सत्यमेव जयते

उपग्रह दूरस्थ संवेदन द्वारा
उकाई जलाशय (गुजरात) का अवसादन आंकलन

SEDIMENTATION ASSESSMENT OF
UKAI RESERVOIR (GUJARAT)
THROUGH SATELLITE REMOTE SENSING

भारत सरकार
केन्द्रीय जल आयोग
पर्यावरण प्रबंध संगठन
दूरस्थ संवेदन निदेशालय

Government of India
Central Water Commission
Environment Management Organization
Remote Sensing Directorate

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SEDIMENTATION ASSESSMENT OF
UKAI RESERVOIR, GUJARAT
THROUGH SATELLITE REMOTE SENSING

Year of Study **2021**
Data Used **2019-2020**

STUDY TEAM

OVERALL GUIDANCE

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PRINCIPAL INVESTIGATOR

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EXECUTIVE SUMMARY

The dynamic aspects of the reservoir, mainly water spread, suspended sediment distribution and concentration requires periodical mapping and monitoring. Sedimentation in a reservoir has a bearing on the capacity of the reservoir as it affects both live and dead storages. In other words, the life of a reservoir depends on the rate of siltation. The satellite data provides opportunity to study these aspects on various scales and at different stages. The present report comprises of use of **Microwave Remote Sensed data** for the years 2019 & 2020 in the sedimentation study of Ukai reservoir, Gujarat. The various aspects of the reservoir sedimentation, like the process of sedimentation in the reservoir, sources of sediment, measures to check the sediment and limitations of space technology have been discussed in the report.

Multi-date satellite remote sensing data provide information on elevation contours in the form of water-spread area. Any reduction in reservoir water spread area at a specified elevation corresponding to the date of satellite data is indicative of sediment deposition. The quantity of sediment load settled down over a period of time can thus be determined by evaluating the change in the aerial spread of the reservoir at various elevations.

In the present study, **microwave data from Sentinel 1A/1B satellites** have been used to estimate water spread area of Ukai Reservoir. As compared to Optical remote sensing, Microwave remote sensing has advantages as the satellite operates day and night allowing the acquisition of imagery at frequent time intervals regardless of weather and illumination conditions. The Sentinel-1 mission is a constellation of two polar-orbiting satellites (Sentinel-1A and Sentinel-1B), with a C-band synthetic aperture radar instrument operating at a center frequency of 5.405 GHz, that acquires Synthetic Aperture Radar (SAR) data in single or dual polarization with a revisit time of 6 days.

Ukai Dam is located on the river Tapi in the Tapi District of Gujarat. It is also called the Vallabh Sagar Dam and it is the second largest reservoir in the state of Gujarat after the Sardar Sarovar Dam. The project construction began in the year 1964 and the first impoundment was done in 1972. Ukai dam is an earth-cum-masonry dam. It has a catchment area of about 62,255 km^2 and the reservoir area at FRL is 520.00 sq km^2. Ukai Dam has a designed gross reservoir capacity of 8511 MCM with live capacity as 7092.5 MCM (dead storage of 1418.5 MCM).

With respect to the original live capacity of 7092.5 MCM in 1972, the Hydrographic survey of 1979 for Ukai reservoir revealed a reduction in live storage capacity by 240.5 MCM in 7 years. Further, the 1983 Hydrographic survey reflected loss of live capacity by another 49 MCM in next 4 years. The subsequent Hydrographic Survey of 1992 showed the live capacity to be 6615.15 MCM which is a loss of 477.462 MCM from the original capacity in a period of 20 years. In the intermediate period from 1992 to 2020, the available live storage capacities for the Ukai reservoir were estimated to be 7144.2 MCM (HS-2001), 6729.90 MCM (HS-2003) & 6002.5 MCM (SRS-2005). However, the output of the 2001 study inhibit lesser confidence in the results due to the increase reported in the live capacity from Hydrographic Survey (2001). Moreover, the SRS survey (2005) may not be as reliable as SRS (2020) owing to the fact that in 2005, the optical imageries of lower resolution (compared to SRS-2020) have been used. The live storage capacity of the Ukai reservoir as per the present study is found to be **6256.055 MCM** for the year 2020, which reflects **11.79% loss (836.445 MCM**) in the original live storage capacity (*at an annual rate of loss of 0.24% since 1972*).

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ABBREVIATIONS

CWC	Central Water Commission
DSL	Dead Storage Level
FRL	Full Reservoir Level
HS	Hydrographic Survey
IRS	Indian Remote Sensing
LISS	Linear Imaging Self Scanner
MDDL	Minimum Draw Down Level
MSL	Mean Sea Level
MWL	Maximum Water Level
NIR	Near Infra-Red
NRSC	National Remote Sensing Centre
SAR	Synthetic Aperture Radar
SNAP	Sentinel Application Platform
SRS	Satellite Remote Sensing
N.A.	Not Available
WSA	Water Spread Area

UNITS USED

Cumec	cubic metre per second
M	Metre
M m^2	million square metre
M m^3/MCM	million cubic metre
Ha	Hectare
Sq km	Square Kilometre
mm/year	millimetre per year

SEDIMENTATION ASSESSMENT OF UKAIRESERVOIR, GUJARATTHROUGH SATELLITE REMOTE SENSING

1 INTRODUCTION

India – the second largest country in the world in terms of population – has about 17.3% of world's population, about 4% of world's water resources, and 2.44% of total geographical land area of the world. Therefore, in spite of having an average annual average precipitation to the tune of more than 1105 mm/year, the population density (lack of land resources) and per capita water resources availability make India a water-stressed country, as a whole. However, at a regional or basin level, many areas in the country are water-scarce or severely water-scarce owing to the spatial and temporal variability of water resources.

