CS/AR-18/1999-2000

RESERVOIR SEDIMENTATION STUDY OF BARGI DAM USING SATELLITE DATA

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAWAN
ROORKEE - 247 667 (UTTARANCHAL)

1999-2000

PREFACE

Reservoirs are constructed across the rivers to change the spatial and temporal availability of water in accordance with the requirements of mankind. More than 3000 major and medium dams have already been completed and multipurpose reservoir projects are quite common among them. However, in order to attain maximum benefits from a multipurpose scheme, it is imperative to regulate the reservoirs in the most efficient and judicious manner. However, a great amount of sediment is carried annually by the Indian rivers down to the reservoirs, lakes, estuaries, bays, and oceans. One of the principal factors which threaten the longevity of reservoir projects , in India, is the accumulation of sediments in reservoirs. Sedimentation reduces the storage capacity of reservoirs and hence, their ability to conserve water for various intended purposes.

To periodically assess the useful life of a reservoir, it is essential to conduct the surveys. With the correct knowledge of the sedimentation processes going on in a reservoir, remedial measures can be undertaken well in advance and reservoir operation schedule can be planned for optimum utilisation of water. Present conventional techniques of sediment quantification in a reservoir, like the hydrographic surveys and inflow-outflow methods, are cumbersome, costly and time consuming. With the introduction of remote sensing techniques, it is possible to obtain the revised storage capacity in the operation zone of a reservoir. This information can be used to quantify the sedimentation rate in a reservoir.

In this report, the revised capacity within a zone (406.00 m to 421.45 m) of Bargi reservoir was determined using remote sensing techniques. Remote sensing data of IRS-1C satellite for nine different dates (during the non-monsoon season) was acquired for the year 1996-97. Imageries of different dates have been analysed and the revised water spread areas have been determined. The results show that the available capacity in the zone of study is more than that originally envisaged in the project. Revised contours of the reservoir have been developed and revised elevation-area-capacity curve is prepared.

This report was prepared by Mr. M. K. Goel, Sc."C", Dr. S. K. Jain, Sc."F" and Mr. P. K. Agarwal, SRA of the Water Resources Systems division of the Institute.

(K. S. Ramasastri)
Director

ABSTRACT

To determine the useful life of a reservoir and to assess the sedimentation rate in a reservoir, it is essential to periodically conduct the surveys. With the correct knowledge of the sedimentation process going on in a reservoir, remedial measures can be undertaken well in advance and reservoir operation schedule can be planned for optimum utilisation of water.

With the deposition of sediments in the reservoir, the waterspread area at an elevation keeps on decreasing. Using the remote sensing techniques, the revised waterspread area can be determined for different reservoir levels and the revised elevation-capacity curves can be prepared. By comparing the original and the revised elevation-capacity curves, the amount of capacity lost to sedimentation can be assessed. Further, for the different reservoir elevations, revised contours can be obtained from the periphery of the waterspread.

In the present study, the revised capacity was assessed in the Bargi reservoir in the Narmada basin. This reservoir was first impounded in the year 1989. The post-monsoon period of the year 1996-97 was chosen for analysis. The remote sensing data of IRS-1C satellite and LISS-III sensor were acquired for nine different dates and the revised water spread areas have been extracted. The original elevation-area-capacity curves and the reservoir levels on the nine dates of pass of satellite were obtained from the dam authorities. Using the trapezoidal formula, the revised capacity in between the maximum (421.45 m) and minimum (406.00 m) observed levels was obtained. The results of the study demonstrate that the available capacity in the zone of study (406.00 m to 421.45 m) has reduced by 26.67 M Cum from the original capacity (2585.56 M Cum). The sedimentation rate in the zone of study comes out to be 0.023 ha-m/Sq. km/year. As per the CWC report of Bargi project sedimentation, the total sedimentation in the entire reservoir for this period was estimated at 85.74 M Cum. The height of the zone of study is about one third of the height of the dam from bed level to the FRL. This reservoir has significant tail portion as compared to its main body.

From the waterspread areas obtained using remote sensing analysis, the revised contours were derived and plotted. The procedure for deriving the continuous waterspread areas from the remote sensing image was also automatized to a considerable extent.

CONTENTS

LIST OF TABLES AND FIGURES

CHAPTER - 1
INTRODUCTION

According to an estimate, the global production of sediments is about $15*10^{16}$ tons/year. A great amount of sediment is carried annually by the Indian rivers down to the reservoirs, lakes, estuaries, bays, and oceans. The rivers from Indian sub-continent carry about 6 billion tons of sediments per year. Soil is eroded due to rainfall and winds, resulting in tremendous sediment movement into watercourses by flood and storm waters. The impact of sediment erosion, transport and deposition is widespread. Deposition of coarse sediments reduces the reservoir storage and channel conveyance for water supply, irrigation, and navigation and causes extensive disturbance to streams. Suspended sediments reduce the water clarity and sunlight penetration, thereby affecting the biotic life. Settlement of sediments to the bottom of water bodies buries and kills the vegetation and changes the ecosystem.

Reservoir sedimentation and consequent loss of storage capacity affects water availability, specially, where water is the most scarce - in the arid and semi arid regions of the world. This process is responsible for reduction in economic life of a reservoir. State-of-art reports on this topic have been prepared by Garde [5] and Varshney [13]. An analysis of sedimentation survey in respect of 43 reservoirs in India indicates that the sedimentation rate varies between 0.3 to 27.85 ha-m/100 sq. km/year [12]. The loss of water storage by reservoir sedimentation is of the order of 1-2 % per year. The impact of storage depletion is aggravated by the fact, that new dam sites are few, restricted mainly to the upper catchments of a few rivers. It is, therefore, essential to preserve the existing storage capacity. Otherwise, the arid regions will be deprived of storage reservoirs and the greater part of renewable resources will be lost leading to inevitable over-exploitation and exhaustion of the non-renewable (mainly groundwater) resources.

India is a vast country with high spatial and temporal variability of rainfall. After independence, it was realized that for the needs of irrigation, hydropower generation, industry and drinking water of ever increasing population of our country, creation of adequate storage capacity was essential to store the rainfall taking place during the four months of monsoon period only. During the last five decades, more than 4000 major and medium dams have been constructed/are under construction. The total capacity now available is about 270 cubic kilometer (Cukm) which is only about 15% of the average annual flows in the river. At present, capacity of about 77 Cukm is likely to be added through on-going schemes and addition of another 131 Cukm capacity is under consideration. The storage capacity available in small ponds/lakes is about 20 Cu km. The completion of all these schemes will enable to create capacity of the order of 400 Cu km in India.

Efficient utilisation of the water resources requires that the reservoirs must be operated in the most judicious and scientific manner. Efficient regulation of the reservoirs can lead to increased benefits from the reservoir as well as significant reduction in damage due to floods. In view of the limited good storage sites, it is particularly important that storage reservoirs should serve the expected functions properly for the whole life span and their life be extended beyond the service period as long as possible. It is therefore essential to monitor the capacities of the existing reservoirs at regular intervals and take suitable measures for controlling the sedimentation rate and utilize the findings in the planning of future reservoirs. To determine the useful life of a reservoir, it is essential to periodically conduct the surveys and assess the sedimentation rate in a reservoir. Also, for proper allocation and management of water from a reservoir, knowledge about the sediment deposition pattern in various zones of a reservoir is essential. With the correct knowledge of the sedimentation processes going on in a reservoir, remedial measures can be undertaken well in advance and reservoir operation schedule can be planned for optimum utilisation of water.

Due to various reasons, the construction of new projects has considerably slowed in India and the pace is unlikely to pick up soon. As the 'easy' or suitable sites are being exploited, the remaining sites will progressively require more elaborate investigations and more sophisticated civil works. Moreover, with the passage of time, the cost of construction is also increasing. Thus, the overall cost of creating a unit volume of storage space will be considerably more for the new projects compared to the existing ones. In view of this, it is more important and necessary that the existing storage is not lost and they are used in the best possible manner.

For assessing the sediment deposition pattern in a reservoir, systematic capacity surveys of the reservoir are conducted periodically. Present conventional techniques of sediment quantification in a reservoir, like the hydrographic surveys and inflow-outflow methods, are cumbersome, costly and time consuming. The remote sensing data, through its spatial, spectral and temporal attributes, can provide synoptic, repetitive and timely information about the water spread area of a reservoir. With the deposition of sediments in the reservoir, the waterspread area at an elevation keeps on decreasing. Using the revised surface area of the reservoir at various elevations, revised elevation-area-capacity table can be prepared and compared with the original capacity table. The reduction in the capacity can be attributed to the sediment deposition in the reservoir. Similarly, by comparing the original and revised contours of the submerged area, the sediment distribution and deposition pattern in a reservoir can also be determined.

1.1 SCOPE OF THE REPORT

The Bargi dam is a major storage dam that has been constructed on the main Narmada river in the upper part of the basin. The reservoir was first impounded in the year 1988. No hydrographic survey has yet been carried out for the reservoir.

The aim of this report is to estimate the sedimentation in the Bargi reservoir. Remote sensing data of nine different dates (during the non-monsoon season) were acquired for the year 1996-97. The revised capacity was determined within a zone of the reservoir (406.00 m to 421.45 m) using remote sensing techniques. Using the aerial estimate of the revised waterspread areas and the corresponding reservoir elevations, revised elevation-capacity graph was prepared and compared with the original graph. Based on the revised waterspread areas, revised contours of the submerged area were derived. It was also envisaged to find the revised contours within the zone of study after the sediment deposition in the reservoir

* * *

CHAPTER - 2
STATUS OF RESERVOIR SEDIMENTATION ASSESSMENT USING REMOTE SENSING IN INDIA

Many of the reservoirs in India are losing capacity at the rate of 0.5 to 1.5 percent annually. About 40,000 minor tanks in Karnataka have lost more than 50 percent [8] of their capacities. It is, therefore, necessary to take steps to plan the future projects on a sound basis so that the sedimentation of the reservoirs does not reduce the benefits faster than envisaged. The Ministry of Agriculture and Irrigation (Department of Irrigation), Government of India, had set up a Reservoir Sedimentation Committee in February, 1978. In its report (July, 1982), the committee made certain recommendations for long term measures such as: sediment observations in major river systems to be carried out with latest equipment, capacity surveys of all major reservoirs to be carried out once in five years and cultivation of areas on the periphery of reservoirs to be prohibited to reduce silt entry into reservoirs. Maintenance of a data bank of sediment inflow, outflow and sedimentation of reservoirs by Central and State Government was also recommended.

. At the planning and design stage of a dam, provision for sediment storage is kept. This provision is arrived at through observed sediment gauge record (bed load & suspended sediment load) of river at or nearby location where the hydraulic structure would be located. For an ungauged site, sediment yield is modeled using empirical model, physical model or conceptual model. However, after the construction of dam & impoundment of reservoir, there is a great need to continuously monitor the reservoir to:

- Know the quantum of annual actual storage loss in reservoir due to sedimentation for estimating reservoir's effective economic life,
- Determine spatial distribution of sediment deposit in the entire body of the reservoir to identify problem location in reservoir and source of sediment-laden water from tributaries,
- Update elevation-area-capacity curve for efficient reservoir operation,
- Gather fresh data to verify and improve sediment accumulation prediction techniques,
- Take up remedial measures at the reservoir and in watershed.

2.1 CAPACITY SURVEYS

Capacity surveys of reservoirs imply direct in-situ measurement of reservoir bed profile. These surveys are periodically carried out to determine the volume of silt deposition, its distribution pattern, rate of sedimentation, and to update the elevation-area-capacity relationships. These surveys are usually carried out by following either the contour method or the range line method. A survey requires extensive fieldwork, costly equipment and skilled manpower. In India, the method of hydrographic survey using echo-sounder along range lines has mostly been adopted. Recently, use of hi-tech methods has been started in which hydrographic surveys are carried out employing computerized methods for data collection and analysis. With the advancement in satellite technology, location accuracy of observation points has been greatly enhanced by using Real Time Differential Global Positioning System (RTDGPS). The reservoir bed-profile is mapped by dual frequency echo-sounder. One popular software for data analysis is HYPACK which can work on a PC in Windows environment. The data received from echo-sounder is automatically logged in the computer, edited and the volume can be calculated. The inflow - outflow method involving measurement of inflows into and outflows from the reservoirs comprising discharge and sediment concentration is also being used in some cases.

The sedimentation survey of reservoirs in India dates back to 1870. However, systematic surveys started only in 1958 when the Central Board of Irrigation and Power undertook a scheme of reservoir sedimentation and entrusted this task to several research stations in the country, viz., Karnataka Engineering Research Station, Directorate of Irrigation Research, Bhopal, Maharashtra Engineering Research Institute, U.P. Irrigation Research Institute, Andhra Pradesh Engineering Research Laboratories etc. Under this scheme, 28 major reservoirs have been surveyed.

After the advancement of the remote sensing technique and the availability of indigenous satellite data from Indian satellites, capacity surveys of reservoirs by remote sensing techniques are gaining much recognition and acceptance.

2.2 BRIEF DESCRIPTION OF REMOTE SENSING BASED METHODOLOGY

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. Advantages of using remote sensing data are that it is highly cost effective, easy to use and it requires lesser time in analysis as compared to conventional methods [1]. Spatial, spectral and temporal attributes of remote sensing provide invaluable synoptic and timely information regarding the revised waterspread area after the occurrence of sedimentation and sediment distribution pattern in the reservoir.

In India, more than 80 % of the annual rainfall is received during the four monsoon months from June to September. Hence, water level in a reservoir can be expected to be at higher elevation after the monsoon season (September/October) before it gradually depletes to lower levels towards the onset of next monsoon (May/June). For tne quantification of volume of sediments deposited in the reservoir, the basic information extracted from the satellite data is the waterspread area of the reservoir at different water surface elevations. The original contour areas at different elevations and the original elevation-area-capacity curves at the dam site can be obtained from the original capacity surveys, which are carried out during the planning and design phase of a dam. With the deposition of sediments in the reservoir, the contour (water spread) area at any elevation gradually keeps on decreasing. Greater deposition of sediments at an elevation causes greater decrease in the contour area. The revised contour area after the deposition of sediments, is the continuous waterspread area of the reservoir at the elevation of water surface in the reservoir at the time of satellite pass. Using the synoptic satellite data and the image interpretation techniques, the waterspread area of the reservoir at the instant of satellite overpass can be determined. The water surface elevation in the reservoir corresponding to the time of satellite pass can be obtained from the dam authorities. In this way, the revised contour areas at different elevations can be calculated and the revised elevation-area curve can be prepared.

The reduction in reservoir capacity between consecutive contour levels is computed using the trapezoidal formula. The overall reduction in capacity between the lowest and the highest observed water levels can be obtained by adding the reduced capacity at all levels. It is important to mention here that the amount of sediments deposited below the lowest observed water level can not be determined using the remote sensing techniques. Because of this reason, it is not possible to estimate the actual sedimentation rate in the whole of the reservoir. It is only possible to calculate the sedimentation rate within the live storage zone of the reservoir. However, if the sedimentation in the entire reservoir is to be found, then the hydrographic survey for the region below the lowest observed water elevation can be carried out. It is also important to emphasise here that for the purpose of judicious operation of the reservoir, the zone of interest of sedimentation analysis is only the live storage zone of the reservoir. Since the reservoir rarely goes below the minimum drawdown level in normal years, the interest mainly lies in knowing the revised capacity and the sediment deposition pattern within the live storage zone.

2.2.1 Identification of Water Pixels

For the determination of waterspread area, it is required to find the number of continuous water pixels of the reservoir in the satellite imagery. Multiplying the number of water pixels with the area of individual pixel gives the waterspread area of a reservoir.

