Reservoir Sedimentation Study for Ukai Dam Using Satellite Data

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ABSTRACT

India is a vast country with high spatial and temporal variability of rainfall. In order to tap the available water resources and to utilise the water in accordance with the requirements, more than 3000 river valley projects have already been constructed in this country. 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 processes going on in a reservoir, remedial measures can be undertaken well in advance and reservoir operation schedule can be planned for optimum utilization 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. Remote sensing, through its spatial, spectral and temporal attributes, can provide synoptic, repetitive and timely information regarding the revised water spread conditions in a reservoir. With the deposition of sediments in the reservoir, the waterspread 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.

In the present study, the sedimentation rate and volume has been determined in the Ukai reservoir using the remote sensing data. The post-monsoon period of the year 1993-94 was chosen for the analysis. The remote sensing data of IRS-1B satellite and LISS-II sensor was acquired for eight different dates and the revised water spread areas were extracted. The original elevation-area-capacity curves and the reservoir levels on the eight dates of pass of satellite were obtained from the dam authorities. Using the trapezoidal formula, the revised capacity in between the maximum (104.446 m) and minimum (92.196 m) observed levels was obtained. The loss of capacity (324.6 M Cum) was attributed to the sediment deposition in the zone of study of the reservoir. The results of this study have been compared with the results of hydrographic survey which was carried out in the year 1992-93.

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CHAPTER - 1
INTRODUCTION

A great amount of sediment is carried annually by the Indian rivers down to the reservoirs, lakes, estuaries, bays, and oceans. Soil is eroded due to rainfall and winds, resulting in tremendous sediment movement into water courses 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.

India is a vast country with high spatial and temporal variability of rainfall. In order to tap the available water resources and to utilise the water in accordance with the requirements, a number of river valley projects have been constructed for serving various conservation purposes, such as water supply for domestic and industrial purposes, irrigation, hydropower generation, navigation and recreation. One of the principal factors which threaten the longevity of such projects is the accumulation of sediments in the reservoirs. Sedimentation reduces the storage capacity of reservoirs and hence their ability to conserve water for various intended purposes. Sedimentation also reduces the survival of aquatic species and restricts the use of water for multiple purposes. It further increases evaporation due to increase in the exposure area of water.

In order 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 utilization of water.

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. Remote sensing, through its spatial, spectral and temporal attributes, can provide synoptic, repetitive and timely information regarding the water spread area of the reservoir. With the deposition of sediments in the reservoir, the waterspread 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.

1.1 SCOPE OF THE REPORT

In the present report, the sediment deposition pattern within a zone of the Ukai reservoir has been determined using remote sensing techniques. Remote sensing data of eight different dates (during the non-monsoon season) has been acquired for the year 1993-94. Imageries of different dates have been analysed and the revised water spread areas have been determined. Using the aerial estimate of the revised waterspread areas and the original waterspread areas at the time of construction of the dam (1972), the sediment deposition pattern in the zone of the reservoir, located in between the maximum and minimum observed levels, has been determined. The results of remote sensing analysis has been compared with that of Hydrographic survey which was conducted in the year 1992-93.

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CHAPTER - 2
SOME ASPECTS OF RESERVOIR SEDIMENTATION

2.1 RESERVOIR SEDIMENTATION - MODELLING & IMPACT

Impounding of a reservoir gives rise to basic changes in sediment regime of the river and results in deposition and scour in up- and down-stream respectively. A right approach to solve reservoir sedimentation problem has the following three components: (a) analysis of field data, (b) development of an operational policy for the reservoir and (c) setting up appropriate models. When different operation modes are adopted for a reservoir, deposition and scour may differ considerably from the results of conventional operation. In order to foresee what changes are likely to occur so that remedial measures could be taken as early as possible, a reliable prediction is needed before the decision is made.

2.2 SEDIMENT YIELD FROM DIFFERENT LANDUSES

The soil erosion and sediment yield problems are important for India primarily because of varying topographical and geological conditions, pressure of human and animal population on the land resources and because of small land holdings. This is further aggravated by improper land use and faulty land management practices being adopted in the upland watersheds. It is estimated that at present 150 million hectares (about 45% of total area of the country) of land under agriculture, forests, grass lands and other land uses is in need of soil conservation. By a comparison of the land use statistics for the year 1950-51 and those of 1978-79, it becomes evident that land use pattern is changing in a significant manner. The land use pattern is being changed at such rapid rate that there is a definite need to carry out studies of the effects of this change on erosion and subsequent sediment yield. Man's activities on or within a watershed can accelerate or decelerate erosion and can affect the operation of water control structures. Watershed may have single land use e.g. agriculture, forests, grasslands, wastelands or a combination of these. Any long term or short term changes in land use are definite to influence the hydrological process in the watershed. These influences become a great cause of concern if they affect the rich top soil or leads to soil erosion. Subsequent to erosion, the problem of sediment yield takes on a new dimension.

In India, the studies of erosion and sediment yield have mostly been concentrated on runoff plots and small watersheds. Very rarely, the studies have been directed towards large catchments. The soil loss and silt production data from various land uses and land management practices are being collected since 1950 in India from experimental plots located in various regions. The results of small plot studies can be taken to be suggestive and indicative only and can not be extrapolated to large catchments.

The various land uses which have been studied include forests, grasslands, agricultural lands, fallow lands, ravinous lands, bare lands and horticultural lands. Scientific studies have been conducted on experimental watersheds to study the effect of forests on soil loss. Decreasing trends in sediment yield have been observed in forested watersheds. A number of studies have also been carried out on small plots and small watersheds to evaluate the effects of different grass species on soil loss in various regions of India. The studies have also been concentrated on considering the effects of grazing on production of sediment. In agricultural lands, soil loss studies for various crops, soils, climatic conditions have been carried out at various places. Such studies have been carried on agricultural lands for different agronomic practices and engineering field measures, e.g., bunding, terracing etc. Experiments have also been directed towards quantifying the effect of land including fallow lands on sediment yield. Studies have also been conducted both under natural cover and treated ravines in the ravinous lands of Yamuna, Chambal, Mahi etc.

The sediment content in rivers varies from month to month, while it is negligible in the winter and summer months; it attains the maximum value in the monsoon months. The sediment load carried by some rivers is indeed very heavy. While the rivers in the Indian peninsula like the Krishna and the Godavari carry about 100 ppm., the silt carried by the Ganga often exceeds 2,000 ppm. In the Kosi, silt content is much larger, being 3,310 ppm.

The origin of all sediment coming into a reservoir lies in its watershed. It has been realised that uncontrolled deforestation, forest fires, grazing, improper method of tillage, unwise agricultural practices and various faulty land uses have accelerated soil erosion resulting in a large increase of sediment inflow into the streams. The deposition of sediment in channels or in reservoirs is a very important phenomena, however, it is also very complex and troublesome process. It creates a variety of problems such as raising of stream beds, increasing flood heights, meandering and overflow along the banks, choking of navigation channels and most important of all, depletion of capacity in storage reservoirs.

In India, the agencies involved in sedimentation studies are Central Water Commission, CWPRS, Soil and Water Conservation Division of the Ministry of Agriculture, River Valley Authorities and various state government departments. The reservoir surveys in India date back to 1870. In the post independence period after 1947, a large number of reservoirs have been surveyed. The mode of surveys is mostly both by inflow and outflow and direct capacity surveys. A reservoir sedimentation has a long range and a short range impact. It is very important to conduct systematic capacity surveys of reservoirs as a regular and continuous program. It is also important to report the sedimentation survey results in uniform format so that the results of various studies can be compared.

2.3 METHODS OF SEDIMENT YIELD RATE DETERMINATION

For the purpose of prediction of reservoir sedimentation, various approaches ranging from the empirical method to the detailed physical model can be used. The choice of prediction method depends on the objectives and it varies in different stages (planning, feasibility study, design and operation). Nowadays, with the rapid development of computer sciences, mathematical modelling has become a competent tool against other methods and in many cases, priority is given to mathematical modelling. As a matter of fact, the function of a good mathematical model is not limited to predicting changes in flow and sediment load in space and time, but it also helps to better understand the processes of deposition and scour with the accompanying changes of particle sizes of the river bed as well as the suspended load. A mathematical model can help to set up physical models when necessary and check the results of each other.

Many methods for determining the sediment yield rate are used. However, there is no best method that can, in general, be used for all the river basins. These method are briefly summarized in the following.

2.3.1 Method Using Sediment Discharge and Discharge Hydrograph

This method is applicable only when the sediment data are available. Applying the sediment-rating curve to the discharge hydrograph at a station yields thc total sediment load passing through the station for the required duration. Then, the sediment yield rate can be obtained easily by dividing the total sediment amount by the basin area and the period. It is important to have a long term sediment data because sediment load varies widely from season to season.

2.3.2 Method Using Data of the Sediment Deposition in the Nearby Reservoirs

If there is a reservoir and its sediment-deposition data are available for many years, sediment yield rate of the basin can be estimated by considering the trap efficiency of the reservoir. The sediment yield rate can be calculated easily by dividing the amount of sediment deposits, sequentially, by the reservoir basin area (km^2), the period for deposition (year), and the reservoir trap efficiency. This method is in use in many countries. However, the results of nearby basins are comparable only if the catchment properties and size and the hydro-meteorological characteristics are identical.

2.3.3 The Saemaeul Formula

This method was proposed by Korean Government during 1970's. It was derived by using the regression analysis of the relationship among the annual sediment amount, basin area, and the initial water storage of the reservoir. The formula is given as:

$$ASR = 255.4\ A^{0.1816}\ S^{0.5774}$$

where ASR is the annual mean amount of sediment deposits (m^3), A is the basin area (km^2) and S is the initial water storage of reservoir (ha-m).

The sediment yield rate is calculated by dividing S by the basin area and trap efficiency. Since it is difficult to determine the trap efficiency, the trap efficiency is usually assumed to be 100% for this formula. It can be applicable only to small basins.

2.3.4 The Yoon Formula

This method is proposed by Young Nam Yoon in Korea University at Seoul. It is similar to the Saemaeul formula and given as:

$$q_s = 1334.08\ A^{0.8}\ E_t^{6.2668}$$

$$E_t = 1 - [\ 1 / \{\ 1+2.1\ (S/A)\}\ ]$$

where q_s is the annual amount of sediment deposits (m^3), A is the basin area (km^2), E_t is the trap efficiency and S is the initial water storage of reservoir (ha-m). Using this formula, one can obtain the sediment yield rate in the similar manner as with Saemaeul formula.

2.3.5 The Tanaka Formula

This method was proposed by Tanaka in Japan. The sediment yield rate is given as:

$$Y = 4.5\ X + 150 \pm 69$$

where Y is the sediment yield rate ($m^3/km^2/year$), X is (average height) x (average height difference) /100. The average height and average height difference are determined using 16 km - grid cell on the map. It can be used only for preliminary estimation.

2.4 BRIEF REVIEW OF DEVELOPMENT OF MATHEMATICAL MODELLING

Before going further to detailed discussion, it is helpful to first have a conceptual picture of the setting up of a mathematical model. The setting up of a model can be decomposed as follows:

1. To grasp the essentials of the engineering problem in real world and logically transform it to a simplified phenomenon in physics by ignoring factors of secondary importance.
2. To idealize the phenomenon in physics and to describe it by formulating a set of

governing equations with appropriate boundary conditions and initial conditions.

3. To select proper computation techniques to solve the equations. For sedimentation problems, only numerical solution can be obtained.

Among the three steps, the first step to simplify an engineering problem to a phenomenon in physics is the most important and sometimes the most difficult one. A combination of the 1st and the 2nd step means a thorough understanding of the mechanism of the changes which are going to happen.

In mathematical modelling for sedimentation problems, the sediment transport equation can be treated in different ways. For suspended load, the sediment concentration of the flow is, in general, not always equal to the sediment carrying capacity of the flow. Usually, it is in excess or deficit to the sediment carrying capacity and deposition or scour takes place by self-adjustment. If the difference between the instantaneous sediment concentration and sediment carrying capacity is being neglected, then it belongs to the equilibrium sediment transport model. In most mathematical models developed in USA and European countries, the equilibrium sediment transport model is adopted. If the readjustment of the difference between the instantaneous sediment concentration and sediment-carrying capacity is taken into account to approach the latter, then it belongs to the non-equilibrium sediment transport model (or non saturated sediment transport). This conception is adopted in mathematical models developed by K. Ashida of Japan, L.C. Van Rijn of the Netherlands, J.A. Cunge of France and nearly all mathematical models developed in China. For coarse sediment particles, equilibrium sediment transport model can be used as well, but for very fine sediment particles, non equilibrium sediment transport model better reflects the reality.

2.5 BASIC EQUATIONS OF 1-D MODEL FOR RESERVOIR SEDIMENTATION

Basic equations of 1-D model in the simplest form can be summarized as follows:

a) Equation of continuity

$$[\partial (Uh) / \partial x] + [\partial h / \partial t] = 0$$

b) Equation of continuity for sediment load

$$[\partial (B U h S) / \partial x] + B [\partial (h s) / \partial t] = - \alpha B \omega (S - S^*)$$

c) Equation of flow motion

$$[\partial U / g \partial t] + [U \partial U / g \partial x] + [\partial (Z_0 + h) / \partial x] + [U^2 / C^2 R] = 0$$

d) Equation of sediment-carrying capacity

$$S_* = S_* (U, H, \omega, ...etc)$$

where B - river width, h - average depth of the cross section, U - average flow velocity, Z_0 - river bed elevation, S - mean sediment concentration in cross-section, S_* - sediment-carrying capacity, ω - fall velocity of sediment particle, C - Chezy's coefficient, R - hydraulic radius, and α - recovering coefficient.

2.6 HEC-6 MODEL

The HEC-6 model was developed by Thomas et. al. (1977) of the Hydrological Engineering Centre in United States. Being a representative mathematical model for reservoir sedimentation of the early time, it is an uncoupled and equilibrium sediment transport model, using finite difference method of explicit scheme. This model first calculates the backwater curve and then computes the flow velocity, water depth, sediment load etc. The model is easy to handle.