It is estimated that average annual precipitation over India is about 3880 BCM. Out of this precipitation, the average annual water resources availability of the country is about 1999.2 BCM, as estimated by Central Water Commission (CWC) in 2019. The water resources availability situation gets murkier due to topographical and other constraints. Due to this, the total utilisable water resources in the country are about 1126 BCM (690 BCM of surface water and 436 BCM of groundwater). On one hand, the per-capita water resource availability is reducing due to increasing population and on the other, per-capita water usage is increasing due to industrialisation, urbanisation and change in lifestyles or dietary habits, making the available water resources still dearer.

India has typical monsoon-based climate where more than 75% rainfall occurs in three months i.e. July, August, and September. The total number of rainy days typically are in the tune of only 20-25 days per year (100-150 hours of rain per year) for most parts of the country. As a result, the bulk of annual water (75-80%) in rivers is available only in these three months. Therefore, in order to sustain life and other activities throughout the year from a resources that is available only through 20-25 rainy days, it is absolutely essential to store the water in appropriately-sized storage structures (depending upon the topography and hydrology of the area).

So far, India has developed just 257.812 BCM as live storage capacity and 46.765 BCM is under construction. Realising the importance of storage structures, a large number of reservoirs have been built, since independence, during each plan in almost all river basins, except Ganga and Brahmaputra, to tap the available surface water and to utilize it as and when needed. The capacity of reservoirs is gradually reducing due to silting and hence sedimentation of reservoir is of great concern for all the water resources development projects.

Correct assessment of the sedimentation rate is essential for assessing useful life of the reservoir as well as optimum reservoir operation schedule. Since 1958, when it was established that the live storage of reservoir is getting reduced due to siltation, a systematic effort has been made by various departments / organizations to evaluate the capacity of reservoirs. Various techniques like boat echo sounder, etc. being replaced by hydrographic data acquisition system (HYDAC) and HITECH method using Differential Global Positioning System (DGPS). The conventional techniques are found either time consuming or costly and require considerable manpower. Remote sensing technique to calculate the present live capacity of reservoir is found to be very useful in this context due to its synoptic and repetitive coverage. The surveys based on remote sensing data are faster, economical and more reliable.These surveys will enable selection of appropriate measures for controlling sedimentation alongwith efficient management and operation of reservoirs thereby deriving maximum benefits for the society.

This report covers the study of Ukai Reservoir, Gujarat by Central Water Commission, New Delhi.

2. SOURCES AND MECHANISM OF SEDIMENTATION

The principal sources of sediments are as follows:

1. Deforestation
2. Excessive erosion in the catchment
3. Disposal of industrial and public wastes
4. Farming
5. Channelisation works
6. Human activities
7. Land development, highways, and mining

The sedimentation is a product of erosion in the catchment areas of the reservoir and hence lesser the rate of erosion, smaller is the sediment load entering the reservoir. Various factors govern the erosion, transport and deposition of sediment in the reservoir. Type of soil, drainage density, vegetation, rainfall intensity and duration, shape of catchment and land use/land cover affect the erosion. Sediment transportation depends upon slope of the catchment, channel geometry and nature of riverbank and bed. Deposition is a function of bed slope of the reservoir, length of reservoir, flow patterns, inflow - outflow rates, grain size distribution, mode of reservoir operation, etc.

In order to obtain the knowledge of sedimentation in the reservoir, it is necessary to study the mechanism of sedimentation, which will help to mitigate reservoir sedimentation, prolong the life span of reservoirs and to take full benefits of reservoirs. The sediment deposition in a reservoir depends on the following:

- Longitudinal and lateral valley shape
- Length and shape of reservoir
- Flow patterns in reservoir
- Capacity to inflow volume ratio (trap efficiency)
- Grain size distribution of sediment
- Water and sediment discharges
- Mode of reservoir operation
- Nature of incoming floods

Reservoirs created by dams on rivers lose their storage capacity due to sedimentation. As water enters a reservoir, its velocity diminishes because of the increased cross-sectional area of the channel. If the water stored in the reservoir is clear and the inflow is muddy, the two fluids have different densities and the heavy turbid water flows along the channel bottom towards the dam under the influence of gravity (Figure 1). This condition is known as "stratified flow" and the underflow is called a "density current". A large proportion of the transported silt eventually gets deposited at different levels of a reservoir and causes reduction not only in dead storage but also in live storage capacities.

