image from the radiance image (using the MODELER option of ERDAS), images corresponding to FCC, NIR, and WI were displayed simultaneously in different windows and the thresholds of WI and NIR, which best differentiate the water pixels from other surrounding pixels, were identified. Different threshold values were applied on the 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. Different thresholds selected in different images for identifying the water pixels are given in Table – 4.4. Remote sensing image of December 1997 overlaid with water spread area of April 2001 is shown in Figure 4.4. For illustration purpose, the FCC image of March 20, 2000 is shown in Figure – 4.5a. The images of water pixels, as obtained from interpretation, were edited to remove the isolated water pixels, extension of tail and joining of rivers around the water spread.

The 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 Gandhisagar reservoir, the tail-end was not obvious and the tails in different images were curtailed on the basis of point of termination of water spread area and the position of tail end in subsequent images. The final reservoir water spread of March 20, 2000 after the application of CLUMP and curtailment of tail-end, is presented in Figure – 4.5b.

Table – 4.4 Various Thresholds Used for Water Identification in Remote Sensing Images

| Date of satellite Image | Reservoir Reach | WI | Radiance in NIR band |
|---|---|---|---|
| 15.12.1997 | Full | > 18 | < 4.90 |
| 12.10.1998 | Head | > 11 | < 5.45 |
| | Tail | > 38 | < 5.30 |
| 16.11.1999 | Head | > 17 | < 5.30 |
| | Tail | > 55 | < 4.60 |
| 05.01.2000 | Head | > 10 | < 6.40 |
| | Tail | > 44 | < 6.00 |
| 20.03.2000 | Head | > 9 | < 6.71 |
| | Tail | > 33 | < 5.95 |
| 12.10.2000 | Head | > 9 | < 7.6 |
| | Tail | > 25 | < 6.50 |
| 05.11.2000 | Head | > 15 | < 6.40 |
| | Tail | > 25 | < 5.95 |
| 22.04.2001 | Full | > 20 | < 8.00 |

### 4.3.2.1 Derivation of contours

After finalising the water spread area for a particular image, the periphery of the water spread area was derived using various image processing techniques. First, the diagonally connected pixels (pixels connected to the main water spread through a corner) were removed. This was achieved by forming the 4-connected clumps and then eliminating those clumps, which have a size less than the specified size (3 pixels in the present case). Next, the three different kinds of filters, namely Edge Detection, Horizontal and Vertical were convoluted with the total water spread image.

Though the edge detection filtered image gives the outer boundary of the water spread area, the slanting contour lines show two layers of pixels. To remove the inner layer of pixels along the slanting lines, few GIS operations were employed. First, the pixels that were common in the horizontal and vertical filtered image were identified. It was observed that the undesirable pixels in the edge detection filtered image occurred at the locations of common pixels of horizontal and vertical filtered image. So, by observing the values of pixels to be removed from the edge detection filtered image and the location of common pixels, undesirable pixels in the edge detection filtered image were removed. After obtaining the peripheral pixels, the elevation values were assigned to them using the MODELER.

Revised contours were developed for all the water spread images and the same were overlaid in one image after assigning elevation values. The revised contours of reservoir submergence are presented in Figure – 4.6.

### 4.3.3 Calculation of revised capacity

After finalising the water spread areas of all the eight date data, the histograms 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 (24 m x 24 m). The reservoir capacity between two consecutive 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 revised capacity of the reservoir at the lowest observed level (380.57 m) was assumed to be the same as the cumulative capacity at this elevation obtained from the hydrographic survey analysis in the year 2001. By linear interpolation, it was found to be 502.0194 M Cum. 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 (398.58 m). The calculations of revised capacity estimation are presented in Table – 4.5.

## 4.4 Discussion of Results

Based on the availability of satellite data and the water level variation in the Gandhisagar reservoir during the period 1997-2001, the study was carried out for the zone of the reservoir lying in-between the elevations 398.58 m and 380.57 m, thus covering almost the entire live storage zone. The revised areas at eight 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 revised capacities of the intermediate zones were calculated by using the trapezoidal formula. The available capacity in the reservoir in-between 398.58 m and 380.57 m comes out to be 5970.7216 M Cum.

**Table 4.5 Revised Area and Capacity at Different Elevations in Gandhisagar reservoir**

| 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) |
|---|---|---|---|---|
| 15.12.1997 | 1063221 | 398.58 | 612.4153 | 6472.741 |
| 12.10.1998 | 904011 | 396.12 | 520.7103 | 5080.526 |
| 16.11.1999 | 720224 | 392.73 | 414.8490 | 3498.155 |
| 05.01.2000 | 577279 | 390.25 | 332.5127 | 2573.302 |
| 20.03.2000 | 406708 | 386.47 | 234.2638 | 1507.501 |
| 12.10.2000 | 326166 | 384.45 | 187.8716 | 1082.007 |
| 05.11.2000 | 268906 | 382.76 | 154.8898 | 792.8214 |
| 22.04.2001 | 194180 | 380.57 | 111.8477 | 502.0194 |

The analysis with hydrographic survey (2001) shows that the revised capacity at highest observed elevation (398.58 m) comes out to be 6377.798 M Cum and the available capacity in the zone of analysis (398.58 m to 380.57 m) comes out to be 5875.7782 M Cum. The difference between the results of hydrographic survey and remote sensing analysis in terms of the available capacity in the zone of study comes out to be 94.943 M Cum which is about 1.61% of the available capacity in this zone. To visualize the zone-wise difference between the results of remote sensing and hydrographic survey, a plot between the cumulative capacities computed by the two techniques is presented in Figure – 4.7.

The original capacity in the zone of study was 6117.789 M Cum and the revised capacity as per remote sensing analysis is 5970.7216 M Cum. So, 147.0674 M Cum of sediments have deposited in the zone in the span of 41 years. This gives the rate of sedimentation of 1.5579 ham/100 sq. km/year in the zone of study. It is observed that though the capacity estimation in whole of the study zone of reservoir by the two techniques is quite close, yet remote sensing method estimates lesser available capacity in the lower portion of the reservoir (below elevation 394 m) and greater available capacity in the upper portion of the reservoir (above 394 m).

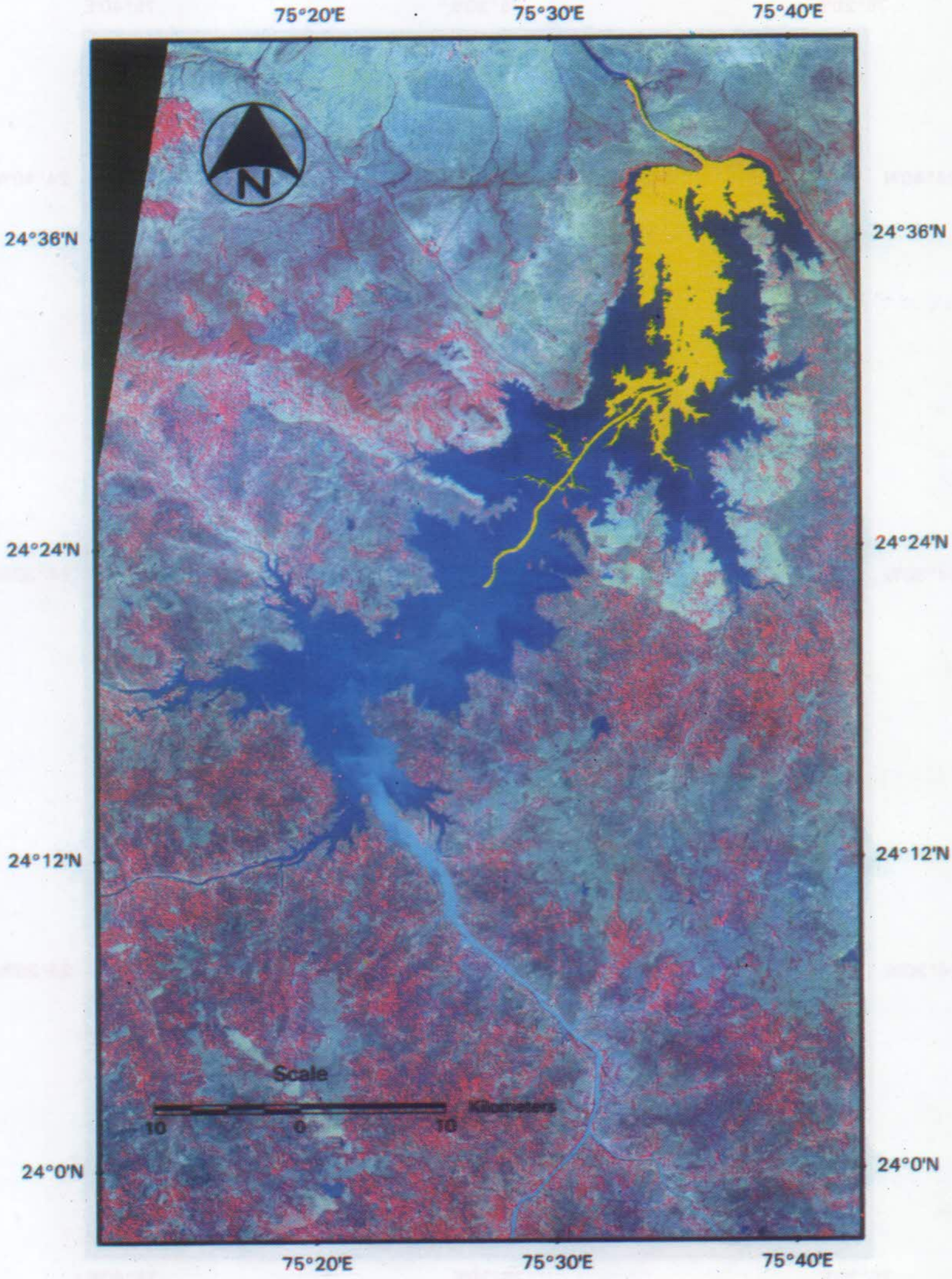


Figure 4.4 : Remote sensing image of December 1997 overlaid with water spread Area of April 2001 showing overall variation in water spread area in the analysis

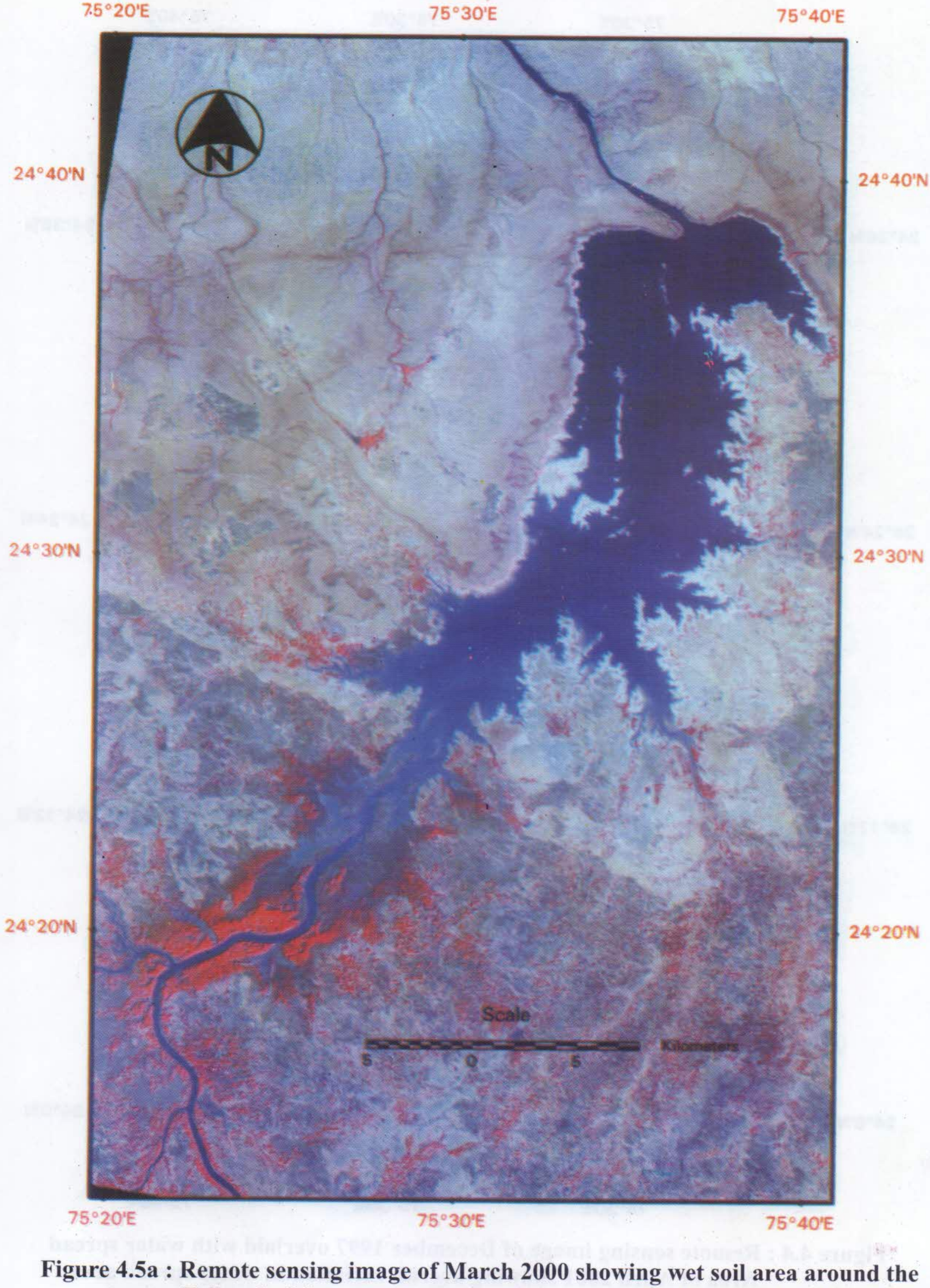


**Figure 4.5a : Remote sensing image of March 2000 showing wet soil area around the Tail end of the water spread**

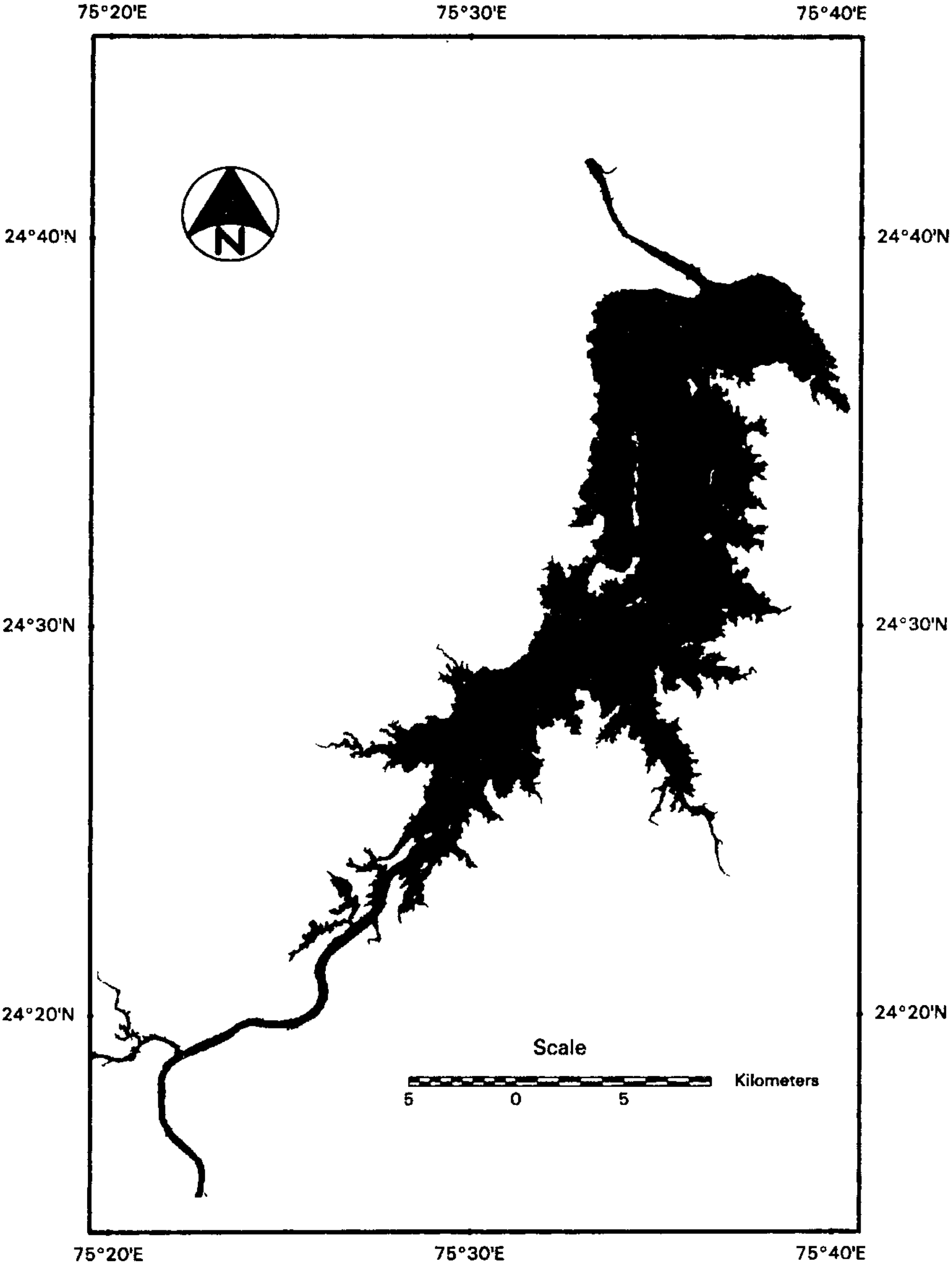


Figure 4.5b : Water spread area obtained from remote sensing image of March 2000

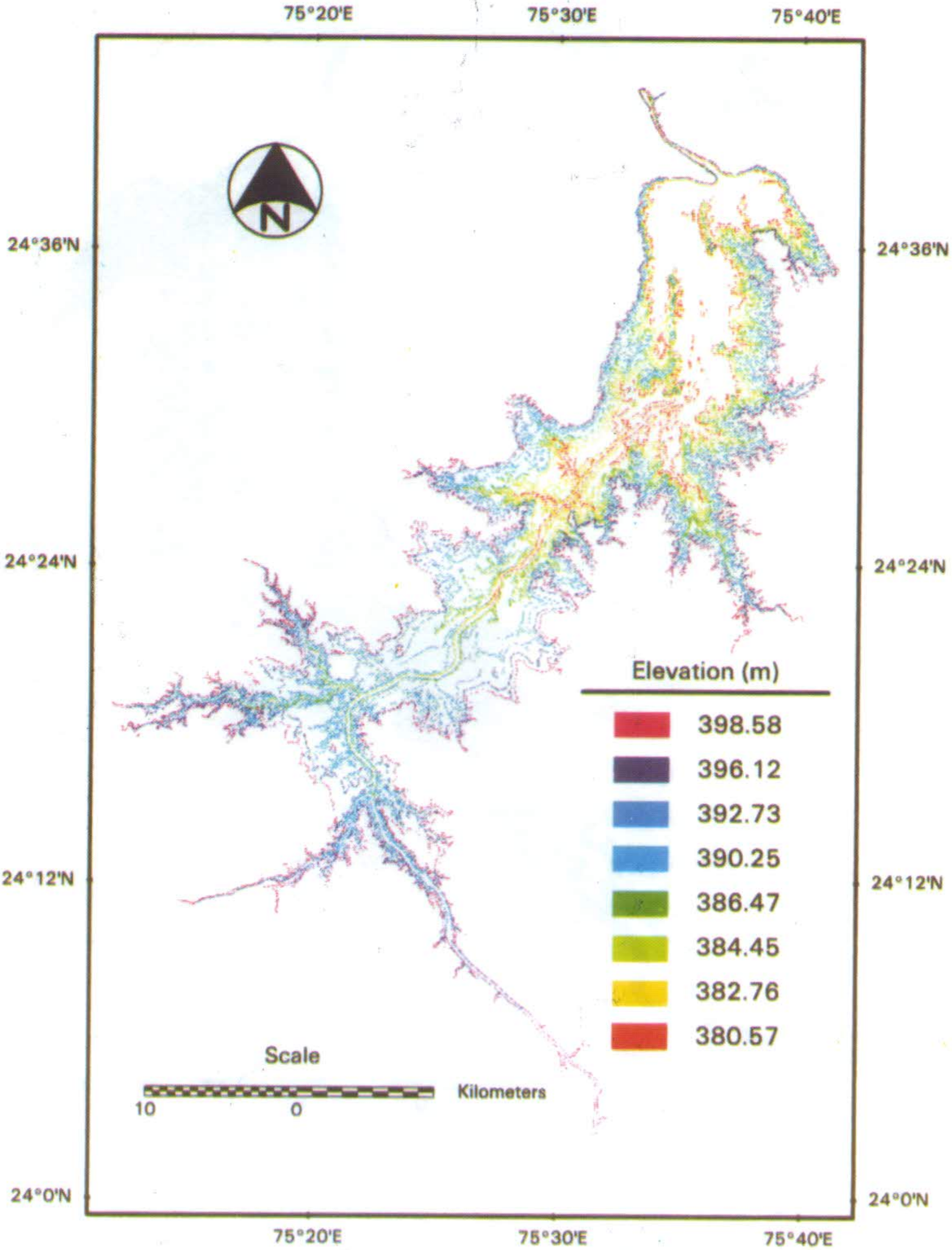


Figure 4.6 : Revised contours of Gandhisagar reservoir as obtained from Remote Sensing data