In the visible region of the spectrum (0.4 - 0.7 μm), the transmittance of water is significant and the absorptance and reflectance are low. The reflectance of water in the visible region scarcely rises above 5%. The absorptance of water rises rapidly in the near-IR where both, the reflectance and transmittance are low. The transmittance of visible radiation through water means that if the water is sufficiently shallow, the radiation can be reflected by the bottom of the water body, 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-IR portion of the spectrum must be inspected as a submerged surface will not be detected in this portion because of lack of transmittance. At near-IR wavelengths, water apparently acts as a black body absorber. In the Band 4 (0.77 - 0.86 μm) of IRS-1A or IRS-1B, the spectrum of reflection of water approaches the status of being completely absorbed and the boundary between the water and other surface features is very clear. Thus, Band 4 of IRS-1A or IRS-1B or Band 3 of IRS-1C can be used in the waterspread area calculation.

In the region near the periphery of the reservoir, the water depth reduces gradually and the soil is saturated. The reflectance from this wet land along the periphery of the waterspread area may be quite similar to the reflectance from the adjacent shallow water. To differentiate water pixels from the adjacent wet land pixels, comparative analysis of the digital numbers in different bands needs to be carried out. The behaviour of the reflectance curves of water and soil/vegetation is different from the Band 2 (0.53 - 0.59 μm) onwards. Beyond Band 2, with increase in wavelength, water reflectance curves show downward trend while soil/vegetation curves show upward trend. This characteristic can be used to differentiate the water pixels from the peripheral wet land pixels. The reflectance characteristic curves of common earth features (soil, water and vegetation) are presented in Fig. – 1. Reflectance curves for different types of soils with varying moisture content are shown in Fig. – 2 while curves for water in different conditions are shown in Fig. – 3. A number of studies have been carried out to estimate reservoir water spreads. The methodologies adopted in such approaches can be classified in three categories:

I. ***Thresholding:*** In this method, a threshold value is adopted in the near-IR image to separate out the water body from surrounding soil/vegetation. This is the most commonly used method.

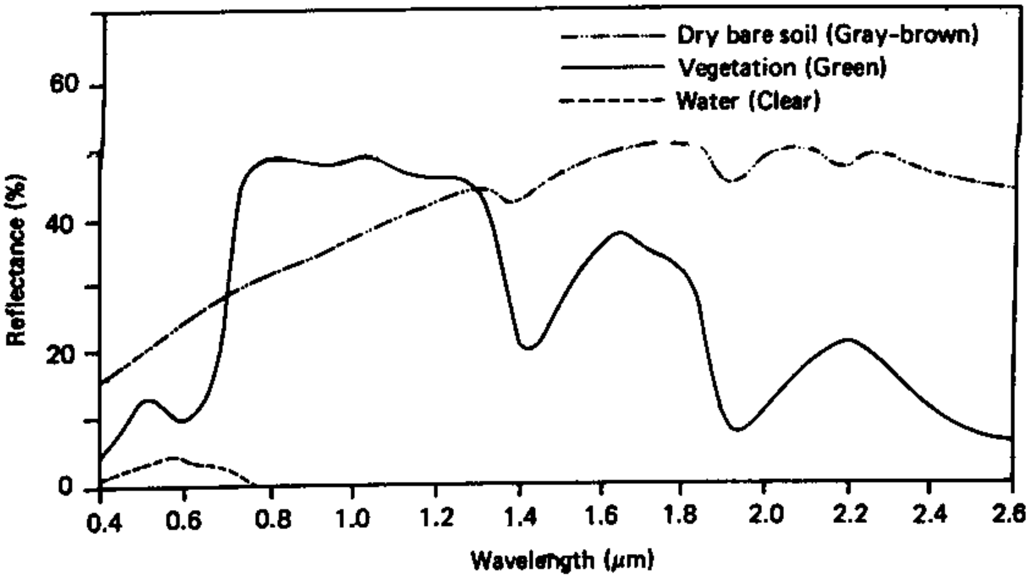


FIG. - 1 Spectral Reflectance Curves for Selected Surface Features

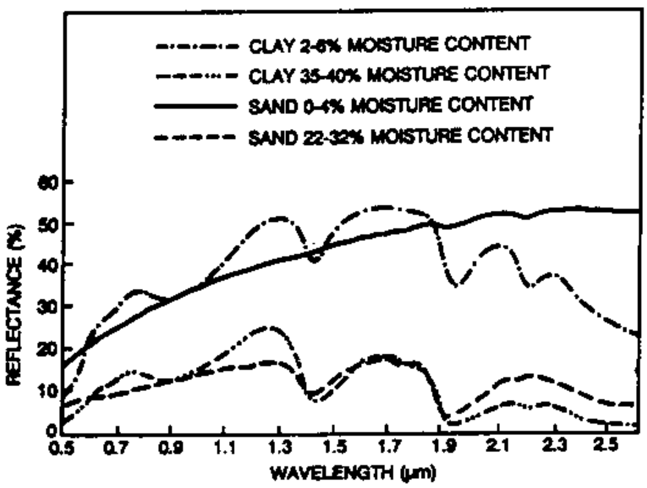


FIG. - 2 Spectral Reflectance Curves for Soil (variation with moisture content)

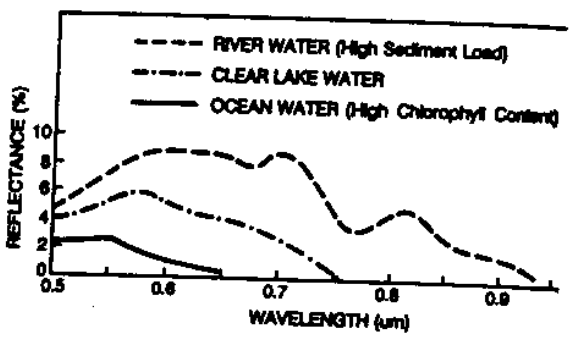


FIG. - 3 Spectral Reflectance Curves for Water (for different water bodies)

2. Modeling: In this method, a model which tests multiple conditions is applied to determine whether a pixel represents water or not. This methodology may involve integrating multiband thresholding, or defining relation between different bands. The approach is useful when thresholding does not give proper results because of confusion pixels, especially around the periphery of a reservoir. This methodology has been used in many studies.

3. Classification: In this method, the image is classified using supervised or unsupervised classification by identified number of training sets of different classes.

2.3 RESERVOIR CAPACITY SURVEYS USING REMOTE SENSING

The conventional methods such as hydrographic surveys are laborious and time consuming. The hydrographic surveys of reservoirs are being conducted at a frequency of 2 to 15 years, though the recommended frequency is 5 years. Remote sensing technique has emerged and established itself as a useful, cost and time effective tool to frequently estimate capacity loss. The procedure does not call for great expertise. By choosing satellite images corresponding to various levels between maximum to minimum reservoir stages, revised elevation-area-capacity curve can be reconstructed. The comparison of this curve with the original curve (prepared before reservoir impoundment or the ones obtained from subsequent sedimentation surveys) provides a realistic picture of change between two periods and enables computation of total volume of sediment deposited in the reservoir.

In the early stages of development of remote sensing technology, the reservoir waterspread areas were delineated using the visual interpretation technique [3]. However, along the periphery of the reservoir, the depth of water generally remains shallow and the difference in reflectance from wet soil and shallow water is not very apparent. So, using this technique, the correct demarcation of water pixels along the periphery was very difficult. Due to the increase in the computational capabilities with time, digital techniques became more popular. Density slicing of the infrared band was mostly employed for the water spread area calculation [4, 9, 10, 11]. Again, this technique is based on the subjective judgement of the analyst and was prone to error. Recently, researchers are trying to classify the water pixels on the basis of spectral signature characteristics of water thereby avoiding the necessity of selecting arbitrary limits.

The elevation-capacity curves of many reservoirs across the country have been re-assessed using remote sensing technique [8]. A list of some case studies of reservoir sedimentation surveys conducted by various agencies using remote sensing techniques is given in Table – 1.

TABLE – 1
SOME CASE STUDIES OF RESERVOIR SEDIMENTATION USING REMOTE SENSING

S. No.	Reservoir	Year of Survey	Agency/ Department	%storage loss / year	Period of Analysis
1.	Bhadra	1986	KERS	0.25	1964-86
2.	Ghatprabha	1989-90	RRSSC, B'lore & KERS	0.57	1974-89
3.	Malaprabha	1988-89	-do-	0.24	1972-88
4.	Krishnaraja sagar	1988-89	-do-	0.03	1932-88
5.	Tungabhadra	1994-95	NRSA	0.59	1953-95
6.	Nath sagar	1991-92	-do-	0.48	1976-92
7.	Ujjani	1991-92	-do-	1.18	1976-92
8.	Ukai	1984-85	SAC		
9.	Osman sagar	1986-89	APERL	0.489	1927-86
10.	Nizamsagar	1990-92	-do-	0.195	1930-90
11.	Sriram sagar	1982-84	-do-	1.85	1970-84
12.	Himayat sagar	1986-89	-do-	0.472	1927-86
13.	Kaddam	1987-90	-do-	1.142	1965-87
14.	Lower Manair	1987-90	-do-	0.324	1982-87
15.	Hirakud	1976-77	ORSAC		
16.	Hirakud	1994-95	CWC	0.64	1957-95
17.	Kadana	1994-96	CWC	0.54	1977-96
18.	Mahi Bajajsagar	1993-94	CWC & RRSSC, Jodhpur	1.23	1983-94
19.	Konar	1995-96 1997	CWC RITES-hydrographic	0.46 0.62	1955-96
20.	Tilaiya	1995-96	CWC	-	-
21.	Bhakra	1998-99	NIH	0.56	1988-89 1996-97
22.	Ukai	1997-98	NIH	0.3	1993-94

* * *

CHAPTER - 3
BRIEF DESCRIPTION OF BARGI (R.A.B.S.) PROJECT

3.1 NARMADA RIVER BASIN

The river Narmada rises in the Mikel range in Shahdol district near Amarkantak at an elevation of 1050 m. Flowing generally in the southwesterly direction in a narrow valley, the river takes a northerly turn near Mandla. After passing through the city of Jabalpur, the river flows through a deep narrow channel through the famous *Marble Rocks* of Bhedaghat.

After emerging from the gorge and continuing west, the river enters the fertile Narmada valley, which is a long and narrow strip, walled by Vindhyas on the north and Satpuras on the south. Coming out of the gorge, the river enters the plains of Gujarat and finally discharges into the Gulf of Khambat.

3.2 GENERAL DESCRIPTION OF THE BARGI DAM

In the series of major dams to be constructed on the river Narmada in Madhya Pradesh, the Bargi project is one of the major schemes, which have been completed till date. The project consists of Bargi dam (later renamed as Rani Avanti Bai Sagar Project) which has been constructed on the river Narmada near village Bargi in the Jabalpur district. The dam is located 43 km downstream of the Jabalpur city. The latitude and longitude of the dam is 22°56′30″ N and 79°55′30″ E respectively. The index map of the basin is presented in Fig. – 4. Some of the proposed and existing hydraulic structures lying upstream of the dam are shown in Fig. – 5.

Bargi is a composite earth and masonry dam, 5374.39 m long. The catchment area at the dam site is 14556 sq. km. The gross, live and dead storage capacity of the reservoir are 3.92 billion cubic meters (B Cum), 3.18 B Cum and 0.740 B Cum respectively. The maximum height of the masonry dam is 69.80 m while that of earth dam is 29 m. Maximum reservoir level, full reservoir level and the dead storage level of the reservoir are at 425.70 m, 422.76 m and 403.55 m respectively. As per project report, the estimated life of the reservoir is 100 years.

The project has been envisaged as a multipurpose scheme meant to serve for water supply for domestic and industrial purposes, irrigation and hydropower generation. One canal system (left bank canal system) is nearing completion and one power plant (river bed power plant) with capacity of 90 MW has already been completed for utilizing the stored water of the Bargi reservoir. The gross and culturable command area of the left bank canal is 2.574 and 1.57

lakh ha respectively. Other canal system (right bank canal system) is under construction. The purpose of right bank canal is to transport 116 M Cum of water for domestic use and around 2300 M Cum of water for irrigation and interbasin transfer annually. One powerhouse (canal powerhouse) with capacity of 15 MW is also to be constructed in the left bank canal system. Annual water requirement from the reservoir through the left bank canal for domestic water supply and irrigation is 54 M Cum and 2160.1 M Cum respectively. In addition, annual firm energy requirement from the reservoir is 363 M Kwh.

For discharging excess water during the flood season, a 385.72 m long spillway has been provided in the center of the masonry section. 21 nos. of radial gates of size 13.71 m length and 15.25 m height have been provided on this spillway. The shape of overflow section of the spillway has been designed to conform to the shape of lower nappe of water flowing over a sharp crested vertical edge. The spillway has been designed to pass a flood hydrograph having base period of 7 days and peak inflow of 45296 cumec. The derivation of design flood hydrograph is based on the unit hydrograph concept. The maximum water level at the Bargi dam site has been limited to 424.28 m because of the Mandla township upstream of the Bargi dam.

The water availability at the dam site was based on the discharge data collected at the Jamtara gauge site. This site is located 16 km downstream of the Bargi dam and has a catchment area of 16576 sq. km. Systematic gauging has been done at this site since 1949. The average annual inflow at the dam site is 7197 M Cum. There are 13 raingauge stations in the catchment area. In some of the raingauge stations, rainfall data for nearly 89 years has been recorded. The average annual rainfall in the catchment up to Jamtara is 1414 mm. Rainfall in the basin mostly occurs during the monsoon months (July to October). About 94% of the annual total rainfall occur during monsoon season.

The reservoir has been classified as hilly according to the I.S. code no. 5477. The shape of the reservoir is almost longitudinal. Its longest periphery from the axis is about 80 km. The width at 16 km and 25 km from the axis is 16 km and 3.2 km respectively.

The dam was first impounded up to RL 407.5 m in the year 1988. In subsequent years 1989, 1990 and 1991, the reservoir was filled up to RL 418.5 m, 422.76 m and 421.8 m respectively. On August 23 – 24, 1991, a flood of 8.18 lakh cusec was passed over the spillways. No hydrographic survey has yet been carried out for the reservoir.