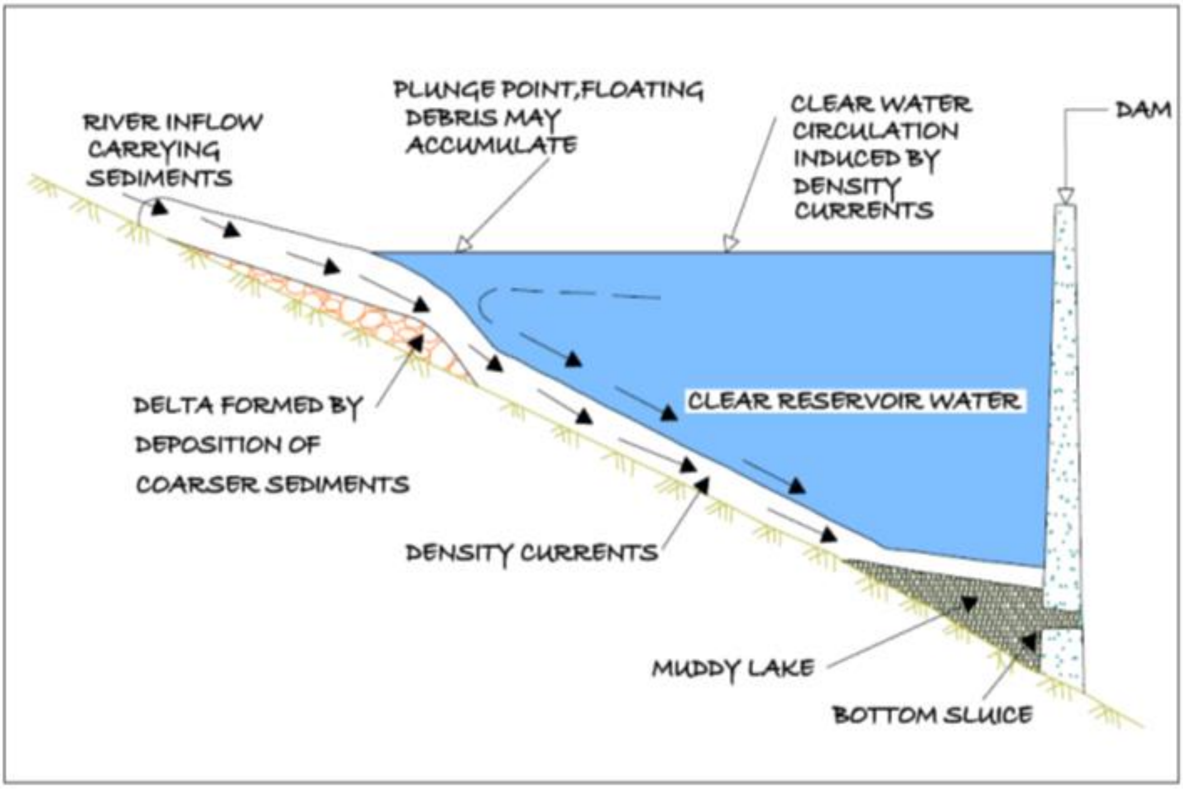


Figure 1: Conceptual sketch of density currents in a reservoir

Earlier, it was believed that sediment always gets deposited in the bottom elevations of reservoir affecting the dead storage rather than depositing throughout the full range of reservoir depth. It is now fully realized that deposition takes place throughout the reservoir reducing the incremental capacity at all elevations.

Longitudinal deposition patterns in the reservoir will vary from one reservoir to another as influenced by pool geometry, discharge and grain size characteristic of the inflowing load and reservoir operation. There can be four types of depositing patterns in the reservoir as shown in the Figure 2 below:

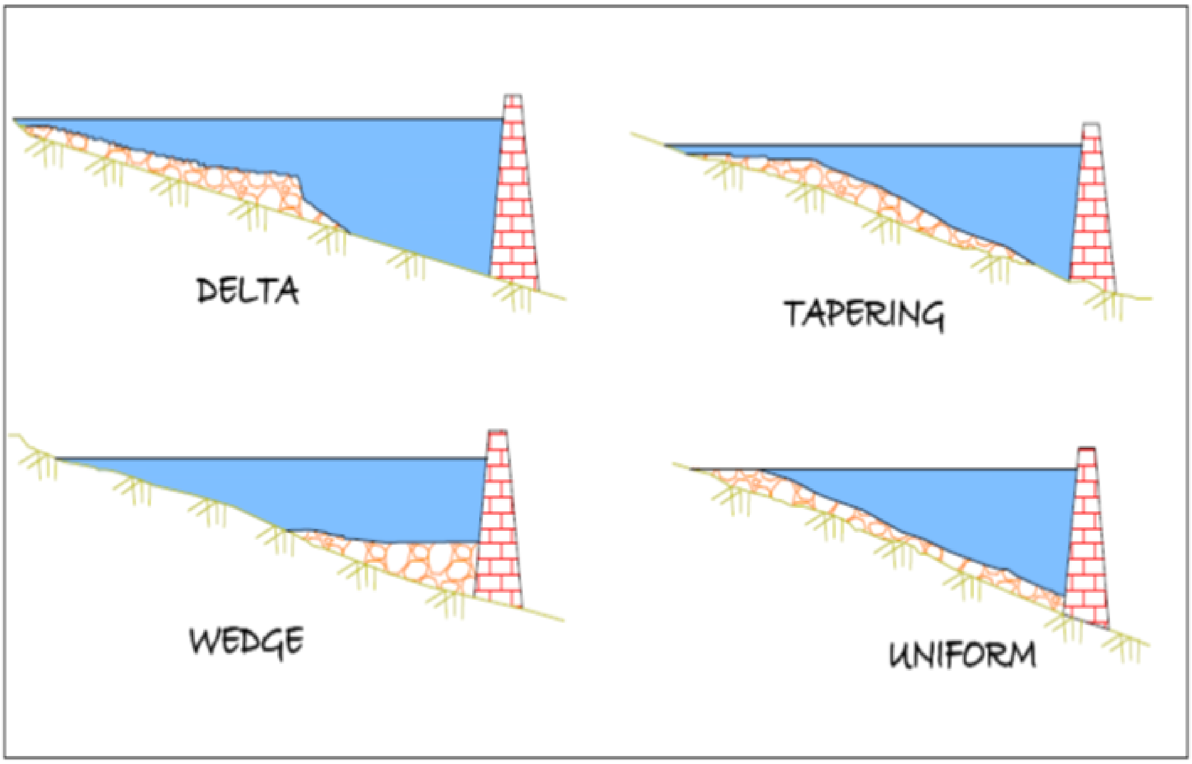


Figure 2: Longitudinal Patterns of sediment deposition in reservoirs

Delta deposits contain the coarsest fraction of the sediment load, which is rapidly deposited at the zone of inflow. It may consist entirely of coarse sediment or may also contain a large fraction of finer sediment such as silt. Wedge-shaped deposits are thickest at the dam and become thinner moving upstream.This pattern is typically caused by the transport of fine sediment to the dam by turbidity currents. Wedge-shaped deposits are also found in small reservoirs with a large inflow of fine sediment, and in large reservoirs operated at low water level during flood events, which causes most sediment to be carried into the vicinity of the dam. Tapering deposits occur when deposits become progressively thinner moving toward the dam. This is a common pattern in long reservoirs normally held at high pool level, and reflects the progressive deposition of fines from the water moving toward the dam. Uniform deposits are unusual but do occur. Narrow reservoirs with frequent water level function and small load of fine sediment can produce nearly uniform deposition depths. Several factors like amount of sediment load, size distribution, fluctuations in stream discharge, shape of reservoir, stream valley slope, vegetation at the head of the reservoir, location and size of reservoir, outlets, etc., control the location of sediment deposits in the reservoir.