2.7 METHODS FOR COMPUTATION OF SILT VOLUME

Jayapragasam & Muthuswamy (1980) have described the methods in common use, to compute the present capacity of reservoir and thereby the silt volume, as follows:

1. Prismoidal Formula
2. Constant Factor Method
3. Contour Area Interval Method
4. Grid Method

2.7.1 Prismoidal Formula

In this method, the cross sectional areas of range lines are planimetered and these data, together with surface areas at full reservoir level between adjacent ranges, are used to compute the sediment volumes.

2.7.2 Constant Factor Method

In this method, the whole reservoir is divided into number of segments along the range lines and further into sub-segments at different levels. In this case, the constant factor "C_0" for each sub-segment is worked out as follows :-

$$C_0 = V_0 / A_0$$

Where V_0 is original capacity and A_0 is sum of original end areas for the subsegment.

2.7.3 Contour Area Interval Method

In this method, the contour map of the reservoir is first prepared and by planimetering the successive areas enclosed by the contour starting from the lowest contour, a submergence area-elevation relationship is obtained. From this relationship, the capacity between successive unit elevations is worked out arithmetically by taking the average submergence area and multiplying by the unit height. From the successive cumulative value of the capacity starting from the lowest elevation, the elevation-capacity relationship is obtained.

2.7.4 Grid Method

In the case of grid method, the whole area of waterspread is divided into a number of square grids and from the bed levels of reservoir along the range lines, the reduced levels for each grid junction point is computed. From these levels, the capacity for each grid is calculated and by summing up, the total capacity is derived. Moreover, by subtracting the reduced level of the grid junction point for the subsequent year, deposition or scour for that grid junction point is worked out and based on these junction values, silt and scour map is drawn. From this silt and scour map, the net deposition of silt can be worked out.

2.8 RATE OF LOSS OF STORAGE CAPACITY

After completion of a dam, a backwater region is formed. Sediment coming from upstream starts to deposit and the storage capacity of reservoir decreases as time passes by. In the end of the fifties, the United States made an investigation on the situation of sedimentation in 1100 reservoirs. Among these, data from 66 representative reservoirs were selected by L.G. Gottschalk as shown in Table - 1. From this table, it can be seen that the total loss of reservoir capacity in 22 years is 15.6 percent with an average loss of 0.71 percent annually. In the late seventies, another investigation showed that about 1200 million tons of sediment gets accumulated in the reservoirs in the United States each year.

Table - 2 gives the sedimentation in 20 representative reservoirs in China (Chien, Dai, 1980). It can be seen that approximately 8,060 M Cum of sediments were accumulated in the reservoirs, and 19.2 percent of the design capacity was lost, even though most of the reservoirs had been put into operation for less than 20 years. Considering the fact that the amount of material washed out from a basin is a function of erosion rate and drainage area of the basin, following empirical formula was derived (Jiang, 1980):

$$R_s = 0.0002\, G^{0.95} (F/v)^{0.8}$$

in which R_s is % average loss rate of reservoir capacity per year; G is average soil erosion from the basin in t/km^2 -year; F is drainage area in m^2 and v is reservoir capacity in m^3.

Table - 1
Reservoir Sedimentation in Different Areas in U.S.A.

Region	Number of reservoirs	Number of years	Loss of storage capacity (%)	Annual loss of storage capacity(%)
Northeast		30	24.7	0.82
Southeast	10	18.6	15.1	0.81
Middle West	11	16.5	14.0	0.85
Middle South	12		8.8	0.51
North Great Plain	9	23.1	29.6	1.28
Southwest	15	29.8	15.7	0.53
Northwest		23.1	7.0	0.30
Whole Country	66	22.1	15.6	0.71

2.9 METHODS TO PREVENT SEDIMENT FROM ENTERING A RESERVOIR

There are broadly two techniques for preventing the sediments from entering a reservoir. These are i) better watershed management for checking the soil erosion and ii) physical barriers in the way of sediment movement. These are briefly described below:

2.9.1 Reduction of Sediment Flow by Better Watershed Management

Soil conservation is effective and basic method in preventing the movement of soil particles or preventing the transport of sediment to the reservoir. A brief description of these measures are given below. Soil erosion caused by water areas can be divided into four categories, e.g. rill erosion, sheet erosion, gully erosion and slop disintegration. Measures for controlling soil erosion are vegetative measures and engineering measures.

2.9.1.1 Vegetative Measures

a) *Forests for Erosion Control*

The characteristics of soil and water conservation forests should possess the characteristics of large area of coverage, multi-levels and high density. Rainfall is slowed down by the tree canopy and it drops down slowly. The trees selected should be able to grow under conditions of drought, thin top soil, strong wind, cold and hot weather, and even scouring by water. They should be fast growing. Their root system should be highly developed to consolidate the soil. Their fallen leaves can be used as forage, fertilizer and fuel. It is desirable that the trees are fruit-bearing, especially when the fruits may substitute for staple food or when the seeds are oil-bearing.

Table - 2
Sedimentation in Some Reservoirs in China

S. No	Reservoir	River	Drainage area (km^2)	Height of dam (m)	Design Capacity (MCum)	Years Surveyed	Total Sediments (M Cum)	%Capacity lost to Sediments
1	Liujiaxia	Yellow	181,700	147	5,720	1968-78	580	10.1
2	Yanguoxia	Yellow	182,800	57	220	1961-78	160	72.7
3	Bapanxia	Yellow	204,700	43	49	1975-77	18	35.7
4	Qingtongxia	Yellow	285,000	42.7	620	1966-77	485	78.2
5	Sanshengong	Yellow	314,000	N A	80	1961-77	40	50
6	Tiangiao	Yellow	388,000	42	68	1976-78	7.5	11
7	Sanmenxia	Yellow	688,421	106	9,640	1960-78	3,760*	39
8	Bajiazui	Pu	3,522	74	525	1960-78	194	37
9	Fengjiashan	Qian	3,232	73	389	1974-78	23	5.9
10	Heisonglin	Yeyu	370	45.5	8.6	1961-77	3.4	39
11	Fenhe	Fen	5,268	60	700	1959-77	260	37.1
12	Guanting	Yongding	47,600	45	2,270	1953-77	552	24.3
13	Hongshan	Xiliao	24,486	31	2,560	1960-77	475	18.5
14	Naodehai	Laoha	4,501	41.5	196	1942	38	19.5
15	Yeyuqn	Mi	786	23.7	168	1959-72	12	7.2
16	Gangnan	Hutuo	15,900	63	1,558	1960-76	235	15.1
17	Gongzui	Dadu	76,400	88	351	1967-78	133	38
18	Sikou	Bailong	27,600	101	521	1976-78	28	5.4
19	Danjiangkou	Han	95,217	110	16,050	1968-79	879	5.6
20	Xinqiao	Hongliu	1,327	47	200	14 Years	156	

***At water level of 335 m.**

b) Land Preparation

The common methods for land preparation are level terraces, level ditches, and fish-scale pits. Level terraces are built along contours by balanced cutting and filling. The exterior edge of the terrace should be higher than the interior edge by 9-18 cm. Width of terrace is 0.6 - 1.2 m, height of terrace is 1.2 - 1.8 m. During construction, mellow soil should be backfilled in the centre of the step, where trees are to be planted.

Level ditches are suitable to sloping land flatter than 35%. In North China, the top width, bottom width and depth of level ditches are all about 30 cm, in general. For ditches in stormy region, the size may be larger. Length of ditch varies with topography. For complicated topography, short ditches are preferable. The spacing between ditches is 1.5 - 3.0 m.

"Fish-scale" pits are suitable to scrappy, steep slope, rocky or thin top soil layer mountainous regions. The pits should be staggered so that surface runoff can be better intercepted. The size of pit depends on the topography. In general, it is 0.6 - 1.2 m long, 0.5 - 1.0 m wide and 0.2 - 0.3 m deep.

c) Wood Plants

Woody plants can be divided into shrubs and arbors. In arid soil eroded areas, highly resistant shrubs are usually planted. In humid areas, arbors are usually planted. For the planting of soil and water conservation forests in China, arbors, shrubs, coniferous trees and broadleaf trees are mixed so as to increase degree of covering.

d) Highly Resistant Grasses

Grass is an important component in vegetative measures for soil and water conservation. It is fast growing with shorter return period. Grasses are planted for soil and water conservation, for soil amelioration as well as for the supply of forage and fuel. Grass seeds should be highly resistant to adverse natural conditions. Land preparation is necessary before seeding of grass, and some manure and fertilizer are applied. Before sowing, germination tests should be carried out to determine the amount of seeds to be sown. The required thickness of covering depends on the size of seeds.

e) Vine Plants

In humid tropical areas, it is very important to plant vines in regions subject to soil erosion. The mixed planting of arbors, shrubs, grasses and vines will be more effective in soil and water conservation.

f) Closing-off Hillsides to Facilitate Afforestation

Additional plantation of arbors and shrubs before closing-of hillsides will be very effective. Closing-off is feasible only when the requirements of fuel and pasturing by the farmers are fully considered and satisfied. Planning of closing-off in rotation should be worked out and implemented in stages.

2.9.1.2 Engineering Measures

They include slope surface engineering works, gully engineering works, and works for controlling slope disintegration.

a) *Slope Surface Engineering Works*

Terracing is an important measure to raise grain yield, to prevent soil erosion, to preserve soil fertility and to maintain long-term stable production. There are three kinds of terraces: a) Bench terraced farmlands; b) sloping terraced farmland; c) Combination level terraced farmlands and natural slope land.

Bench terraced is the basic type of farmlands in mountainous. A bench terrace with its level platform and projection or ridged rim may hold rain water for irrigation. In very rainy area, drainage system should be provided. In long terraces, on-farm roads should be built to facilitate cultivation and transportation. Under sloping or retention terraced farmlands, only riser dikes are built and no land levelling is made. The land surface will be flattened gradually by deep ploughing over the years. The spacing between riser dikes varies with the natural slope. In parallel with the siltation of the sloping terraces the riser dikes are made higher. The sloping terrace is less effective than the bench terrace both in soil and water conservation. It is mostly adopted in regions where more land per capita is available.

b) Gully Engineering Works

Gully engineering works include check dams and sediment-trapping dams. Check Dams are small dams, generally lower than 5 m built across creeks or gullies. Their uses are to retain silt, to fix gully bed, to raise erosion datum, to stop downward cutting of gully bed and to prevent slope disintegration. Sediment- trapping dam is an important engineering work for farmland construction. The dam is usually 5 to 10 m high or even higher. In a small watershed, overall planning is necessary for a system of sediment-trapping dams consisting of main dams and auxiliary dams.

c) *Works for Controlling Slope Disintegration*

Slope disintegration is a special type of gully erosion which is noticed mostly in hill slopes with very thick crust of weathered granite. Its occurrence is due to the joint action of gravitational erosion and water erosion and is very harmful to the lives and properties of the rural people. It may happen individually or in group together. A group of slope disintegrations can cover an area as large as 25 sq km.

2.9.2 Trapping and Retention of Sediment by a Vegetative Screen

A vegetative screen is most effective in preventing the sediment from entering the reservoir or lake. Such screens, whether artificial or naural at the head of the reservoir, serve to diffuse the incoming flow, reduce its velocity and cause the sediment to deposit.

Thus, a great amount of incoming sediment can be trapped at the head of the reservoir and prevented from penetrating farther into the basin.

2.10 METHOD TO RELEASE MUDDY WATER OUT OF THE RESERVOIR

The purpose of regulating the flow by a reservoir during the flood season is to release as much sediment as possible from the reservoir by making use of the silt carrying capacity of the flood. Generally, the regulation of flow is achieved by lowering the water level during the flood season by operating the deep or bottom outlets under controlled (partial opening) or uncontrolled conditions.

During the period of rising water level of a flood in detention reservoir, the outflow silt discharge is always smaller than that of the inflow, as a result of the backwater effect, and the consequent decrease in the velocity of the flood waters. Subsequently, during the lowering of the water level at the dam in the absence of a backwater effect, the outflow silt discharge is often greater than the inflow, due to erosion occurring in the reservoir.

2.11 RECOVERY OF STORAGE CAPACITY

Various methods of recovering the storage capacity of a reservoir are briefly described in the following:

a) Drawdown Flushing

Drawing down the water level in a reservoir, for the sake of reducing the amount of sedimentation or to induce erosion of the deposited sediment to recover storage capacity, is a method often used in reservoirs, especially those of hydropower stations. The efficiency of sediment flushing depends on the topographic position of the reservoir, the capacity of the outlet, the outlet elevation, and the characteristics of the inflowing sediment discharge etc.

b) Emptying and Flushing of Deposited Sediment

Reservoir emptying operations may be used periodically for small reservoirs where storage capacity could not be maintained for beneficial use after a period of several years of operation. Since a great part of the useful storage capacity in a small reservoir is located near the dam site, the sediment deposits may be removed by flood flow if the outlet gates are left open for a period of time. The channel thus scoured in the deposits, becomes a part of the storage capacity.

Emptying and flushing operations may be used in reservoirs where a balance between deposition and erosion cannot be obtained by flushing sediment during the flood period and storing clearer water during the non-flood seasons.

c) Dredging

Generally speaking, dredging is an expensive means of restoring the storage capacity of a reservoir unless the deposits removed can be used for the beneficial purposes. Some coarse sediments dredged may be used as construction material. To remove sediments from the reservoir, dredging is undertaken in the following circumstances:

(i) Flushing is not successful,
(ii) Building of a bypass is impossible,
(iii) Drawdown of the pool level for flushing is not allowed for the sake of saving water,
(iv) Dam is irreplaceable with no possibility of further raising the dam height, or
(v) The energy consumed in flushing by lowering pool level or emptying the reservoir is uneconomic for reducing rate of silting in the reservoir.

d) Siphoning

Siphon dredging used for desilting reservoirs differs from ordinary suction. Dredging in done exploiting the hydraulic head difference between the upstream and downstream levels of the dam as the source of power for the suction dredging.

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CHAPTER - 3
ASSESSMENT OF RESERVOIR SEDIMENTATION USING REMOTE SENSING

Most common conventional techniques for sedimentation quantification are: a) direct measurement of sediment deposition by hydrographic surveys, and b) indirect measurement by inflow - outflow method. Both these methods are laborious, time consuming and costly and have their own limitations. Sampling and measurement of suspended sediments is a tedious and expensive program for either in-situ or laboratory work.