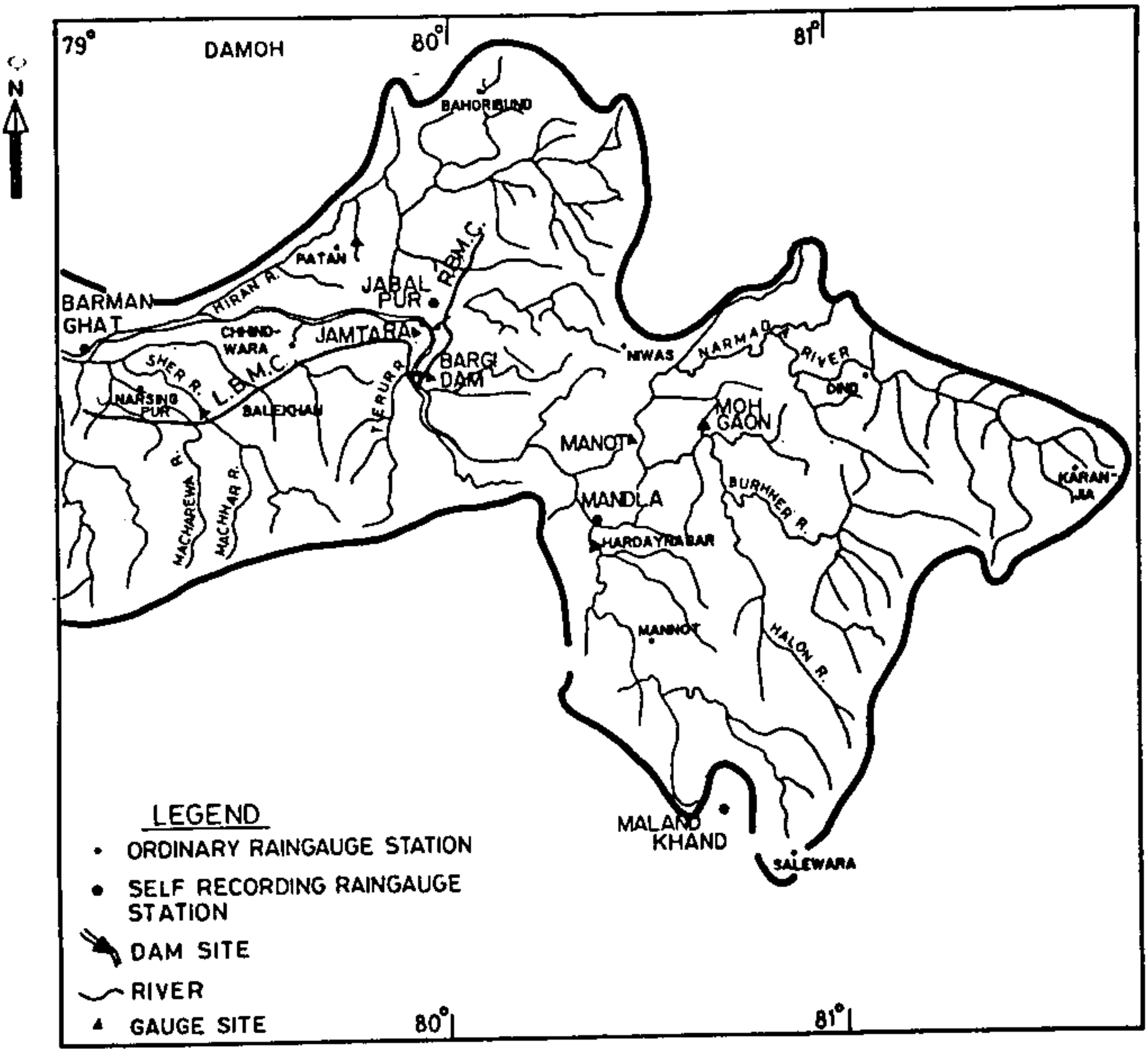


FIG. – 4 Index Map of Narmada Basin up to BARGI Dam

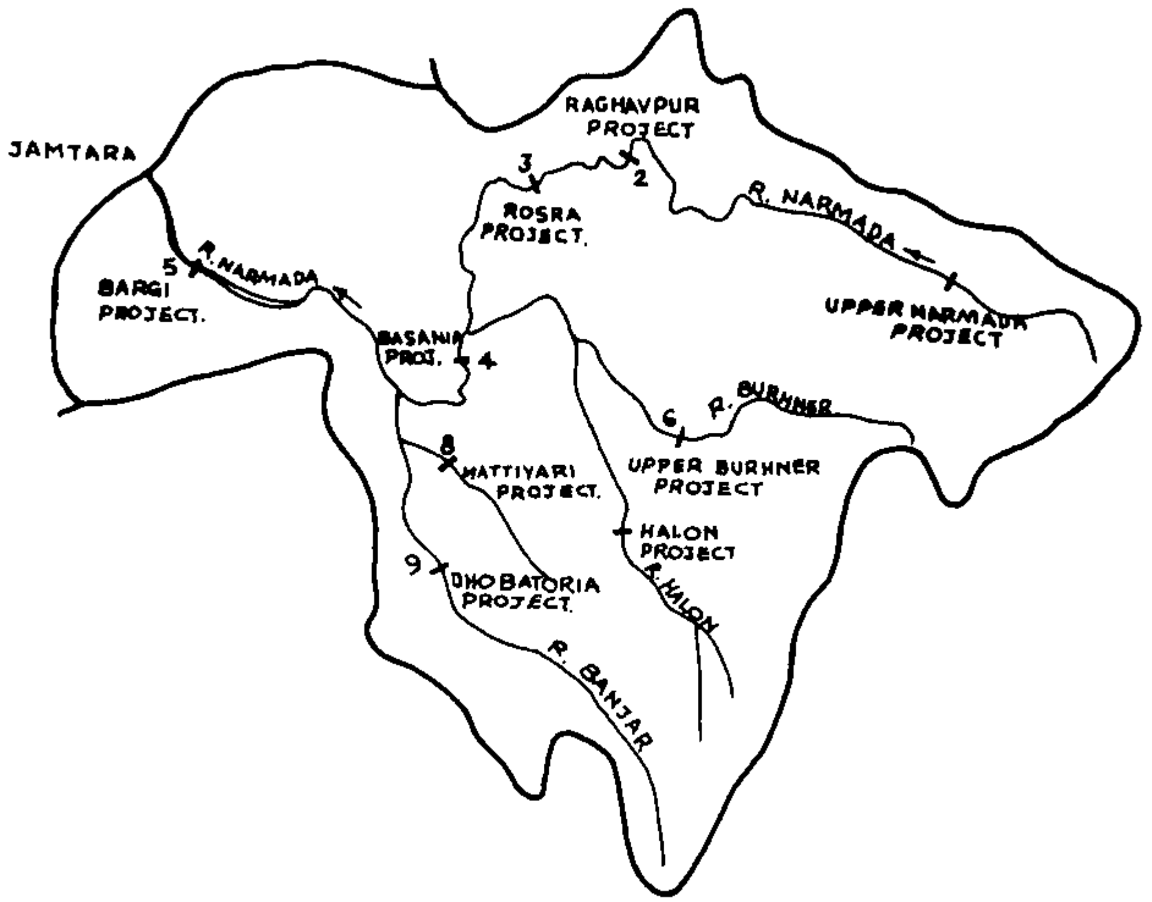


FIG. – 5 Existing & proposed locations of major projects in Narmada Basin (up to BARGI dam)

CHAPTER - 4
INTERPRETATION AND ANALYSIS

To determine the useful life of the reservoir, it is essential to periodically assess the available capacity in the live storage zone of 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 utilisation of water. For this reason, systematic capacity surveys of a reservoir should be conducted periodically. Remote sensing technology, offering data acquisition over a long time period and broad spectral range, can provide synoptic, repetitive and timely information regarding the sedimentation characteristics in a reservoir. Advantages of using remote sensing data is that it is highly cost effective, easy to use and it takes lesser time in analysis as compared to conventional methods.

4.1 SELECTION OF PERIOD OF ANALYSIS

This is the first and important step in carrying out the analysis for reservoir sedimentation assessment using remote sensing data. The information extracted from the remote sensing imageries is the water spread area at different dates of pass of the satellite over the reservoir area. It is best to use the remote sensing data of that water year in which there is maximum variation in the elevation of the reservoir water surface and consequently, the water spread area.

For the Bargi dam, the historical record of annual maximum and minimum observed levels were obtained from the dam authorities. The variation of water level was the maximum in the year 1996-97, covering most of the live storage zone. Therefore, the period (October, 1996 to June, 1997) was selected for this study.

4.2 SELECTION OF SUITABLE SATELLITE AND SENSOR

A number of satellites are available for acquiring remote sensing data and the most common among them are listed below along with their sensors and spatial resolution:

a) IRS - 1A/ IRS - 1B [LISS-I (72.5 m) & LISS-II (36.25 m)]

b) IRS - 1C/1D [PAN (5.8 m) & LISS-III (23.5 m)]

c) LANDSAT [MSS (80 m) & TM (30 m)]

d) SPOT [PAN (10 m) & spectral (20 m)]

Multi-spectral information is required for the identification of water pixels and to differentiate the water pixels from the peripheral wet land pixels. It is also desirable to use the data of higher resolution for obtaining accurate results. Since the multispectral data of LISS-III sensor of IRS-1C satellite was available for the period of analysis, the same was used in this study. Bargi reservoir waterspread is covered in one scene of Path 100 and Row 56 of 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. Based on the status and availability of remote sensing data and the time spacing in-between the satellite data, nine scenes were ordered for the following dates of pass: 10.10.96, 03.11.96, 27.11.96, 07.02.97, 03.03.97, 27.03.97, 20.04.97, 14.05.97, and 07.06.97. It was found that the reservoir level varied from 421.45 m on 10.10.96 to 406.00 m on 07.06.97. Hence, the capacity evaluation was restricted to this zone of reservoir only. It is worth mentioning here that under normal conditions, the reservoir level varies within or around this range and the main concern is to quantify the revised capacity in this zone of operation of the live storage.

4.3 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 interpretative capability of the analyst and it is not possible to use the information of different bands, after the visual product is generated. Around the periphery of the waterspread area, the wet land pixels appear very similar to the water pixels and it becomes very difficult for the eye to decide whether a pixel near the periphery is to be classified as water or land. Moreover, in case of clouds or noise in the scene around the periphery, it is not visually possible to demarcate the waterspread area.

Using digital techniques, the information of different bands can be utilised to the maximum extent and consistent analysis can be carried out over the entire range of the reservoir. The information below the clouds can be extracted indirectly using the interpreted imageries of past and future periods. It is also easy to calculate the water spread area. 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. The analysis was performed using the ERDAS/IMAGINE image processing software. The various steps followed in the analysis are described below.

4.3.1 Import and Visualisation

The data of IRS-1C satellite and LISS-III sensor for nine different dates were received from NRSA on CD-ROM media. The data were loaded on the computer from the CD-ROM and were imported in the ERDAS system. Each scene had 6480 columns, different number of rows and the information of four bands. The header bytes for IRS-1C LISS-III data were 540. The pixel size of the processed data was 24 m. Reservoir area was located approx. in the centre of the full scene. Imageries of reservoir portion of all dates were imported and stored in hard disk.

A false colour composite (FCC) of 3, 2 and 1 Bands combination was prepared which correspond to the standard FCC. The waterspread area (except at the periphery) of the reservoir was quite distinct and clear in the FCC. Except at a few places, all the scenes were free from noise. In the scenes of May and June, 1997, some clouds were observed in the full scene but the reservoir spread area was free of the clouds and their shadows in all the nine date imageries.

4.3.2 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 landuse/land cover changes can be made.

In the present study, detection of land use change was not the objective. Further, the determination of the waterspread area did not require the geo-referencing of the different scenes. However, using the geo-referenced imageries, 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. Geo-referencing was also required to manipulate the information below the clouds and under the noise pixels using the imageries of adjacent dates. Using the geographic waterspread information, revised contours (prevailing in the present situation after sedimentation) could also be prepared from the revised waterspread data.

First, the drainage pattern of the area around and within the reservoir waterspread was digitised from 1:50,000 scale toposheets of the Survey of India (SOI). The toposheets of higher scale were not available either from the SOI or from the project authorities. The drainage pattern was rasterised and resampled in Polyconic projection with a pixel size of 24 m (same as remote sensing data). In the similar way, the original contours of the catchment upstream of the dam site were digitised. The contours on these toposheets were available for elevations of 400 m, 420 m, 440 m and 460 m.

Next, image–to–image registration was carried out for all the images. Each imagery was georeferenced with its subsequent date image as it was easy to identify the corresponding pixels. This way, all the imageries were geo-referenced with respect to each other. The results were checked for all the images by displaying the two images at a time one over the other and comparing the two using the SWIPE facility. The match between the images was found to be satisfactory. After image–to-image registration, the resulting images were georeferenced with the drainage map as mentioned above. All the images were georeferenced with the drainage using the similar model, since all of them were already georeferenced with each other. The results were checked in similar way by displaying the drainage layer over the image and comparing the two. The FCC of georeferenced image of Bargi reservoir of 10 October, 1996 is shown in Fig. – 6. Finally extracted waterspread of June 07, 1997 is overlaid on this image to have a view about the overall waterspread variation in this analysis. The drainage network used for geo-referencing is presented in Fig. – 7 and the original contours are presented in Fig. – 8.

4.3.3 Identification of Water Pixels

This was the basic interpretation factor from the remote sensing data. 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. At the soil/water interface, it is also possible that a pixel may represent mixed conditions (some part as water and other part as soil).

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 *Normalised Difference Water Index* ((Green-NIR)/(Green+NIR)) which is created as a separate image. In all the images, it is found that the NDWI for water is either equal to or greater than 0.44. 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 NDWI is ≥0.44, then it is classified as water otherwise not".

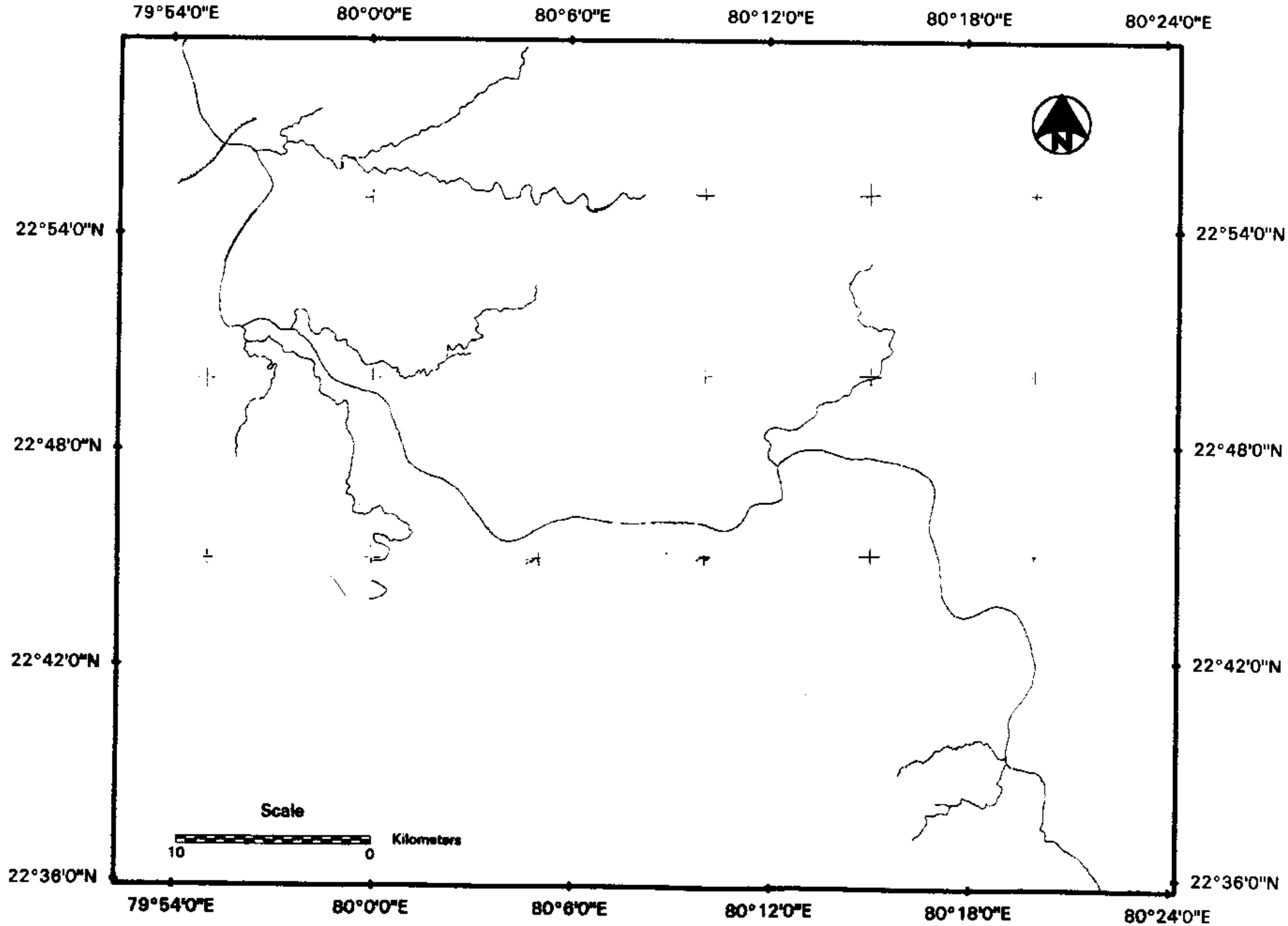


FIG. - 7 Drainage network around the BARGI reservoir used for Geo-referencing the RS images