Figure 3 shows the different levels in the reservoir where-in the capacity is affected.Reservoirs operate between Minimum Draw Down Level (MDDL), which is at sluice level to Full Reservoir Level (FRL), which is at the dam level. The storage between these two levels is the live storage as shown in Figure 3. The storage below MDDL is the dead storage. Water stored along the valley bed is known as valley storage.

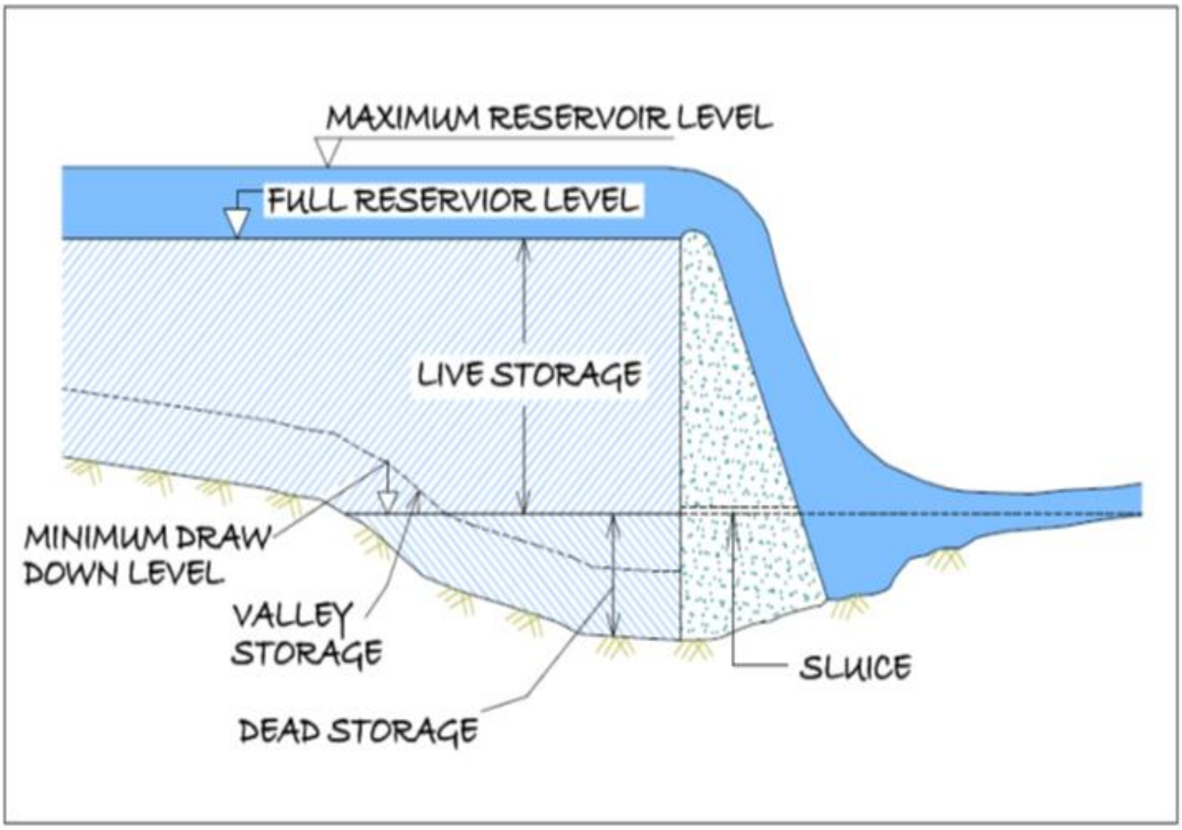


Figure 3: Conceptual sketch of different levels in a reservoir

3. CONTROL OF SEDIMENTATION

Due to the multiple variables involved in reservoir sedimentation, no single control measure can be considered as the most effective control measure. The measures, which can be employed to limit sedimentation and turbidity, are as under:

1. Soil and water conservation measures within the drainage basin which include contour ploughing, strip cropping, suitable farming practices, improvement of agricultural land, construction of small dams/ponds/terraces/check dams on gullies
2. Revetment and vegetation cover
3. Evacuation of sediment
4. Reservoir shoreline protection
5. Stream bank and flood plain protection
6. Ridge plantation such as pasture development and reservoir shoreline protection

Silting not only occurs in the dead storage but also encroaches into the live storage zone, which impairs the intended benefits from the reservoirs. Therefore, the problem of sedimentation needs careful consideration. Adequate provision has to be made in the reservoir for accumulation of anticipated quantities of silt. Steps are also required to be taken to ensure that the storage capacities available are not lost or get reduced by accelerated sedimentation.

4. REMOTE SENSING IN RESERVOIR SEDIMENTATION

Remote sensing is the art and science of collecting information about earth's feature without being in physical contact with it. Various features on earth surface reflect or emit electromagnetic energy depending upon their characteristics. The reflected radiation depends upon physical properties of the terrain and emitted radiation depends upon temperature and emissivity. The radiations are recorded by the sensor on-board satellite and then are transmitted back to earth. Difference between features depends on the fact that response from different features like vegetation, soil, water is different and discernable. Data received at ground stations, is digitally or visually interpreted to generate thematic maps.

The data from satellites such as Landsat, SPOT and IRS are useful for mapping and monitoring the surface water bodies and other land resources based on which, better water management strategies could be planned. Data from microwave remote sensing technique such as SENTINEL-1 is more useful as it is an imaging radar mission providing continuous all-weather, day-and-night imagery at C-band. The SENTINEL-1 constellation provides high reliability, improved revisit time, geographical coverage and rapid data dissemination to support operational applications in the priority areas of marine monitoring, land monitoring and emergency services.