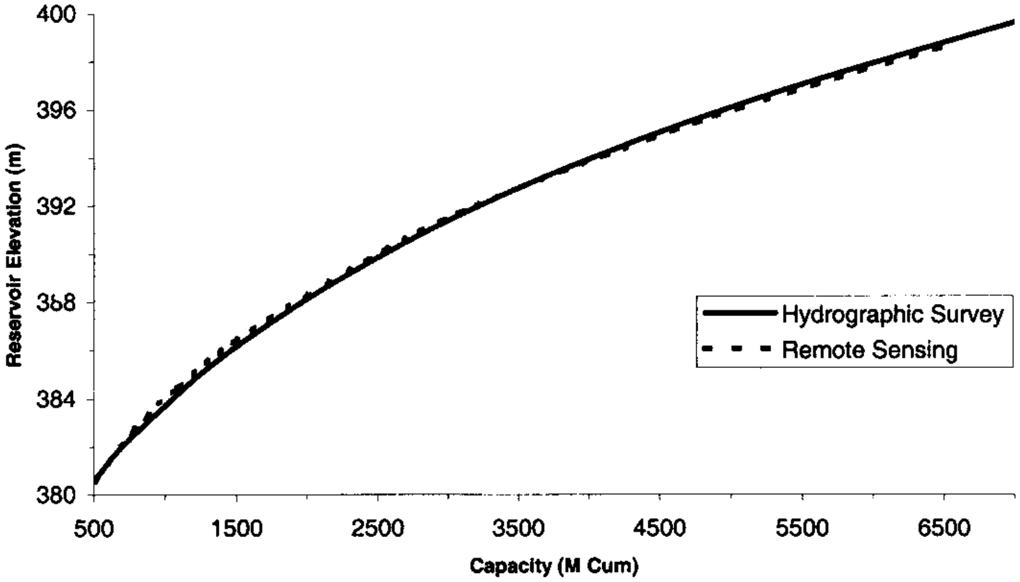


Figure – 4.7. Comparison of Capacity Estimation Using Remote Sensing and Hydrographic survey

## 5.0 SEDIMENTATION STUDY OF VAIGAI RESERVOIR

### 5.1 THE STUDY AREA

The Vaigai reservoir lies in the middle of the Vaigai River basin (Fig.5.1), which is one of the seventeen river basins of Tamil Nadu. Cauvery being the first this basin is considered as the second granary of Tamil Nadu. Vaigai basin is about 7031 sq. km and its catchment area covers the Theni, Madurai and Ramanathapuram Districts of Tamil Nadu. A small portion of the basin is also located in the Idukki District of Kerala. It lies between the geographic coordinates of 90° 15' N to 10° 20' N latitude and 77° 10' E to 79° 15' E longitude and falls within the survey of India toposheets 58G, 58F and 58K. The total area is covered within the administrative boundaries of Uthamapalayam, Periyakulam taluks of Theni District, Nilakottai, Dindugal, Madurai, Melur taluks of Madurai District and Sivaganga, Manamadurai, Paramakudi, Ramanathapuram taluks of Ramanathapuram District. It has varied climatic condition resulting often in unreliable rainfall, drought prone, sudden floods, etc. This gives rise to unpredictable water resources condition.

Vaigai basin is surrounded by Cauveri and Kottakaraiyar basins in the north, Gundar basin in the South, Periyar basin in the West and in the East by Bay of Bengal. The length of the b asin is about 250 km and the width varies from 6-50 km. Madurai the famous Temple City is located in the centre of the basin and the Vaigai reservoir is at a distance of about 60 km from the city. Some of the important urban centers in the river basin are Kambam, Uthamapalayam, Bodinayakkanur, Theni, Periyakulam, Nilakottai, Melur, Manamadurai, Paramakudi and Ramanathapuram.

#### 5.1.1 PHYSIOGRAPHY

The Vaigai River basin occupies an arc shaped area, which stretches from the Westernghat mountain of Kerala in the West to the Bay of Bengal in the East, with a general gradient towards Northeast, initially upto Theni and then towards South East direction up to the sea. The river basin is flanked by Western ghats on the South and West, Southern slope of Palani hills (Kodaikanal hills) Sirumalai hills, Alagar Hills, etc on the North, Nagamalai ridges on the South and Megamalai Hills and Bay of Bengal on the east. Physiograhically the area is broadly divided into three zones, as follows

(a) Western Mountainous terrain with valley complexes

(b) Central elevated terrain and

(c) Eastern Coastal plain

The western mountainous terrains are of relict type, representing the oldest part of the peninsula that has escaped the denudation and are composed of ancient crystalline rocks. The average

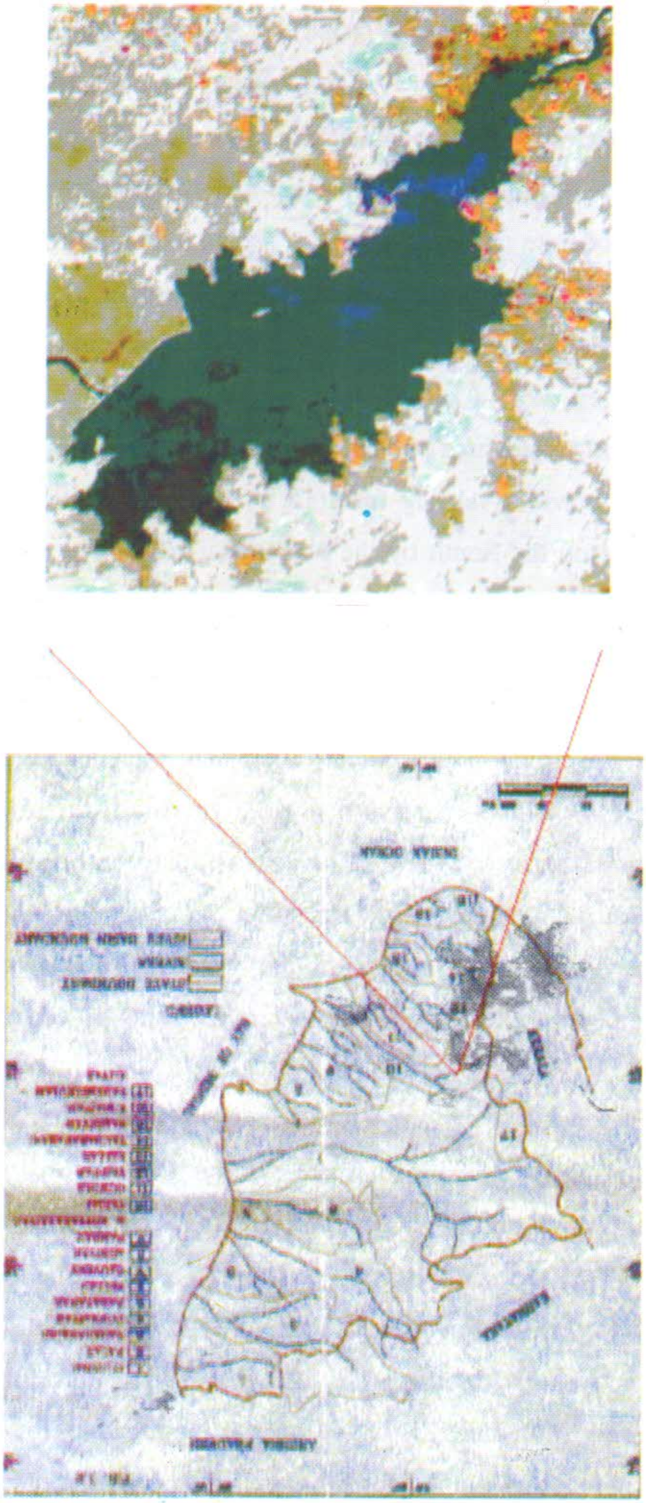


Fig 5.1 Study Area  Vaigai Reservoir

elevation varies from 1000m to 1400m above m.s.l., but many peaks rise over 2000m. The Palani hills, Megamalai hill, etc are essentially spurs and are the offshoot of Westernghat mountains. Some of the prominent peaks are Ibex peak (2519m), Mariyan chola (2426m), Agamalai (1987 m) etc., in the Palani hills (2642m), Bodimettur (1984 m), Kambam Mettu (1058m), Kombai hills (1041m) etc., in the Cardomam hills of Western ghats, Mangaladevi (1341m), Suruliparai (1740m) on the southern western ghat mountain, Koverumalai (1554m), hill (1392m) etc. The slopes of the Western Ghats Mountains are very steep and are escarpment type while the Kodai hills, Megamalai shows moderate to gentle gradient. Nagamalai and Varushanad Mountains are well dissected to give rise to numerous erosional ridges extending from SW to NE direction. Among the hills famous valley complexes have been developed the prominent being the Kambam valley and Varushanad Valley, etc

The Central Elevated terrain area stretches from Nilakottai to Manamadurai over a length of 90 to 100 km and has a width varying from 15 to 40 km. The Northern part is met with Sirumalai, Alagar hills and on the South by the Nagamalai ridge. The average elevation varies from 500m to 1000m towards South. Manjalar, Marudhanathi, Sirumaiaiyar and Sathiar and Uppar drain this part of the area. The plain is generally sloping towards south and undulating with a gradient of one to three degrees.

The Eastern Coastal Plain area stretches between Manamadurai and to the tip of Mandapam, over a length of about 95 km, with a width varying from 15-25 km. The average elevation is varying from 100m to sea level. The area is gently undulating to flat terrain with gradient towards southeast. Alluvium and coastal alluvium cover this plain area. The area is studded with numerous irrigations tanks and distributary canals. Near the coast, sand dunes and bars occur away from the beach. Marshes are also seen in the southern coast.

### 5.1.2 DRAINAGE

The river Vaigai originates in the eastern slope of the Western Ghat mountainous offshoot in the Varushanad area and flows northwards through Gandamanayakkanur. It is joined by several tributaries over a length of 43 km, and reaches the plain area. Surullur and Teniar join Vaigai near Kottapatti. There after Vaigai flows east and Southeast directions till it confluence's with Bay of Bengal. Varattar, Nagalar, Varahanadhi, Manjalar, Marudhanadhi, Sirumaliar, Sathiar, originate in Palani hills and Sirumalai hills which are the main tributaries, join Vaigai along its course. Upper River originates in the Alagar hills and joins Vaigai near Manamadurai. Then Vaigai enters into the Ramnad big tank and the surplus only reaches the sea. The total length of the Vaigai River up to Ramnad big tank is 230 km. Vaigai River and its tributaries are semiperrennial to ephemeral in nature. Out of the ten sub basins (Upper Vaigai, Suruliar, Teniar, Varattar-Nagalar, Varahanadhi, Manjalar Marudhanadi, Sirumalaiar, Sathiar, Uppar and Lower Vaigai basin) drainage area of Vaigai reservoir consists of first three sub-basins.

### 5.1.3 HYDROMETEOROLOGY

The total number of hydromet stations that are in operation in the Vaigai river basin is 81. Revenue Department, Public Works Department, Forest Department, Railways, IMD and Electricity Board maintain these stations. The parameters such as rainfall, air temperature, air humidity, wind velocity, sunshine hours, evaporation etc. are observed in these stations. The stations with long term observations are located mainly in the plain regions at an elevation of 0-400 m above msl, these are maintained by PWD and Revenue Department. The hilly portions are covered by only a few stations viz. Kodaikanal (2090m). There is not much variation in mean annual rainfall in the Vaigai river basin, particularly in plains. Annually 800-900 mm is being recorded generally in the region between the seacoast and the Vaigai reservoir and 700-800 mm in the Suruliar Valley surrounded by mountain ridges.

## 5.2 SOURCE OF SATELLITE DATA

Satellite data products were obtained from NRSA Data Centre (NDC), Hyderabad. The specifications to be provided by the user for catalogue generation include geographical area, satellite sensor, percentage acceptable cloud cover, and seasonal preference. Since cloud cover is reported for the overall scene it is recommended that the intending user visit NDC or 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.

## 5.3 METHODOLOGY

### 5.3.1 PROCESSING OF REMOTE SENSING DATA

The basic output from the remote sensing data analysis is the water spread area of the reservoir. The two techniques of remote sensing interpretation, i.e. visual and digital, can be used for water spread delineation. Visual techniques are based purely on the interpretive capability of the analyst and it is not possible to use the information of different bands, in case of visual products. Using digital techniques, the information of different bands can be utilized to the maximum extent and consistent analysis can be carried out over the entire range of the reservoir.

Water spread underneath the clouds can be extracted indirectly using the interpreted imageries of past and future periods and noise can be removed using different algorithms. Usage of digital data makes easy to calculate the water spread. For these reasons, digital techniques are superior and are gaining recognition now-a-days. In this study, digital analysis was carried out for identifying the water pixels and for determining the water spread area.

### 5.3.2 EXTRACTION OF WATER PIXELS

Different techniques were tried to distinguish and separate out the water pixels. Intensity 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. The sliced pixels may include some saturated soil pixels also as the reflectance value of saturated soil is very low in the near – IR band. Supervised classification is another way of identification. Though clearly distinguishable water pixels could be easily separated out by this technique, accurate training sets for peripheral pixels could not be given. To exactly 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 Band 2 and Band 3, 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 Band 4 will cause the DN value to be less than Band 3 and Band 2. 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 water spread, 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. Water spread areas that existed during the study period at different elevations are shown in Fig 5.2.

## 5.4 RESULTS AND DISCUSSION

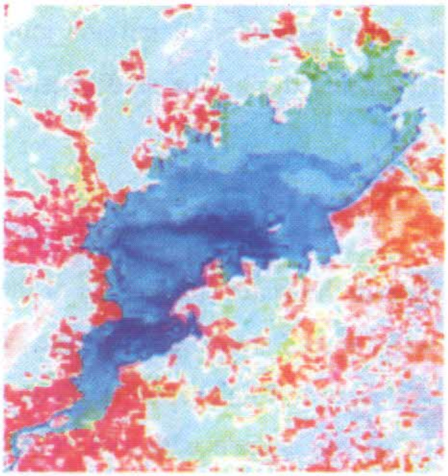
Remote sensing data has been used to calculate the water spread area of the reservoir at different water levels or elevations. The usage of water spread area to estimate the capacity of the reservoir has been explained in detail in the earlier chapters. This chapter deals on the results of estimated present capacity (2002) of the reservoir, its comparison with 1983 (Third) and 2000 (Fourth) hydrographic survey.

### 5.4.1 Estimation of Present Capacity (2002) and Comparison with 1983 Capacity Survey.

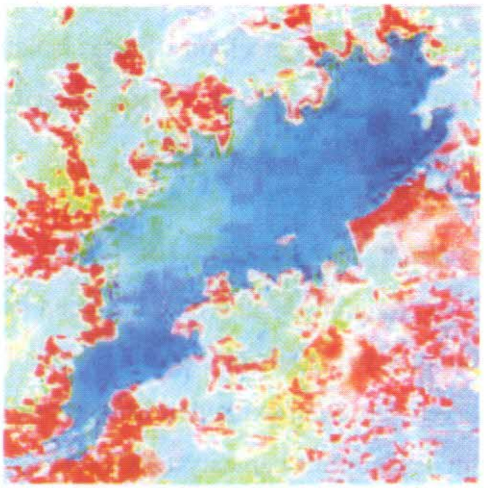
To calculate the prevailing water spread area of 2002, ten different elevations have been selected which various from 257.556 m (MDDL) to 279.197 m (FRL). Out of ten elevations data pertaining to nine (264.946 m to 279.026 m) were cloud free. The satellite data pertaining to these water levels or elevations are procured and revised water spread areas were calculated.

Water spread areas of 1983 (henceforth 1983 elevation-area-capacity data will be called as original data) against the above selected elevations are drawn from the elevation area table obtained from the dam authority.

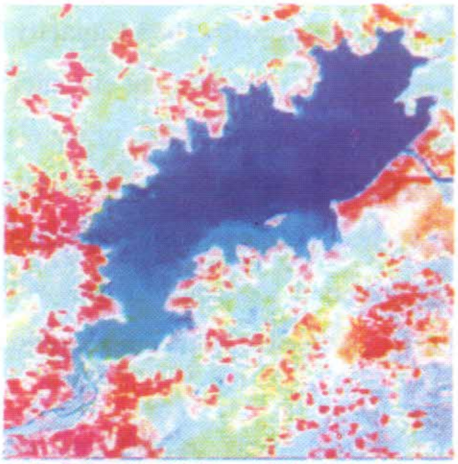
From the known values of original and revised areas at different elevations the corresponding original and revised volumes were worked out using trapezoidal formula. The cumulative revised capacity of the reservoir at the lowest observed level (264.946 m) was drawn from the capacity area table (4.006 Mm$^3$) of 2000 survey to estimate the accurate present capacity of the reservoir. The calculations of cumulative capacity of the reservoir are presented in the Table 5.1. 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 (1983) and revised cumulative capacity (2002) represents the loss of capacity due to sedimentation. The results show that the volume of sediment deposition is 21.55 M cum (167.98 – 146.43) for the period 1983 to 2002. If a uniform rate of sedimentation is assumed in 19 years of occurrence of the reservoir then the sedimentation rate is 1.13 M cum per year.