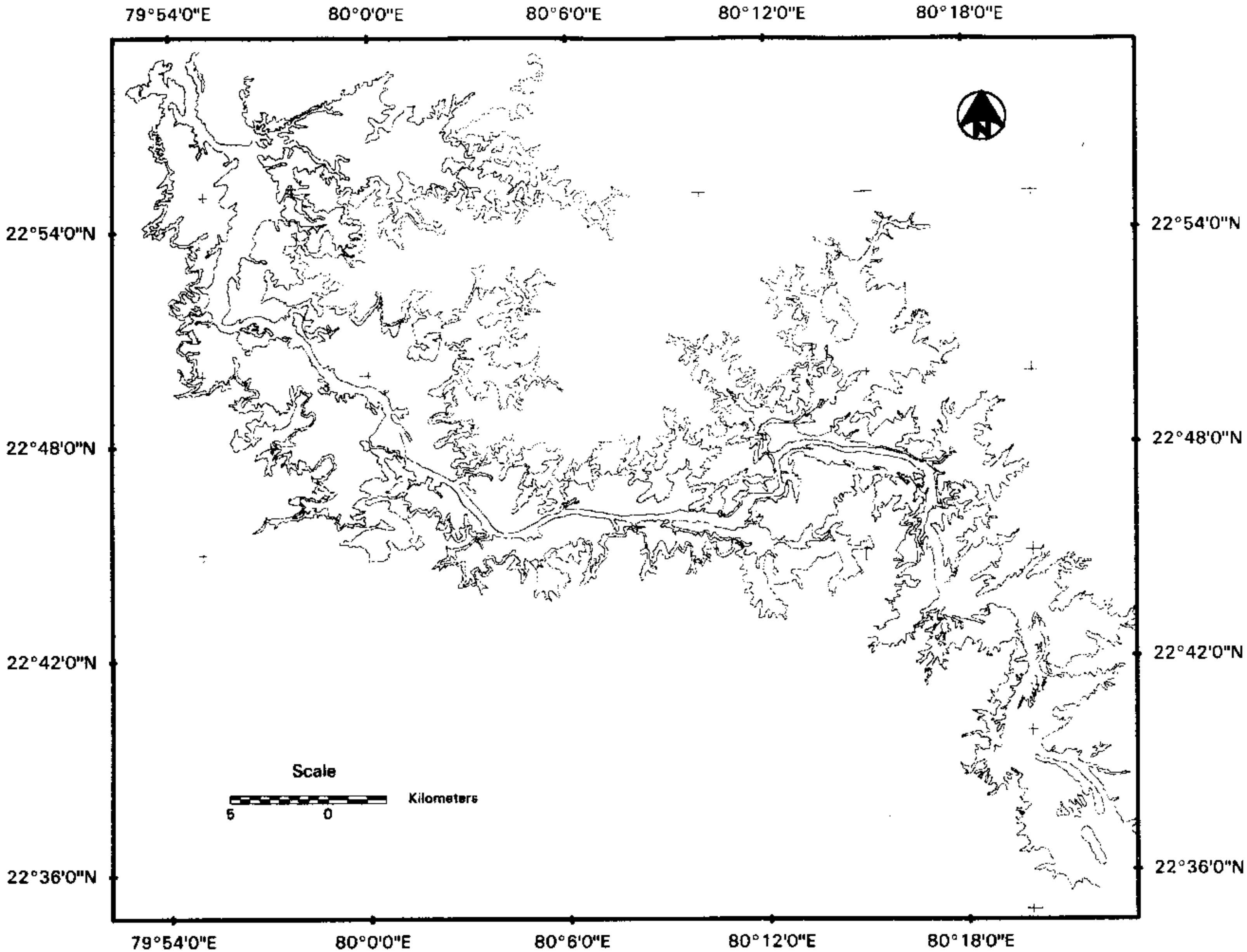


FIG. - 8 Original contours upstream of BARGI dam obtained from 1:50,000 toposheets (represent elevations of 400 m, 420 m, 440 m & 460 m)

Since the absorptance of electromagnetic radiation by water is the 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 3 will cause the DN value to be less than Band 2 and Band 1. This condition differentiates water pixels 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 in different images as required in density slicing. The near-IR image of Nov. 27, 1996 and the corresponding NDWI image are shown in Fig. - 9. The image of water pixels obtained after the application of the model, as mentioned above, is presented in Fig. – 10 (a).

Some problems like, presence of noise etc. were encountered in the process of interpretation in this way. The images of waterspread, as obtained from the interpretation, were edited to remove the effect of noise, isolated water pixels, extension of tail and joining of rivers around the water spread. These are discussed in the following:

4.3.3.1 Removal of Discontinuous 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 waterspread area and/or located within the islands, be removed from the interpreted water image.

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. These pixels do not form part of the continuous waterspread and need to be removed. Similarly, the water pixels representing flow downstream of the dam do not form part of reservoir and need to be removed.

For removing most of these unwanted pixels, a mask was generated from the edited water image of October 10, 1996. The water image of this date was edited manually so as to remove the discontinuous pixels and the downstream river pixels. The water pixels of all the images were identified by applying the model mentioned above. Then, the mask was applied and all the pixels outside the mask were classified as not part of the reservoir. After mask application, most of the discontinuous pixels were removed. However, some of the pixels, that were discontinuous and lie within the mask, needed to be edited. For removing these pixels, a GIS utility known as "CLUMP" was used. An 8-connected clump image was formed for all the water images. This utility created a clump around the discontinuous pixels and assigned a different value to the pixel. Using the "MODELER" option, these clumped pixels were removed so that only continuous waterspread remained in the water image. The final waterspread for the Nov. 27, 1996 image, after the application of MASK and CLUMP, is presented in Fig. – 10 (b).

4.3.3.2 Removal of Extended Tail and Channels

Main river at the tail end of the reservoir and numerous small channels join the reservoir from different directions around the periphery of the reservoir. The water in these channels is classified as water. However, the elevation of water in these channels and rivers remain higher than the water surface and must be excluded from the calculation of the waterspread area.

In the present case, there were no extended channels around the periphery of the reservoir. However, the tail portion of the reservoir was truncated in eight out of nine imageries except for the image of October 1996. The selection of the truncation point was based on the difference between the water levels in the subsequent date imageries, the tail end of the lower level image and the termination of waterspread that depends on one's personal interpretation. First, the tail end of the June 07, 1997 image was finalised and then the tail end of next higher level image, i.e. May 14, 1997 and so on. The truncated part of the tail was removed by manual editing of the water image.

After the finalisation of the water pixels of an image (Model application -> Mask -> Clump -> curtailment of tail), the water image of different dates were compared with their subsequent date water image. For example, water image of May 14, 1997 was compared with that of June 07, 1997 and so on. It was based on the reasoning that the waterspread area at the lower elevation must always be contained within the waterspread at the higher elevation. This way, the noise pixels, if any, could be eliminated. First, the water image of June 07, 1997 was finalised and then, the May 14, 1997 water image and so on. A comparison was made between the two. If a pixel within the June waterspread image was water pixel (except at the periphery, which may be due to some error in geo-referencing), but the pixel within the May image at the same location was not a water pixel (either due to some noise or otherwise), then that pixel in the May image was changed to water pixel. After finalisation of the May 14, 1997 water image, the April 20, 1997 water image was finalised and so on. It needs to be mentioned here that such additional water pixels were found to be very few and did not alter the final results in any significant way.

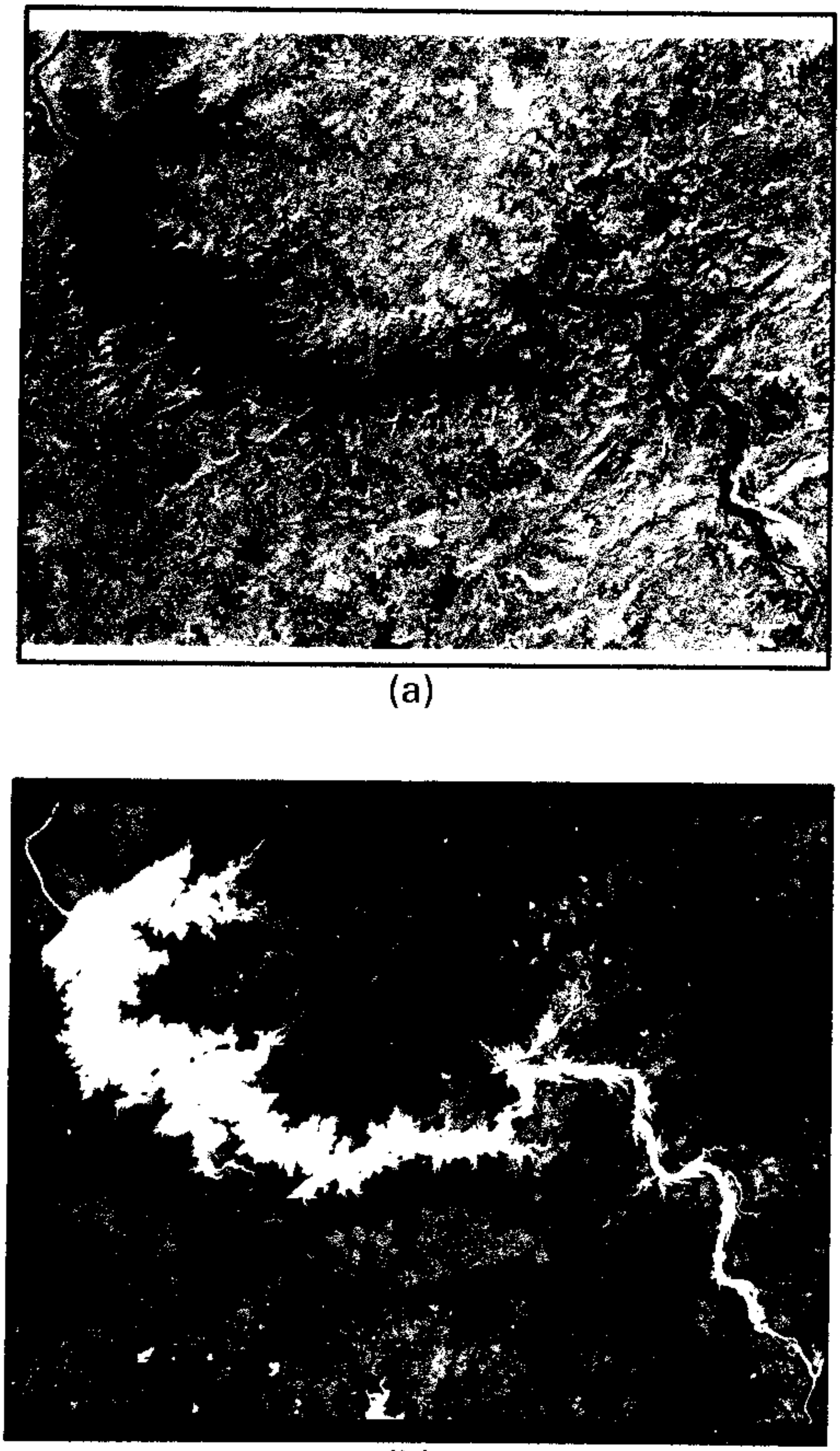
4.3.3.3 Derivation of Contour

After finalising the waterspread area for a particular image, the periphery of the waterspread area was derived from the image processing techniques. First, the islands within the spread area and the diagonally connected pixels were removed. This was achieved using the CLUMP, in the same way, as was done for removing the discontinuous water pixels. The water spread of Nov. 27, 1996, after the removal of within-reservoir islands and the diagonally connected pixels, is shown in Fig. – 11 (a). Then, the three different kinds of filters, namely Edge Detection, Horizontal and Vertical were convoluted with the total waterspread image. Generally, the edge detection filtered image contained the periphery of the total waterspread. However, on close examination, it was found to contain additional layer of pixels along the slanting edge line and at the points of change of direction. To remove the inner slanting line pixels and the pixels at the points of direction change, results of horizontal and vertical filters were used in conjunction with the results of edge detection filter. After obtaining the final peripheral pixels, the elevation values were assigned to them using the MODELER. The contour derived using the remote sensing analysis for the Nov. 27, 1996 image is shown in Fig. – 11 (b).

After finalising the waterspreads of all the nine date imageries, the histograms of the imageries were analysed and the number of water pixels in each was recorded. It is important to mention here that before recording the number of pixels from the histogram, the skip factor for the statistics calculation was set equal to 1. The imageries of different dates showing the near-IR image and the corresponding final waterspread area are presented in Fig. - 12 to 20.

4.4 CALCULATION OF REVISED CAPACITY

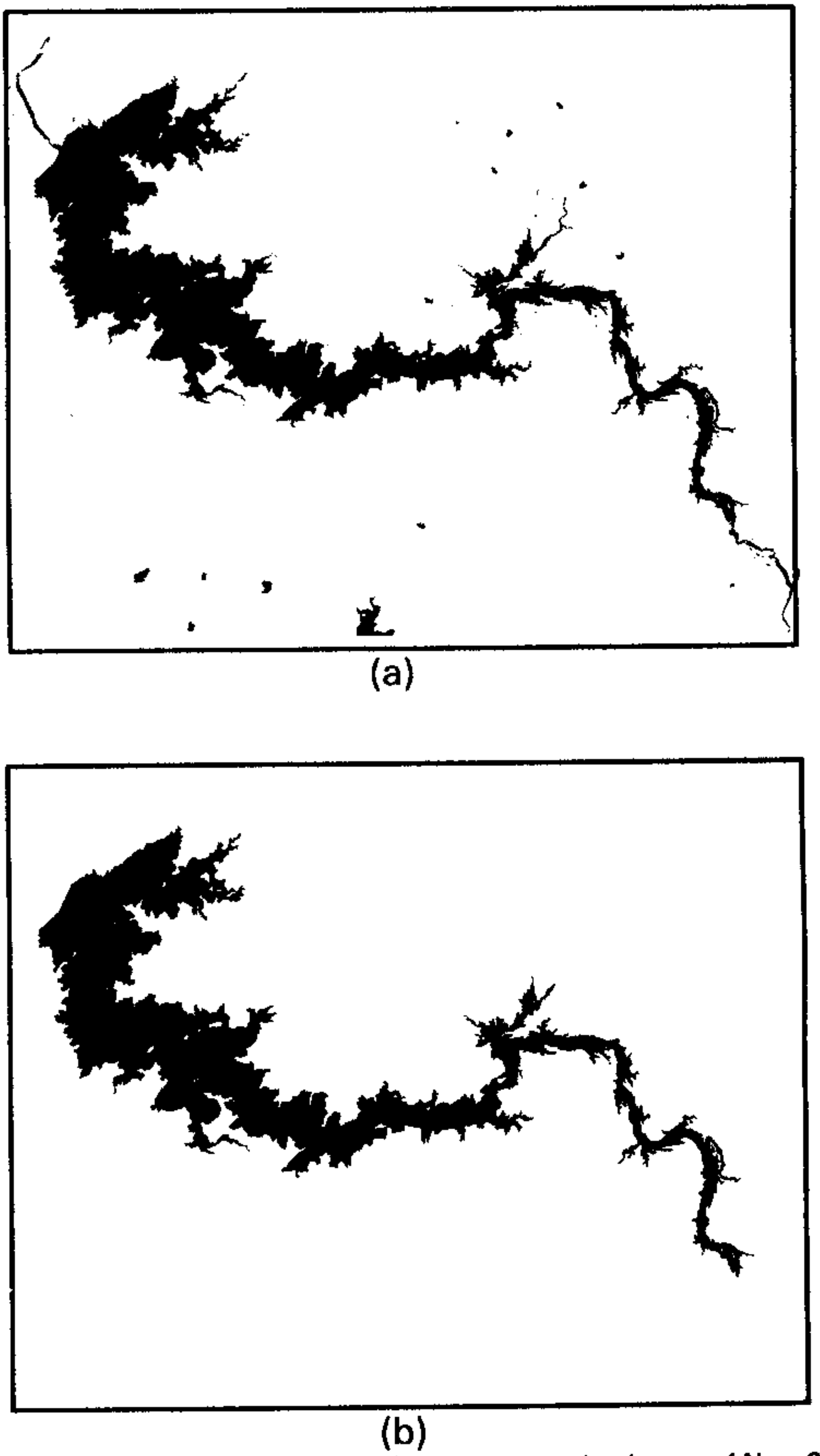
The original elevation-capacity table before the impoundment of dam (1988) was obtained from the Reservoir Operation & Maintenance manual of the Narmada Valley Development Department of Govt. of Madhya Pradesh. It is presented in Table - 2.