Spectral response of water is affected by variables like time of the year, sun elevation angle, water vapour content in the atmosphere, roughness of water surface, water colour,turbidity, type and concentration of suspended particles, depth of water, characteristics of bottom material and submerged or emergent vegetation.

Reservoir sedimentation surveys are essentially based on mapping of water-spread area at the time of satellite over pass. Multi-date satellite data is needed which covers the operating level of reservoir at close interval. Water spread area is nothing but water level contour at that level. Using different contours, capacity between them is calculated. With the sedimentation, the water spread area of the reservoir reduces at different levels. The water spread area and the elevation information is used to calculate the volume of water stored between different levels. These capacity values are then compared with the previously calculated capacity values to find out the change in capacity between different levels.

Remote Sensing based reservoir capacity estimation has certain limitations. The capacity estimation works between MDDL and FRL only as these are the levels between which reservoir operates. Thus, changes can be estimated only in live capacity of reservoir. For capacity estimation below MDDL corresponding to dead storage other methods like hydrographic survey are to be used. Availability of cloud free data throughout reservoir operations that was a limitation in earlier optical analysis has been taken care of by using microwave datasets that are not affected by weather or illumination conditions. This technique gives accurate estimates for fan shaped reservoir where there is a considerable change in water spread area with change in water level.

5. OBJECTIVES

The objective of the present study is to estimate the loss in the live capacity of Ukai Reservoir (Gujarat) due to sedimentation through Satellite Remote Sensing. Following objectives will be achieved in the study.

- Updation of Elevation - Area - Capacity curve using satellite data in the live storage zone.
- Estimation of storage loss due to Sedimentation.

6. STUDY AREA

The Ukai Reservoir is located at 21°14'53.67" N and 73°35'21.87" E on the river Tapi near the village Ukai, in Fort Songarh Taluk of Tapi District, Gujarat. The construction of the Ukai Dam began in the year 1964 and the first impoundment was done in the year 1972. The dam serves the purposes of irrigation, power generation and flood control.

The Kakrapara weir and canals form the first stage of the project. The second stage is the Ukai Dam. The dam is located across river Tapi, about 29 km upstream of theKakrapara weir. River Tapi originates in Betul district of Madhya Pradesh and flows over a length of about 724 km before joining the gulf of Cambay. The important tributaries of the river are *Purna, Panjara, Vaghur, Bori, and Aner*. The bed gradient of the river varies from 1 in 460 in the initial 260 km stretch in the dense forest region of Madhya Pradesh to 1 in 900 in a further stretch of 270 km, as it widens with a large number of tributaries joining it in Maharashtra. In the next 70 km stretch upto the Ukai dam, the river passes through forested hilly areas with bed width varying from 300 to 340 m. The average bed slope in this reach is 1 in 760. On the downstream side of dam, the river reach of 114 km upto the sea forms the fertile plains of Gujarat state. *Figure 4* shows the Index map of the Ukai Reservoir.

The maximum annual rainfall in the water shed is 1191 mm and the mean annual rainfall inthe catchment is 785 mm. The average annual temperature in the region is 27.2° C. The soil of the Ukai catchment area is mainly black cotton soil in Upper zone while in Satpuda range, it is brown to black clay loam. The soils are derived from the

Deccan trap rocks, intra-Trappeans & Deccan Alluvium deposits. Soils in culturable command are medium to shallow.

Ukai dam is an earth-cum-masonry dam with 4,927 m long embankment wall. Its earth dam is 105.156 m high, whereas the masonry dam is 68.68 m high. Ukai Dam has a catchment area of about 62,255 km^2 and the reservoir area at FRL is 520.00 sq km^2. Ukai Dam has a designed gross reservoir capacity of 8511 MCM with live capacity as 7092.5 MCM (dead storage of 1418.5 MCM). The dam's left bank canal feeds water to an area of 1,522 km^2 and its right canal provides water to 2,275 km^2 of land. The salient features of Ukai Project are given in **Annexure-I**.

7. APPROACH FOR PRESENT STUDY

The present sedimentation assessment study uses the Remote Sensing technique. The Remote Sensing technique makes use of the water-spread of the reservoir between the maximum and minimum operating levels during the observation period. Since the reservoir levels generally do not go below the MDDL, the water spread observations are not possible below MDDL. The same are to be extrapolated from observed Elevation-Area Curve to find out the capacity below MDDL. In the case of Ukai reservoir, the height difference between the FRL (105.156 m) and MDDL (82.296 m) levels is 22.86 m.