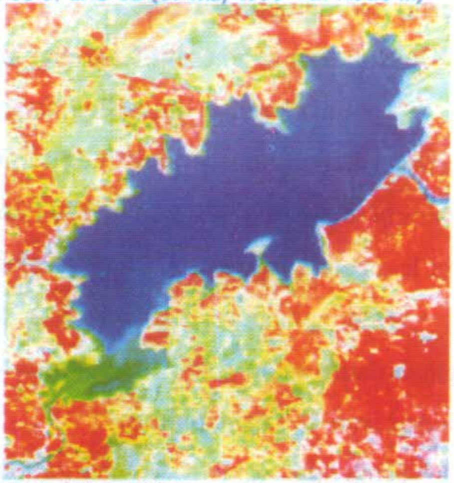
FCC of IRS-1C (26 Feb 1999 - 279.026 m)



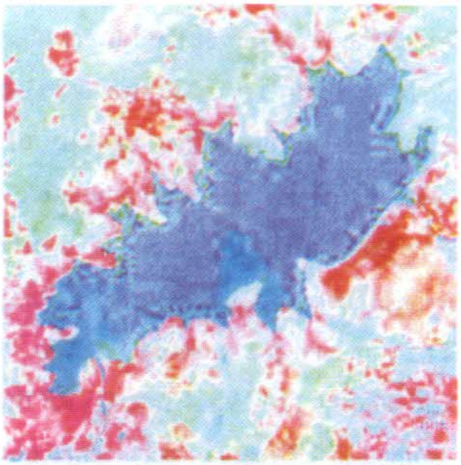
FCC of IRS-1D (07 May 1999 - 277.926 m)



FCC of IRS-1D (26 June 1999 - 276.636 m)



FCC of IRS-1C (17 Nov 1999 - 275.75 m)



FCC of IRS-1D (21 April 2000 - 273.396 m)

Figure 5.2 : **Vaigai reservoir and its water spread area at different elevations**

Table-5.1 Calculation of Sediment Deposition in Vaigai Reservoir Using Remote Sensing.

| Date of Satellite Pass | Reservoir Elevation (m) | Original Area - 1983 ($Mm^2$) | Revised Area – 1999 (RS) ($Mm^2$) | Original Volume ($Mm^3$) | Revised Volume ($Mm^3$) | Original Cumulative Volume 1983 ($Mm^3$) | Revised Cumulative Vol.1999 (RS) ($Mm^3$) |
|---|---|---|---|---|---|---|---|
| 26.02.1999 | 279.026 | 23.36 | 21.45 | | | 167.98 | 146.43 |
| 07.05.1999 | 277.926 | 22.21 | 19.41 | 25.06 | 22.47 | 142.92 | 123.96 |
| 26.06.1999 | 276.636 | 19.73 | 17.20 | 27.04 | 23.59 | 115.88 | 100.36 |
| 17.11.1999 | 275.746 | 17.93 | 14.99 | 16.75 | 14.31 | 99.13 | 86.05 |
| 21.04.2000 | 273.396 | 12.56 | 11.15 | 35.64 | 30.60 | 63.49 | 55.45 |
| 06.01.2002 | 271.716 | 9.48 | 8.99 | 18.45 | 17.69 | 45.04 | 38.56 |
| 25.02.2002 | 269.136 | 6.57 | 5.49 | 20.59 | 19.61 | 24.45 | 20.07 |
| 19.08.2002 | 265.95 | 3.13 | 3.05 | 15.89 | 13.42 | 9.36 | 6.68 |
| 30.06.2002 | 264.946 | 2.54 | 2.2 | 2.86 | 2.65 | 6.50 | 4.006 |

(Note:Year 2001 was a dry year)

### 5.4.2 COMPARISION OF RESULTS WITH HYDROGRAPHIC SURVEY

Hydrographic survey of the Vaigai reservoir was carried out in the year 2000, but remote sensing study was carried for the year 2002 hence both could not be compared. Available data for the 1999-2000 has been utilized to compare the remote sensing study with the above said survey, which is shown in table 5.3. (Details of hydrographic survey 2000 are shown in table 5.2).

Table – 5.2 Revised Elevation-Area-Capacity Table for Vaigai Reservoir
(Results of Hydrographic Survey 2000)

| Reservoir Elevation (m) | Surveyed Water Spread Area ($Mm^2$) | Reservoir Cumulative Capacity ($Mm^3$) |
|---|---|---|
| 279.197 | 24.15 | 167.24 |
| 278.00 | 21.69 | 139.79 |
| 276.00 | 17.75 | 100.35 |
| 274.00 | 13.66 | 68.93 |
| 272.00 | 10.10 | 45.17 |
| 270.00 | 7.73 | 27.34 |
| 268.00 | 5.30 | 14.31 |
| 266.00 | 2.87 | 6.13 |
| 264.00 | 1.16 | 2.12 |
| 262.00 | 0.36 | 0.59 |
| 260.00 | 0.11 | 0.13 |
| 258.00 | 0.02 | 0.001 |
| 257.556 | 0.00 | 0.00 |

Table-5.3 Calculation of Sediment Deposition (1999-2000) Using Remote Sensing.

| Date of Satellite Pass | Reservoir Elevation (m) | Revised Area – 1999 (RS) ($Mm^2$) | Revised Volume ($Mm^3$) | Revised Cumulative Vol.1999 (RS) ($Mm^3$) |
|---|---|---|---|---|
| 26.02.1999 | 279.026 | 21.45 | 22.47<br>23.59<br>14.31<br>30.60 | 152.78 |
| 07.05.1999 | 277.926 | 19.41 | | 130.32 |
| 26.06.1999 | 276.636 | 17.20 | | 106.72 |
| 17.11.1999 | 275.746 | 14.99 | | 92.40 |
| 21.04.2000 | 273.396 | 11.15 | | 61.8 |

Table 5.4 Comparisons of Remote Sensing Results with Hydrographic Survey.

| Reservoir Elevation (m) | Revised Cumulative Volume (HS) ($Mm^3$) | Revised Cumulative Volume (RS) ($Mm^3$) |
|---|---|---|
| 279.026 | 163.32 | 152.78 |
| 277.926 | 138.34 | 130.32 |
| 276.636 | 128.89 | 106.72 |
| 275.746 | 96.36 | 92.40 |
| 273.396 | 61.80 | 61.80 |

Comparison of hydrographic survey (HS) and remote sensing (RS) results are shown in Table 5.4. The intermediate elevations are obtained by linear interpolation from Table 5.2. It is seen from the analysis that there is considerable difference between the two results. As per the hydrographic survey the revised capacity of the reservoir at elevation 279.026 m is 163.32 M Cum where as using remote sensing analysis it comes out to be 152.78 M Cum.

To know why there is a difference between the HS and RS survey, an analysis on the prior five hydrographic survey's (1958-2000) conducted has been worked out in Table.5.5. Until 2000 hydrographic survey the average rate of loss of capacity of the reservoir/year is around 0.94 $Mm^3$ (0.933+0.987+0.9/3) result obtained by remote sensing methodology (42/42=1.00 $Mm^3$) is in agreement with this, whereas the hydrographic survey-2000's result (31.463/42=0.75 $Mm^3$) is far less than the average value. This shows that the results arrived through remote sensing data are more reliable than the hydrographic survey results.

Table 5.5 Comparison of Hydrographic Surveys of Vaigai Reservoir.

| Sl.No. | Year of Survey | Period From Impoundment | Capacity in $Mm^3$ (at FRL) | Reduction in Capacity from impoundment ($Mm^3$) | Average rate of loss of capacity/year ($Mm^3$) |
|---|---|---|---|---|---|
| 1. | 1958 (Impoundment) | --- | 194.783 | --- | --- |
| 2. | 1976 | 18 | 177.987 | 16.796 | 0.933 |

|  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| 3. | 1981 | 23 | 172.074 |  | 22.709 |  | 0.987 |  |
| 4 | 1983 | 25 | 172.261 |  | 22.522 |  | 0.90 |  |
| 5. | 2000 | 42 | 163.32 | *152.78*<br>*(RSR)* | 31.463 | *42.00*<br>*(RSR)* | 0.75 | *1.00*<br>*(RSR)* |

RSR- Remote Sensing Result.

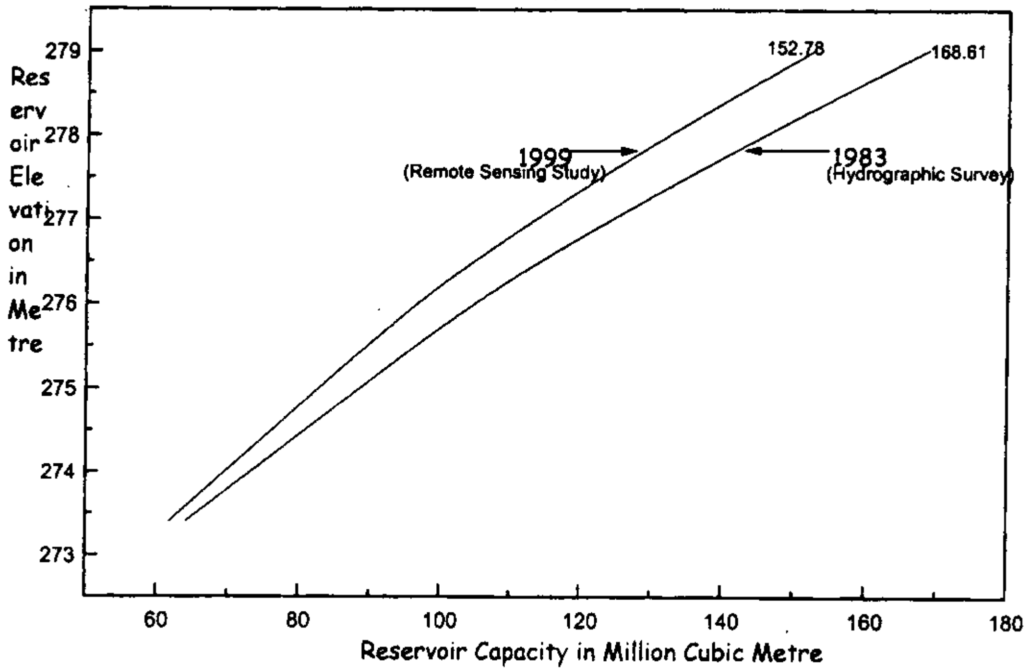
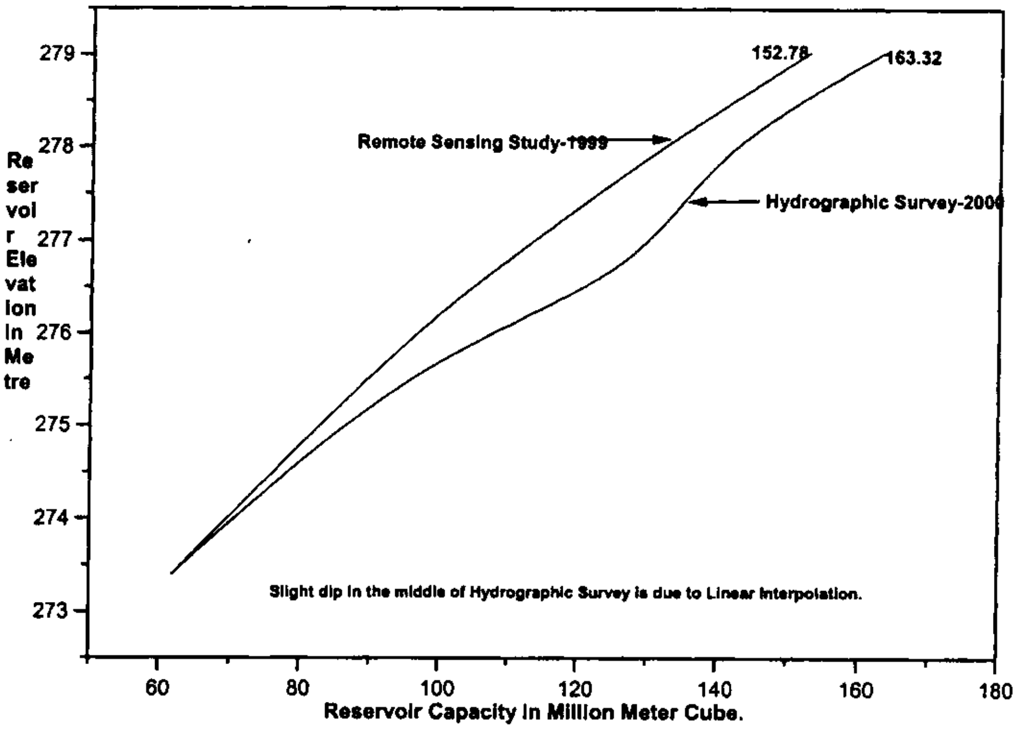


Figure 5.3.Capacity Curves of Vaigai Reservoir for 1983 and



Slight dip in the middle of Hydrographic Survey is due to Linear Interpolation.

**Figure 5.4 : Comparison of Hydrographic and Remote**

## 6.0 SEDIMENTATION STUDY OF TANDULA RESERVOIR

## 6.1 THE STUDY AREA

Tandula dam is situated in Durg district of Chhattisgarh state. The Durg district occupies the southwestern part of the Chhattisgarh plain and possesses belts of hilly country in the south, southwest and northwest, bestowed with mineral resources and forests. The district lying in the Raipur Commissioner's Revenue Division, extends between the latitudes 20°23' N and 22° 02' N and the longitudes 80°48' E and 81° 57' E. The Altitude of the district is 317 meters from mean sea level. The area occupied by the district is 8537 km$^2$ while the population of the district is 2397134 as per 1991 Census.

As the catchment and command area of the reservoir lies in the Durg district. The Durg district occupies the southwestern part of the Upper Sheonath-Mahanadi valley and the bordering hills in the south and southwest. Physiographically, the district can be divided into two divisions, namely, Chhattisgarh plains and the southern plateau with scattered hill features. The Chhattisgarh plain occupies the largest area in the District. The general slope of the district is from southwest to northeast direction. The Sheonath, the Kharun and the Tandula of Mahanadi river basin are the main rainfed streams, which drain the district.

### 6.1.1 TANDULA DAM AND ITS CATCHMENT

The Tandula complex project is one of the major river projects of Chattisgarh State. The Tandula reservoir is situated in Balod tahsil of Durg district at about 5 km from the Balod city. This reservoir has been developed by constructing a dam on the confluence of Sukha nala and Tandula River. The construction of the dam was started in the year 1910 and completed in 1921. The total catchment area of the reservoir is about 319.40 sq. mile (827.197 sq. km). The length of the dam is 4420 meters. The Low Supply Level (LSL) and Full Tank Level (FTL) of the reservoir are 320.445 meters and 332.180 meters respectively. The Highest Flood Level (HFL) and the Top Bund Level (TBL) have been designed as 333.415 meters and 335.230 meters respectively. The water-spread area of the reservoir at full supply level is 4610.23 hectares. The average monsoon rainfall adopted for the project is 1397 mm. The actual cost of the project per hectare of the irrigated area has been worked out as Rs.27.52 only in the year 1921.

The total capacity of the reservoir is 31225 ha-m, while the live and dead capacities of the reservoir are 30228.25 ha-m and 996.75 ha-m respectively. The length of the main canal and distributaries are 110 km and the total length of minors is 880 km. The reservoir has been designed to irrigate about 68,219 hectare of Kharif crop. The mean monsoon rainfall in the command area is about 1293 mm. An index map showing the Tandula reservoir has been presented in Fig. 6.1.

After increasing the irrigated area in the Tandula command, it was found that the existing capacity of the Tandula reservoir was not adequate to fulfil the proper irrigation demand in the command area. Therefore, an additional reservoir called Gondali reservoir has been constructed on Jujhara nala during the years 1955 to 1957 and a supplementary canal of 9 km length has been constructed to supply water from Gondali reservoir to Tandula dam. The Gondali reservoir is 10 km away from Balod. The catchment area of this dam is 192 sq. km. Initially it was proposed to irrigate about 21,053 hectare of kharif crops of Tandula command from the supplementary canal of Gondali reservoir. After construction of Bhilai Steel Plant in the year 1956, the water of Gondali reservoir is being supplied to the plant and irrigation in the command area from Gondali reservoir has been stopped. It has been observed that after supplying water to Bhilai Steel Plant and other allied industries, the irrigation capacities in the command area has been affected drastically and hence the height of both the dam has been increased by 0.61 m.

The major portion of the catchment area of the Tandula river up to the reservoir is covered by the forest and a small portion which is along the river are agricultural area. The catchment area lies in the zone of more than 1400 mm rains but ground water yield is less than 1 lit/sec. Red loamy soil predominantly found in the basin. The land slope in the catchment area varies from 300-600 m/km to 10-20 m/km. Granite and Gneisses are the rocks found in the catchment area. The catchment area of Tandula river is famous for its iron mines.

## 6.2 SOURCE OF DATA USED

The Tandula reservoir is full in the month of November, and it is empty in May. Therefore, data of IRS 1C/1D satellite during this period was browsed and cloud free data of nine dates covering from dead storage level to the maximum reservoir level at approximately equal intervals were selected. The data used in this study are given in Table-6.1.

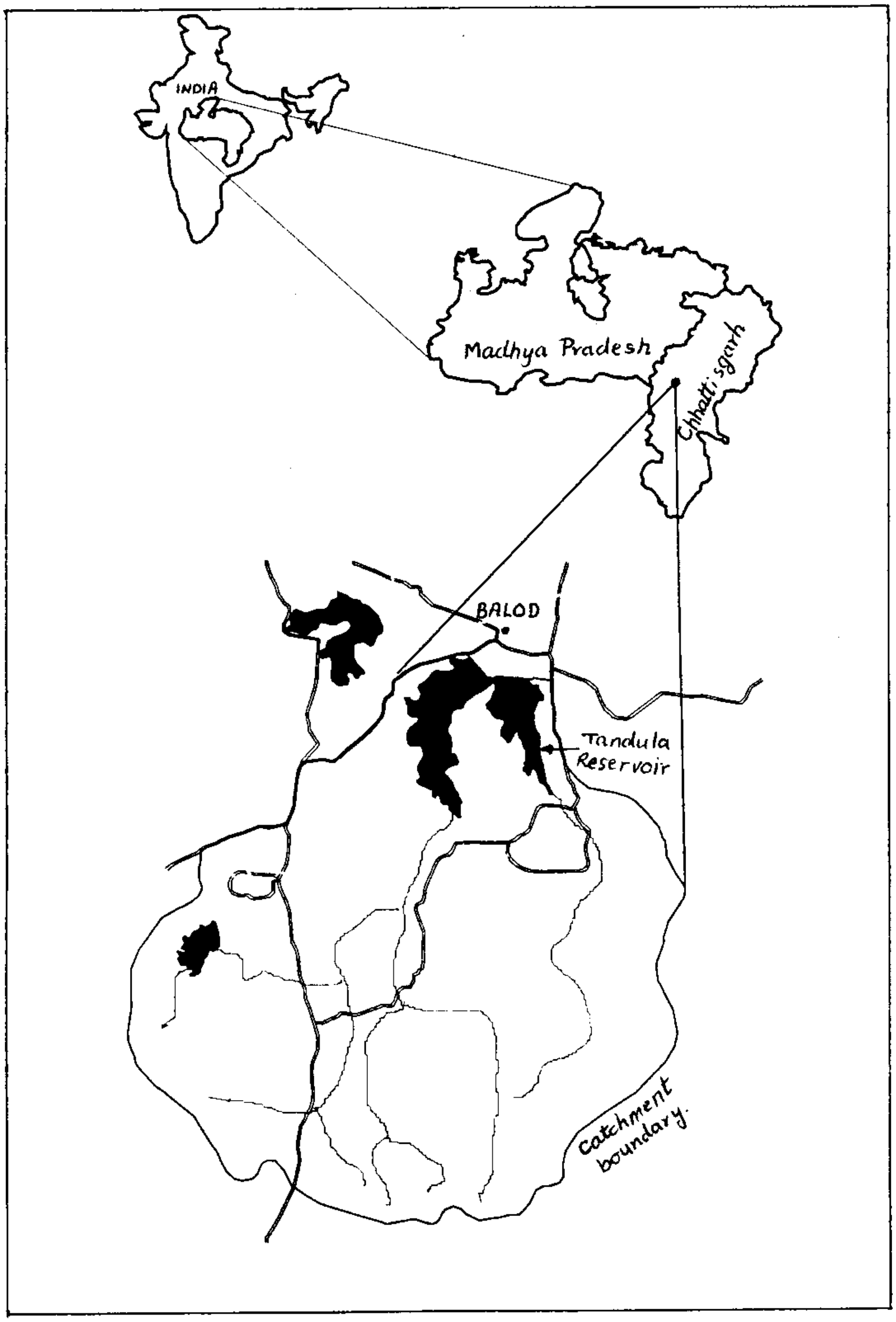


Figure 6.1 : Index map of Tandula reservoir

**Table 6.1: Satellite data (LISS III sensor) used for estimation of water spread area**

| Sl. No. | Date of Pass | Elevation (meters) | Satellite |
|---|---|---|---|
| 1 | 24-Dec-2000 | 325.23 | IRS 1-D |
| 2 | 03-Apr-2001 | 322.88 | IRS 1-D |
| 3 | 28-Apr-2001 | 321.79 | IRS 1-D |
| 4 | 23-May-2001 | 320.96 | IRS 1-D |
| 5 | 31-Aug-2001 | 332.18 | IRS 1-D |
| 6 | 24-Sept-2001 | 330.47 | IRS 1-C |
| 7 | 09-Dec-2001 | 328.13 | IRS 1-D |
| 8 | 13-Apr-2002 | 326.57 | IRS 1-D |
| 9 | 02-Jan-2002 | 324.07 | IRS 1-D |

**Ancillary Data**

The satellite data provides water spread area only, therefore additional field data, like water level in the reservoir or elevation on the date of pass of the satellite; original elevation-area-capacity curve etc. is also required. The daily water levels in the reservoir from the year 2000 to 2002; elevation-capacity table before impounding of the reservoir at the intervals of mks unit. Information regarding hydrology of the reservoir, minimum and maximum water levels, storage etc. was also collected from the office of the Executive Engineer, Water Resources Department Shivnath Mandal, Durg. The Elevation-Capacity data collected from WRD are given in Table 6.1. The original Elevation- -Capacity table was used to compare the present capacity and original capacity at selected elevations. The difference in the capacity is assumed as sediment deposit in the reservoir.