(a)

(b)

FIG. - 9 (a) NIR of BARGI reservoir on Nov. 27, 1996
(b) Corresponding normalized difference water index image



(a)

(b)

FIG. - 10 (a) Derived water pixels from the remote sensing image of Nov. 27, 19
(b) Continuous waterspread reservoir area on Nov. 27, 1996

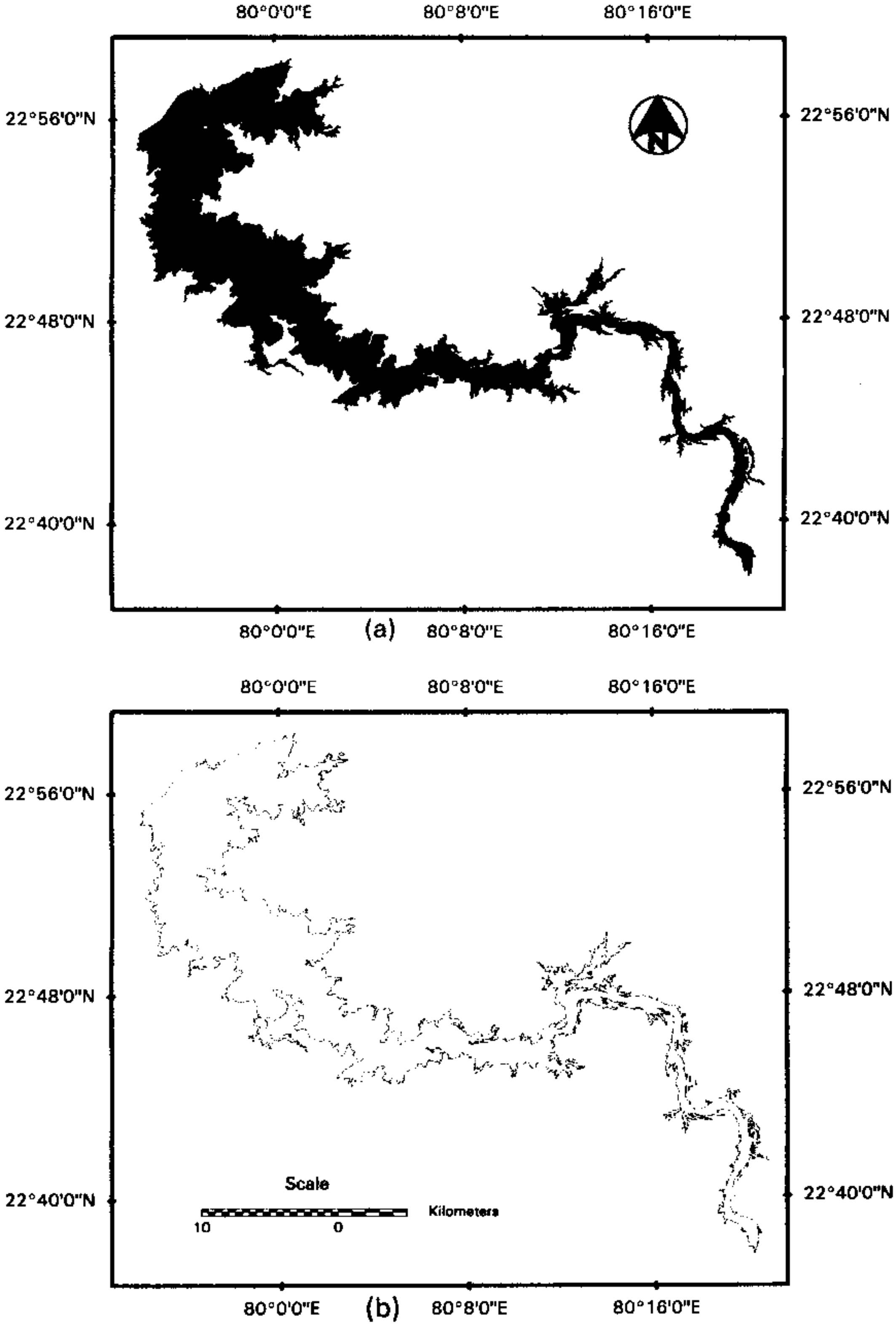


FIG. - 11 (a) Waterspread area after removing the inner islands on Nov. 27, 1996
(b) Corresponding periphery contour derived using digital image processing

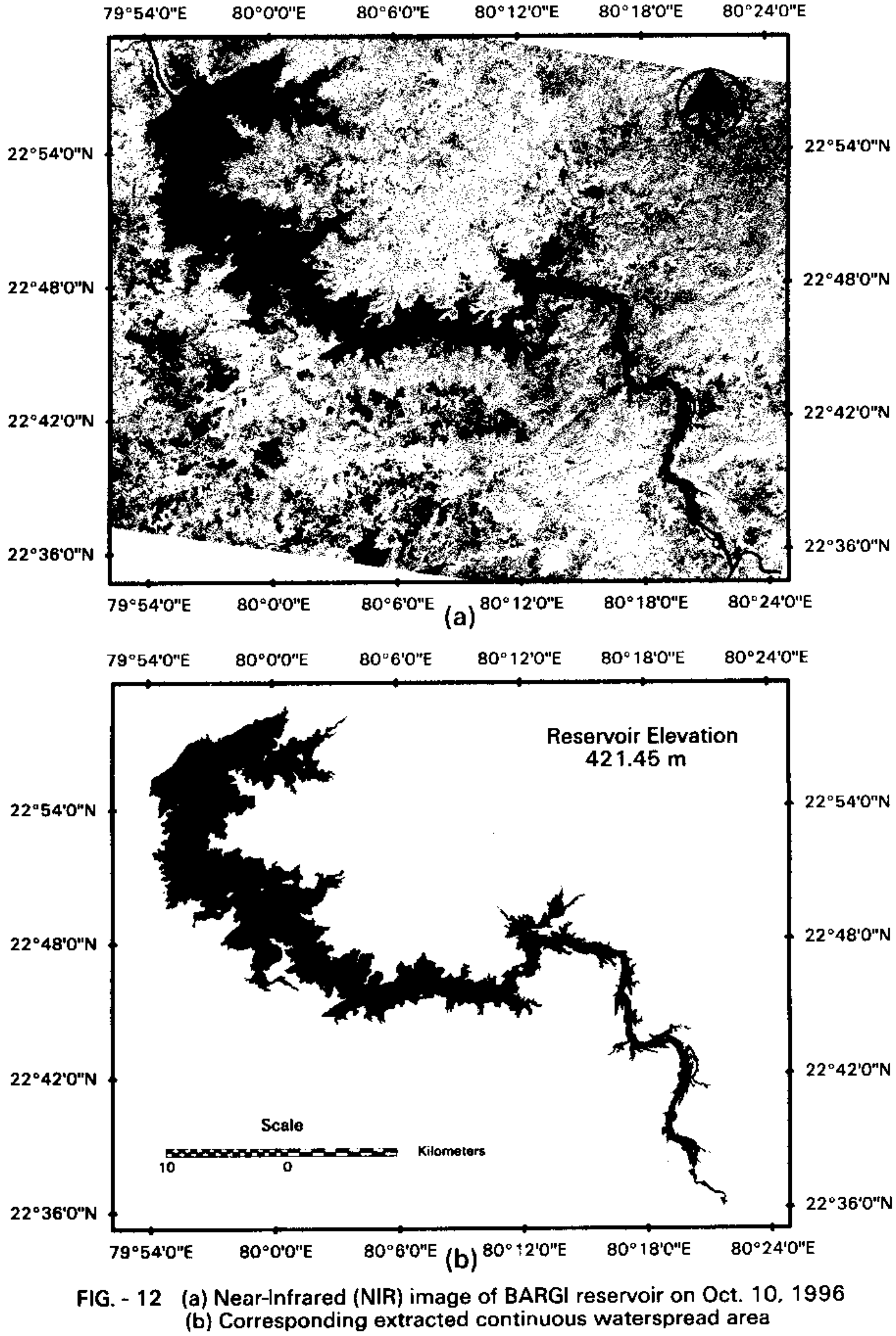


FIG. - 12 (a) Near-Infrared (NIR) image of BARGI reservoir on Oct. 10, 1996
(b) Corresponding extracted continuous waterspread area

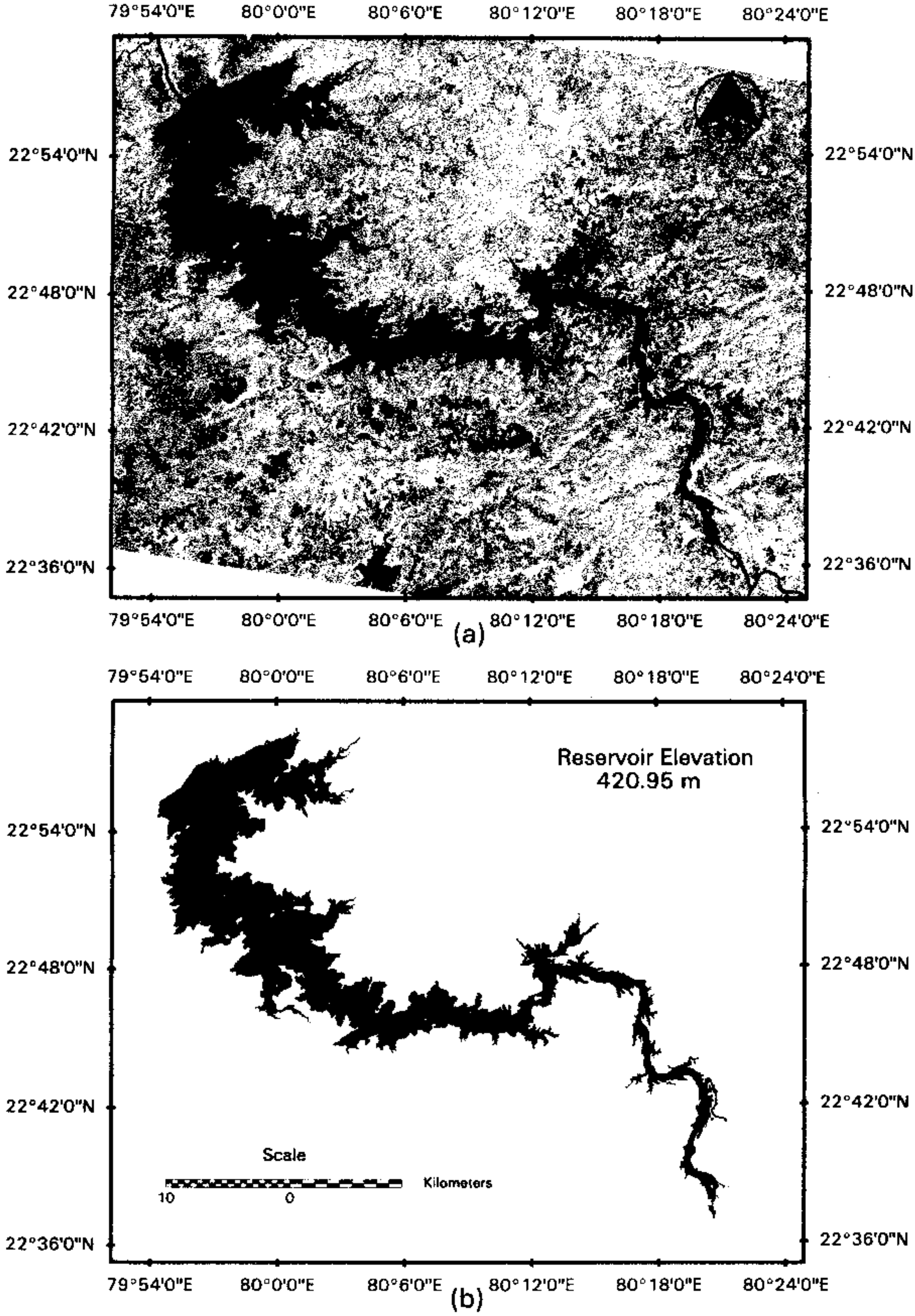


FIG. - 13 (a) NIR image of BARGI reservoir on Nov. 03, 1996
(b) Corresponding waterspread area

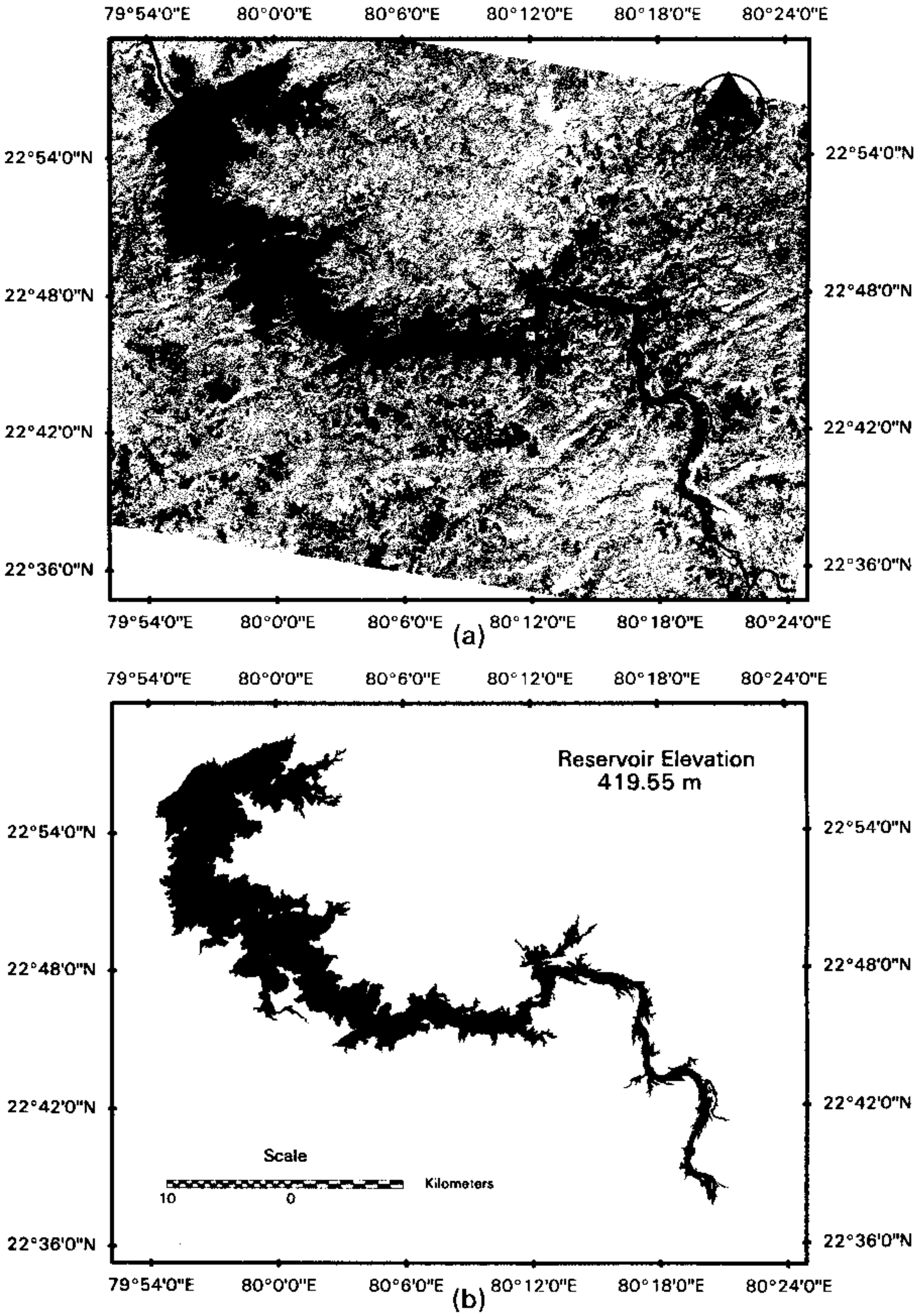


FIG. - 14 (a) NIR image of BARGI reservoir on Nov. 27, 1996
(b) Corresponding waterspread area