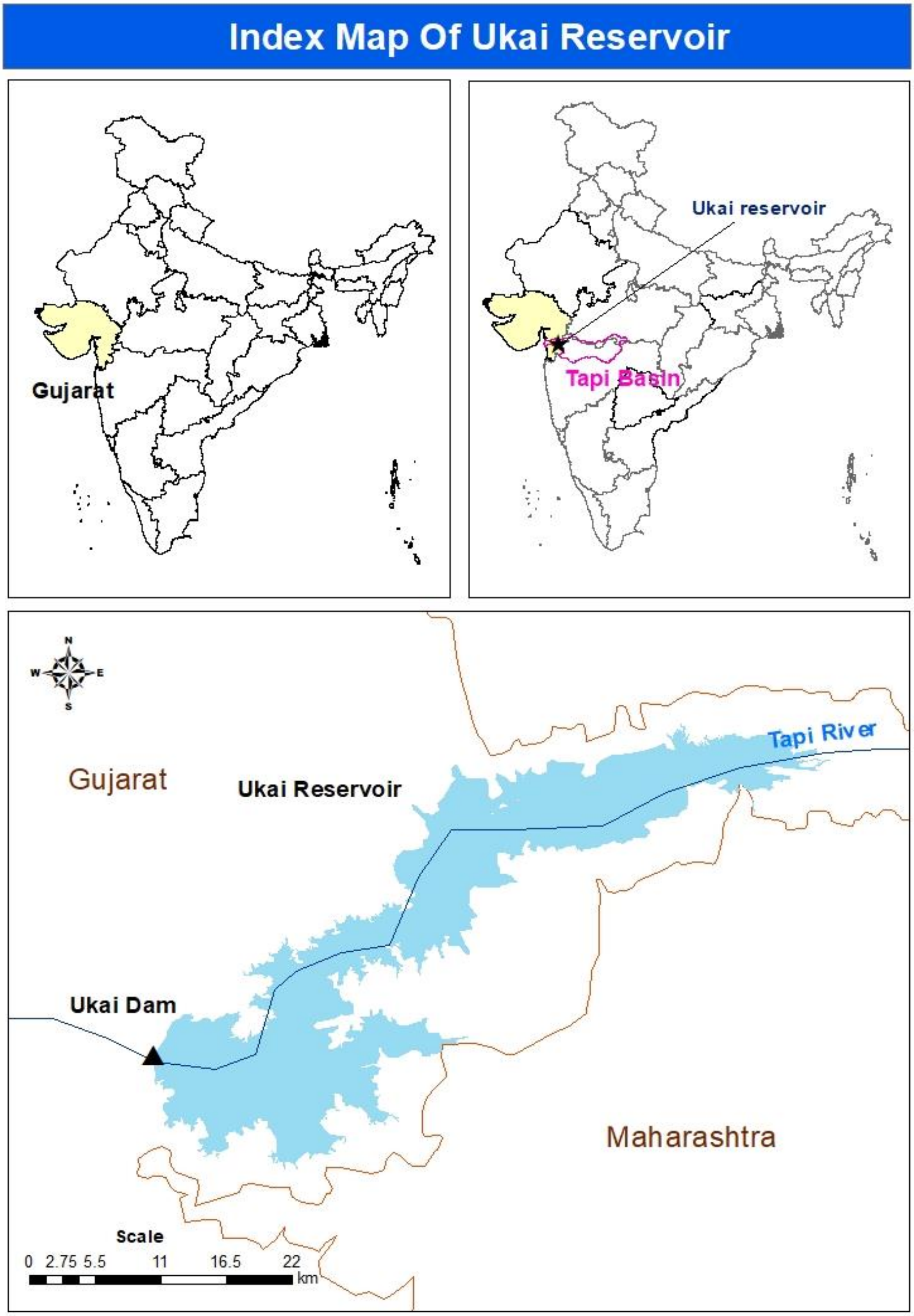


Figure 4: Index map of the UkaiReservoir (Gujarat)

8. DATA USED

8.1 SATELLITE DATA

The Microwave data from Sentinel 1A/1B for **nine (09)** dates during the period **January, 2019 to October, 2020** has been used in the analysis. Table 1 below depicts the dates of pass of satellite along with the elevation observed for the reservoir on that date:

Table 1: Date of pass for satellite data

Satellite	Date of pass	Elevation (in m)
Sentinel 1A	02-07-2019	84.064
Sentinel 1A	03-05-2019	87.584
Sentinel 1A	03-01-2019	93.503
Sentinel 1A	26-06-2020	96.844
Sentinel 1A	21-05-2020	98.191
Sentinel 1A	13-08-2020	100.813
Sentinel 1A	27-02-2020	102.513
Sentinel 1A	10-01-2020	104.065
Sentinel 1A	24-10-2020	105.156

8.2 FIELD DATA

The following field data have been obtained from the Ukai Reservoir project authorities for the purpose of this study:

- Elevation- Capacity data
- Salient features of the Ukai Reservoir, levels and capacity data on specified dates.

9. METHODOLOGY

Digital analysis has an edge over visual analysis in identifying the water spread and turbidity levels in detail and more accurately because of minimizing human error or subjectivity. For Ukai Reservoir study, multi-date Sentinel 1 (09 nos. imageries) is used for the analysis. Image processing with SNAP software and Arc GIS software was used for the analysis. The analysis comprised,

- Geo-referenced Data base.
- Water spread area (WSA) estimation.
- Estimation of reservoir capacity.
- Comparison with original capacity.

The methodology followed by this study for sedimentation analysis is depicted by the flowchart given in Figure 5.

9.1 DATA BASE

The satellite data from Sentinel 1 satellite corresponding to the reservoir areaobtained from Copernicus open access hub was loaded on the system. The Sentinel-1 mission is a constellation of two polar-orbiting satellites (Sentinel-1A and Sentinel-1B), that operate day and night, sensing with a C-band synthetic aperture radar instrument operating at a centre frequency of 5.405 GHz, allowing the acquisition of imagery regardless of weather and illumination conditions. Sentinel-1 satellite constellations acquire Synthetic Aperture Radar (SAR) data in single or dual polarization with a revisit time of 6 days. A series of standard corrections was applied to the data using SNAP software to apply a precise *orbit of acquisition, remove thermal and image border noise, perform radiometric calibration, and apply range Doppler and terrain correction*.

9.2 WATER SPREAD AREA ESTIMATION

Reduction in the capacity of reservoir at different levels is depicted by the reduction in water-spread area (WSA) of the reservoir at different water levels. The estimation of water-spread area is done using various digital image processing (DIP) techniques. The technique adopted for water-spread area estimation are as follows:

- SAR data Pre-processing using Sentinel Application Platform (SNAP)
- Thresholding using ARC-GIS

9.2.1 SAR DATA PRE-PROCESSING USING SNAP

The open-source Sentinel Application Platform (SNAP) Toolkit developed by European Space Agency was used for SAR data pre-processing. Sentinel-1 intensities from high-resolution Level-1 ground range detected products (10 m; GRDH) were calibrated, speckle-filtered, and geometrically corrected using Range Doppler Terrain Correction. Specifically, the improved Lee-Sigma single product speckle filter with a window size of 7 by 7 was used to reduce speckle noise. Terrain correction were conducted using the recently released STRM 1 arc-second HGT digital elevation model (DEM) and UTM/WGS84 (Automatic) Map projection was used wherein SNAP automatically selects the required UTM zones.