With the introduction of remote sensing techniques in the recent past, it has become convenient and far less expensive to quantify sedimentation in a reservoir and to assess its distribution and deposition pattern. Remote sensing techniques, offering data acquisition over a long time period and broad spectral range, are superior to conventional methods for data acquisition. 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.

3.1 SEDIMENTATION ASSESSMENT USING REMOTE SENSING

Multitemporal satellite data are extremely useful in determining sedimentation rate in a reservoir. 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. 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.

3.1.1 Methodology

In India, more than 80 % of the annual rainfall is received during the four monsoon months from June to September. Hence, depending on the amount of rainfall in a monsoon, 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 the 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. Revised contour areas, after the deposition of sediments, can be taken as the continuous waterspread area of the reservoir having elevation as 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 date of imagery and 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 or prismoidal 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. Hence, the volume of reservoir below the lowest observed level is assumed to be the same before and after the sedimentation. 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 particular zone of the reservoir. However, if accurate results are required, then the hydrographic survey for the area within the lowest observed waterspread area can be carried out. It is also important to emphasize here that for the purpose of optimum and judicious operation of the reservoir, the zone of interest of sedimentation analysis is only the live storage of the reservoir. Since, the reservoir hardly goes below the minimum drawdown level, the interest mainly lies in knowing the loss of capacity and the pattern of sediment deposition within the live storage.

3.1.2 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-infrared 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 (Band 1, 2 and 3) 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 must be inspected as a submerged surface will not be detected in this portion because of lack of transmittance. At near-infrared wavelengths, water apparently act 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.

However, the reflectance from the wet land, along the periphery of the waterspread area, may be quite similar to the reflectance from the adjacent shallow water. For differentiating 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.

3.2 REVIEW OF STUDIES ON RESERVOIR SEDIMENTATION

Garde and Kothyari (1987) studied sediment yield estimation. In the study, average erosion rates for large river catchments have been calculated and are presented in Table - 3. Average erosion rates for river catchments in other countries are shown in Table - 4.

Choubey (1992) studied the suspended sediments distribution in Tungbhadra reservoir. Data used were Landsat black and white imageries for January, April, and May. Visual interpretation technique was used. Reservoir water spread was delineated using Band 4 imageries. The suspended sediment pattern was delineated using Band 1 and 2 for January and May data. In January imageries, four levels were delineated qualitatively. These were very high, high, moderate, and low. In May imageries, three levels, namely, high, moderate and low were delineated. The suspended sediment concentration classes were found respectively very high, high, moderate and low from reservoir tail to its head.

Suspended sediment concentration was studied in Tawa reservoir using the satellite data and synchronous collection of field data (Choubey and Subramanian, 1992). IRS-1A LISS-I satellite data were used for September and October. Suspended sediment samples were

Table - 3
Average Erosion Rates for Large River Catchments in India

River	No. of points at which erosion rates were considered	Catchment area in 10^{-2} M km^2	Erosion rate T/km^2-yr estimated by Garde and Kothyari
Indus	4	32.13	1942.5
Ganga	23	86.15	1969.0
Brahmaputra	5	18.71	1891.0
Sabarmati	7	2.17	1277.0
Mahi	3	3.76	820.0
Narmada	10	9.88	906.0
Tapi	10	6.69	935.0
Luni	1	0.001	250.0
Mahanadi	11	14.16	1287.0
Godavari	10	31.28	954.0
Krishna	7	25.0	1191.0
Cauvery	5	8.79	1214.0

collected from 44 locations on the day of satellite overpass from 6 AM to 7 PM. Suspended sediment concentration (SSC) was determined from all sediment samples. For selected samples, mineralogical composition was determined. It was found that SSC is high in the Denwa river segment and the main body of the reservoir. SSC decreases from reservoir tail end to its head. SSC varies between 10 to 50 ppm. DN at sample locations were averaged in windows of size 3 x 3. Visible bands were highly correlated with (SSC). Band 3 had maximum variation in DN. Multiple linear regression was also fitted using several combinations of bands for October data. The best combination has two variables, namely, sum DN from Bands 1, 2 and 3 and sum of DN from Bands 1 and 3. The relationship was validated using the September data. This had overestimated SSC. It was attributed to atmospheric effect and the higher solar elevation.

Suspended sediment levels were qualitatively delineated on IRS LISS-I digital data for the Tungbhadra reservoir (Jain et. al, 1993). The data used were for the months of October, December and March. Band 1 DN values were taken as one slice to represent a concentration level of suspended sediment. Water spread area of the reservoir was delineated using Band 4 DN from 0 to 20.

Table - 4
Average Erosion Rates for Catchments in Some Countries

River	Country	Catchment Area in 10^3 km^2	Erosion Rate Tonnes/km^2-yr
Yellow	China	673.6	2480.0
Yangtze	China	1943.0	540.0
Daling	China	23.2	1490.0
Ching	China	57.0	7913.0
Haihe	China	50.8	1944.0
Lo	China	25.9	7797.2
Mississippi	U.S.A.	3222.8	108.1
Missouri	U.S.A.	1370.5	'173.7
Colorado	U.S.A.	637.3	416.9
Amazan	Brazil	5777.0	65.62
Irrawadi	Burma	430.0	903.2
Mekong	Thailand	62.2	478.6
Red	Vietnam	119.2	1192.7
Nile	Egypt	2979.3	38.6

Raju et. al (1993) carried out the field radiometric and satellite data analysis for Upper lake, Bhopal. Satellite data used were of TM sensor for the month of February. Synchronous collection of field data was completed starting two days prior to satellite overpass date. The field data were collected before noon in all days. Field radiometric data showed high correlation with total suspended sediments (TSS). TSS was in the range from 38 to 110 ppm. Only one reading of TSS was for 110 ppm. Other reading were between 38 to 70 ppm. Thus, the range of TSS was small for this study. A regression equation was fitted between radiometric Bands 1 and 2 and TSS. TSS was an independent variable in the equation. The correlation coefficient and error of estimate were respectively 0.8843 and 5.8 ppm. There was no correlation between satellite data and TSS. Satellite data were also classified into five classes using supervised method for TSS concentrations. The merging of classes was observed in the map.

Bathymetric study in Hooghly river was performed by Vinod Kumar et al. (1997) using IRS LISS-II digital data of January. At this time of the year, sediment load was less in the river. The river is fed from Farrakka barrage. The depth mapped was up to 10 m. Tidal height was 1.22 m. DN values for water were in the range from 13 to 21. Sand bar had DN values 22 and 23.

George (1997) studied the lake bathymetry using airborne hyperspectral data. Data were collected in November over a turbid mesotrophic lake. The lake was clear during the data collection. The chlorophyll content was 3 μg/l. DN was converted to radiance using a spectral radiance unit (SRU) of 3.0 μ wcm^{-2} $sr^{-1}nm^{-1}$.

$$\text{Radiance} = \text{DN} * \text{SRU}/255$$

It was concluded that for this lake, shorter wave lengths, e.g. blue electromagnetic radiations, were not suitable for bathymetric mapping. Differences in shallow and deep water radiances were maximum in infrared wavelengths. A dimensionless depth reflectance parameter (VR) was computed as:

$$VR = 255 * (V_s)^2/(V_d)^2$$

where

V_S is the radiance for shallow depths and

V_d is the radiance for deep water at 746 to 759 nm. The VR varies between 0 to 300 for depths 0 to 25 m.

* * *

CHAPTER - 4
STUDY AREA - THE UKAI PROJECT

4.1 GENERAL

The Ukai is the largest multipurpose project so far completed in Gujarat state. The Ukai dam is located across river Tapi near village Ukai of Fort-Songadh taluka in district Surat in Gujarat state. It is located between longitudes 73°32'25" to 78°36'30"E and latitudes 20°5'0" to 22°52'30"N. The dam is located at about 29 km upstream of the Kakrapar weir. The total catchment area of the Ukai reservoir is 62,225 sq. km which lies in the Deccan plateau. The catchment of the dam covers the large areas of 12 districts of Maharashtra, Madhya Pradesh & Gujarat. The districts that lie in the catchment include Betul, Hoshangabad, Khandwa and Khargaon of Madhya Pradesh; Akola, Amravati, Buldhana, Dhule, Jalgaon and Nasik of Maharastra and Bharuch and Surat of Gujarat state. The catchment area falls in the Survey of India topographical maps 46 G,H, K, L, O, P and 55 C, D, G, N and K. The salient features of the Ukai reservoir are given in Appendix-I.

The dam comprises of a 4927 m long earth cum masonry dam across the river Tapi. The reservoir impounds a live storage capacity of 0.71 Million Hectare meter at F.R.L. 105.156 m. The earth dam is 80.77 meter high above the lowest foundation level, while the masonry dam is 68.68 meter high above the lowest foundation. The storage extends irrigation facilities to an area of 3,76,000 acres under the Ukai left bank canal and Ukai right bank canal system besides firming up irrigation in area of 5,62,250 acres under the command of pick up weir at Kakrapar. Thus, the total irrigation facilities provided are for 9,38,250 acres under Ukai and Kakrapar. The hydropower house is constructed at the foot of the dam consisting of four units of 75 MW each. In addition to the irrigation benefits, an average of 190 MW of hydropower is being generated at present. The power generation utilise about 368 cumecs of water. The dam provides partial flood control for the downstream areas including the Surat city.

The Ukai headworks were completed in a construction period of seven years, ending in the year 1972. There are 22 nos. of radial gates of 15.545 x 14.783 m size each. The length of the spillway is 425.195 m. The area under submergence due to the construction of reservoir is 1,48,584 acres, out which 75,000 acres is agricultural land, 55,000 acres is forest land and the remaining 18,584 acres is wasteland.

4.2 CATCHMENT CHARACTERISTICS

4.2.1 Physiography and Slope

The catchment is bounded on the north by the Satpura range, on the east by the Mahadeo hills, on the south by the Ajanta range and the Satmala hills and on the West by the alluvial plains. The catchment has an elongated shape with a maximum length of approx. 650 km from east to west and a maximum width of approx. 200 km from north to south.

Physiographically, the area is a basaltic landscape with major physiographic units of plateau lands, escarpments, hills, dykes, piedmont plains, colluvio-alluvial plains and valley plains.

4.2.2 Drainage

The Tapi, originating at Multai, district Betul in Gawaligarh hill ranges of the Satpura mountains in Madhya Pradesh, is the principal river draining the area. The river is about 634 km long and flows generally east to west through Madhya Pradesh, Maharashtra and Gujarat states. The length of river in Madhya Pradesh, Maharashtra and Gujarat is 208, 323 and 103 km respectively. Major perennial tributaries viz.,the Buray, the Vaghur, the Purna, the Bori, the Gomai, the Aner, the Panjhra, the Girna, the Arunavati etc. emanate from the hill ranges on the north and south of the river Tapi and join the main stream. The drainage density is moderate to high. Broadly speaking, the pattern is dendritic with a sub-parallel system existing adjacent to stream courses, particularly in the alluvial belt.

4.2.3 Climate

The climate of the area is subtropical monsoonic, characterized by mild winter, hot summer and short monsoon. There are striking variations in rainfall from east to west. Temperature differences are associated with relief features. The annual rainfall in the area is around 840 mm while the average annual temperature is 27.2 °C.

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CHAPTER - 5
INTERPRETATION AND ANALYSIS

To determine the useful life of the 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. For this reason, systematic capacity surveys of a reservoir should be conducted periodically.

The conventional techniques of sediment quantification in a reservoir are cumbersome, costly and time consuming. Using the remote sensing techniques, it has become very cheap and convenient to quantify the sedimentation in a reservoir and to assess its distribution and deposition pattern. 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, very easy to use and it takes little time in analysis as compared to conventional methods.

5.1 SELECTION OF APPROPRIATE PERIOD FOR ANALYSIS

This is the first and an important step in carrying out the analysis for 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, it can not be used to quantify the amount of sediment deposited 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 dam authorities. It is presented in Table - 5. In the year 1993, maximum level at 104.775 m (343.75 ft) was observed on 5.10.93. The reservoir level fell gradually till the minimum level of 85.033 m (278.98 ft) was observed on 6.7.94. Thus, the period (5 October, 1993 to 6 July, 1994) was selected for this study.

5.2 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 [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 for differentiating the water pixels from the peripheral wet land pixels. It is also desirable to use the data of higher resolution for obtaining accurate results. However, the use of PAN sensor data was not usable because it lacked spectral information. IRS-1C satellite was launched in the year 1995. Though the LANDSAT and SPOT satellites were having better resolution than IRS satellites, the difference is only marginal while the cost of their data is comparatively very high. Considering all the aspects involved and the availability of Indian satellite data at a reasonably higher resolution (36.25 m), it was decided to use the data of LISS-II sensor of IRS - 1B satellite. This multispectral 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 A1 quadrant of Path 30 and Row 53 of the satellite.

5.3 AVAILABILITY OF REMOTE SENSING DATA

The National Remote Sensing Agency (NRSA), Hyderabad, was contacted for enquiring about the availability of the remote sensing data for the period selected above. The satellite passed 13 times over the reservoir during the period of interest and dates of pass and the status of remote sensing data is presented in Table - 6.