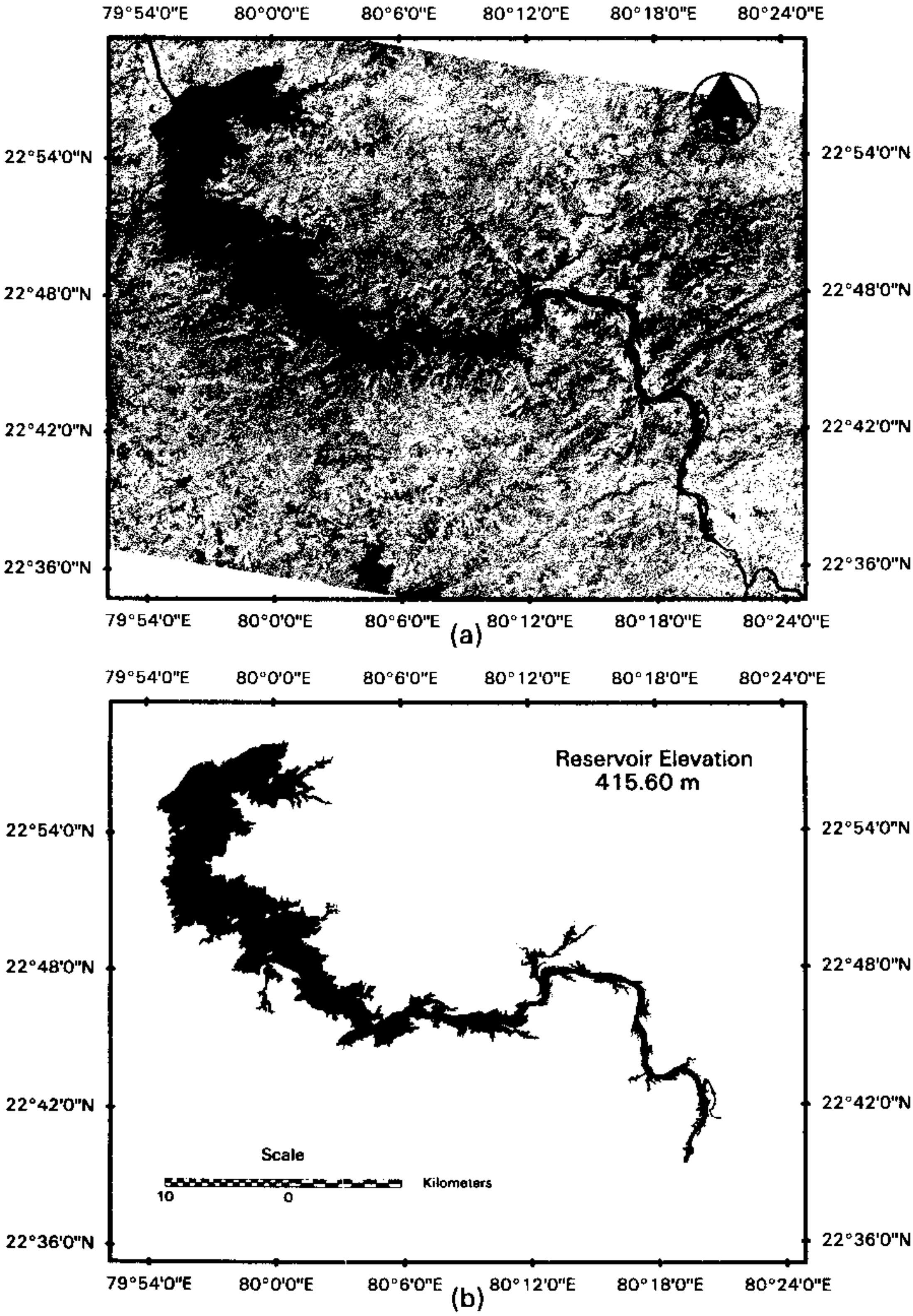


FIG. - 15 (a) NIR image of BARGI reservoir on Feb. 07, 1997
(b) Corresponding waterspread area

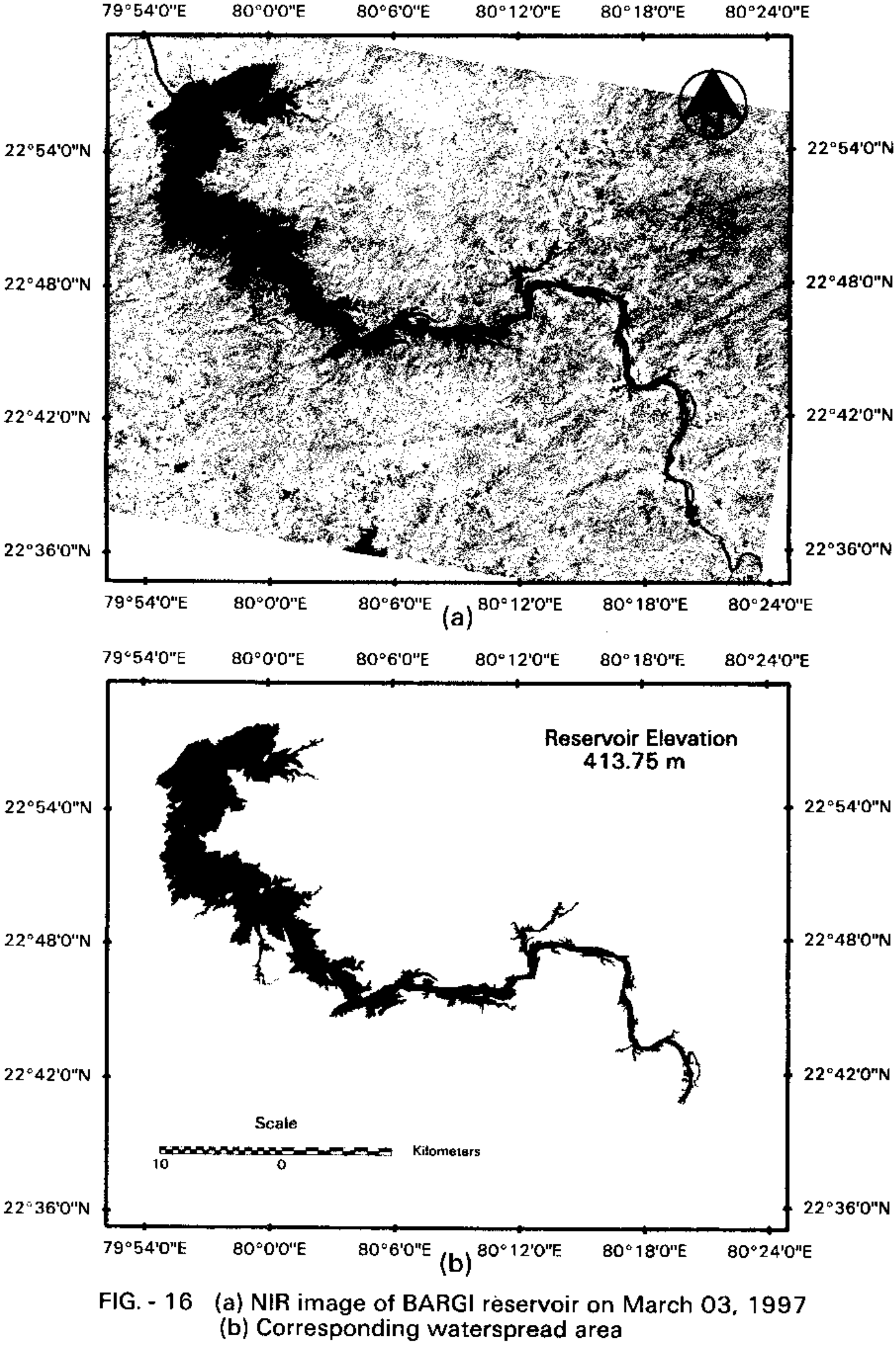


FIG. - 16 (a) NIR image of BARGI reservoir on March 03, 1997
(b) Corresponding waterspread area

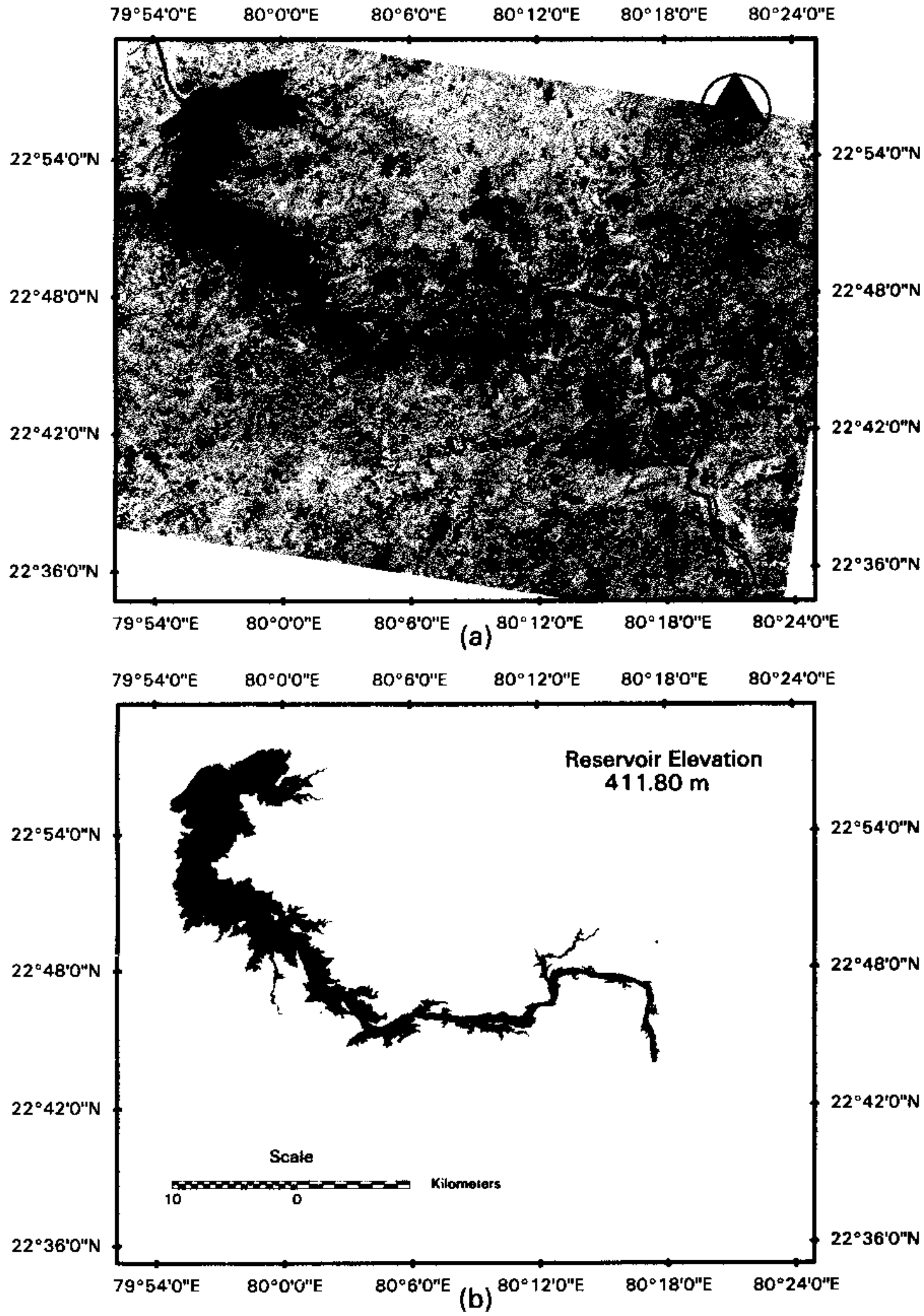


FIG. - 17 (a) NIR image of BARGI reservoir on March 27, 1997
(b) Corresponding waterspread area

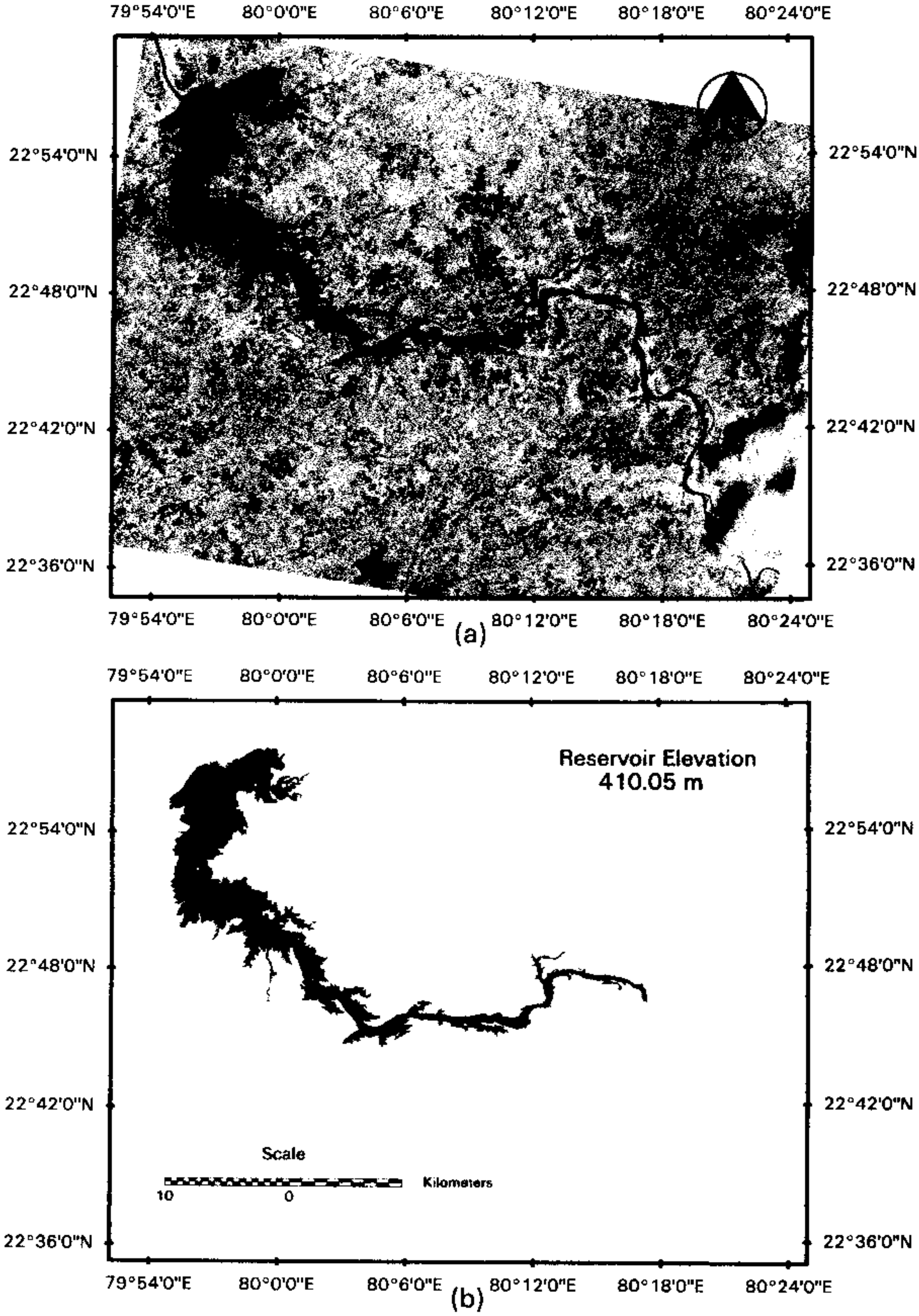


FIG. - 18 (a) NIR image of BARGI reservoir on April 20, 1997
(b) Corresponding waterspread area