9.2.2 THRESHOLDING

The areas where clear water/land demarcation is there, density slicing is successfully used for delineation of water spread areas. *Density slicing* is a technique where the entire grey values of pixels occurring in the image are divided into a series of specified intervals. All the grey values falling within a range are grouped in one grey value, which is displayed in output. This process divides the image into water and land pixels. From the study of histogram peaks, minimum and maximum value for water pixels is identified and image is then density sliced.

Water spread areas are extracted for all the scenes. Figure 6 shows Sentinel 1A/1B images of different dates and Figure 7 shows the superimposed reservoir water spreads for the different dates. Water spread area has been calculated by multiplying number of pixels with area of each pixeli.e. (10m x 10m) in case of Sentinel 1 imagery. Table 2 shows satellite-derived reservoir water spread areas for different satellite overpass dates along with the water levels of the reservoir at the corresponding dates collected from the project authtorites.

Table – 2: Water Spread Areas estimated from Satellite Images			
S N	**Date of pass of Satellite**	**Water level (in m)**	**Water spread area (by SRS) (in M m²)**
1	02-07-2019	84.064	114.058
2	03-05-2019	87.584	177.641
3	03-01-2019	93.503	251.525
4	26-06-2020	96.844	308.254
5	21-05-2020	98.191	351.377
6	13-08-2020	100.813	390.768
7	27-02-2020	102.513	446.49
8	10-01-2020	104.065	480.035
9	24-10-2020	105.15	493.78

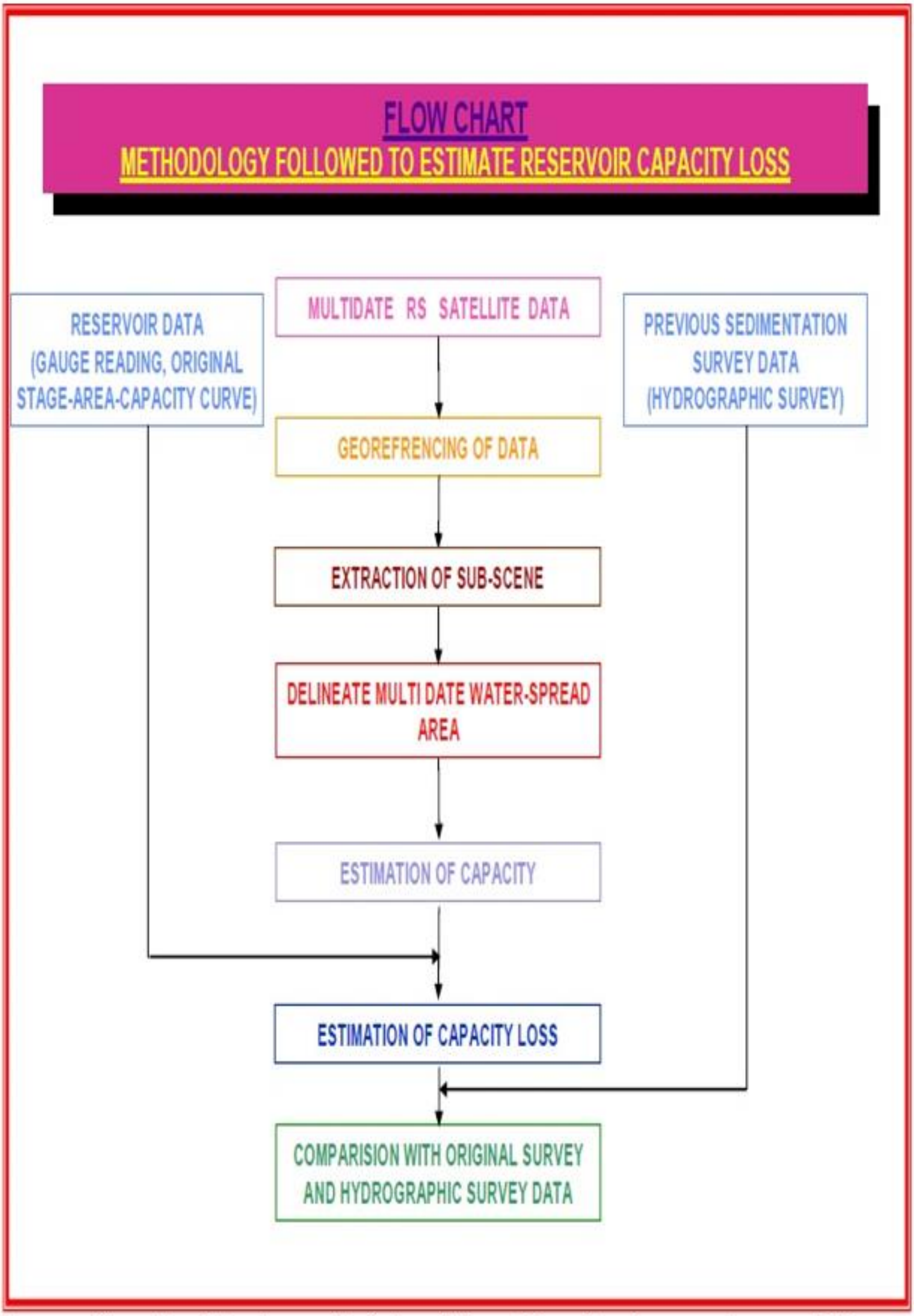
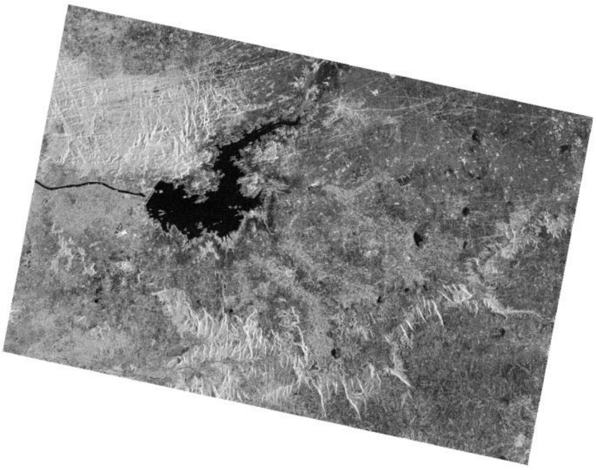
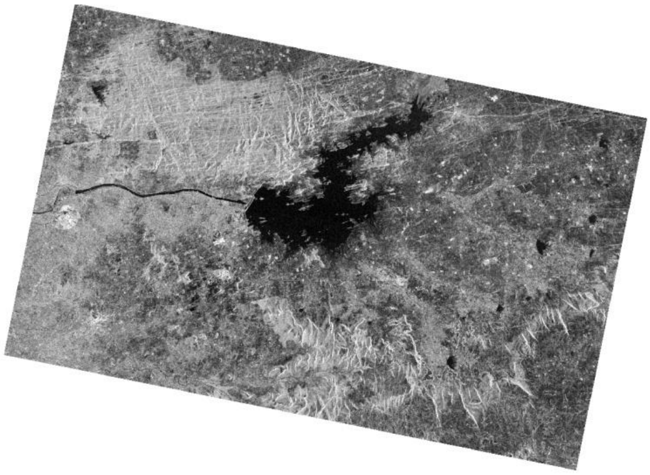