## 6.3 METHODOLOGY

### 6.3.3 Identification of Water Pixels

After analysing the spectral reflectance of water pixels in various imageries, an algorithm was used for identifying the water pixels using data of different bands. The algorithm matches the signatures of a pixel with that of water and then identifies whether a pixel represents water or not.

In addition, it also checks for the 'Water Index' (NIR/Green), which is created as a separate image. In all the images, it is found that the 'Water Index' (WI) for water is either equal to or less than 0.41. The algorithm checks for following condition for each pixel. If the condition is satisfied, then it is recorded as water, otherwise not:

> "If the DN value of near-IR band (B3) of a pixel is less than the DN value of the red band (B2) and the green band (B1), and the WI is ≤ 0.41, then it is classified as water otherwise non-water".

A flow chart showing the methodology followed for identification of water pixels and calculation of revised water spread area of the reservoir has been shown in Fig.-6.2.

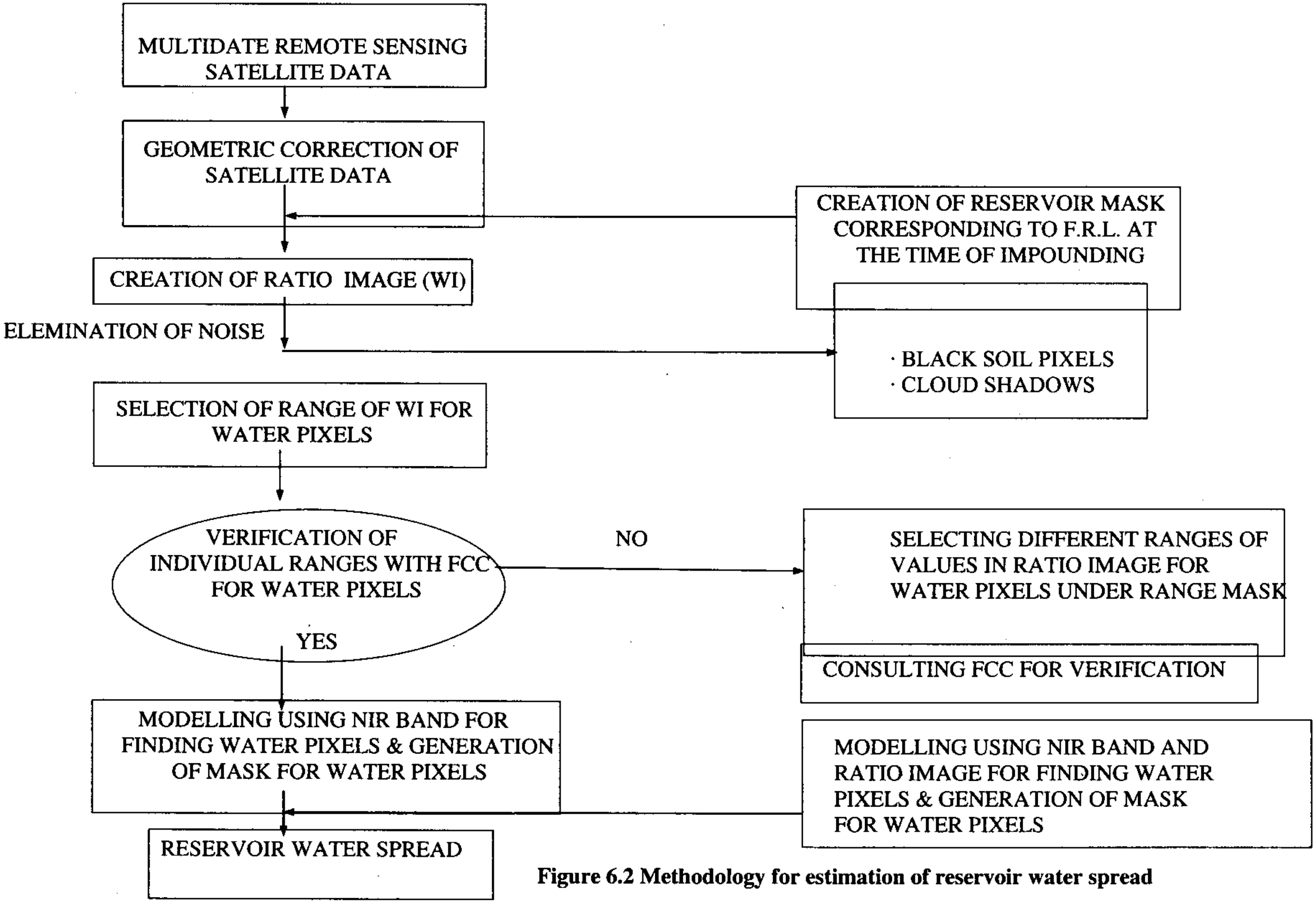


**Figure 6.2 Methodology for estimation of reservoir water spread**

## 6.4 STORAGE CAPACITY OF A RESERVOIR

The present elevation-capacity curve is compared with the original elevation-capacity curve, and the reduction in capacity at different elevations is the sediment deposited. Thus, difference in capacity at full reservoir level gives the total silt deposit in the reservoir.

## 6.5 RESULTS AND DISCUSSIONS

Satellite remote sensing technology provides synoptic, repetitive and unbiased information of the earth surface. Water features on the surface can be delineated with more accuracy using satellite data due to complete absorption of EMR in the NIR band (band 4 in case of IRS 1C/1D). Therefore, delineation of water spread area of a reservoir using satellite data is more accurate, economical and less time consuming than the conventional methods of hydrographic surveying. Multi-date satellite data provides the water spread area at different elevations. Therefore, reservoir capacity can be calculated by knowing the spread area of the reservoir at different elevations using the cone formula and subsequently revised elevation-capacity curve can be drawn. The revised elevation-capacity curve can be compared with the original elevation-capacity curve to get the difference in capacity at various elevations. The reduction in the reservoir capacity may be assumed as sedimentation loss at different elevations. The revised elevation-capacity curve can be used to estimate the available water in the reservoir at different elevations.

### 6.5.1 Original Capacity of Tandula Reservoir

The Tandula reservoir was completed in 1921 and detailed topographic survey was carried out to get the elevation -capacity curve. This curve is also used for designing the optimum height of the dam, capacity of dam at dead storage level, full reservoir level and maximum water level. The original elevation-capacity table has been collected from the Executive Engineer Office, Shivnath Mandal, Water Resources Department, Durg (Chhattisgarh). The original elevation-capacity table for Tandula reservoir has been obtained from the Water Resources Deptt., Durg (C.G.) and the same has been presented here in the following Table 6.2.

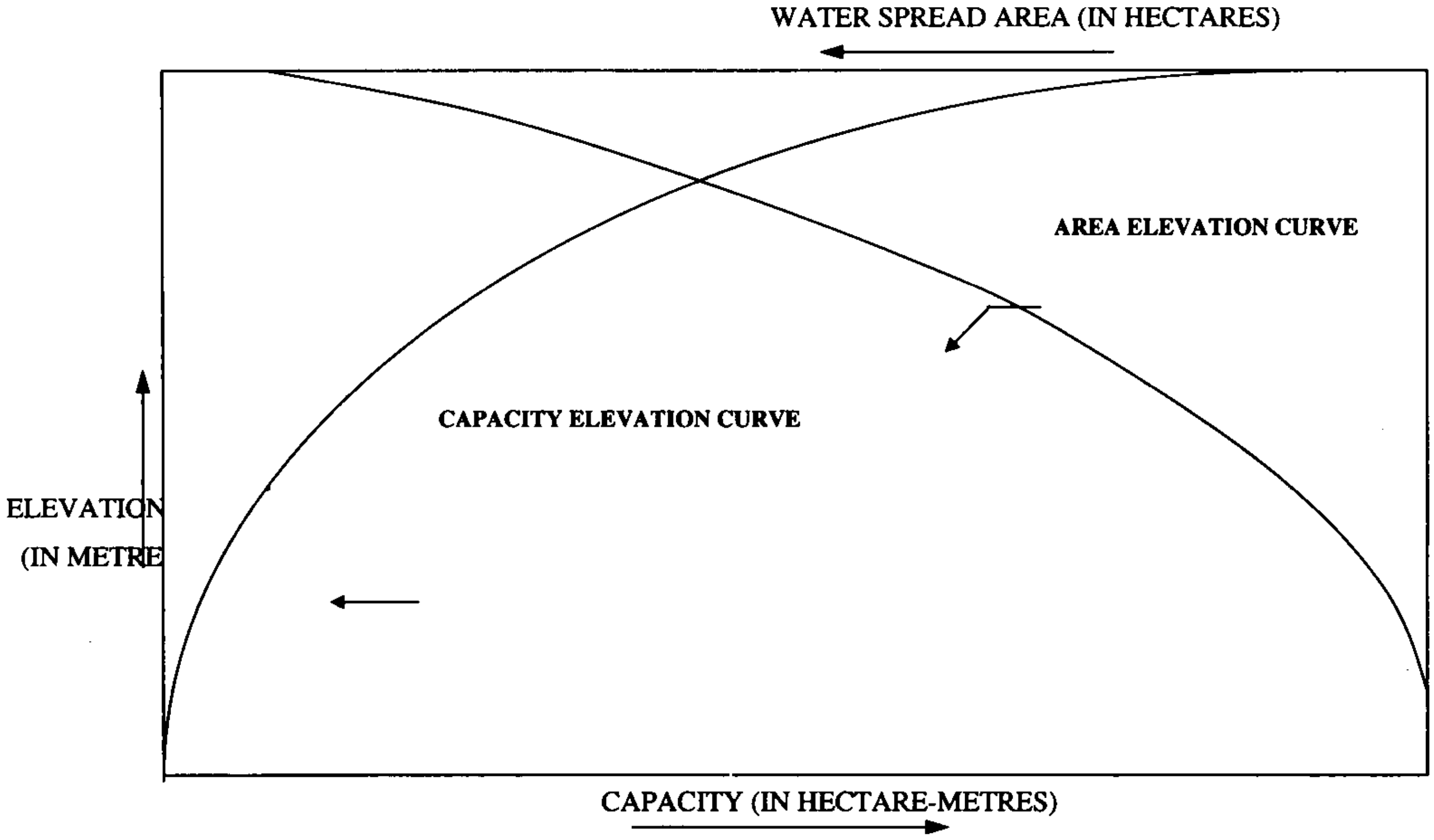


Figure 6.3: A Typical Elevation Area Capacity Curve

### 6.5.2 Estimation of Revised Capacity

The IRS 1C/1D LISS-3 digital data of selected dates were obtained and image processing carried out using ILWIS 2.2 as discussed in chapter-4. The satellite data were transferred from compact disk to personal computer for further analysis. All the images were cut down to cover the Tandula reservoir and surroundings.

**Table 6.2: The original elevation-capacity table of Tandula reservoir**

| R.L. (meter) | Cumulative Capacity (ha-m) | R.L. (meter) | Cumulative Capacity (ha-m) | R.L. (meter) | Cumulative Capacity (ha-m) |
|---|---|---|---|---|---|
| 320.35 | 998.17 | 324.93 | 6825.07 | 328.58 | 16926.34 |
| 320.51 | 1048.74 | 325.08 | 7133.75 | 328.74 | 17456.43 |
| 320.66 | 1185.09 | 325.23 | 7496.63 | 328.89 | 17986.52 |
| 320.81 | 1375.24 | 325.38 | 7859.51 | 329.04 | 18516.61 |
| 320.96 | 1452.12 | 325.54 | 8222.39 | 329.19 | 19046.70 |
| 321.12 | 1585.63 | 325.69 | 8868.44 | 329.35 | 19576.80 |
| 322.15 | 2564.86 | 325.84 | 8948.15 | 329.50 | 20106.89 |
| 322.18 | 2603.48 | 325.99 | 9311.03 | 329.65 | 20666.09 |
| 322.34 | 2796.46 | 326.15 | 9673.91 | 329.80 | 21268.95 |
| 322.49 | 2989.44 | 326.30 | 10036.79 | 329.96 | 21871.82 |
| 322.64 | 3182.42 | 326.45 | 10399.67 | 330.11 | 22474.68 |
| 322.82 | 3413.31 | 326.60 | 10797.67 | 330.26 | 23077.55 |
| 322.94 | 3568.38 | 326.75 | 11248.33 | 330.41 | 23680.42 |
| 323.10 | 3761.36 | 326.91 | 11349.39 | 330.56 | 24283.28 |
| 323.25 | 3954.25 | 327.06 | 12149.65 | 330.72 | 24886.15 |
| 323.40 | 4145.87 | 327.15 | 12420.05 | 330.87 | 25371.47 |
| 323.55 | 4372.12 | 327.21 | 12600.32 | 331.02 | 26113.09 |
| 323.71 | 4644.67 | 327.36 | 13050.98 | 331.17 | 26752.51 |
| 323.86 | 4917.22 | 327.52 | 13501.61 | 331.33 | 27424.04 |
| 324.01 | 5189.77 | 327.67 | 13952.30 | 331.48 | 28095.58 |

| | | | | | |
|---|---|---|---|---|---|
| 324.16 | 5462.32 | 327.82 | 14402.97 | 331.63 | 28767.11 |
| 324.32 | 5789.38 | 327.97 | 14853.63 | 331.78 | 29444.14 |
| 324.47 | 6007.42 | 328.13 | 15336.06 | 331.94 | 30129.41 |
| 324.62 | 6279.97 | 328.28 | 15866.16 | 332.09 | 30814.68 |
| 324.77 | 6552.52 | 328.43 | 16396.25 | 332.18 | 31225.84 |

The images were 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 Water Index (WI) 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 Fig.- 6.4 to Fig.- 6.9.

The revised volume of the reservoir has been calculated using water spread area obtained from satellite data and respective elevations using cone formula as given in equation 3.3. The live storage of the reservoir falls between RL 320.445 meters and 332.18 meters. The remote sensing data availability is limited to the date of pass of the IRS 1C/1D satellite. The satellite data available for the present study cover the reservoir elevations from 320.96 meters to 332.18 meters. Generally, the percentage of silting in lower elevations is greater than the silting rate at higher elevations. But for computation purpose, the percentage loss in capacity below elevation 320.96 meters has been assumed the same as loss between elevations 320.96 to 321.79 meters i.e., 14.69 %. The revised cumulative capacities at various elevations were obtained by adding the revised volume between consecutive elevations. The original cumulative capacities on different stages of pass have been obtained from the capacity table obtained from the Water Resources Department.

The computation of revised capacity and the original capacity at different elevations have been shown in the Table 6.3. The difference between the original and revised cumulative capacity represents the loss in capacity due to sedimentation. The graph given in Fig.- 6.10 shows the elevation vs. original and revised cumulative capacity of Tandula reservoir. The total loss in the live storage capacity of Tandula reservoir has been estimated to be 2031.085 ha-m. The percentage loss in the live storage zone is 6.94 % of the live storage. Further, by assuming a constant rate of silting of 14.69% in the dead storage zone (same as the rate estimated for the lowest live storage zone), silting in the dead storage zone is 213.416 ha-m. Hence total loss in the gross storage capacity is estimated as 2244.501 ha-m during last 80 years.

**Table 6.3 Revised elevation-area-capacity tables for Tandula reservoir**

| Date of Pass | Reservoir Elevation (meters) | Number of Water Pixel | Revised Area (hectare) | Revised Volume (ha-m) | Original Cumu. Capacity (ha-m) | Original Volume (ha-m) | Loss in Volume(ha-m) | % Loss in Volume between Successive Elevations |
|---|---|---|---|---|---|---|---|---|
| | Dead Storage | | | | | 998.169* | 146.732* | 14.69 * |
| | 320.45 | | | | 998.169 | | | |
| | | | | | | 453.947* | 66.686* | 14.69 * |
| 23-May-01 | 320.96 | 10686 | 609.1 | | 1452.116 | | | |
| | | | | 615.067 | | 720.975 | 105.908 | 14.69 |
| 28-Apr-01 | 321.79 | 15698 | 894.8 | | 2173.091 | | | |
| | | | | 1097.000 | | 1318.093 | 221.092 | 16.77 |
| 03-Apr-01 | 322.88 | 19447 | 1108.5 | | 3491.184 | | | |
| | | | | 1568.742 | | 1807.606 | 238.864 | 13.21 |
| 02-Jan-02 | 324.07 | 27067 | 1542.8 | | 5298.790 | | | |
| | | | | 2010.003 | | 2197.840 | 187.837 | 8.55 |
| 24-Dec-00 | 325.23 | 33954 | 1935.4 | | 7496.630 | | | |
| | | | | 2958.097 | | 3210.904 | 252.807 | 7.87 |
| 13-Apr-02 | 326.57 | 43641 | 2487.5 | | 10707.53 | | | |
| | | | | 4265.856 | | 4628.530 | 362.674 | 7.84 |
| 09-Dec-01 | 328.13 | 52793 | 3009.2 | | 15336.06 | | | |
| | | | | 8226.480 | | 8585.498 | 359.015 | 4.18 |
| 24-Sep-01 | 330.47 | 70627 | 4025.7 | | 23921.56 | | | |
| | | | | 6996.005 | | 7298.894 | 302.888 | 4.15 |
| 31-Aug-01 | 332.18 | 73133 | 4172.1 | | 31220.45 | | | |

## 6.6 DISCUSSION OF RESULTS

Based on the availability of remote sensing data and the water level variation of the Tandula reservoir in the year 2000-02, the revised capacities at nine different elevations have been estimated for the zone of the reservoir lying in-between the elevations 320.96 meters and 332.18 meters. The revised capacity between the intermediate zones was calculated by using the cone formula. The satellite data of elevations below 320.96 meters could not be obtained, because the water level in the reservoir did not fall below this elevation during last five years. The sedimentation below this elevation has been considered as 14.69 % and computations have been made as discussed earlier. Based on the analysis, it has been observed that 2031.085 ha-m of live storage capacity has been lost due to sedimentation in a period of last 80 years (1922 – 2002).

The sedimentation in gross storage capacity has been estimated as 2244.501 ha-m. If we assume a constant rate of sedimentation over the period of 80 years, it comes out to be 28.056 ha-m /year. The catchment area of Tandula reservoir being 827.197 sq. km, the silting rate in the common unit is computed to be 3.392 ha-m/100sq. km/year.