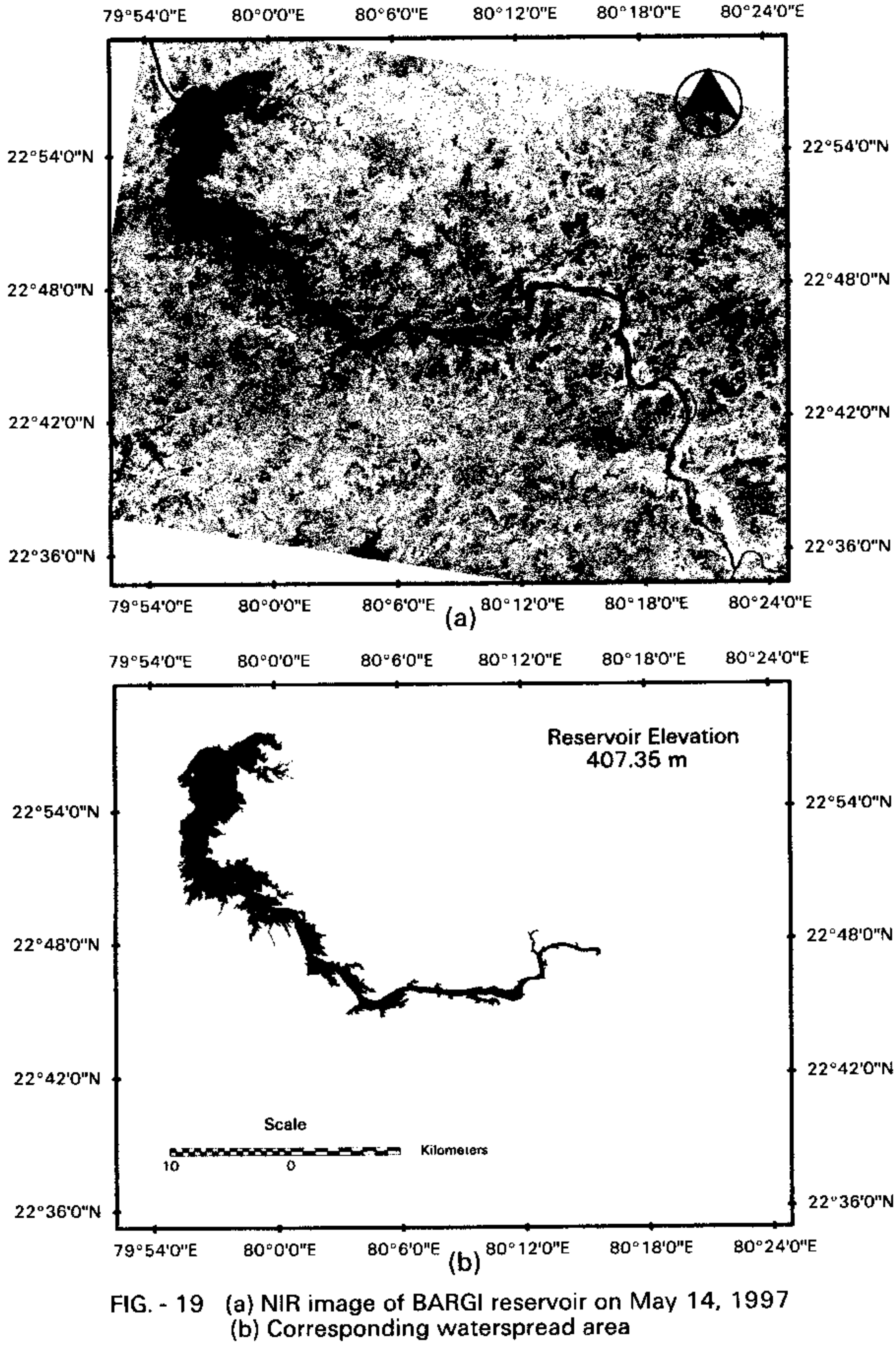


FIG. - 19 (a) NIR image of BARGI reservoir on May 14, 1997
(b) Corresponding waterspread area

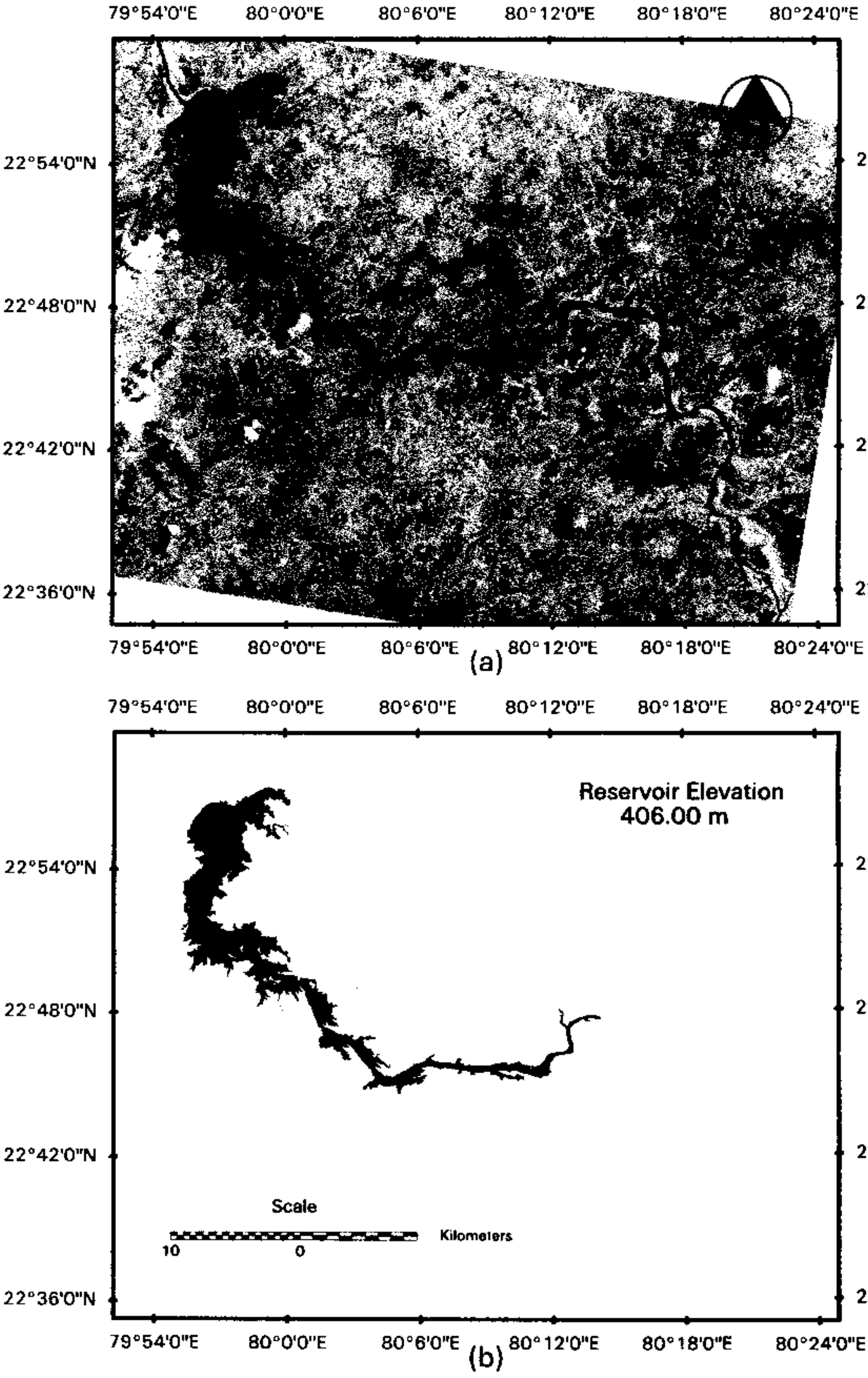


FIG. - 20 (a) NIR image of BARGI reservoir on June 07, 1997
(b) Corresponding waterspread area

Table – 2
Original Elevation-Capacity Table for BARGI Reservoir

Reservoir Elevation (m)	Total Capacity (Mm^3)
400.00	620.00
401.00	670.00
402.00	720.00
403.00	780.00
404.00	855.00
405.00	930.00
406.00	1010.00
407.00	1100.00
408.00	1190.00
409.00	1300.00
410.00	1415.00
411.00	1535.00
412.00	1660.00
413.00	1798.00
414.00	1930.00
415.00	2090.00
416.00	2280.00
417.00	2480.00
418.00	2690.00
419.00	2910.00
420.00	3190.00
421.00	3470.00
422.00	3750.00
423.00	4030.00
424.00	4310.00

Revised areas at different elevations in the reservoir (obtained from the remote sensing analysis) were calculated by multiplying the number of pixels in the waterspread area by the size of one pixel (24m x 24m). The reservoir elevations at the time of satellite pass were obtained from the reservoir authorities. Revised areas and corresponding elevations are presented in Table - 3.

Table - 3

Reservoir Elevation & Revised Area on the Date of Satellite Pass

Date of Pass	Number of Water Pixels	Reservoir Elevation (m)	Revised Area Using R.S. (M Sq. m)
10.10.96	444769	421.45	256.190
03.11.96	434779	420.95	250.430
27.11.96	412645	419.55	237.680
07.02.97	325571	415.60	187.530
03.03.97	286184	413.75	164.842
27.03.97	243760	411.80	140.405
20.04.97	207605	410.05	119.580
14.05.97	161653	407.35	093.112
07.06.97	137337	406.00	079.106

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

$$V = H\,(A_1 + A_2 + \sqrt{A_1 * A_2})/3$$

where V is the volume between two consecutive elevations 1 and 2; A_1 is the contour area at elevation 1; A_2 is the contour area at elevation 2 and H is difference between elevation 1 and 2.

It is important to mention here that the revised capacity above the highest observed level (421.45 m) and below the lowest observed level (406.00 m) can not be determined using the remote sensing data. However, if accurate results are required for the whole range of the reservoir, then hydrographic survey for the area within the lowest observed waterspread area (as obtained from 07 June, 1997 image) needs to be carried out.

From the original elevation-capacity table, the original capacity at the intermediate elevations (reservoir elevations on the dates of satellite pass) was obtained by linear interpolation. From the known 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 (406 00 m) was assumed to be the same as the original cumulative capacity (1010.00 M Cum) at this elevation at the time of construction of the dam. 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 (421.45 m). The calculations of revised capacity estimation are presented in Table - 4.

Table - 4
Calculation of Sediment Deposition in Bargi Reservoir Using Remote Sensing

Date of Satellite Pass	Reservoir Elevation (m)	Revised Area (R.S.) (Mm^2)	Original Volume (Mm^3)	Revised Volume (R.S.) (Mm^3)	Original Cumulative Volume (Mm^3)	Revised Cumulative Vol. (R.S.) (Mm^3)
10.10.96	421.45	256.190			3595.833	3568.89
			139.966	126.65		
03.11.96	420.95	250.430			3455.867	3442.24
			391.904	341.64		
27.11.96	419.55	237.680			3063.963	3100.60
			860.072	837.84		
07.02.97	415.60	187.530			2203.891	2262.76
			306.907	325.72		
03.03.97	413.75	164.842			1896.984	1937.04
			262.161	297.29		
27.03.97	411.80	140.405			1634.823	1639.75
			213.942	227.24		
20.04.97	410.05	119.580			1420.881	1412.51
			290.028	286.39		
14.05.97	407.35	093.112			1130.853	1126.12
			120.853	116.12		
07.06.97	406.00	079.106	1010.00	1010.000	1010.000	1010.000

The difference between the original and revised cumulative capacity represents the loss of capacity due to sedimentation in the zone under study. The results show that the revised capacity in the zone under consideration is 2558.89 M Cum while the original capacity as calculated and envisaged in the project before the impoundment of the dam was 2585.56 M Cum. Thus, it can be inferred that 26.67 M Cum of the capacity has been lost to sedimentation in the zone under study in a period of 8 years (1989 to 1996). The year 1988 is not considered because the impoundment of dam in that year was only up to 407 m. Thus, the rate of sedimentation in the reservoir comes out to be 3.33 M Cum per year. Since no hydrographic survey has yet been carried out for the project, it is not possible to verify the results. The plot of original and revised elevation-capacity curves is shown in Fig. - 21.

4.5 REVISED CONTOURS OF SUBMERGENCE

Initially, it was envisaged to prepare the original and revised digital elevation models of the submergence area to find the depth of deposition pattern of the sediments. However, based on the results of revised capacity, it does not seem appropriate to find the spatial sedimentation depths. Since the revised contours were developed for all the imageries individually, the same were overlaid in one image after assigning the elevation values. The revised contours of the submergence area are presented in Fig. – 22.

A comparison between the original and revised contour was also made. The original contours were digitised from 1:50,000 toposheet at a contour interval of 20 m. The original contour of 420 m elevation and the revised contour of 419.55 m are plotted in Fig. – 23. A comparison of these two shows that the contour derived from remote sensing analysis matches quite closely with the original contour. This proves that the remote sensing methodology is fairly accurate.

4.6 DISCUSSION OF RESULTS

In the present study, the revised capacity was calculated for a zone of the Bargi reservoir. Based on the availability of remote sensing data and the water level variation in the Bargi reservoir in the year 1996-97, the study was carried out for the zone of the reservoir lying in-between the elevations 406.00 m and421.45 m. The revised areas at different intermediate elevations were calculated by determining the continuous waterspread areas from the remote sensing data and multiplying the number of pixels with the size of each pixel. The revised capacity between the intermediate zones was calculated by using the trapezoidal formula. For calculating the cumulative revised capacity, the revised capacity (1010.00 M Cum) at the lowest observed level (406.00 m) was considered to be the same as the original capacity at this elevation. Based on the analysis, it was seen that about 26.67 M Cum of capacity has been lost to sedimentation in the zone of study in a period of 8 years (1989 – 1996). Since the catchment area at the dam site is 14556 Sq. km, the sedimentation rate comes out to be 0.023 ha-m/sq. km/year.

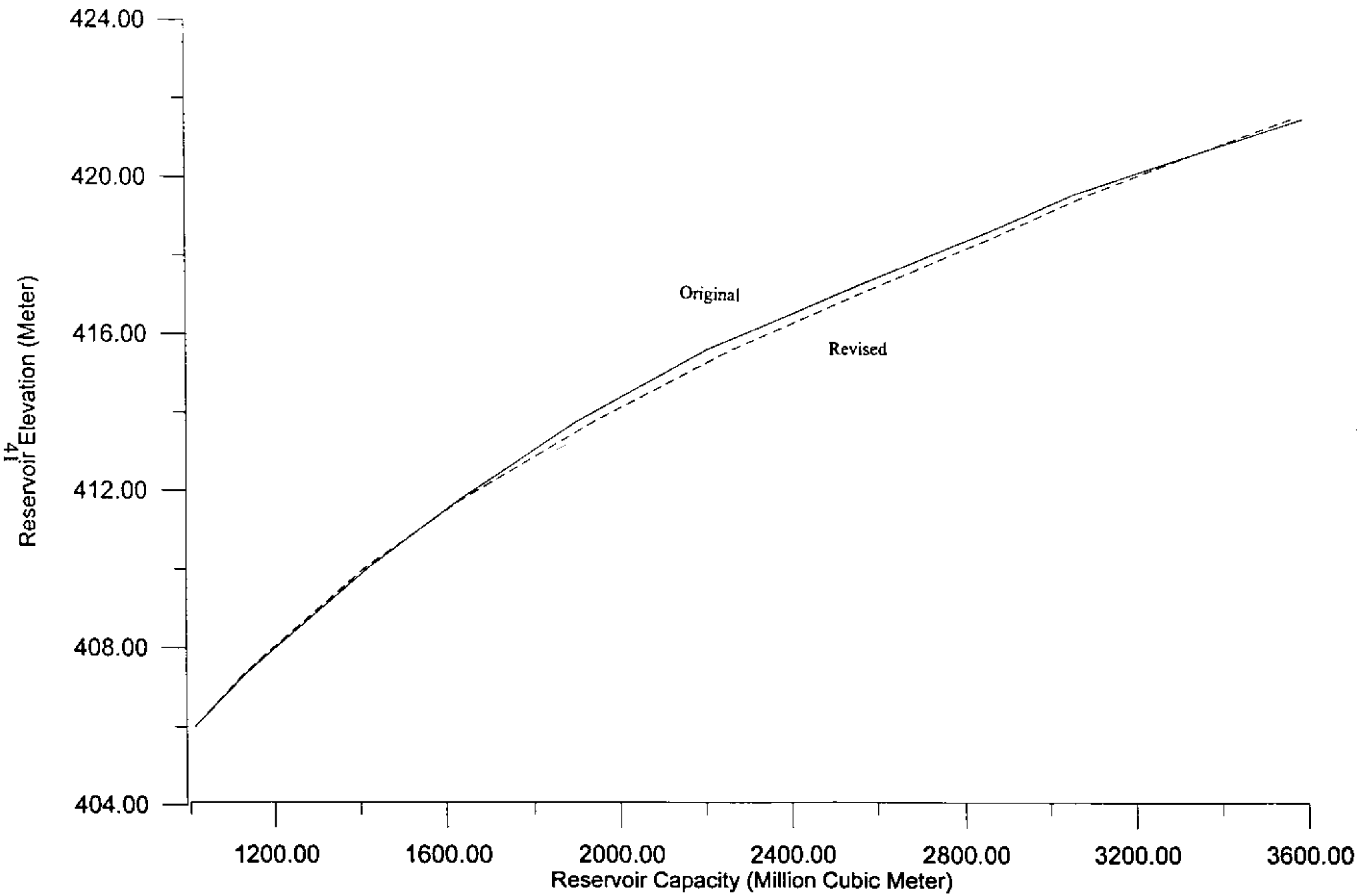


Fig. 21: Original and Revised Reservoir Elevation - Capacity curves for Bargi Reservoir