Table - 5
Annual Maximum and Minimum Water Levels in Ukai Reservoir (1973 - 1997)

Year	Min. Drawdown Level (m)	Date of Min. Drawdown Level	Maximum Level Attained (m)	Date of Maximum Level
1972	96.149	20.09.72	-	-
1973	86.472	01.07.73	102.352	24.09.73
1974	97.064	05.07.74	102.169	15.08.74
1975	84.521	20.06.75	105.186	28.09.75
1976	89.565	05.06.76	104.821	27.09.76
1977	86.789	15.06.77	105.086	08.10.77
1978	83.241	15.06.78	104.190	31.08.78
1979	81.778	25.06.79	103.745	02.10.79
1980	84.850	06.06.80	100.581	24.09.80
1981	82.262	25.06.81	105.229	04.10.81
1982	83.250	12.07.82	091.117	03.10.82
1983	83.866	26.06.83	105.129	14.10.83
1984	85.442	14.06.84	101.492	14.09.84
1985	84.716	28.06.85	094.372	29.08.85
1986	83.101	19.06.86	103.839	27.08.86
1987	89.459	16.06.87	096.704	06.09.87
1988	83.018	16.06.88	105.479	30.09.88
1989	88.362	27.06.89	105.443	07.09.89
1990	89.505	20.06.90	105.525	08.10.90
1991	89.922	12.06.91	098.865	07.09.91
1992	83.857	20.06.92	103.358	12.09.92
1993	90.955	23.06.93	104.775	05.10.93
1994	85.033	06.07.94	105.391	08.09.94
1995	86.892	12.07.95	100.011	24.09.95
1996	85.341	15.07.96	103.227	12.09.96
1997	89.060	23.06.97	104.900	05.09.97

Table - 6
Status of Remote Sensing Data for the Year 1993-94

Date of Pass	Status of RS Data
12.10.93	70% cloud over the reservoir
03.11.93■	Cloud free
25.11.93	25% haze over the reservoir
17.12.93■	Cloud free
08.01.94	Poor data quality
30.01.94■	Cloud free
21.02.94■	20% scattered cloud around the reservoir
15.03.94■	Cloud free
06.04.94	10% scattered cloud
28.04.94■	Cloud free
20.05.94■	Cloud free
11.06.94■	10% cloud on the reservoir
03.07.94	90% cloud cover

■ *Images for these dates were acquired from NRSA, Hyderabad.*

Based on the status and availability of remote sensing data and the time spacing in-between the satellite data, eight scenes were ordered for the dates as marked above. It was found that the reservoir level varied from 104.446 m (342.67 ft) on 03.11.93 to 92.196 m (302.48 ft) on 11.06.94. Hence, the sedimentation assessment was restricted to this 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 to assess the sediment deposition pattern in the zone of operation (live storage).

5.4 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, after the visual product is generated. Around the periphery of the waterspread area, the wet land appears 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 water spread 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 and noise can be removed using different algorithms. 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 various steps followed in the analysis are described below:

5.4.1 Import and Visualization

The data of IRS-1B satellite and LISS-II sensor for eight different dates were received from NRSA on the CD-ROM media. The data were processed and analysed using the ERDAS/IMAGINE 8.3.1 software. The data were loaded on the computer from the CD-ROM and was imported in the ERDAS system. Each scene was having 2500 rows, 2520 columns and the information of four bands (three visual and one near-IR). There were no header bytes in the data. Imageries of all the eight dates were imported and stored in the hard disk. Reservoir water spread was mostly covered in lower right quadrant of the full scene.

Initially, a false colour composite of 4, 3 and 2 Bands combination was prepared and visualised. Then, each individual band was visualised one by one. It was found that the bands, as specified by the NRSA, do not represent the true bands. In all the scenes, it was found that Band 1 represents actual Band 4 (0.77 - 0.86 μm), Band 2 represents actual Band 1 (0.45 - 0.52 μm), Band 3 represents actual Band 2 (0.52 - 0.59 μm) and Band 4 represents actual Band 3 (0.62 - 0.68 μm). This identification was based on the standard spectral signatures of water and vegetation. So, the standard FCC (combination 4, 3 and 2) was prepared using 1, 4, 3 combination. The pixels representing water spread area (except at the periphery) of the reservoir were quite distinct and clear in the FCC.

Very high amount of noise was observed in the imagery of November, 1993. The imageries of December, 1993, January, 1994, March, 1994, April, 1994 and May, 1994 were cloud free over the reservoir and noise free. In the imageries of February, 1994 and June, 1994, some clouds were observed over the reservoir and along its periphery.

5.4.2 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 case, detection of land use change was not the objective. Further, the determination of the water spread 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, particularly the tail end of the reservoir. 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 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 imagery of January, 1994 was considered as the base (master) since it was very sharp and clear and cloud and noise free. The imageries of seven other dates were considered slaves and geo-referenced with the master. Though the reservoir area is covered in one fourth of the area of the full scene, yet full scenes were utilised for geo-referencing since sufficient distinct points around or within the reservoir area were not available.

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, roads or lineaments, sharp turns in the rivers, bridges, rock outcrops etc. were located on both the images and were selected as control points. About 15 such points were selected for geo-referencing in all the cases. Now looking at the statistics, some points which generated big errors were deleted and replaced by other points so as to obtain the satisfactory geo-referencing. In this manner, all the available images were geo referenced.

After completing this process, different images were displayed one over the other and the superimposition was compared. The geo-referencing was found to be satisfactory. The cumulative errors in all the cases was less than half a pixel. From the geo-referenced images, the area of interest was extracted as described below:

5.4.3 Separation of Area of Interest (AOI)

Since the size of each full scene was about 26 MB 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 imageries. 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. The size of each area of interest file was roughly 8 MB.

5.4.4 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 interpretive 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).

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 absorptance 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 (Band 1, 2 and 3) 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 act as a black body absorber and the boundary between the water and other surface features becomes quite prominent. However, along the periphery of the waterspread area, the reflectance from the wet land 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 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 was mainly used to differentiate the exclusive water pixels from other pixels in all the imageries. The spectral reflectance curves for vegetation, soil and water are presented in Fig. - 1. Variation of soil reflectance with moisture content and the reflectance of water in different conditions is demonstrated in Fig. - 2 and 3 respectively.

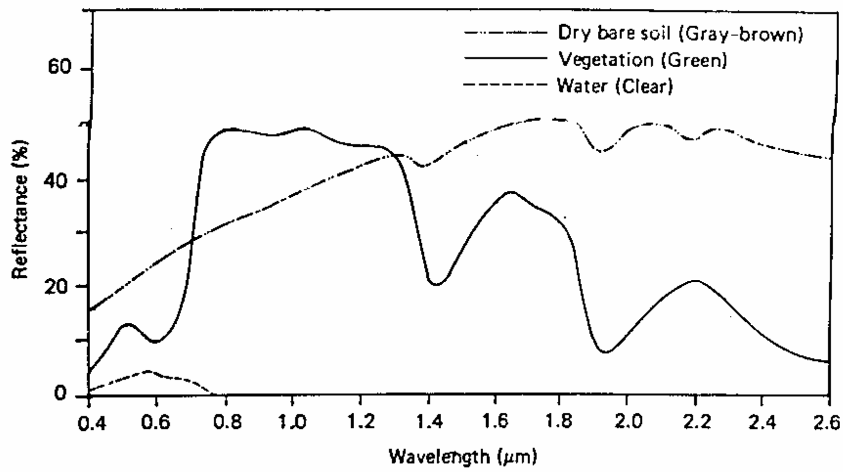


FIG. - 1 Spectral Reflectance Curves for Selected Surface Features

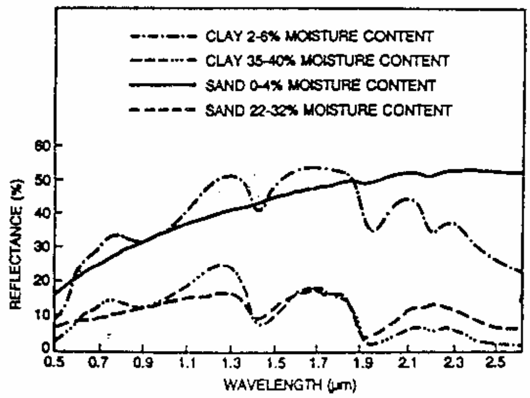


FIG. - 2 Spectral Reflectance Curves for Soil (variation with moisture content)

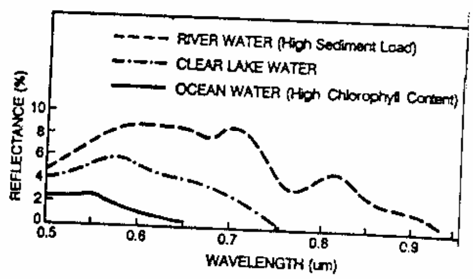


FIG. - 3 Spectral Reflectance Curves for Water (for different water bodies)

Different techniques were tried to distinguish and separate out the water pixels. Density slicing of the near-IR band was carried out and compared with the standard FCC. Though most of the water pixels could be accounted for 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. A new algorithm was developed for differentiating the water pixels 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. Selection of different limits in different imageries can cause some non-water pixels to be selected or some water pixels to be rejected.

There was possibility of some error in the interpretation because of the presence of mixed pixels along the periphery of the spread area. However, depending on the area covered by the water or soil in a mixed pixel, classification of some pixels as pure water and some as pure soil can mutually counterbalance the effect of misclassification to some extent. It was not possible to confirm the results of remote sensing interpretation from the field because the data pertained to the year 1993-94 and no field data, regarding the actual spread area on dates of satellite pass, were available. Even if the study is to be planned for future, it is very difficult to collect and demarcate the exact periphery of the water spread using conventional ground methods. The only possible way can be to make simultaneous observations from the satellite and aerial platforms.

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. These are discussed in the following:

5.4.4.1 Elimination of Cloud Effect

As indicated above, some of the imageries had significant cloud cover. These clouds and their shadows were present above the reservoir area and along the periphery of the reservoir. For the correct estimation of the water pixels, it was necessary to identify whether the pixels covered by clouds & shadows correspond to water surface or to the land. In case the clouds & shadows were present over the reservoir area or around the periphery, the imagery for the next available cloud free date was examined. If the area covered by the cloud in a particular imagery had water at the same location on the subsequent date's imagery, the pixels below the cloud were classified as water pixels. The reason was that the reservoir water surface area decreases with time during the draw-down cycle and hence the pixels representing water on a given date will also have water on the previous date. To analyse the data, the cloud and noise free imageries were first interpreted. For the classification of pixels under the clouds, the imagery (after the application of the model, as mentioned above) was displayed over the cloud free interpreted imagery of the adjacent date. Clouds and their shadows were not classified as water by the model. So, from the waterspread of the interpreted imagery of adjacent date, the trend of water line was demarcated and the pixels under the clouds or shadows were classified as water by copying the water pixels. For editing, help of the FCC and the imagery from adjacent dates was taken.

5.4.4.2 Elimination of Noise

In some imageries, especially November, 1993, there were disturbances in pixels due to the presence of noise in the data. Most of the noise affected pixels were isolated and it was relatively easy to determine whether the affected pixels represent the presence water or land. Noise pixels were not classified as water by the model. Most of the noise within the water spread was removed from the imagery by editing the individual noise pixels in the same way as the effect of clouds. For the rest of the waterspread area which was not covered in the subsequent date imagery, noise pixels were removed by confirming the status of the pixel from the FCC and then copying the water pixel over the noise pixel.

5.4.4.3 Removal of Discontinuous Pixels

The main objective of calculating the water spread area was 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 that surround the water spread area and that are located within the islands, must be removed from the interpreted 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 appear to be water pixels. These pixels do not form part of the continuous water spread and were removed by copying the non-water pixels over these water pixels.

5.4.4.4 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 reservoir water surface elevation and must be excluded from the calculation of the water spread area. So along these channels and rivers, those points were selected where the spreading of water in the reservoir is terminating. The extended channels were removed from these points onwards. For selecting the tail end on different dates, the tail end of the imagery of November, 1993 and June, 1994 were fixed depending on the termination of spreading and their X-coordinates were noted. For the intermediate imageries, the tail end X-coordinate was determined by interpolation depending on the variation of elevation. Based on the actual waterspread termination in the imagery, the probable tail end was selected near the interpolated value.

After editing and correcting all the eight imageries as discussed above, the histogram of the imageries was analysed and the number of water pixels in each imagery were recorded. Water spread area was calculated by multiplying the number of pixels by the size of one pixel (36.25 m x 36.25 m). The imageries of different dates showing the FCC and the final water spread area are presented in Fig. - 4 to 11. For the sake of comparison, the water spread areas of different months were overlaid and presented in Fig. - 12 & 13.

5.5 CALCULATION OF SEDIMENT DEPOSITION

The original elevation-area-capacity curves at the time of construction of dam (1972) were obtained from the Ukai reservoir authorities and are presented in tabular form in Table - 7.

Table - 7
Original Elevation-Area-Capacity Table for Ukai Reservoir

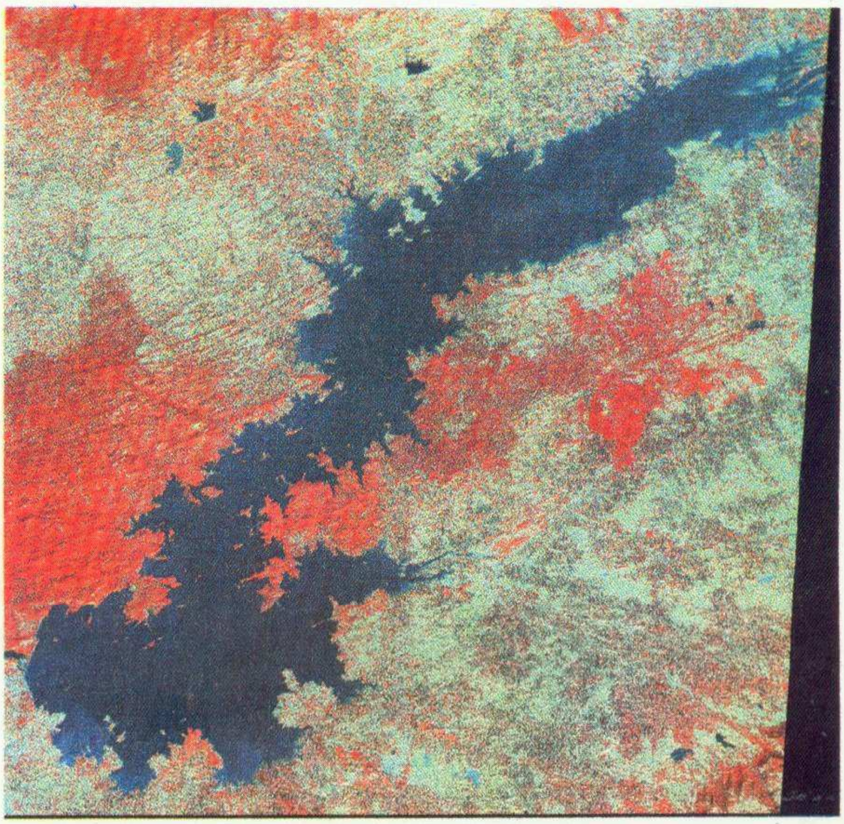
Reservoir Elevation (m)	Area (Mm^2)	Capacity (Mm^3)
090.00	224.600	2759.920
091.00	237.753	3006.617
092.00	254.952	3237.895
093.00	272.152	3484.592
094.00	290.374	3746.707
095.00	310.799	402i.157
096.00	331.842	4329.528
097.00	354.100	4656.401
098.00	374.335	4980.191
099.00	398.616	5334.817
100.00	422.897	5828.210
101.00	447.178	6136.582
103.00	511.321	7172.708
104.00	547.94	7801.780
105.00	590.842	8449.364
106.00	629.287	9189.454
107.00	669.756	9898.707

Revised contour areas at different elevations, after the deposition of sediments, were calculated by multiplying the number of pixels in the water spread area by the size of one pixel (36.25 m x 36.25 m). The reservoir elevations at the time of satellite pass were obtained from the reservoir authorities. The revised areas and the corresponding elevations are presented in Table - 8.