The results of this study were compared with that of the sedimentation rate calculated by Khosla's formula. Khosla analysed the data from the reservoirs located in India and abroad and observed that the annual rate of sediment deposition decreased with the age of reservoirs. He plotted a curve between the annual sediment deposited and the catchment area and suggested the following empirical equation for the enveloping curve:

$$Q_s = \frac{0.323}{A^{0.28}} \qquad \text{... (4.1)}$$

where, $Q_s$ = the annual silting rate from 100 sq. km of watershed area (M cu.m/100 sq. km), and A = the catchment area (sq. km). The catchment area of the Tandula reservoir is 827.197 sq. km, therefore substituting the value of 'A' in eq. 4.1,

$Q_s$ = 0.04923 M cu. m/100 sq. km/year
= 4.923 ha-m/100 sq. km/year

The Tandula reservoir is constructed at the confluence of rivers Tandula and Sukha. Also, some small streams join directly to the main body of the reservoir forming very small tails in the perimeter of the reservoir at FRL. In general the length of the tails are very short. Tandula and Sukha rivers carry most of the sediment into the reservoir. The velocity of water in these streams is generally high during monsoon period, therefore the silt and small particles in the stream flow deep into the reservoir and deposit at greater depths, i.e. at lower elevations. It is also clear from the Table 6.4 that sediment deposition is more (15-17 %) near dead storage level

(RL 320.96 m to 324.07 m), however at higher elevations the percentage of sedimentation reduces gradually to about 4 %. Deposition of silt is less at higher elevations may be due to steep topography at those levels. The satellite data used for this study belongs to IRS 1C/1D, LISS-3 sensors, which has high spatial resolution of about 24 m pixel size. The water spread area at FRL is covered by 73133 pixels having periphery of 60.106 km and at elevation of 320.96 m it is covered by 10686 pixels having 31.5 km. Numbers of pixels along the periphery at elevations of 332.18 m (FRL) and 320.96 m is 2504 and 1312 respectively. If 50% error is considered in the identification of boundary pixels, there may be 2 % to 6 % error in the calculation of water spread area in the live storage zone. However, the NDWI based digital image processing technique provides more than 90 percent accuracy in identification of water pixels, which causes only 0.4 - 1.2 % error in the calculation of water spread area due to misclassification of the boundary pixels. Also, the same error may occur in calculation of revised capacities.

## 6.7 CONCLUSIONS

The remote sensing technology has emerged as a unique and extremely important tool in understanding, assessing and monitoring the natural resources. The data obtained from the remote sensing platforms by virtue of their repetitive and synoptic coverage and computer aided data analysis make significant contributions in understanding and monitoring the environmental degradations. With these facts, the remote sensing technology has definitely an edge over the conventional data collection methods.

In the present study, the revised capacities of the Tandula dam have been estimated using the remote sensing and GIS technique. IRS-1C/1D, LISS-3 data of nine different dates for the year 2000-2002 have been used for determination of revised water spread area. The signature characteristics of different surface features (water, soil and vegetation) were utilised for separating the water pixels from other surface features. A uniform method of analysis was adopted for the identification of water pixels in all the images. A numerical limit of Water Index was selected as 0.41 for differentiation of water pixels from wet soil pixel. The tail end of the reservoir and the rivers joining the reservoir around the periphery were truncated based on the termination of spread and visual interpretation. Using revised water spread obtained from the satellite data, the revised volume in between the successive intervals and revised cumulative capacities of the reservoir have been computed. The following conclusions may be drawn from the analysis of the results.

i. From the analysis of remotely sensed data, it has been found that the live storage of

Tandula reservoir has reduced by 2031.085 ha-m in the 80 years/(1922-2002).

ii. More loss in the live storage has been found in the zone between 320.96 m to 324.07 m, it may be due to accumulation of sediments in the lower zone.

iii. Annual rate of silting is estimated to be 28.056 ha-m /year since impoundment of reservoir in 1922 to 2002. This comes out to be about 0.1 % reduction in live storage capacity every year.

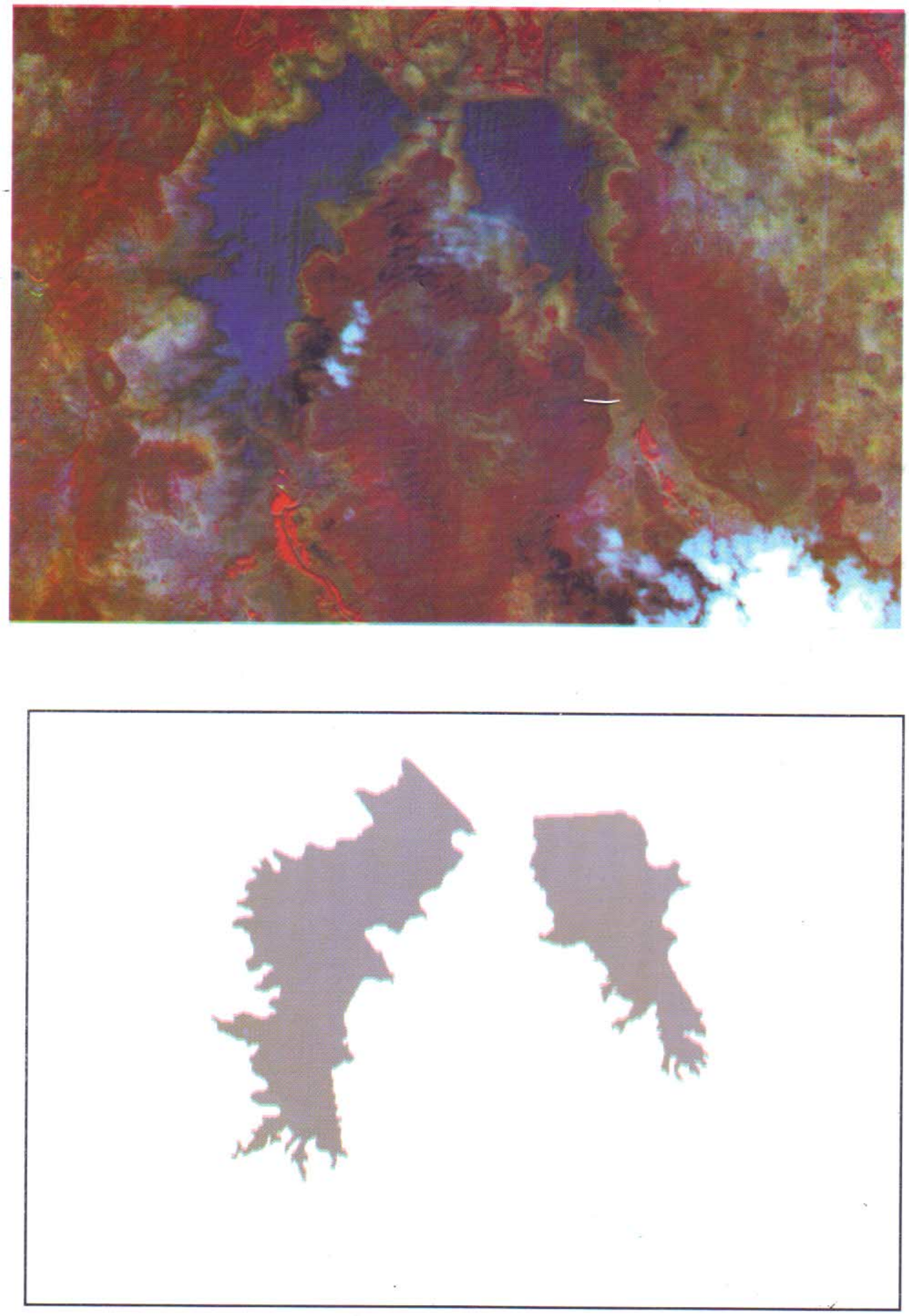


Figure 6.4: Standard FCC and extracted water spread area of Jan. 02, 2002

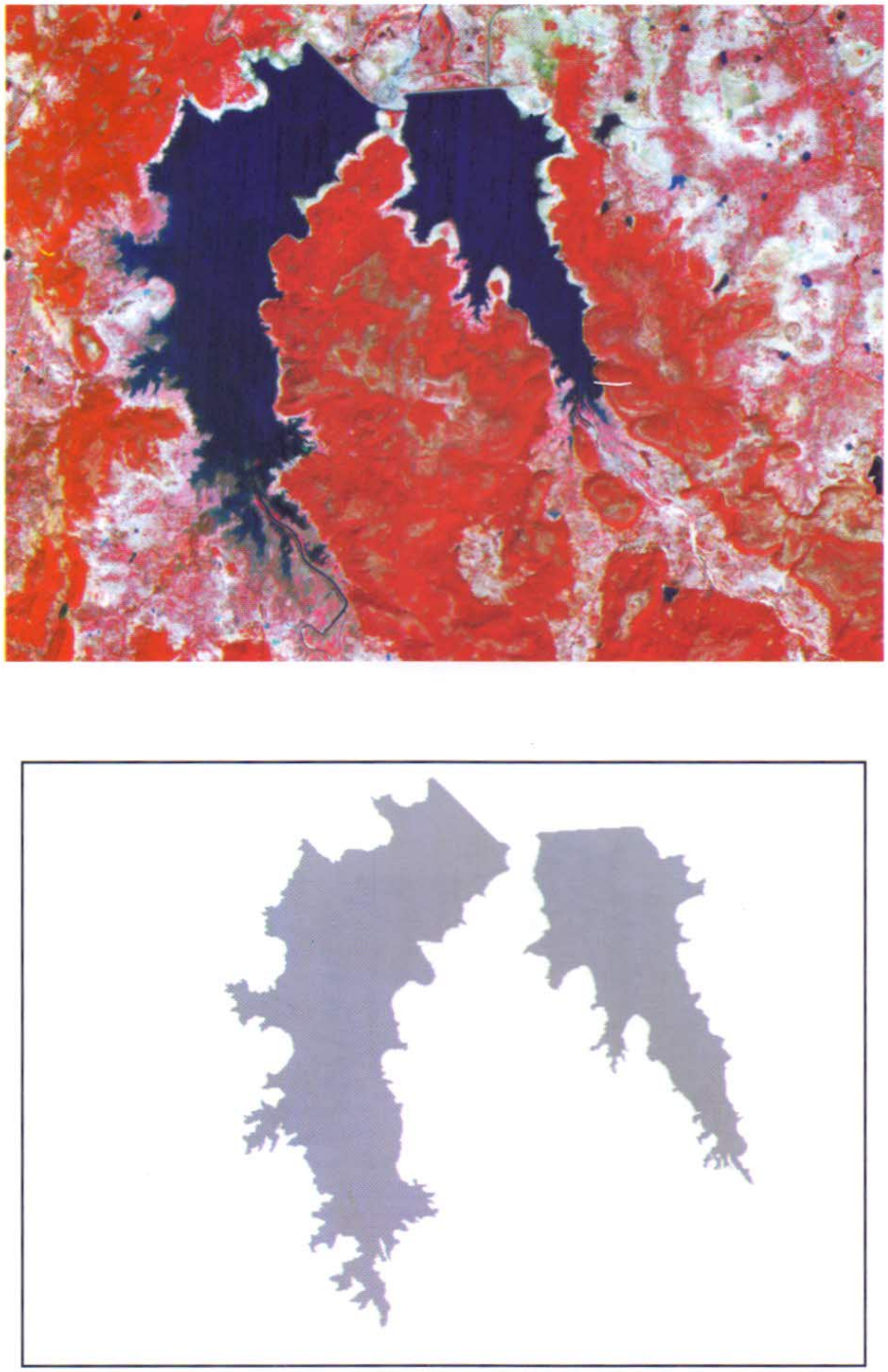
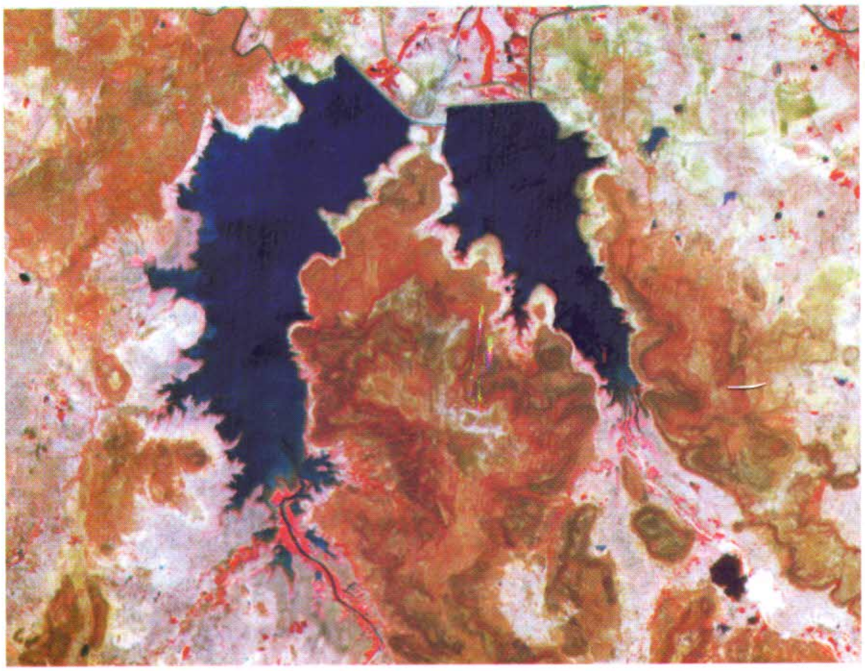