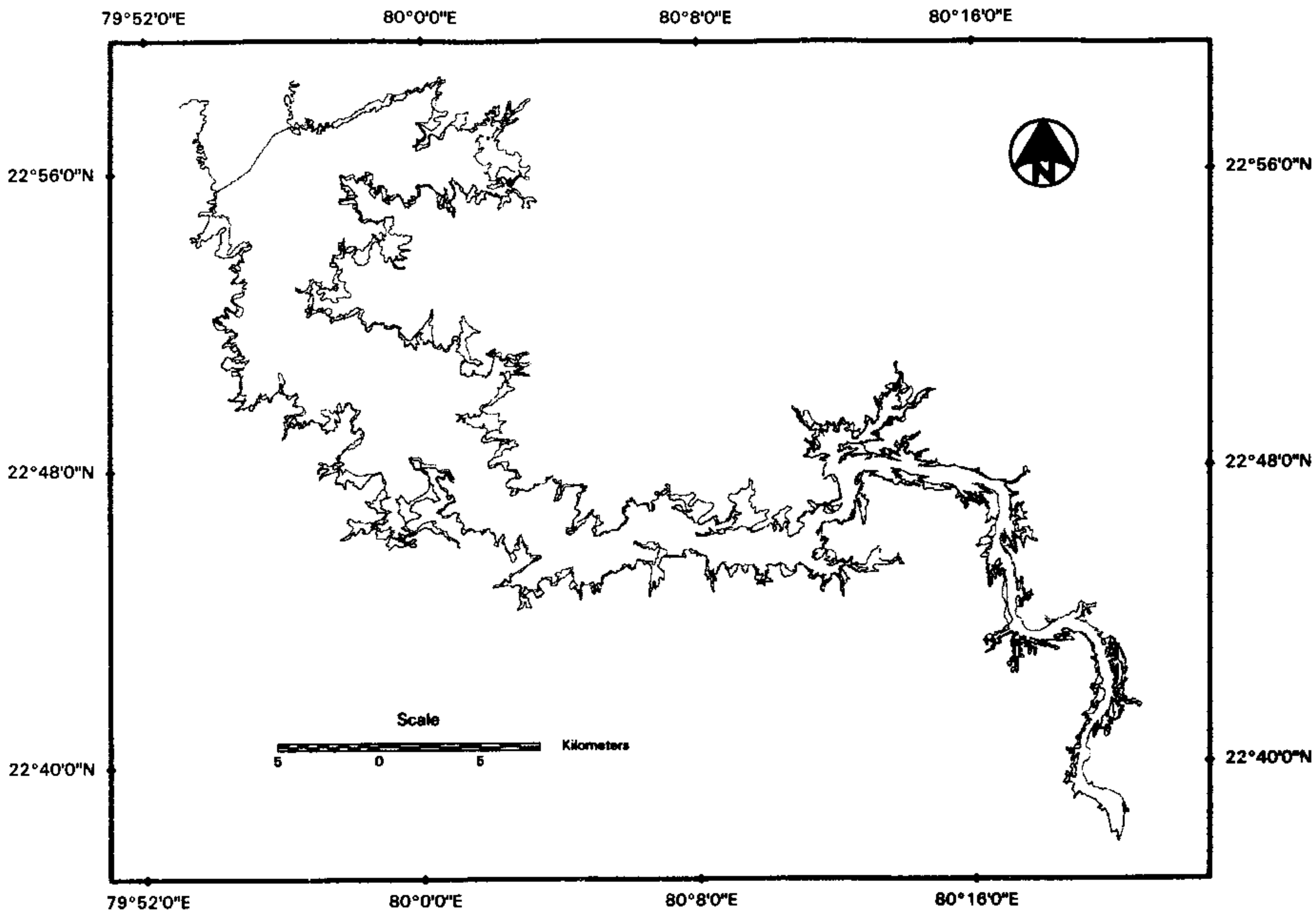


Figure - 23 Comparison of Original Contour (420.00 m) with Derived Contour (419.55 m)

The results of this study were compared with that of the sedimentation study report prepared by Central Water Commission. Based on the upstream developments, the report predicts that considering the trap efficiency of 95%, the total sediment trapped in the reservoir will be 5746.5 ha-m during the period 1989 to 1993 and 5655.0 ha-m during the period 1994 to 1999. Thus, the total sediment that will get trapped in the whole of the reservoir during the period 1989 to 1996 comes out to be 8574.0 ha-m. The results of the present study show that 2667 ha-m of sediment has deposited in the zone from 406.00 m to 421.45 m.

The height of dead storage zone of this reservoir (367.00 m to 403.55 m) is about 36.5 m while that of live storage zone (403.55 m to 422.76 m) is 19.21 m. The tail portion of the reservoir is quite significant as compared to the main body of the reservoir. Since the reduction in velocity in the tail portion of a reservoir is generally considered small, the sediment carrying capacity does not reduce appreciably resulting in the transportation of most of the sediments towards the main reservoir and their deposition at greater depths.

Further, it needs to be mentioned here that the accuracy of assessment of sedimentation depends on the accuracy of the original capacity table also, in addition to the accuracy of remote sensing analysis. The Bargi reservoir has a dendritic shape with a number of narrow but long branches jutting out at many places, in addition to the main tail. It is possible that at the time of project survey, many of these tails were not considered in the calculation of original capacity. The combined volume of all these limbs becomes quite significant.

It is seen that the estimation of sedimentation by remote sensing is highly sensitive to: accuracy in determining the waterspread area, the accuracy of water level information, and the original elevation-area-capacity table. In the present case, every effort was made to estimate the waterspread area as precisely as possible and a uniform method of analysis was adopted for all the imageries. Further, all the images were of good quality with no cloud cover effect on the reservoir area and noise pixels were also very few. The data of highest multi-spectral resolution Indian sensor, LISS - III of IRS-1C satellite, were used.

* * *

CHAPTER - 5
CONCLUSIONS

The remote sensing technique is an inexpensive and convenient to estimate the storage capacity of a reservoir. Spatial, spectral and temporal attributes of remote sensing provide invaluable synoptic and timely information about the water spread area in a reservoir at various elevations.

In the present study, the revised capacities of the Bargi reservoir were determined using the remote sensing data. Based on the annual maximum and minimum observed levels, the drawdown period of the water year 1996-97 was chosen for analysis. Remote sensing data of LISS-III sensor of IRS-1C satellite were acquired for nine different dates and the waterspread areas 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. A numerical limit of *Normalised Difference Water Index* was selected based on the comparison with the near-IR image. The resulting imageries of water pixels were compared with the standard FCC and the near-IR imagery. Corrections were applied for the 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 curve and the reservoir levels on the nine dates of satellite pass were obtained from the field authorities. Using the trapezoidal formula, the revised capacities in-between the maximum (421.45 m) and minimum (406.00 m) levels were obtained. The revised capacity came out to be 2558.89 M Cum while the original capacity in the zone under consideration, as reported in the Reservoir Operation & Maintenance Manual of the Govt. of Madhya Pradesh, was 2585.56 M Cum. Based on these results, the sedimentation rate in the zone of study comes out to be 0.023 ha-m/Sq. km/year. The total sediment deposition in the zone during the period from 1989 to 1996 comes out to be 2667 ha-m. As per the CWC report of Bargi project sedimentation, the total sedimentation in the entire reservoir for this period was estimated at 8574 ha-m. This reservoir has significant tail portion as compared to its main body. Since the velocity reduction in the tail portion is generally very small, most of the sediments reach the main body of the dam and get deposited at greater depths. No hydrographic survey has yet been carried out for this reservoir. Under these circumstances, the results obtained in this study can serve as a guide to the operating authorities for considering the actual available capacity in planning the operation of this reservoir.

From the waterspread areas obtained using remote sensing analysis, the revised contours were derived and plotted. It was initially planned to derive the original digital elevation model (DEM) from the original contours of the submerged areas, digitised from the Survey of India toposheets, and the revised DEM from the revised contours, obtained from remote sensing analysis. However, it was realised that the exercise of determining the depth of sediment deposition using original and revised DEMs require perfect registration of the original and revised DEMs, which requires original contour map at very large scale, say 1:10000 and contour interval of 1m. Such maps were not available in this case.

In the present study, the procedure for deriving the continuous waterspread areas from the remote sensing image was also automatised to a considerable extent. After the images were georeferenced to one common co-ordinate system, the water pixels were identified using a generalised algorithm. Based on the largest waterspread area, a mask was created and the water pixels lying outside the mask were eliminated. Further, the discontinuous and the diagonal pixels lying within the mask area were removed using the CLUMP analysis. The derivation of the contour boundary from the waterspread and the overlaying of contours were also performed using digital processing techniques. In all the operations, MODELER facility of the ERDAS/IMAGINE software was extensively used.

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 not 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 spread area at the lowest observed elevation can be carried out and the results can be combined.

* * *

REFERENCES

1. Bhar, A. K. (1987), "Remote sensing application to sedimentation studies", RN-45, NIH, Roorkee.
2. Central Water Commission (1988), "Water and related statistics".
3. Central water Commission (1990), "Sedimentation study of Bargi Project (M.P.)".
4. Choubey, V. K. (1992), "Quantitative assessment of sediment distribution in the Tungbhadra reservoir using satellite imagery", CS-84, NIH, Roorkee.
5. Jain, Sanjay K. and Goel, M. K. (1993), "Reservoir sedimentation using digital image processing of IRS-1 LISS-I data", Proc. of National Symposium on Remote Sensing Applications for Resource Management with Special Emphasis on N.E. Region, Guwahati, Nov. 25-27, 1993, pp. 504 - 510.
6. Garde, R. J. (1995), "Reservoir Sedimentation", State of Art report of INCOH, No. INCOH/SAR-6/95, NIH, Roorkee.
7. Goel, M. K. and Jain, Sanjay K. (1996), "Evaluation of reservoir sedimentation using multi-temporal IRS-1A LISS-II data", Asian-Pacific Remote Sensing and GIS Journal, Vol. 8, No. 2, Jan. 1996, pp. 39 - 43.
8. Goel, M. K. and Jain, Sharad K. (1998), "Reservoir sedimentation study for Ukai dam using satellite data", UM-1/97-98, NIH., Roorkee
9. Gupta, S. C. (1999), "Status paper on reservoir sedimentation assessment using remote sensing techniques", Proc. of the National workshop on Reservoir sedimentation assessment using remote sensing data, May 7 – 8, NIH, Roorkee
10. Manvalan, P., Rajegowda, G. L. and Srinivas, M. V. (1991), "Capacity evaluation of Ghatprabha reservoir using digital analysis of IRS LISS-II data", Project report no. B/003/91, RRSSC, Bangalore.
11. Manvalan, P., Rajegowda, G. L. and Srinivas, M. V. (1994), "Capacity evaluation of the Krishnarajasagar reservoir using IRS satellite data", Proceedings of the workshop on Reservoir Sedimentation held at Mysore by CBIP
12. Narmada Valley Development Authority (1992), "Reservoir operation & maintenance manual", Rani Avanti Bai Sagar Project.
13. Rao, H. S. S. and Mahabaleswara, H. (1990), "Prediction of rate of sedimentation of Tungabhadra reservoir", International Symposium on Water Erosion, Sedimentation and Resource Conservation", October 9 - 13, 1990, Dehradun.
14. Shangle, A. K. (1991), "Reservoir sedimentation status in India", Jalvigyan Sameeksha, Vol. VI, No. 1 & 2, INCOH, NIH, Roorkee.
15. Varshney, R. S. (1997), "Impact of siltation on the useful life of large reservoirs", State of Art report of INCOH, No. INCOH/SAR-11/97, NIH, Roorkee.
16. Vishwanathan, R. (1994), "Remote sensing – An advanced technique for evaluation of capacity and sedimentation in storage reservoirs", Proc. of workshop on Reservoir sedimentation, held at Mysore by C.B.I.P.

* * *

SALIENT FEATURES OF BARGI RESERVOIR

LOCATION	
	Village - Bijora
	Distt. - Jabalpur
	State - Madhya Pradesh
River	Narmada
Latitude	22°56'30" N
Longitude	79°55'30" E
Toposheet No.	55 N
HYDROLOGY	
Catchment Area	14556 sq. km
Maximum rainfall in the catchment	2311 mm
Minimum rainfall in the catchment	665 mm
Average rainfall in the catchment	1448 mm
Maximum annual yield	16.02 B Cum
Minimum annual yield	3.67 B Cum
Average annual yield	7.19 B Cum
50% dependable yield	8.07 B Cum
75% dependable yield	5.29 B Cum
90% dependable yield	4.10 B Cum
100 yr frequency flood at Jamtara	14744 cumec
1000 yr frequency flood at Jamtara	19782 cumec
Maximum designed flood	51510 cumec
Moderated flood	43000 cumec
RESERVOIR DATA	
River bed level	367.00 m
Minimum draw down level (MDDL)	403.55 m
Spillway crest level	407.50 m
Full reservoir level (FRL)	422.76 m
Maximum reservoir level (MWL)	425.70 m
Top of dam Level (TBL)	426.90 m
Sill level (L.B.C)	401.00 m
Sill level (R.B.C)	410.00 m
Minimum tail water level	369.05 m
Maximum tail water level	370.88 m
Dead storage capacity at MDDL	740 Mm^3
Gross storage capacity at crest level	1140 Mm^3
Gross storage capacity at FRL	3920 Mm^3
Gross storage capacity at MWL	4806 Mm^3
Live storage capacity at FRL	3180 Mm^3
Area of submergence at MDDL	30860 ha
Area of submergence at FRL	26797 ha

DAM DATA

Type of dam	Composite earthen & masonry
Lenght of masonry dam	827 m
Length of earthen dam	2750.51 m
Maximum height of masonry dam	69 m
Maximum height of earthen dam	29 m
Free board above FRL	4.14 m
Free board above MWL	1.20 m

SPILLWAY

Length of spillway	385.72 m
Number of gates	21 Nos.
Size of gates	13.71 m x 15.25 m
Type of gates	Radial
Top level of gates	422.76 m

OUTLETS

Length of L.B.C.	135 km
Size of L.B.C.	3 x 4 m
Maximum discharge capacity of L.B.C.	127.8 cumec
Length of R.B.C.	95.5 km
Size of R.B.C.	2.62 x 2.62 m

POWER HOUSE

Location	Right bank of Dam
Installed capacity	2 x 45 MW 2 x 7.5 MW (Proposed)
Firm power & load factor	58 MW at 60% Load factor
Head maximum	56.40 m
minimum	35.67 m
designed	47.85 m

* * *

STUDY GROUP

SCIENTISTS	:	Shri M. K. Goel Dr. S. K. Jain
SCIENTIFIC STAFF	:	Shri P. K. Agarwal
TYPING	:	Smt. Mahima Gupta