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 levels; A_1 is the contour area at elevation 1; A_2 is the contour area at elevation 2 and H is the difference between elevation 1 and 2.



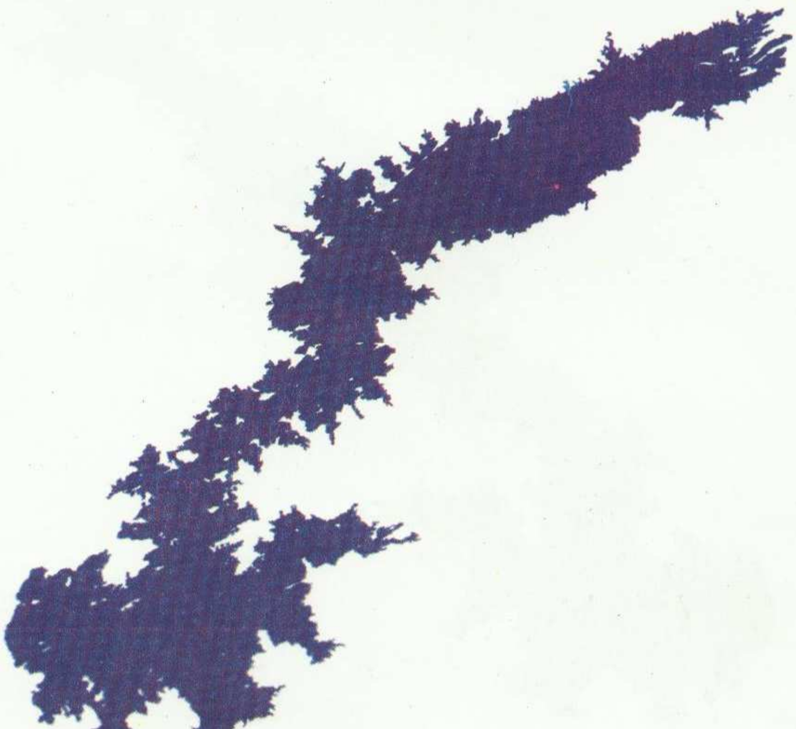


FIG. - 4 FCC and Extracted Water Spread Area of UKAI Reservoir on November 3, 1993

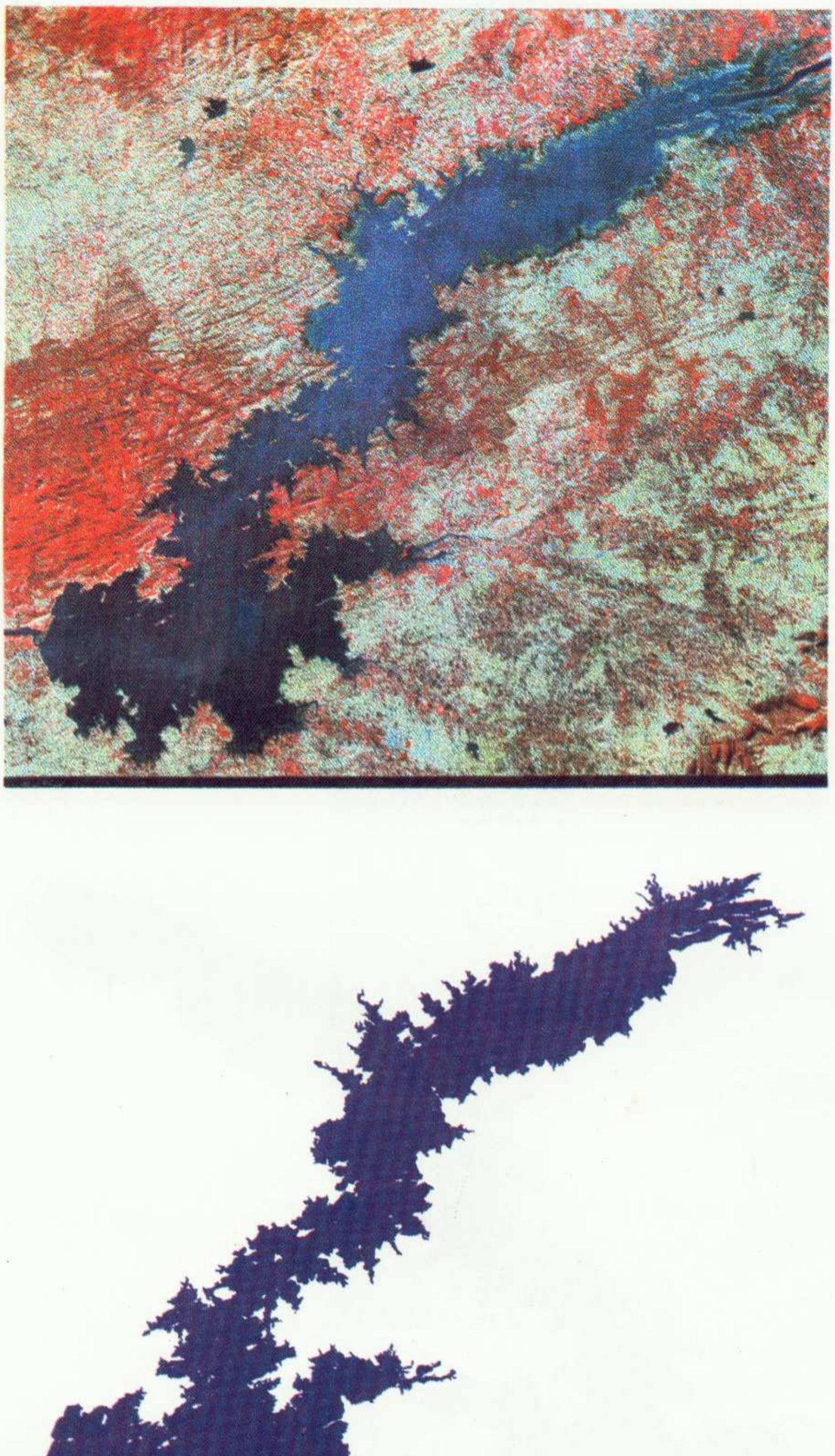


FIG. - 5 FCC and Extracted Water Spread Area of UKAI Reservoir on December 17, 1993

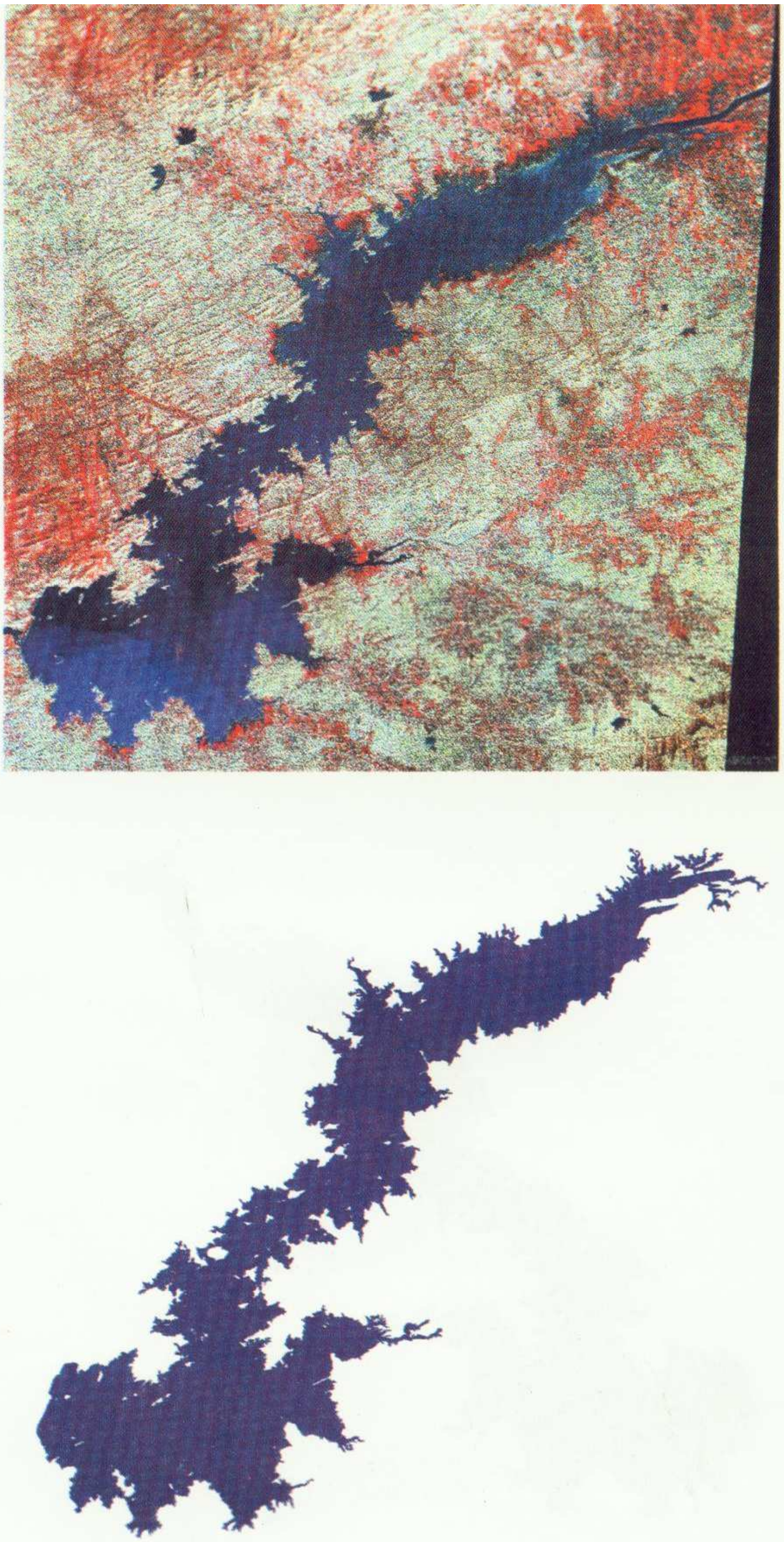


FIG. - 6 FCC and Extracted Water Spread Area of UKAI Reservoir on January 30, 1994

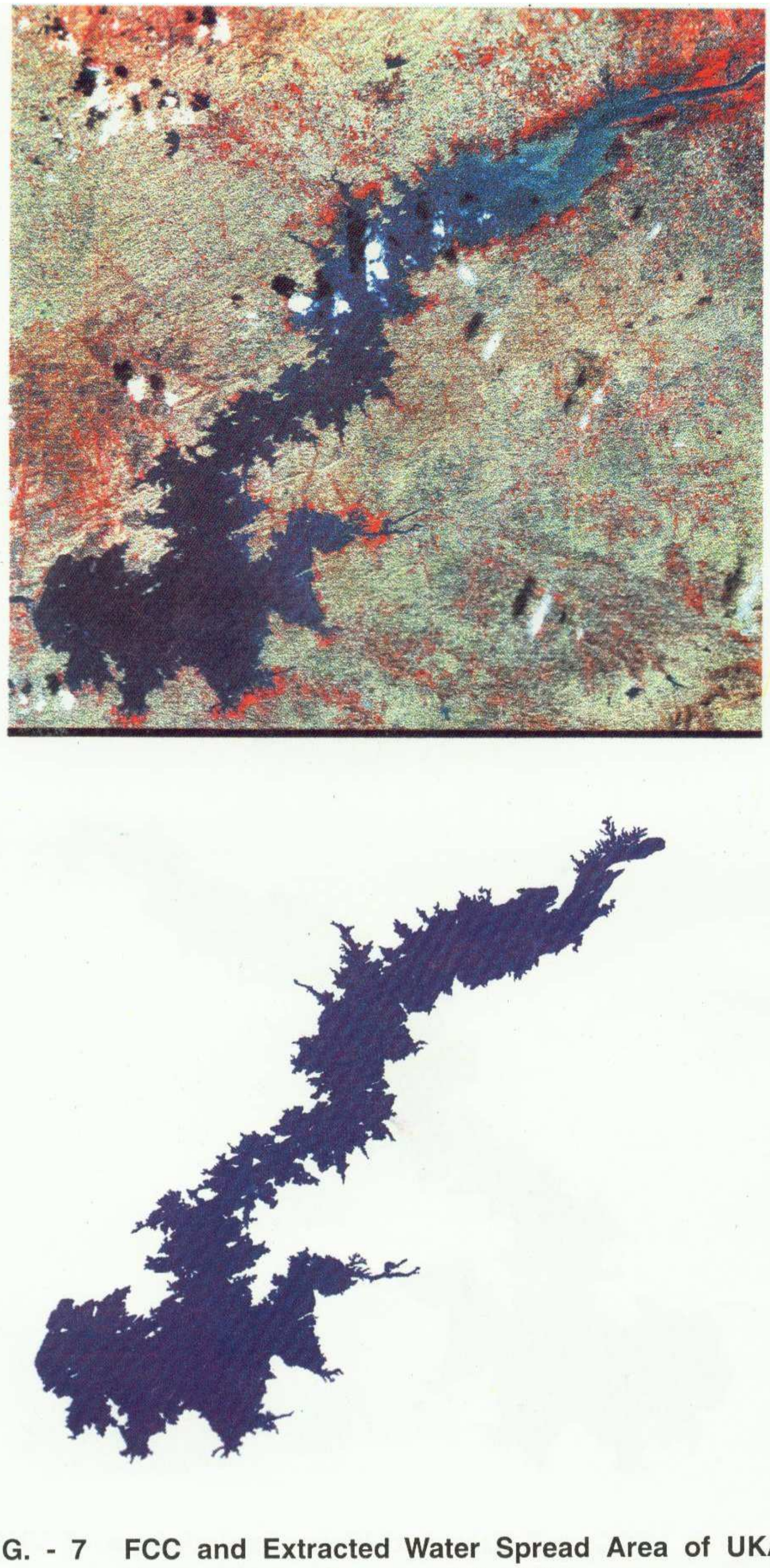


FIG. - 7 FCC and Extracted Water Spread Area of UKAI Reservoir on February 21. 1994