**Figure 6.5: FCC and extracted water spread area of Dec. 09, 2001**



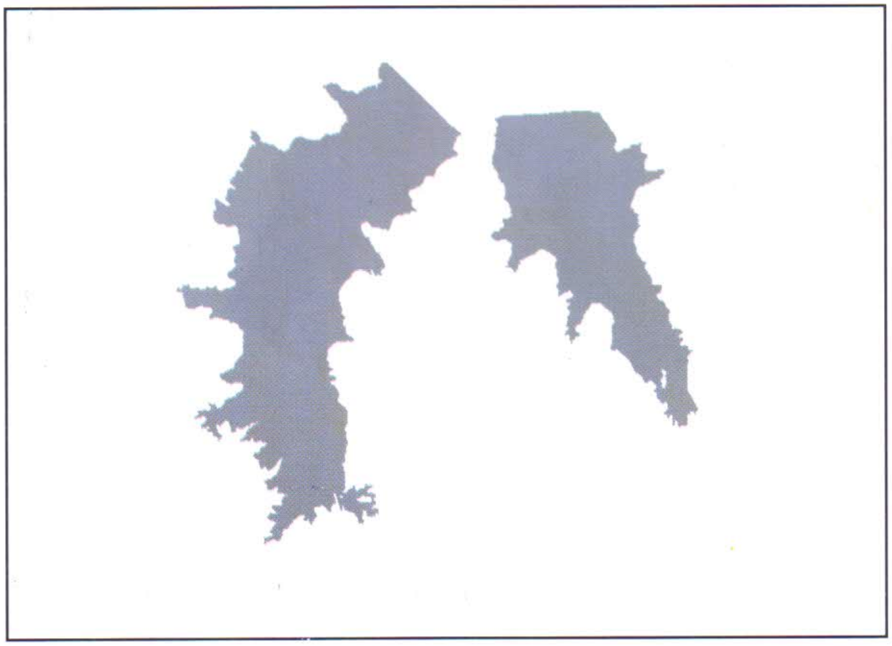


Figure 6.6: FCC and extracted water spread area of Apr. 13, 2002

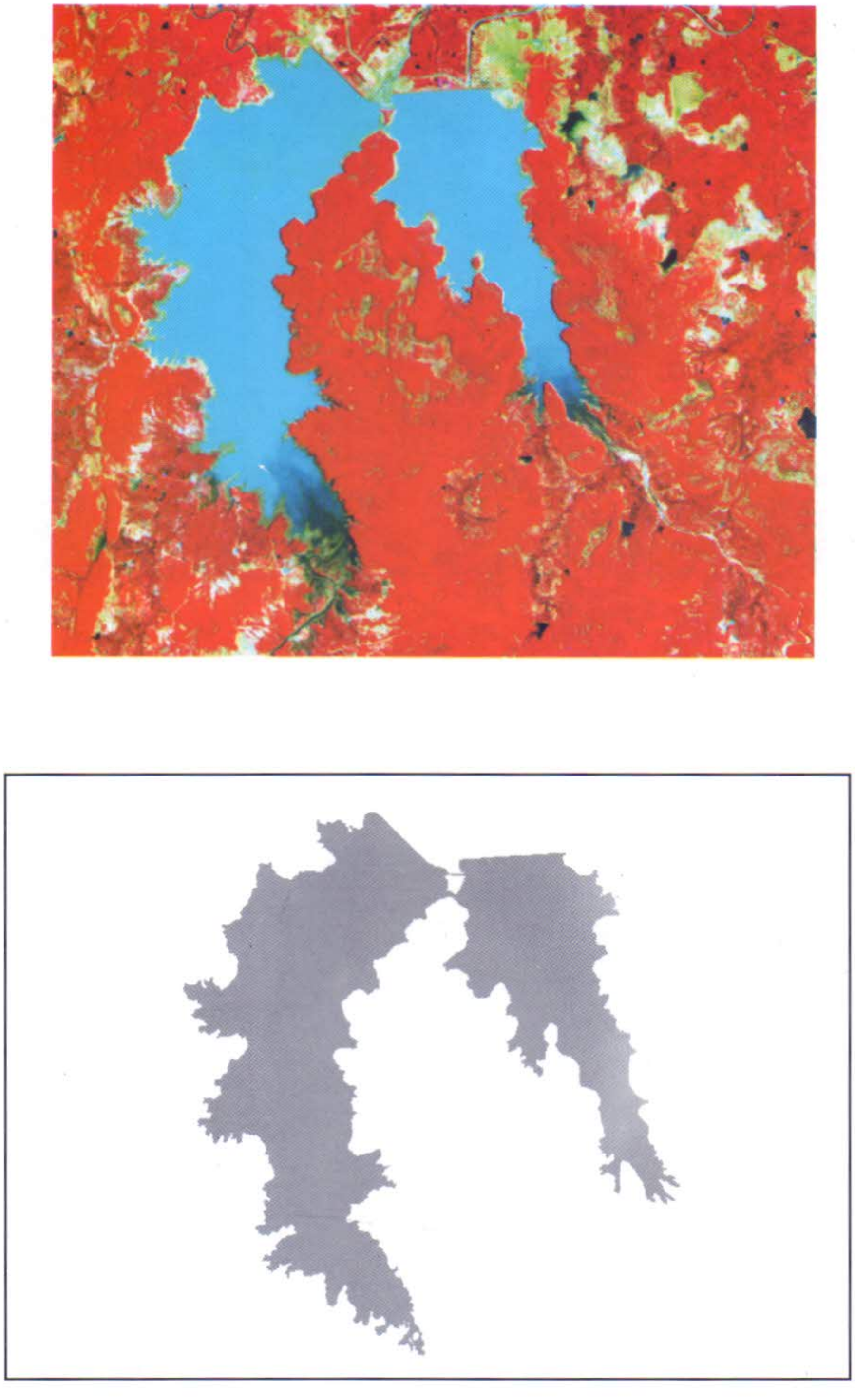


Figure 6.7: Standard FCC and extracted water spread area of Sep. 24, 2001

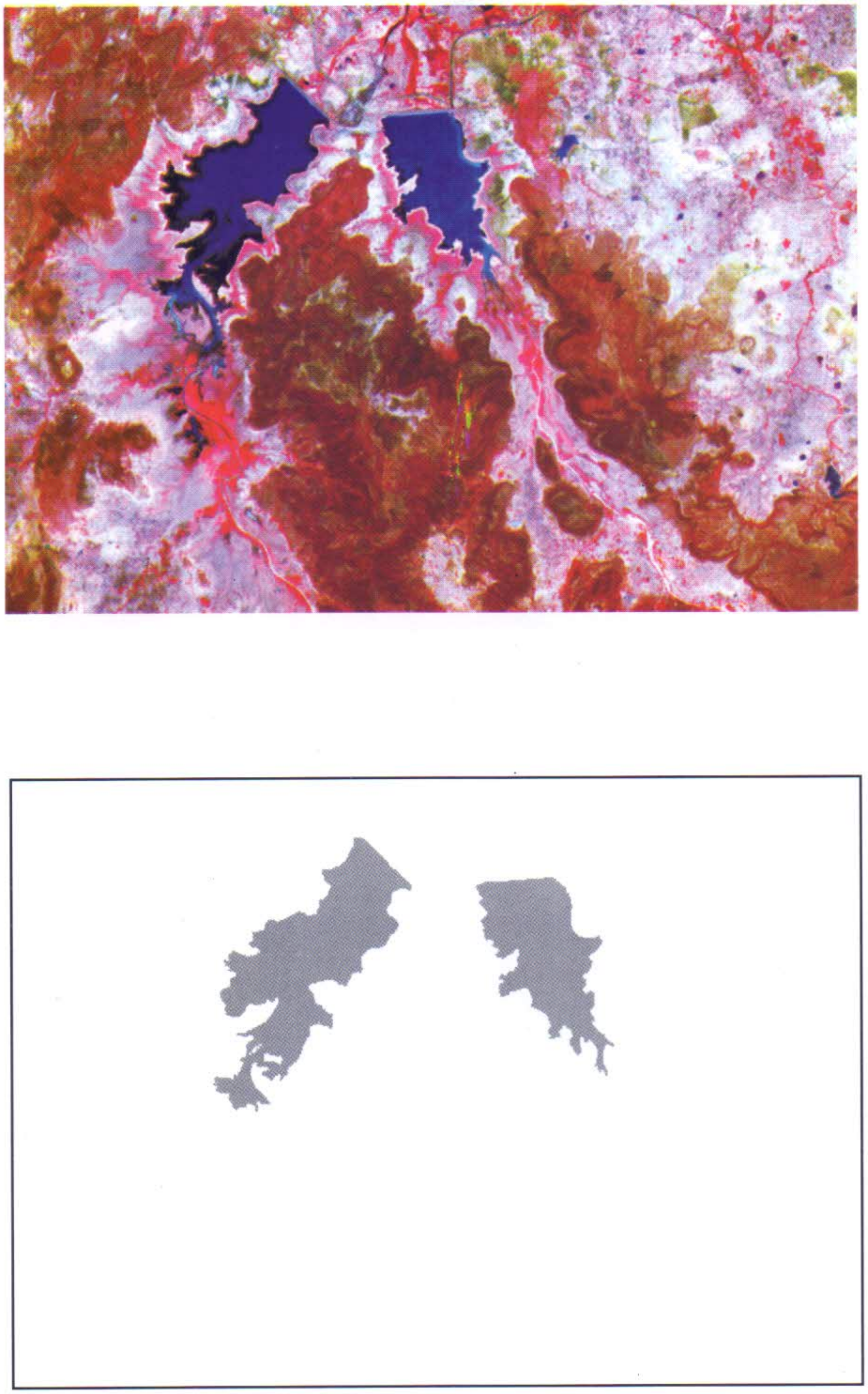


Figure 6.8: FCC and extracted water spread area of Apr. 28, 2001

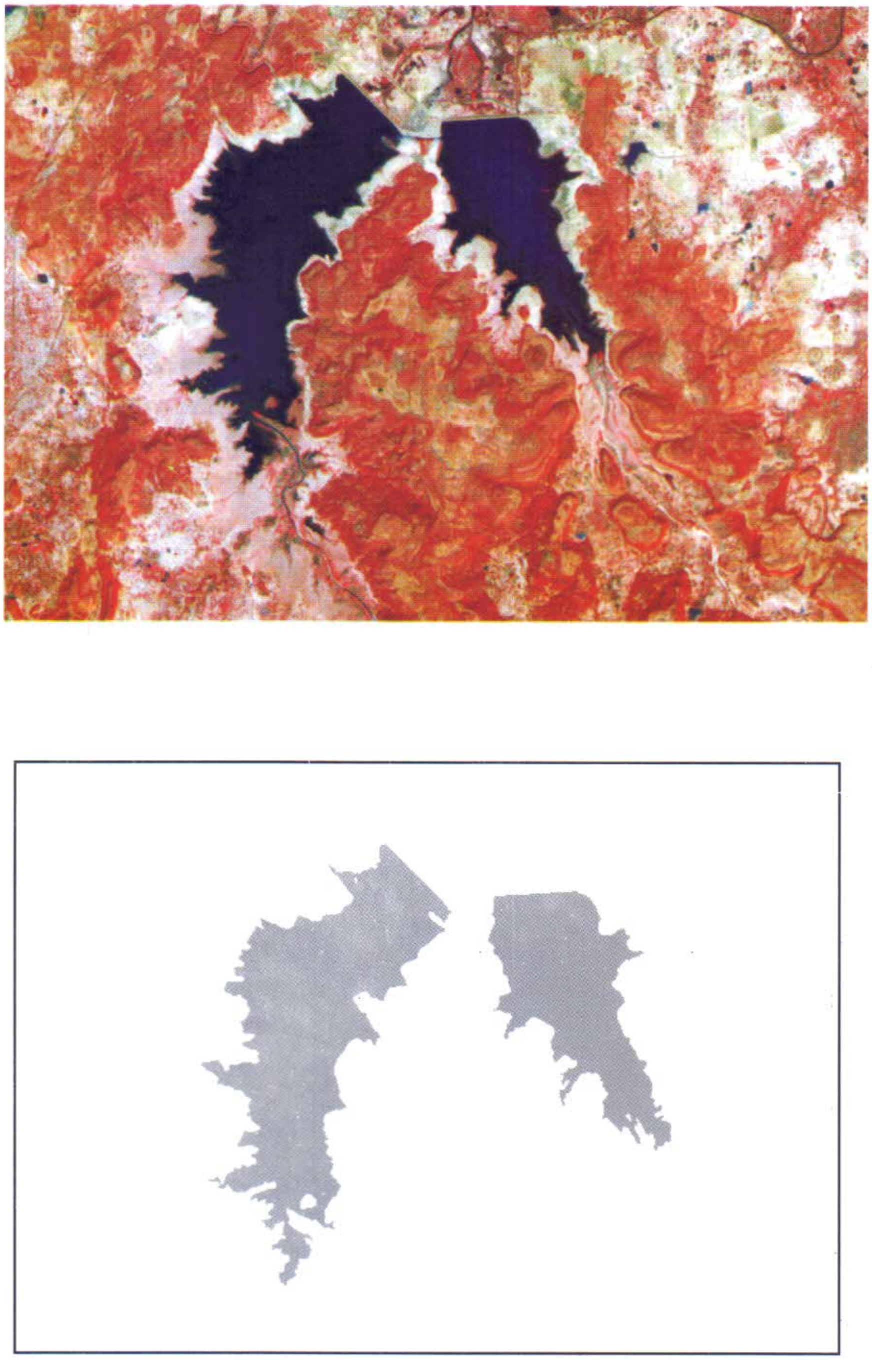


Figure 6.9: FCC and extracted water spread area of Dec. 24, 2000

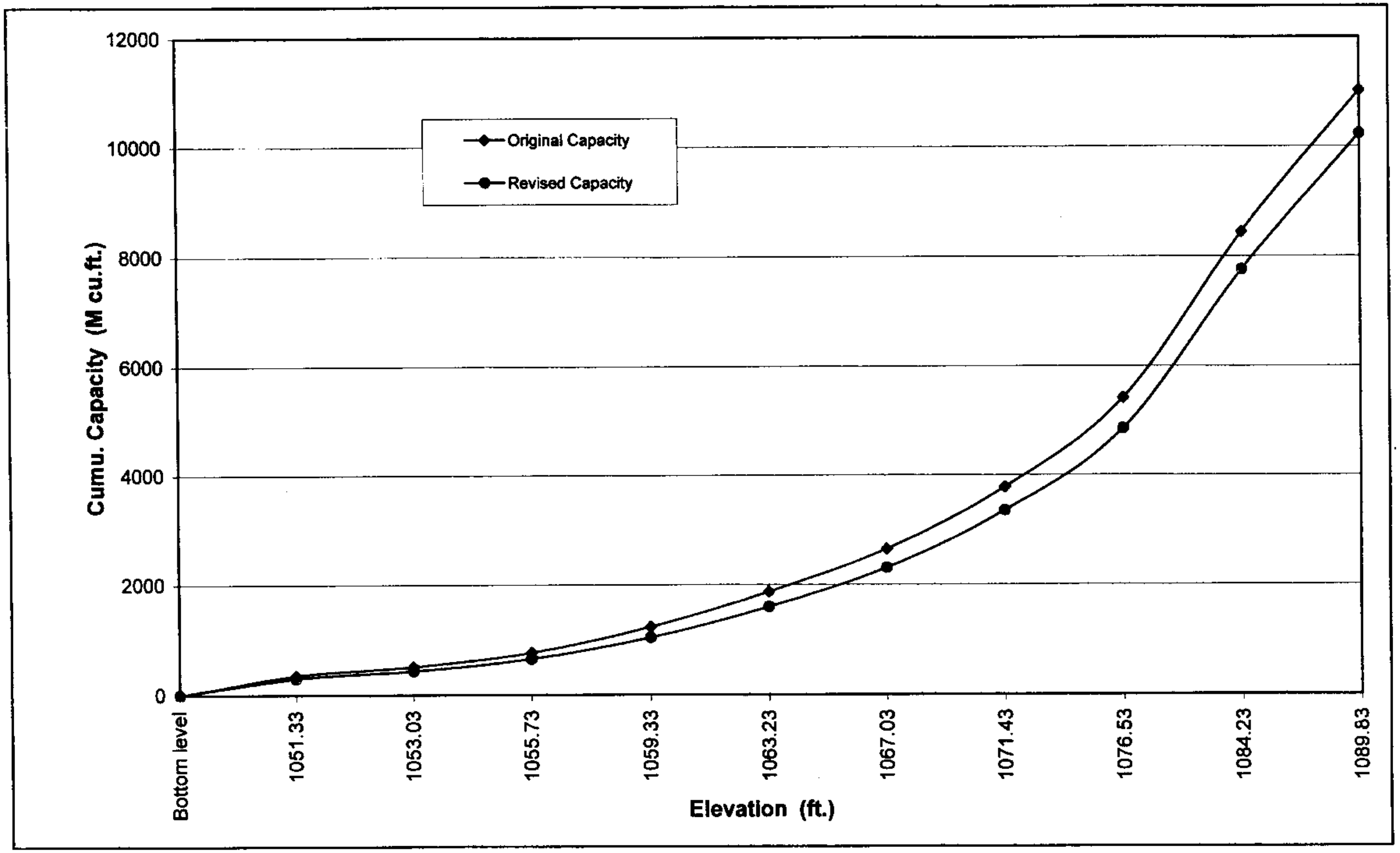


Figure 6.10 : Original and revised capacities reservoir

## 7.0 SEDIMENTATION STUDY OF LINGANAMAKKI RESERVOIR

### 7.1 THE STUDY AREA

The Sharavathi is one of the important west flowing rivers of Karnataka, which takes its origin in Western Ghats near Ambutirtha in Tirthahalli Taluk of Shimoga district. The river Sharavathi flows in northwest direction and is mainly utilized for generation of hydroelectric power. Its length is about 128 km and has a total drainage area of 2,771 km$^2$. The river along with its tributaries flows along the rugged terrain of Western Ghats of southwest Shimoga and southeast Uttar Kannada. The river drops to a vertical fall of about 253 m near Jog and it joins the Arabian Sea at Honavar in Uttar Kannada (Karnataka State Gazetteer Part I, 1982). This region, by virtue of its geographical sketch, varied terrain and climate supports a rich diversity of flora and fauna.

The Karnataka Power Corporation Limited has constructed a composite dam across the river in 1964 near Linganamakki, which is at present one of the oldest Hydro electric power projects in India. The dam is located at about 14$^0$41'24" N latitude and 74$^0$50'54" E longitude with an altitude of 512 m. The location of the reservoir is shown in the figure 7.1. The total capacity of the reservoir is 4417.51 M. cum. It has a catchment area of nearly 1991.71 km$^2$. It receives water mainly from rainfall and also from the Chakra and Savahaklu reservoirs, which are linked through Linganamakki through a canal. The water from Linganamakki dam flows to Talakalale balancing reservoir through a trapezoidal canal with a discharge capacity of 175.56 cumecs. The length of this channel is about 4318.40 m with a submersion of 7.77 km$^2$. It has a catchment area of about 46.60 km$^2$ and the gross capacity of the reservoir is 129.60 cu m. The salient features of Linganamakki Dam are given in Appendix II.

The construction of the Linganamakki dam has caused submersion of a large area (326.34 km$^2$). The dam was first impounded in the year 1964 (date of first filling is 12.08.1964). Water flowing from the catchment through the river carries sediment load and thus affecting the capacity of reservoir.

### 7.2 METHODOLOGY

The following steps were performed to assess the reservoir capacity loss due to the sediment load carried from the catchment through the flow of water in the river.

#### 7.2.1 Satellite Data

Satellite data corresponding to various water elevations procured from NRSA Data

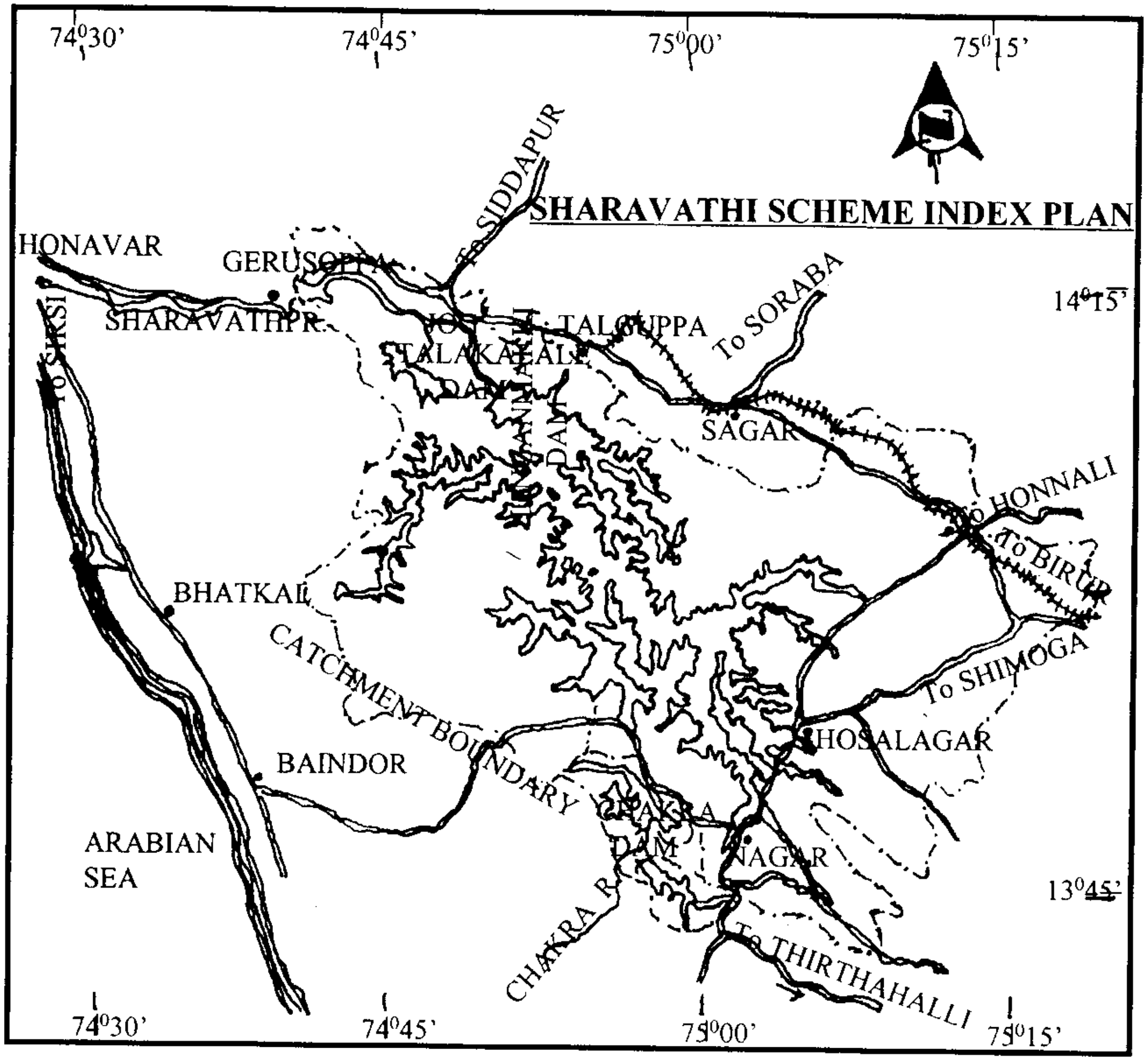


**Figure 7.1 Location Map of Linganmakki Reservoir**

Center for the year 1989-1990 and 2001-2002, which is given in the table 7.1 and the corresponding reservoir elevations were collected from Karnataka Power Corporation Limited, Karnataka State. Since, no information regarding sedimentation rate is available, the data sets for the two water years were selected and analysed to compare the result and further verification.

**Table 7.1. Specification Details of the IRS Satellite Data**

| Sr. No. | Date of Pass of satellite | Satellite/Sensor | Path/Row |
|---|---|---|---|
| | 1989-1990 | | |
| 1. | 21/11/89 | IRS 1B, LISS II | 28/58 |
| 2. | 11/03/90 | IRS 1B, LISS II | 28/58 |
| 3. | 16/05/90 | IRS 1B, LISS II | 28/58 |
| | 2001-2002 | | |
| 1. | 04/11/01 | IRS 1D, LISS III | 97/63 |
| 2. | 24/12/01 | IRS 1D, LISS III | 97/63 |
| 3. | 18/01/02 | IRS 1D, LISS III | 97/63 |
| 4. | 12/02/02 | IRS 1D, LISS III | 97/63 |
| 5. | 09/03/02 | IRS 1D, LISS III | 97/63 |
| 6. | 28/04/02 | IRS 1D, LISS III | 97/63 |

The satellite data were loaded in the system. The ILWIS software was used to identify the reservoir location and extraction of water spread area of the reservoir. The extracted views of the Liganamakki reservoir area from the satellite imagery are shown in the Figure 7.2.

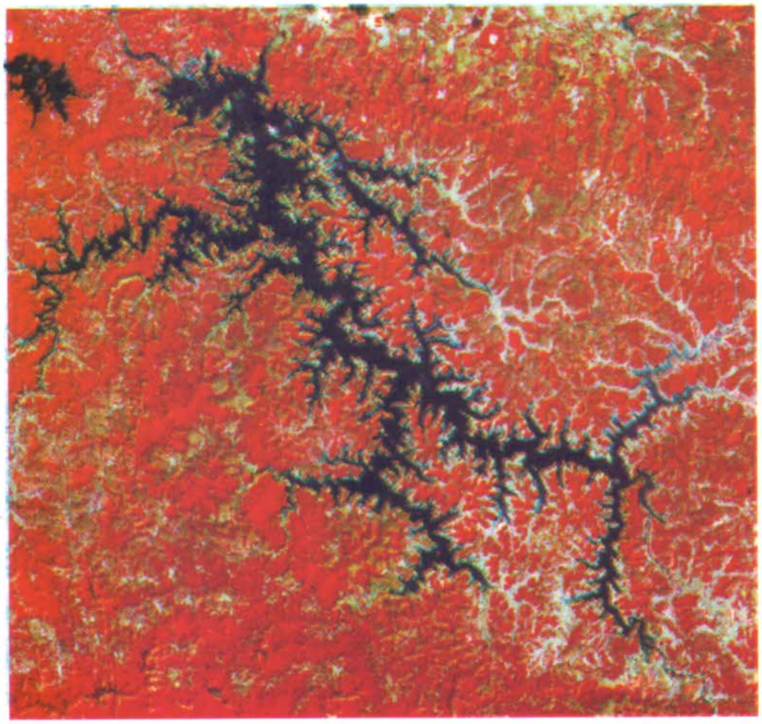
### 7.2.2 Water Spread Area Estimation

The near-IR image of various dates of pass of satellite and the corresponding water pixel image are shown in figure 7.3 to 7.6. Water Spread area has been calculated by multiplying number of pixels with area of each pixel (for LISS II data- 36.25X36.25 and LISS III data - 23.5m X 23.5m).

### 7.2.3 Estimation of Reservoir Capacity

Computation of reservoir capacity at various elevations has been made using following prismoidal formula. Capacities thus calculated between the consecutive levels were added up so as to each at the cumulative revised capacity. The difference between the original and

4th Nov. 2001



18th Jan. 2002

Figure 7.2. FCCs of the Water Spread Area of Linganmakki Reservoir

revised cumulative capacities represents the loss in capacity of the reservoir.

## 7.3 RESULTS AND DISCUSSIONS

The original elevation-capacity table before impoundment of Dam (1957) was obtained from Karnataka Power Corporation Limited (KPTCL), Govt. of Karnataka. It is presented in the table 7.2.

**Table 7.2: Original Elevation-Area-Capacity Table for Linganamakki Reservoir**

| Sr. No. | Reservoir elevation (m) | Water Spread Area ($km^2$) | Total capacity (M. cum) |
|---|---|---|---|
| 1. | 530 | 57.21 | 431.86 |
| 2. | 531 | 62.88 | 491.85 |
| 3. | 532 | 68.76 | 557.29 |
| 4. | 533 | 74.87 | 629.84 |
| 5. | 534 | 81.25 | 707.63 |
| 6. | 535 | 88.01 | 791.76 |
| 7. | 536 | 95.23 | 883.71 |
| 8. | 537 | 102.86 | 984.20 |
| 9. | 538 | 110.69 | 1098.27 |
| 10. | 539 | 119.80 | 1205.56 |
| 11. | 540 | 129.17 | 1331.51 |
| 12. | 541 | 138.99 | 1464.75 |
| 13. | 542 | 149.74 | 1610.16 |
| 14. | 543 | 160.93 | 1765.50 |
| 15. | 544 | 172.38 | 1928.20 |
| 16. | 545 | 184.21 | 2110.93 |
| 17. | 546 | 196.45 | 2300.95 |
| 18. | 547 | 209.23 | 2499.62 |
| 19. | 548 | 223.05 | 2720.86 |
| 20. | 549 | 236.96 | 2952.39 |
| 21. | 550 | 250.58 | 3191.92 |

To calculate the prevailing water spread area, ten different elevations has been selected which various from 522.73 m minimum draw down level (MDDL) to 554.43 m full reservoir level (FRL). Out of four elevations data (for IRS 1 B LISS II during 1989-1990) pertaining to only three were found cloud free and clear. While for IRS LISS III during the year 2001-2002, out of ten elevation data pertaining to only six were found cloud free and clear. These data are procured from NRSA, Hyderabad and revised water spread area calculated against the respective elevations by multiplying the number of water pixels by the size of one pixel. The reservoir elevations at the time of satellite pass were obtained from the dam authority. The revised areas and corresponding elevations are presented in Table 7.3.

**Table 7.3 Reservoir Elevation and Revised Water Spread 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$^2$) |
|---|---|---|---|---|
| | 1989-1990 | | | |
| 1. | 21/11/89 | 171457 | 548.78 | 225.31 |
| 2. | 11/03/90 | 103626 | 541.15 | 136.17 |
| 3. | 16/05/90 | 56488 | 533.05 | 74.23 |
| | 2001-2002 | | | |
| 1. | 04/11/01 | 341892 | 545.91 | 188.81 |
| 2. | 24/12/01 | 289760 | 543.29 | 160.02 |
| 3. | 18/01/02 | 259176 | 541.95 | 143.13 |
| 4. | 12/02/02 | 229264 | 540.38 | 126.61 |
| 5. | 09/03/02 | 192373 | 538.35 | 106.24 |
| 6. | 28/04/02 | 121836 | 532.20 | 67.28 |

The comparison between previous and revised water spread area is shown in figure 7.7. 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 (532.20 m) was assumed to be the same as that of previous cumulative capacity (571.80 M. cum) as on 1957. 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.

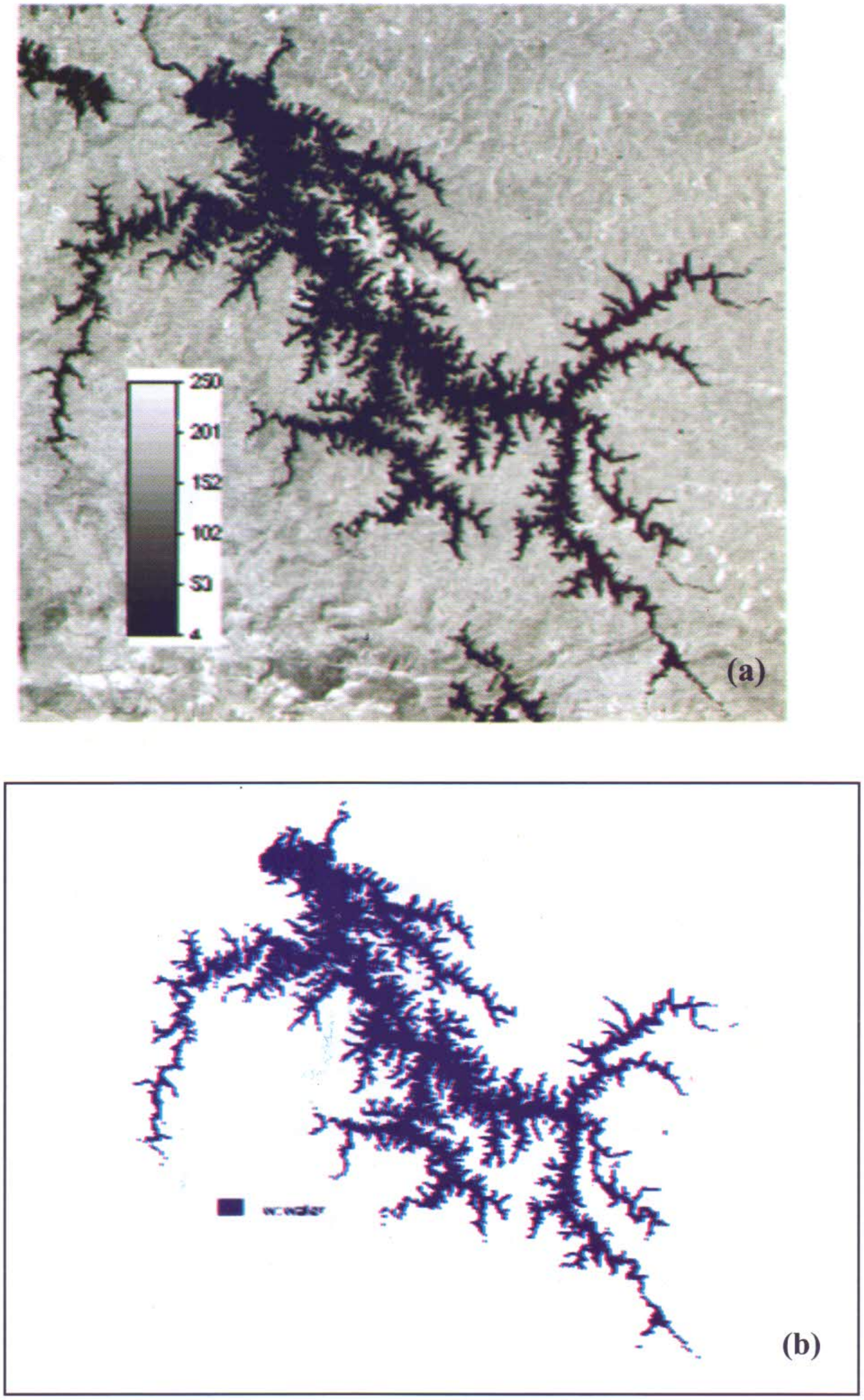


Figure 7.3 a. Near-Infrared (NIR) Image of Linganmakki Reservoir on 21 Nov., 1989
b. Corresponding Extracted Continuous Water Spread Area

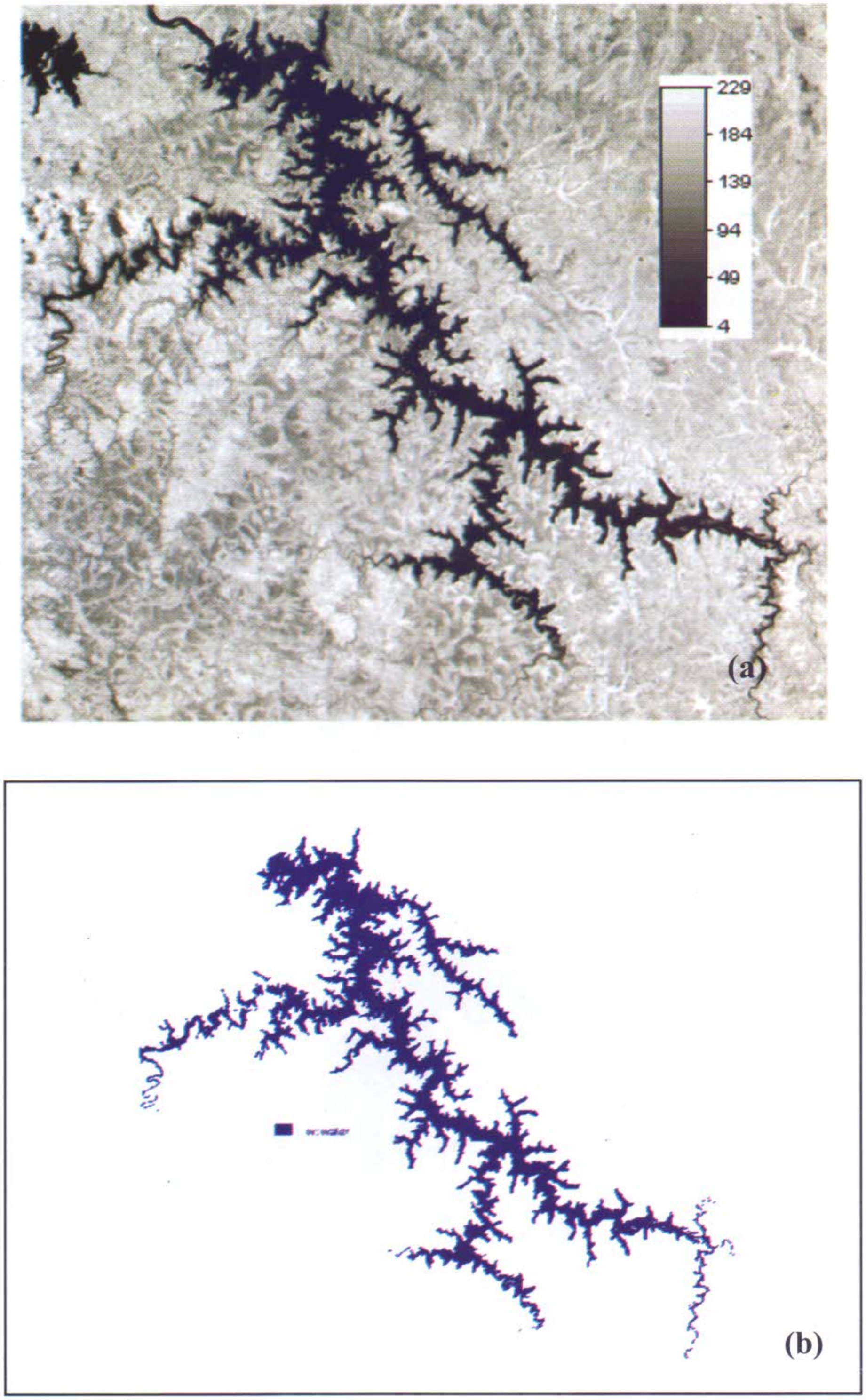


Figure 7.4 a. Near-Infrared (NIR) Image of Linganmakki Reservoir on 16 May, 1990
b. Corresponding Extracted Continuous Water Spread Area

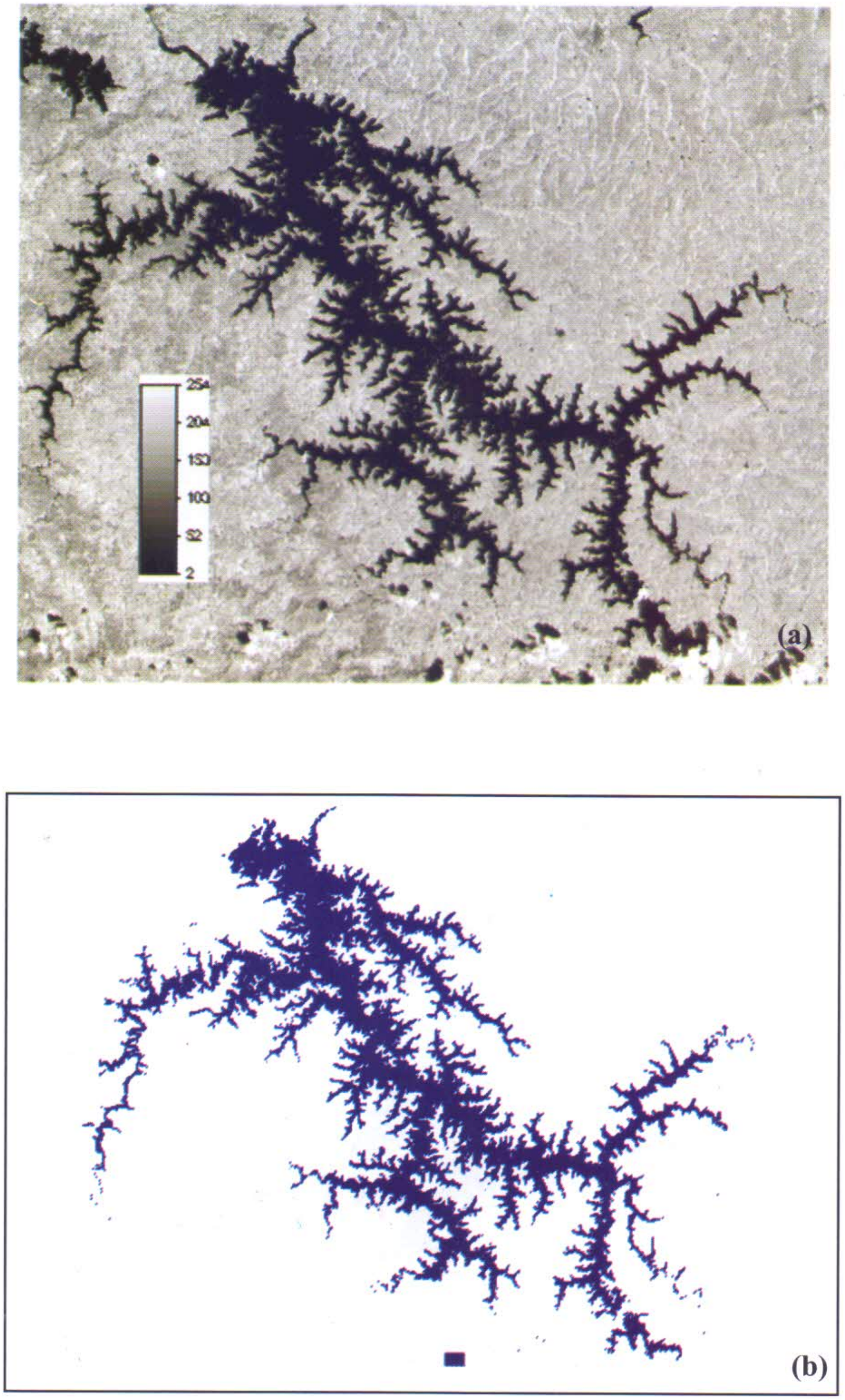


**Figure 7.5 a. Near-Infrared (NIR) Image of Linganmakki Reservoir on 4 Nov., 2001**
**b. Corresponding Extracted Continuous Water Spread Area**

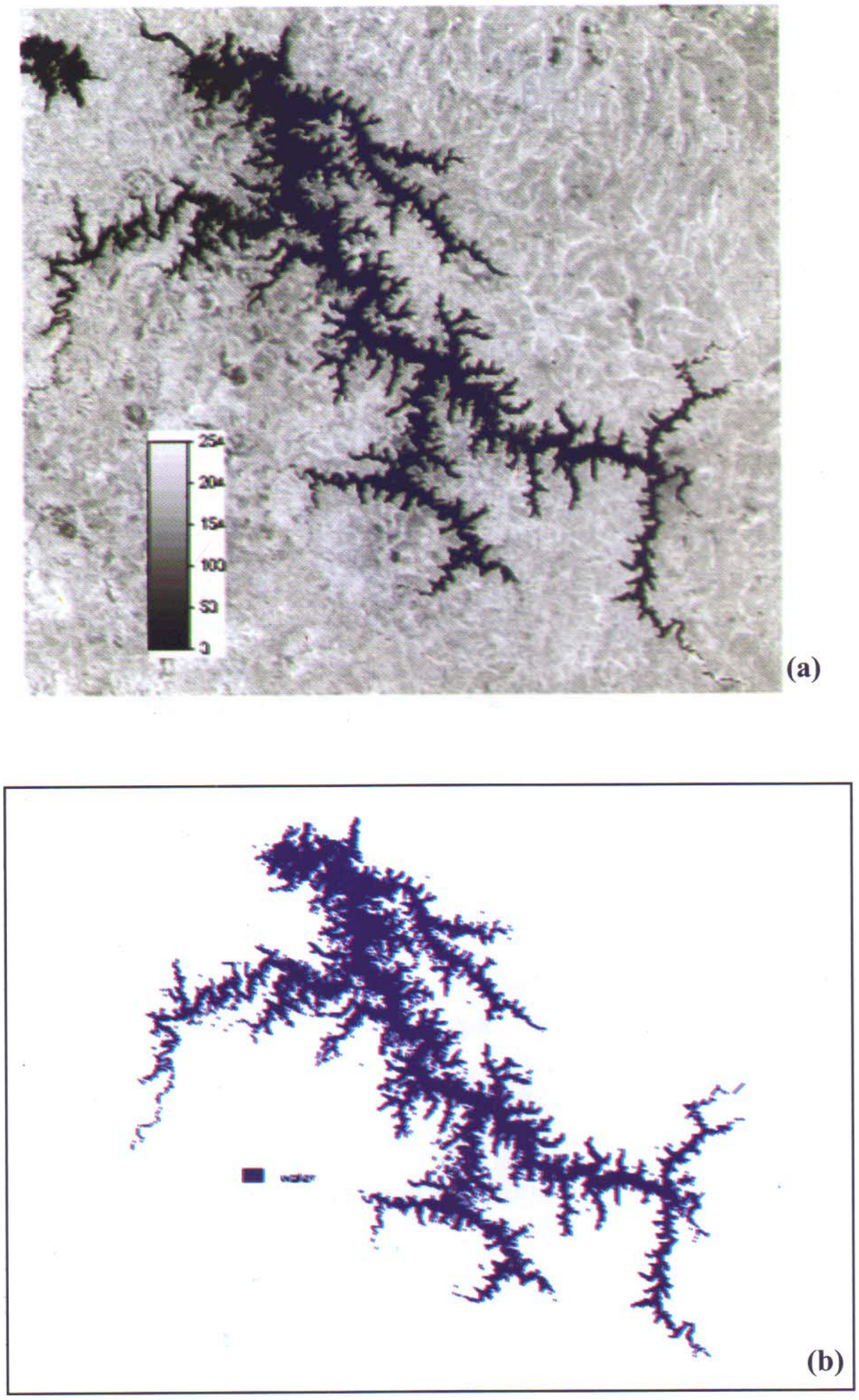


**Figure 7.6a.Near-Infrared (NIR) Image of Linganmakki Reservoir on 9 March, 2002**
**b. Corresponding Extracted Continuous Water Spread Area**