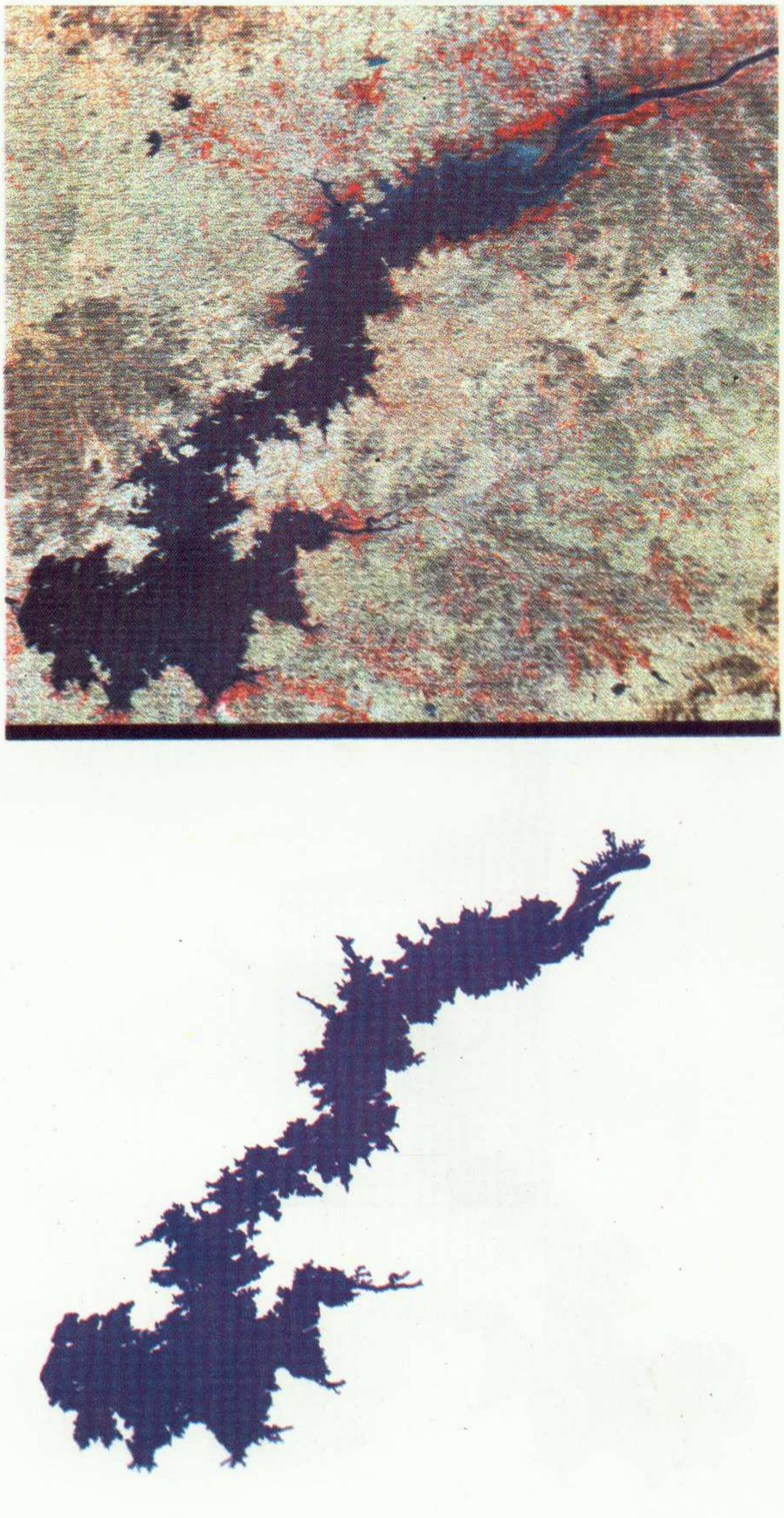
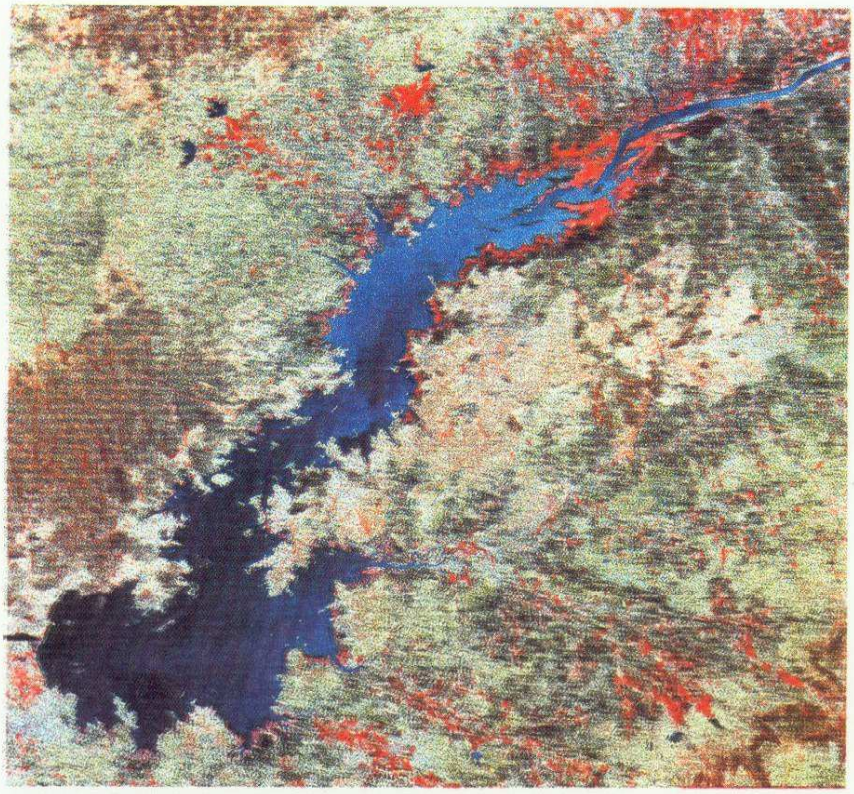