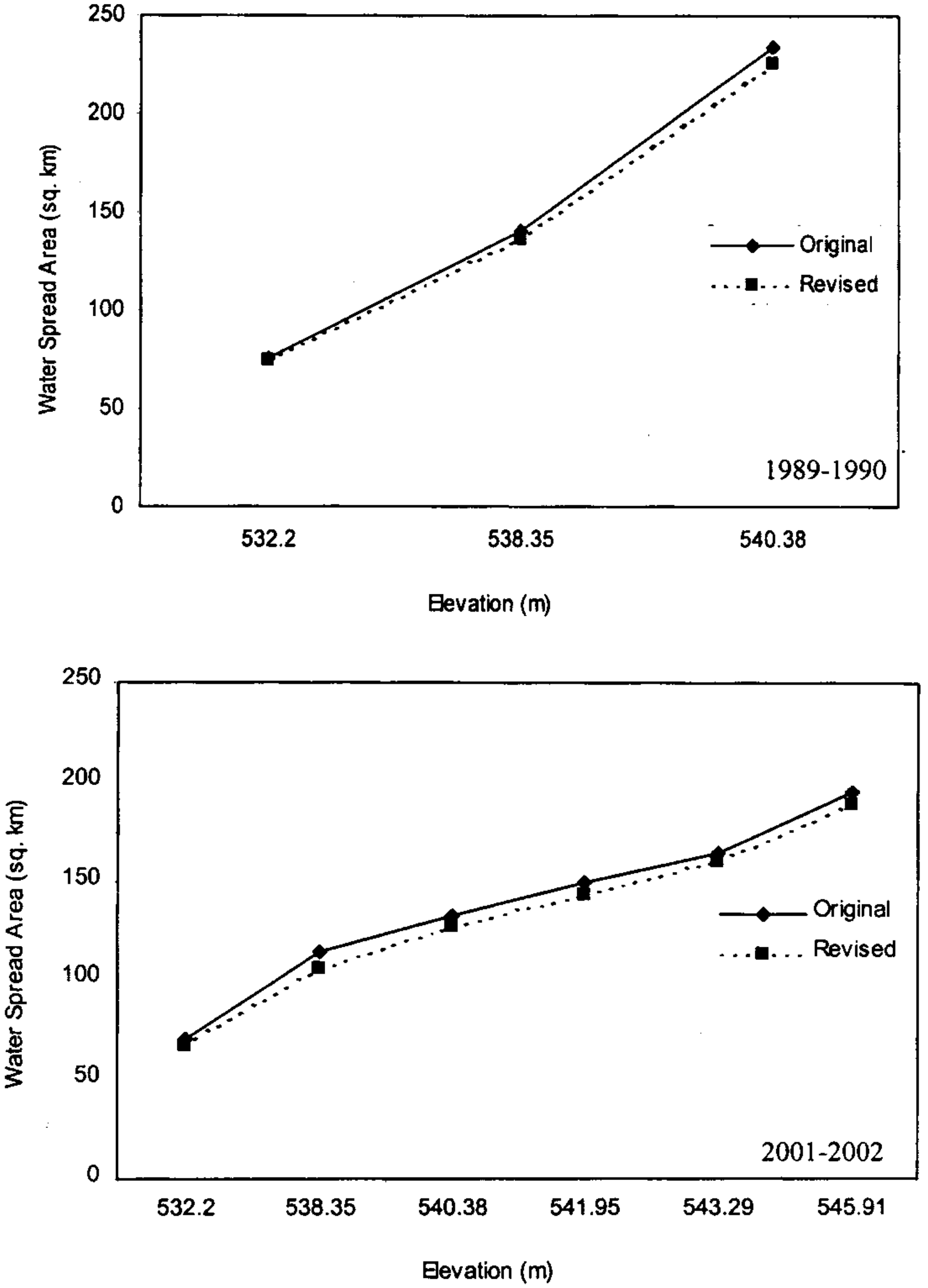


**Figure 7.7 : Original and Revised Spread Area Curves for Linganmakki Reservoir**

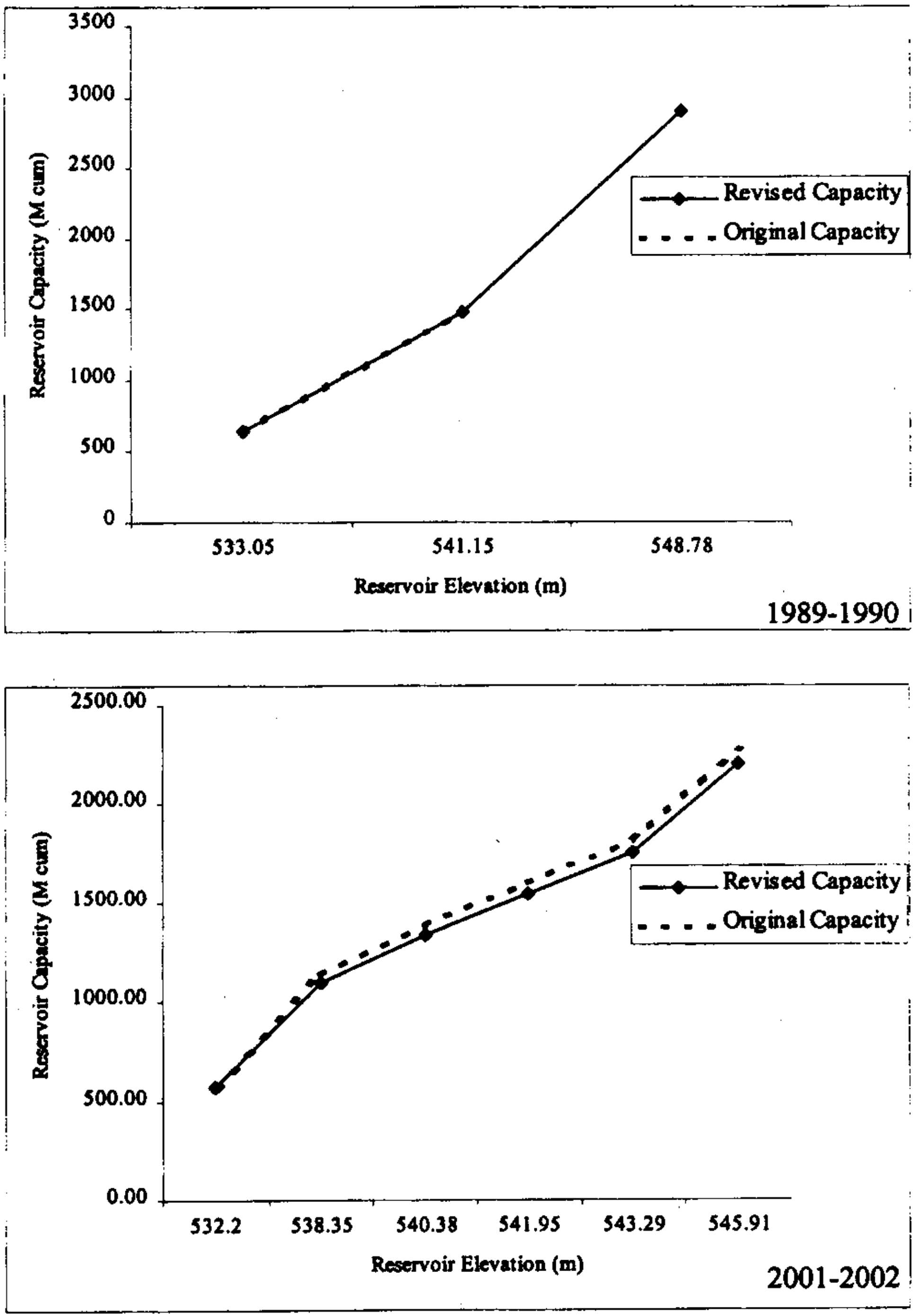


Figure 7.8 : Original and Revised Elevation-Capacity Curves for Linganmakki Reservoir

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 7.4.

**Table 7.4 Assessment of Sediment Deposition in Linganamakki Reservoir using Remote Sensing (RS) for the years 1989/1990 and 2001/2002**

| Date of Pass of Satellite | Reservoir elevation (m) | Original Area (k $m^2$) | Revised area using RS data ($km^2$) | Original Volume (M cum) | Revised Volume (M cum) | Original Cumulative Volume (M cum) | Revised Cumulative Volume (M cum) |
|---|---|---|---|---|---|---|---|
| 1989-1990 | | | | | | | |
| 16/05/90 | 533.05 | 75.19 | 74.23 | | | 633.47 | 633.47 |
| 11/03/90 | 541.15 | 140.38 | 136.17 | 850.16 | 839.53 | 1483.63 | 1473.00 |
| 21/11/89 | 548.78 | 233.80 | 225.31 | 1413.12 | 1364.84 | 2896.75 | 2837.84 |
| 2001-2002 | | | | | | | |
| 28/04/02 | 532.20 | 69.98 | 67.28 | | | 571.80 | 571.80 |
| 09/03/02 | 538.35 | 113.79 | 106.24 | 559.66 | 529.04 | 1131.46 | 1100.84 |
| 12/02/02 | 540.38 | 132.85 | 126.61 | 250.08 | 236.04 | 1381.54 | 1336.88 |
| 18/01/02 | 541.95 | 149.19 | 143.13 | 221.28 | 211.62 | 1602.82 | 1548.50 |
| 24/12/01 | 543.29 | 164.29 | 160.02 | 209.95 | 203.01 | 1812.77 | 1751.50 |
| 04/11/01 | 545.91 | 195.30 | 188.81 | 470.48 | 456.45 | 2283.25 | 2207.95 |

Figure 7.8 shows the comparison between original and revised capacity of the reservoir. The results show that the volume of sediment deposition in the zone under study for the period 1957 to 1989 (533.05m to 548.78m) is 58.91 M. cum (2896.75 M. cum - 2837.84 M. cum) and for the period 1957 to 2001(532.20m to 545.91m), it is (2283.25 M. cum - 2207.95 M cum) 74.94 M. cum. If a uniform rate of sedimentation is assumed in 34 years up to the year 1989 of occurrence of the reservoir then the sedimentation rate is 8.96 ha-m/100 $km^2$/year, while the sedimentation rate up to the year 2001 (44 years), it is 8.55 ha-m/100 $km^2$/year. During the period between 1989 to 2001, there is a reduction of 16.03M cum gross capacity of the reservoir. The reduction in capacity during the initial period up to 1989 is found in an average 1.73 M. cum, while it reduces in later stage up to 1.60 M. cum.

## 7.4 SUMMARY

The revised capacities of the Linganamakki reservoir were determined using remote sensing data. Since, no hydrographic survey was carried out, remote sensing data of IRS 1D LISS III sensor for the two set of years i.e. 1989-1990 and 2001-2002 were chosen to compare the results and the same were acquired for four different dates for 1989-1990 and six dates for 2001-2002. The revised water spreads areas for all the scenes were determined. The signature characteristics of different surface features (water, soil and vegetation) were utilised for separating the water pixels from other surface features. A uniform method of analysis was adopted for the identification of water pixels in all the images. The resulting imageries of water pixels were compared with the standard FCC and the near-IR imagery. Corrections were applied for noise and isolated water pixels by using subsequent date imageries in the digital image processing environment. The tail end of the reservoir and the rivers joining the reservoir around the periphery were truncated based on the termination of spread and visual interpretation.

The original elevation-capacity and the reservoir levels on all dates of satellite pass were obtained from KPCL. Using the prismoidal formula, the revised capacities in-between the maximum (548.78m) and minimum (532.20m) levels were obtained. The revised capacities in the zone of reservoir levels (533.05m to 548.78m) for the year 1989-1990 is found 2837.84 M. cum and for the year 2001-20002, it is found to be equal to 2207.95 M cum in the zone of 532.20m to 545.91m of reservoir levels, while the original capacities for the year 1989-1990 was 2896.75 M. cum and 2283.25 M. cum for the year 2001-2002 as reported during the survey in the year 1957. Based on these results, the sedimentation rates in the zone (533.05m to 548.78m) come out to be 8.96 ha-m/100 $km^2$/year and for the zone (532.20m to 545.91m) is 8.57 ha-m/100 $km^2$/year. The total sediment deposition in the zone (533.05m to 548.78m) during the period 1957 to 1989 comes out to be 58.91 M. cum, while during the period 1957 to 2001, it is 74.94 M cum. The sediment deposit during the year 1989-2001 is found to be 16.03 M cum. As per results obtained through the sediment assessment during the period 1957 to 1989 and 1957 to 2001, it is found that the results are comparable and the uniform sediment rate of 8.57 ha-m/100 $km^2$/year can be considered for the present study. No hydrographic survey has yet been carried out for this reservoir. Under these circumstances, the results obtained in this study can be serve as a guide to the operating authorities for considering the actual available capacity in planning the operation of this reservoir.

# Appendix - II

## Salient features of Linganmakki Dam (Sharavathy Valley Project)

### I. GENERAL

Catchment Area : 1991.71 km$^2$

Area of Submersion : 326.34 km$^2$

Max. Rainfall in Catchment : 8150 mm

Type of Dam : Composite Dam

Gross Capacity of Reservoir : 4417.51 M. cum

Top of Dam : EL 558.08 m

Maximum Water Level : EL 555.04 m

Full Reservoir Level : EL 554.43 m

Minimum Drawdown Level : EL 522.73 m

Length of Masonary Dam : 1749.55 m

Total length of Dam : 2657.85 m

Height of Dam

i) Above Deepest Foundation : 59.13 m

ii) Above Lowest River bed : 55.16 m

Deepest Foundation Level : 498.95 m

Flood Disposal System : 11 Nos. Radial Gates of Size 15.24m x 7.31m

Year of Completion of Dam : 1964

Date of First Filling : 12.08.1964

### II. SPILLWAY SECTION :

Design Maximum Flood : 8070.45 cumecs

Length of Spillway : 198.12 m

No. of Radial Gates : 11

Size of Gates : 15.24m x 7.31m

Buk Radius : 18.28 m

Spillway Crest : EL 547.11 m

## 8.0 CONCLUSIONS

For taking remedial measures well in advance and for optimum allocation and management of water from the reservoirs, it is very essential to have up-to-date knowledge about the sedimentation pattern going-on in the reservoir and the loss of capacity because of sediment deposition in the various zones. Satellite remote sensing by virtue of its synoptic coverage and repetitivity is found to be very useful in capacity surveys of the reservoirs. Its multi date data directly provides the elevations contours in the form of water spread area.

The close match between the results of remote sensing and the hydrographic survey proves the accuracy of remote sensing technique in the assessment of revised capacities of reservoirs. In view of the cost and time effectiveness and the amount of efforts required in comparison to the hydrographic survey, the remote sensing technique has proved to be a useful tool in the assessment of revised capacities of reservoirs.

Limitation of the remote sensing technique is that the revised capacity in the portion below the lowest observed level and above the highest observed level can be determined. This limitation is not significant since the zone of interest, from the point of view of operation, is the live storage zone only. Further, if such analysis is required for the whole of the reservoir, then the hydrographic survey for the water area at the lowest observed elevation can be carried out and the results can be combined.

For the evaluation of sedimentation rate, Ghatprabha reservoir , Gandhisagar reservoir, Vaigai reservoir, Tandula reservoir and Lingnamakki reservoir have been selected for the present study. The results of Ghatprabha reservoir shows that the volume of sediment deposition during 1974 to 2000-2001 (26 years) in-between the maximum and minimum observed levels (658.6 m and 631.1 m) is 117.27 $Mm^3$. If the uniform rate of sedimentation is assumed, then as per the 2000-2001 analysis, the sedimentation rate in the zone (658.6 m to 631.1 m) is 4.510 M $m^3$ per year. For Gandhisagar reservoir the sedimentation for the period 1960 to 2001 has come out to be 1.5579 ha-m/$km^2$ per year. The sedimentation rate has been computed for the levels (398.58-380.57 m). For Vaigai reservoir, the sedimentation has been estimated between 168.61 to 152.78 m. The sedimentation rate for the period 1983 to 1999 has come out to be 0.99 $Mm^3$/year. For Tandula reservoir the sedimentation rate has been computed between 1089.93-1053.03 ft. and the sedimentation rate for the period 1921 to 2001 has been computed as 3.392 ha-m/$km^2$/year. For Lignamakki the sedimentation rate has been computed for level difference of 548.78 to 532.20 m. The sedimentation rate for the period 1957 to 2001 is 8.57 ha-m/100 $km^2$/year.

## REFERENCES

Agarwal, S. (1991), "Effect of Sedimentation - Reservoir Planning", Proceedings for Regional Training Course on Reservoir Sedimentation & Flood Control, organised by CWC, December 9-22, 1991.

CWC, 2002, Sedimentation analysis of Maithon reservoir using satellite data, June, 2002, Remote sensing Dte., CWC.

Choubey V.K. and V. Subramaniam (1992), ' Estimation of suspended solids using IRS 1A data: A case study from Central India, IJRS, Vol. 13, No. 8, 1992.

Dey, W., and Jiahua, F., (1991), "Method of Preserving Reservoir Capacity", Proceedings for Regional Training Course on Reservoir Sedimentation & Flood Control, organised by CWC, December 9-22, 1991.

Engman E.T. and R.J.Guruney, (1981), Remote sensing application in Hydrology, Chapman and Hall, 1991.

Garde, R. J. and Kothyari, U. C. (1987), "Sediment Yield Estimation", Journal of Irrigation & Power, CBIP, Vol 44, No. 3, pp 97-123.

Goel M.K and S.K.Jain (1998),' Reservoir sedimentation study of Ukai dam using satellite data, UM-1/97-98, National Institute of Hydrology, Roorkee

Jain, S.K., Pratap Singh and M.K.Goel, 1999, Capacity evaluation of Bhakra reservoir using digital analysis of Satellite data, CS(AR)-24/98-99, National Institute of Hydrology, Roorkee.

Jayapragasam, R., and Muthuswamy, K. (1980), "Sedimentation Studies in Vaigai Reservoir Using Grid System", Journal of Irrigation & Power, CBIP, Vol 37 , No.1, pp 337-350.

Jonna S., K.V.S.Badrinath and J. Saibaba (1989),' Digital image processing of remote sensing data for water quality studies, Journal of Indian society of remote sensing, Vol. 17, No. 2, 1989.

Kim, C. W., and Seok, Y. (1991), "Practice and Prospect of Determining Sediment Yield Rate for Planning of Dams in Korea", Proceedings for Regional Training Course on Reservoir Sedimentation & Flood Control, organised by CWC, December 9-22,1991.

Lianzhen, D., and Zhide, Z., (1991), "Mathematical Modelling for Reservoir Sedimentation", Proceedings for Regional Training Course on Reservoir Sedimentation & Flood Control, organised by CWC, December 9-22, 1991.

Manavalan, P., G.L. Rajegowda and M.V. Sriniwas (1984),' Capacity evaluation of Ghatprabha reservor using digital analysis of IRS LISS-II data, Project report No. B/003/91/RRSSC, Banglore.

Morris G.L. and Jiahua Fan (1997),' Reservoir sedimentation handbook, McGraw Hill, New York

Sahai B.N. and R.L.Karale (1987),' Application of remote sensing techniques for watershed characterisation in a part of the Ukai catchment,' Scientific report, All India Soil and land use survey and SAC (ISRO).

Sedimentation survey report. Bhakra dam circle, Bhakra Beas Management Board (BBMB), Nangal, India, 1997.

Shangale, A.K., 1991, Sedimentation in Indian reservoirs, Paper presented at the International symposium on special problems of Alluvial rivers including those of international rivers, held at Seoul, Korea, Sept., 1991.

## DIRECTOR

Dr. K. D. Sharma

## DIVISIONAL HEAD

Dr. Sharad K. Jain

## STUDY GROUP

| | |
|---|---|
| Ghatprabha reservoir | Dr. S. K. Jain, Sc.'E1' and Mrs. Anju Chaudhry, S.R.A |
| Gandhi sagar reservoir | Dr. M. K. Goel, Sc.'E1' and Mr. P.K.Agarwal, P.R.A. |
| Vaigai reservoir | Mr. V.S.Jeyakanthan, Sc.'C', Mr. D.Mohana Rangan and Mr. U.V.N. Rao, S.R.A. |
| Tandula reservoir | Mr. T.R.Nayak, Sc.'C' and Mr. Rahul K. Jaiswal, P.R.A. |
| Lingnamakki reservoir | Mr. Dilip Durbude, Sc.'B'and Dr. B.Purendra, Sc.'C' |