FIG. - 8 FCC and Extracted Water Spread Area of UKAI Reservoir on March 15, 1994



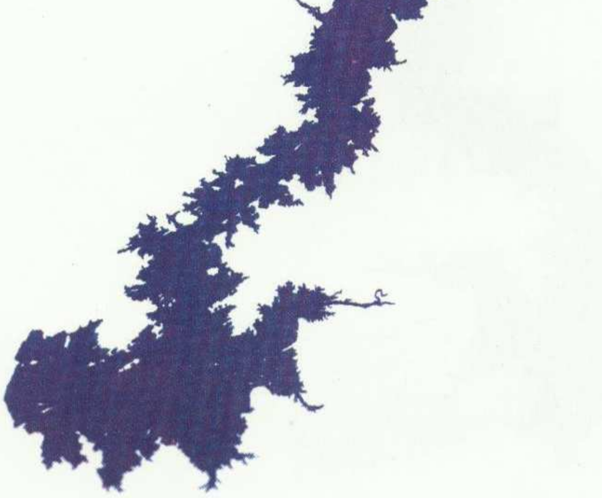


FIG. - 9 FCC and Extracted Water Spread Area of UKAI Reservoir on April 28, 1994

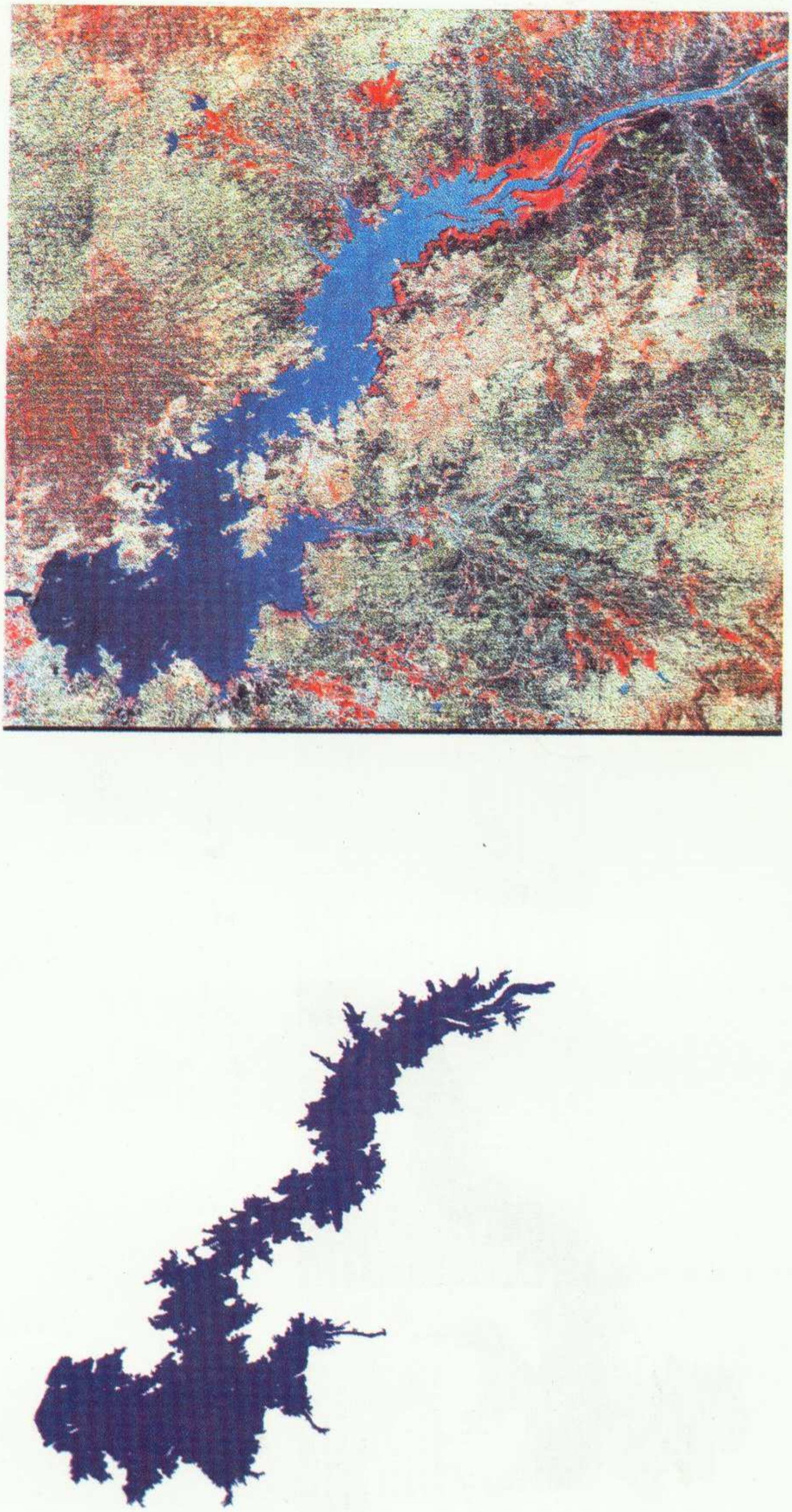


FIG. - 10 FCC and Extracted Water Spread Area of UKAI Reservoir on May 20, 1994

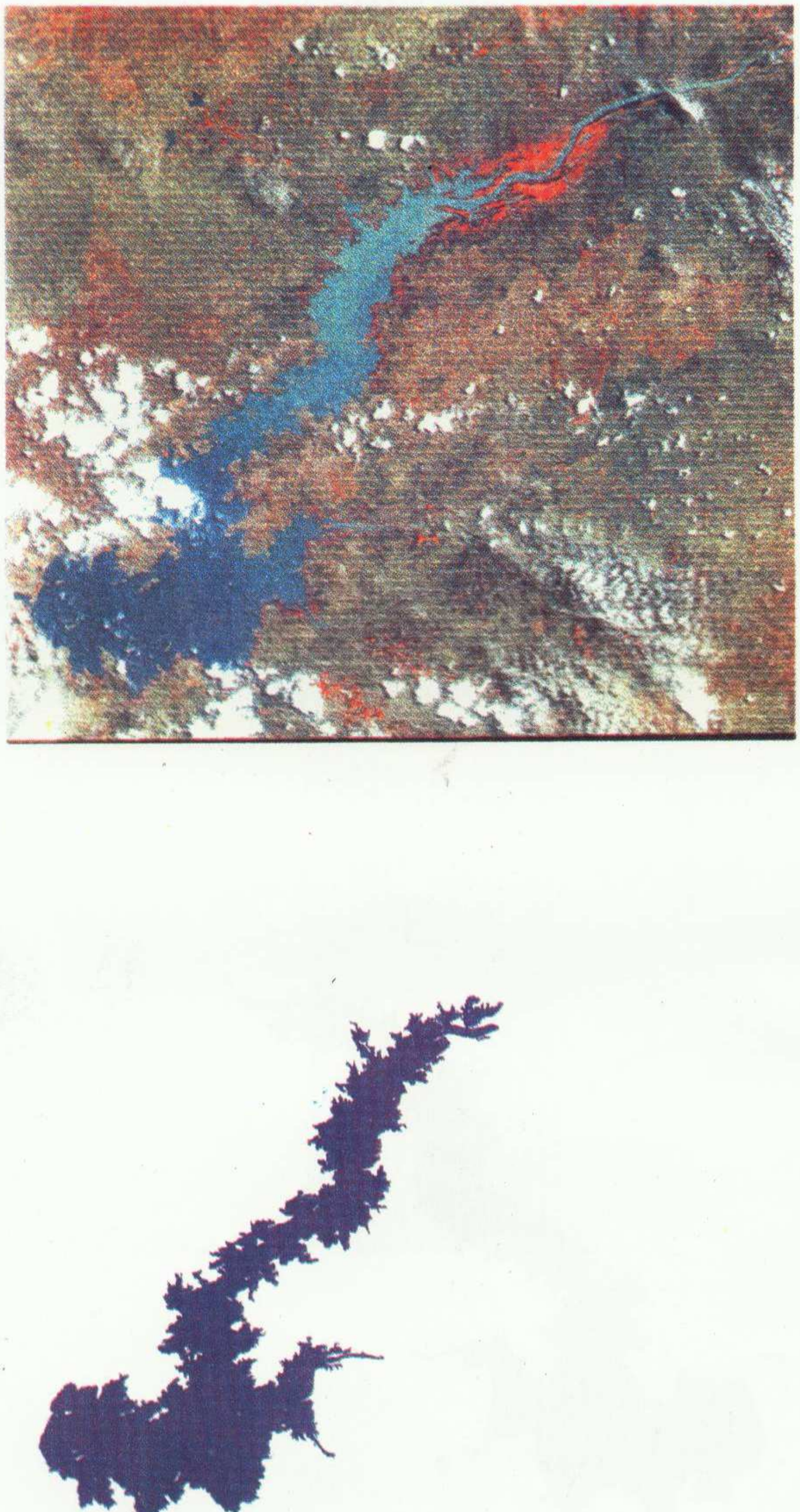


FIG. - 11 FCC and Extracted Water Spread Area of UKAI Reservoir on June 11, 1994

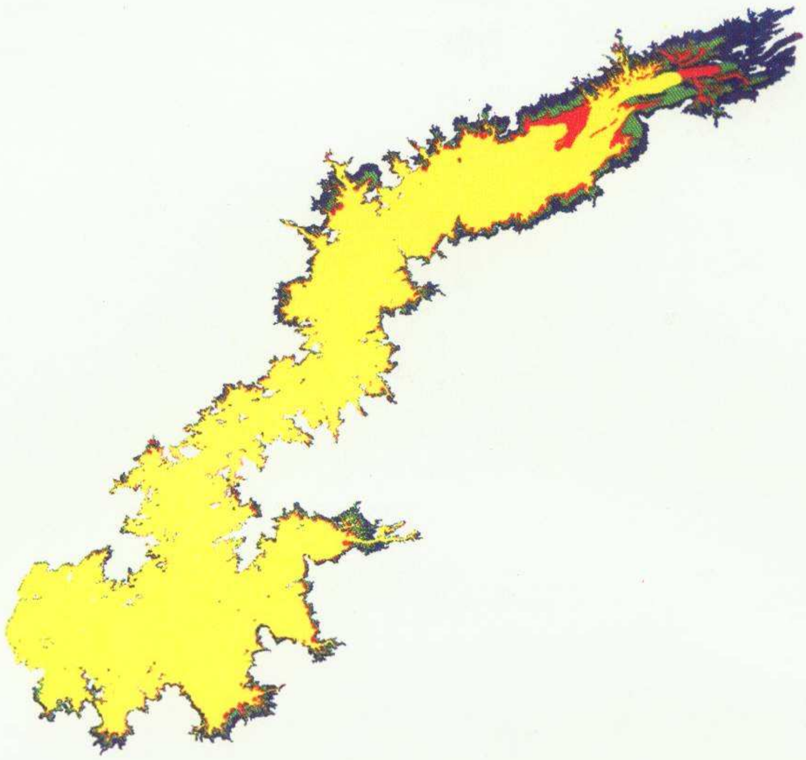


FIG. - 12 Comparison of Water Spread Area in Different Months
[Nov. (Blue), Dec. (Green), Jan. (Pink), Feb. (Yellow)]

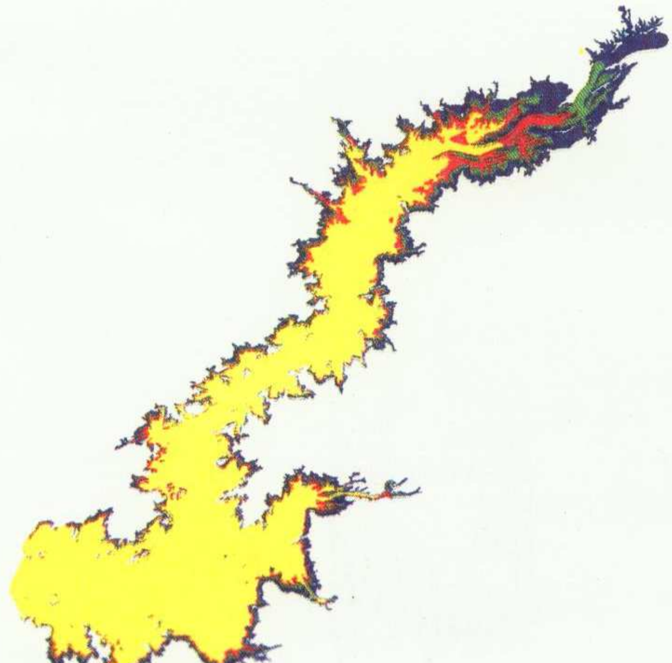


FIG. - 13 Comparison of Water Spread Area in Different Months
[Mar. (Blue), Apr. (Green), May (Pink), Jun. (Yellow)]

Table - 8
Reservoir Elevation & Revised Area on the Date of Satellite Pass

Date of Pass	Number of Water Pixels	Reservoir Elevation (m)	Revised Area Using Remote Sensing (M Sq m)
03.11.93	372596	104.446	489.61
17.12.93	335356	101.828	440.68
30.01.94	310625	99.865	408.18
21.02.94	282240	98.819	370.88
15.03.94	268324	97.823	352.59
28.04.94	221676	95.092	291.30
20.05.94	205604	93.967	270.18
11.06.94	186396	92.196	244.94

It is important to mention here that the amount of sediments deposited below the lowest observed level could not be determined using the remote sensing data. Because of this reason, the sedimentation rate above the highest observed level and below the lowest observed level could not be determined using remote sensing technique. However, if accurate results are required, then the hydrographic survey for the area within the lowest observed waterspread area needs to be carried out.

From the original elevation-area table, the original area at the intermediate elevations (reservoir elevations on the dates of satellite pass) was obtained by linear interpolation. From the known values of original and revised areas at different elevations, the corresponding original and revised capacities were worked out as mentioned above. The cumulative revised capacity of the reservoir at the lowest observed level (92.196 m) was assumed to be the same as the original cumulative capacity (3247.02 M Cum) at this elevation before the construction of the dam. 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 capacities at the maximum observed level. The difference between the original and revised cumulative capacity represents the loss of capacity due to sedimentation in the zone under study. The calculations of sediment deposition are presented in Table - 9. The results show that the volume of sediment deposition in-between the maximum and minimum observed levels (104.446 m and 92.196 m) is 324.64 M Cum. If the uniform rate of sedimentation is assumed in 21 years of occurrence of the reservoir, then the sedimentation rate in this zone is 15.46 M Cum per year.

Table - 9
Calculation of Sediment Deposition in Ukai Reservoir Using Remote Sensing

Date of Satellite Pass	Reservoir Elevation (m)	Original Area (Mm^2)	Revised Area (RS) (Mm^2)	Original Volume (Mm^3)	Revised Volume (RS) (Mm^3)	Original Cumulative Volume (Mm^3)	Revised Cumulative Vol. (RS) (Mm^3)
03.11.93	104.446	565.674	489.61	1601.07	1217.19	8038.96	7714.32
17.12.93	101.828	473.866	440.68			6683.52	6497.13
				848.02	832.95		
30.01.94	99.865	418.293	408.18			5809.57	5664.18
				394.59	407.29		
21.02.94	98.819	395.283	370.88			5384.12	5256.89
				337.85	360.25		
15.03.94	97.823	370.496	352.59			5002.83	4896.64
				827.91	877.90		
28.04.94	95.092	312.901	291.30			4070.76	4018.74
				313.43	315.76		
20.05.94	93.967	289.555	270.18			3731.96	3702.98
				448.37	455.96		
11.06.94	92.196	258.392	244.94			3247.02	3247.02

5.6 COMPARISON OF RESULTS WITH HYDROGRAPHIC SURVEY

Hydrographic survey of the Ukai reservoir was carried out in the year 1992-93. Only the revised capacity values at different levels (from the bed level of the river up to the FRL) were available. These are presented in Table - 10.

The detailed report of the survey was not available and the method of calculation of the revised capacity could not be ascertained. The maximum observed water level in the year of hydrographic survey (1992-93) was 103.358 m. It is assumed that above this level, revised levels at different points were collected using the methods of surveying. It is also assumed that revised elevations at different points within the reservoir were obtained by using sounding method and the contours corresponding to different elevations were interpolated. Further, using the revised contour area at different elevations, the intermediate capacity between two contours was obtained using the trapezoidal formula. For the purpose of comparison of results of hydrographic survey with those of remote sensing, the revised capacity as per hydrographic survey at the intermediate elevations (reservoir elevations on the date of satellite pass) were obtained by linear interpolation as was done previously.

The revised capacity at the lowest observed level (92.196 m) was assumed to be equal to the revised cumulative capacity (2619.56 M Cum) as reported by the hydrographic survey. Above this level, the revised capacity was calculated based on the remote sensing analysis

Table - 10
Revised Elevation-Capacity Table for Ukai Reservoir
(Results of Hydrographic Survey of 1992-93)

Reservoir Elevation (m)	Reservoir Cum. Capacity (Mm^3)	Reservoir Elevation (m)	Reservoir Cum. Capacity (Mm^3)
105.15	7496.8046	82.15	735.36013
104.15	7064.0589	81.15	621.15456
103.15	6638.3204	80.15	516.93912
102.15	6216.8476	79.15	423.34076
101.15	5801.7087	78.15	341.72634
100.15	5396.0396	77.15	271.16724
99.15	4997.5921	76.15	209.89197
98.15	4612.0155	75.15	157.70841
97.15	4236.7531	74.15	111.95622
96.15	3873.9305	73.15	76.933502
95.15	3528.7650	72.15	48.297078
94.15	3201.4180	71.15	25.715678
93.15	2893.9793	70.15	12.164261
92.15	2606.3285	69.15	4.9513760
91.15	2340.2486	68.15	2.1962419
90.15	2093.8930	67.15	1.5908872
89.15	1870.8112	66.15	1.213460
88.15	1668.8810	65.15	0.909741
87.15	1481.6347	64.15	0.6428619
86.15	1307.9140	63.15	0.4103638
85.15	1147.4950	62.15	0.2098148
84.15	999.24425	61.15	0.0412097
83.15	861.66416	60.61	0.0412097

and the cumulative capacity at the highest observed level was obtained. This was compared with results of hydrographic survey. The calculations are presented in Table - 11.

Table - 11
Comparison of Results of Hydrographic Survey with Remote Sensing

Date of Satellite Pass	Reservoir Elevation (m)	Revised Volume (HS) (Mm^3)	Revised Volume (RS) (Mm^3)	Revised Cumulative Vol. (HS) (Mm^3)	Revised Cumulative Vol. (RS) (Mm^3)
03.11.93	104.446	1100.32	1217.19	7192.16	7086.86
17.12.93	101.828			6083.18	5869.67
		800.69	832.95		
30.01.94	99.865			5282.49	5036.72
		412.49	407.29		
21.02.94	98.819			4870.00	4629.43
		380.69	360.25		
15.03.94	97.823			4489.31	4269.18
		979.53	877.90		
28.04.94	95.092			3509.78	3391.28
		364.62	315.76		
20.05.94	93.967			3145.16	3075.52
		525.60	455.96		
11.06.94	92 196			2619.56	2619.56

It is seen from the analysis that there is appreciable difference between the two results. As per the hydrographic survey, the revised capacity of the reservoir in the year 1992-93 in the zone of analysis was 4572.6 M Cum after 20 years of operation. As per the remote sensing analysis, in the year 1993-94, it comes out to be 4467.3 M Cum after 21 years of operation. The original volume of this zone was 4791.94 M Cum.

If an average rate of sediment deposition is assumed, then, as per hydrographic survey, the sedimentation rate in the zone of study is 10.97 M Cum per year. So, for the year 1993-94, the volume of sediment deposition in the zone under study can be assumed to be 4561.63 M Cum. Thus, the sediment deposition volume by hydrographic survey and remote sensing comes out to be 230.31 M Cum and 324.6 M Cum respectively. From the Table - 11, it is seen that as per the remote sensing analysis, the sediment deposition in the first two zones (in-between the levels 104.446 m and 99.865 m) is less than that reported by the hydrographic survey while in the subsequent six zones (in-between levels 99.865 m and 92.196 m), the sediment deposition is higher than what is reported in the hydrographic survey results. One reason for the same can be the movement of the deposited sediments from the higher elevation zones to the lower portion of the reservoir. However, with the present set of available data, the results of either of the techniques could not be confirmed.

The plot of original and revised cumulative capacity as derived using remote sensing technique is shown in Fig. - 14. The plots of the revised cumulative capacity as per the hydrographic study and as per the remote sensing analysis is presented in Fig. - 15.

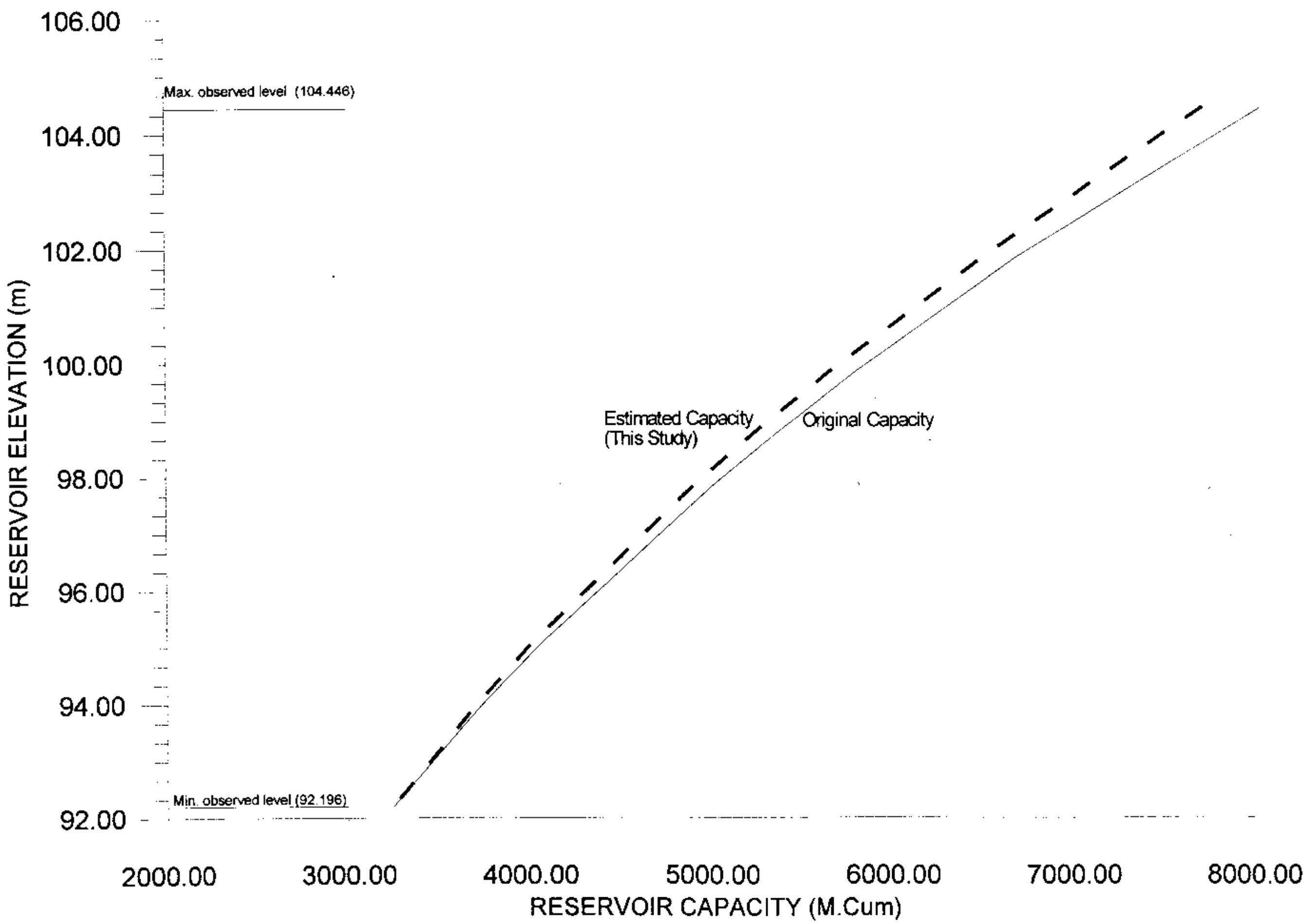


Fig. 14 : Elevation - Capacity Curves for Ukai Reservoir

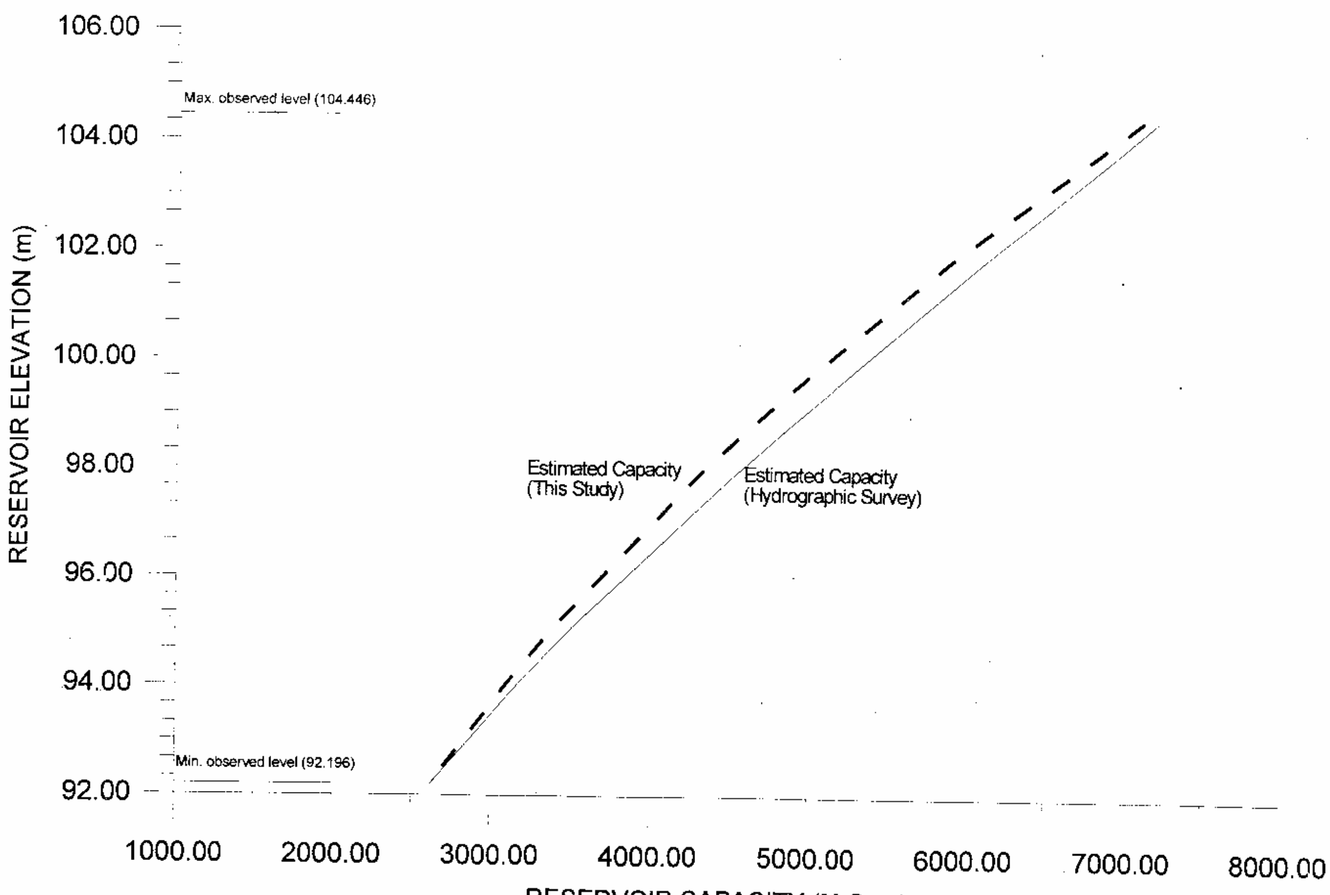


Fig. 15 : Comparison of Results (RS) with Hydrographic Survey

5.7 DISCUSSION OF RESULTS

Since the details of the hydrographic survey were not available, the method of calculation of revised capacity could not be ascertained. Further, it is seen that the estimation of sedimentation by remote sensing is highly sensitive to the accurate determination of water spread area. In the present case, an error of 1% in the estimation of water spread area would result in the sedimentation difference of 45 M Cum. Though every effort has been made to estimate the water spread area as precisely as possible and uniform method of analysis has been adopted for all the imageries, yet the difference is equivalent to approximately 2% error in the area estimation. Some of the reasons for the difference between the two results can be either of the or a combination of the following:

a) Difference in the method adopted for the calculation of cumulative capacity in both the techniques. In the present study, trapezoidal formula has been used for the capacity determination between two contours and actual contour areas have been considered rather than considering the areas from the smooth curve of best fit.

b) One year gap in the application of the two techniques can cause pronounced difference in the results. The sedimentation pattern in a reservoir gets modified after each monsoon season and the change depends on the nature and volume of new sediments entering the reservoir and the flow pattern in the reservoir.

c) Very high amount of noise in the scene of November, 1993 and the cloud cover in the two scenes (Feb., 1994 and June, 1994) can cause misinterpretation of some pixels.

d) Different criteria of demarcating the tail end of the reservoir. In the present study, the tail has been truncated at the termination point of water spread. Extension of the tail end can result in the increase in spread area and the subsequent lesser volume of sediment deposition.

e) Mixed pixels having larger proportion of land and smaller proportion of water around the periphery of the reservoir.

To minimize the discrepancy of remote sensing technique, it is desirable to use the data of higher resolution sensor. The data of LISS - III sensor of IRS-1C satellite, with a resolution of 23.5 m, is available from December, 1995 onwards and can be used for such studies. Further, for the sake of comparison, it is desirable to carry out the hydrographic survey analysis and the remote sensing analysis for the same year of record. In the present case, one possible way to validate the results of either of the techniques could be to carry out the remote sensing analysis for one subsequent year also.

* * *

CHAPTER - 6
CONCLUSION

India has more than 3000 major and medium reservoir projects. One of the principal factors which threaten the longevity of such projects is the accumulation of sediments in the reservoirs. 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. Present conventional techniques of sediment quantification, like the hydrographic survey and inflow-outflow methods, are cumbersome, costly and time consuming. With the introduction of remote sensing techniques, it has become very cheap and convenient to estimate the sediment deposition in the various zones of a reservoir. Multitemporal satellite data are extremely useful in determining sedimentation rate in a reservoir. Spatial, spectral and temporal attributes of remote sensing provide invaluable synoptic and timely information regarding the revised waterspread conditions in the water body.

In the present study, the sedimentation rate and volume was determined in the Ukai reservoir using the remote sensing data. Based on the annual maximum and minimum observed levels, the post-monsoon period of the year 1993-94 was chosen for the analysis. Remote sensing data of IRS-1B satellite and LISS-II sensor was acquired for eight different dates and the revised water spread area was extracted. The standard signature characteristics of different surface features (water, soil and vegetation) were utilised for separating the water pixels from other surface features. The resulting imagery of water pixels was compared with the standard FCC and the near-IR imagery. Corrections were applied for the clouds, noise, islands, and isolated water pixels by editing the imageries. For these corrections, the information from the past and subsequent date imageries was utilised. The tail end of the reservoir and the rivers joining the reservoir around the periphery were truncated on the basis of termination of water spread conditions. The original elevation-area-capacity curve and the reservoir levels on the eight dates of pass of satellite were obtained from the dam authorities. Using the trapezoidal formula, the revised capacity in between the maximum (104.446 m) and minimum (92.196 m) observed levels was obtained. The revised capacity (4467.3 M Cum) was subtracted from the original capacity (4791.94 M Cum) and the loss in capacity (324.6 M Cum) was attributed to the sediment deposition in the zone of study (104.446 m to 92.196 m) of the reservoir. Thus, the average rate of loss of capacity in this zone came out to be 15.46 M Cum per year.

The hydrographic survey of the reservoir was carried out in the year 1992-93. As per the results of this survey, the revised capacity in the year 1992-93 of the zone under study comes out to be 4561.63 M Cum with an average capacity loss rate of 10.97 M Cum per year. This value is appreciably lower than what was found from the remote sensing analysis. Some possible reasons for this difference have been discussed in the report. It was seen that the remote sensing method of determining sedimentation is highly sensitive to the interpretation of the water spread area. For the present study, it was estimated that 1% change in the interpretation of water spread area can result in change of sedimentation volume by about 45 M Cum. In remote sensing analysis, various factors which can cause difference in the calculation of the water spread area include: i) clouds and noise in the data, ii) number of mixed pixels, and iii) the method of analysis. The selection of tail end is also based on subjective interpretation and can influence the results. However, the use of better resolution (spatial and temporal) satellite data can be a remedy for these problems to some extent. Further, it is suggested that for the sake of comparison of the results from the two techniques, the period of analysis must be same. In the present study, there is one-year gap in the two analysis and the sedimentation pattern in a reservoir gets modified after each monsoon season.

Limitation of the remote sensing technique is that the sedimentation 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 of sedimentation analysis, from the point of view of operation, is the live storage zone only. Further, if sedimentation 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.

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SALIENT FEATURES FOR UKAI RESERVOIR

1. Location of Dam

a. River	:	Tapi
b. Village	:	Ukai
c. Taluka	:	Fort-Songadh
d. District	:	Surat
e. State	:	Gujarat

2. Hydrology

a. Drainage area of the river above dam site	:	62.225 km^2
b. Mean annual rainfall in watershed	:	785 mm
c. Max. annual rainfall in the watershed	:	1191 mm
d. Minimum annual rainfall	:	270 mm
e. Mean annual runoff at the dam site	:	1.722 x 10^6 ha.m
f. Observed maximum flood at Dam	:	42,470 m^3/s
g. Observed minimum dry weather flow	:	0.3813 x 10^6
h. Design Flood	:	49,490 m^3/s
i. Probable Flood	:	59,920 m^3/s
j. Max. regulated outflow from the reservoir	:	22,650 m^3/s

3. Reservoir

a. Gross storage capacity at FRL	:	0.8511 x 10^6 ha.m
b. Dead storage below R.L. 82.296 m	:	0.14185 x 10^6 ha.m
c. Live storage	:	0.70920 x 10^6 ha.m
d. Maximum storage level	:	105.156 m
e. Water spread at R.L. 105.156 M.	:	60,095 ha
f. i) Cultivated land submerged.	:	30,350 ha
ii) Other land submerged.	:	7,485 ha
iii) Forest land submerged.	:	22,260 ha
g. Village affected by submergence.	:	170 Nos.

4. Dam

a. Length of dam

Masonry section (including spillway)	:	868.82 m
Earth section	:	4057.96 m
Total Length	:	4926.79 m

b. Maximum height of Main Dam		
i) Earth dam (Above river bed)	:	68.500 m
ii) Masonry dam (Above deepest foundation)	:	80.772 m
c. Total earth work	:	232.40 x 10^3 m^3
d. Total quantity of stripping	:	4950 x 103 m^3
e. Total quantity of Masonry/concrete	:	1484 x 103 m^3
f. Top of Dam	:	111.252 m
g. Road width on spillway	:	6.706 m

5. Spillway

a. Crest level of spillway	:	91.135 m
b. Length of spillway	:	425.195 m
c. Top of crest level	:	105.461 m
d. Type of Gates	:	Radial
e. Size and No. of Gates	:	15.545 x 14.783 m 22 Nos.

6. Power Section (Hydro)

a. Size of penstock	:	4 Nos. 7.01 m dia.
b. Installation 4 Units of 75 MW each	:	300 MW
c. Generation at 35% load factor	:	193 MW
d. Annual Energy (Units)	:	670 x 10 Kwh.

7. Canal Bed Power House

a. Size of penstock	:	3.96 m x 2.05 m
b. Installation of 2 Units of 2.5 M.W. each	:	5 MW
c. Type of hoist	:	Hydraulic hoist
d. Discharge through each unit	:	550 Cusecs.

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