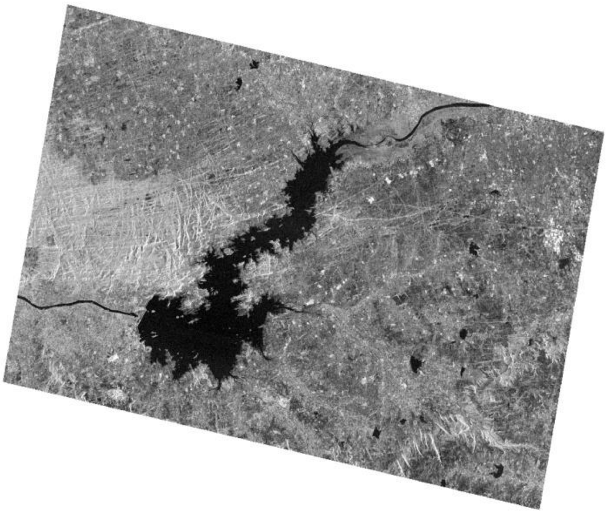
Figure 5 : Flow chart showing methodology followed to estimate reservoir capacity loss



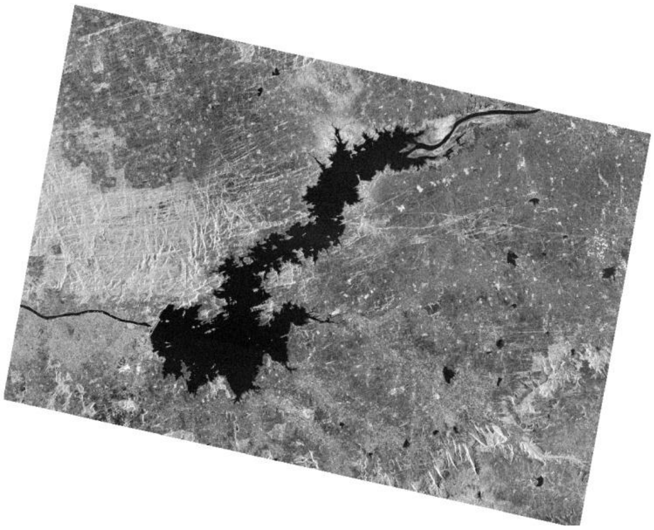
02-July-2010 (84.064 m)



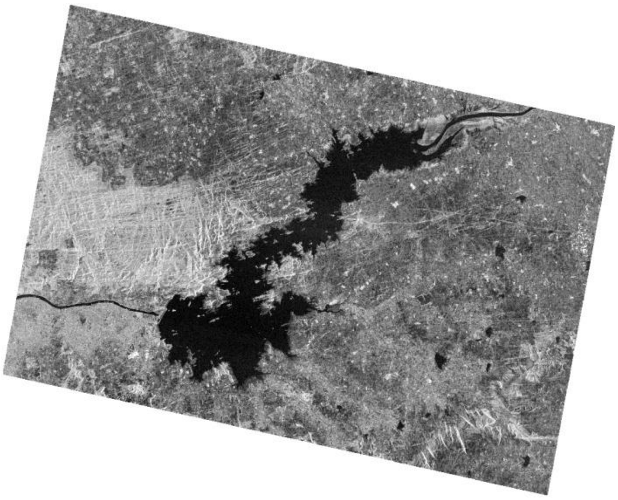
03-May-2019 (87.584 m)



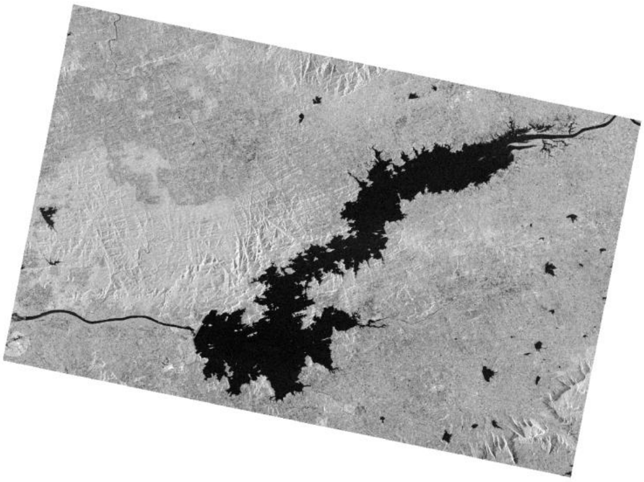
03-Jan-2019 (93.503 m)



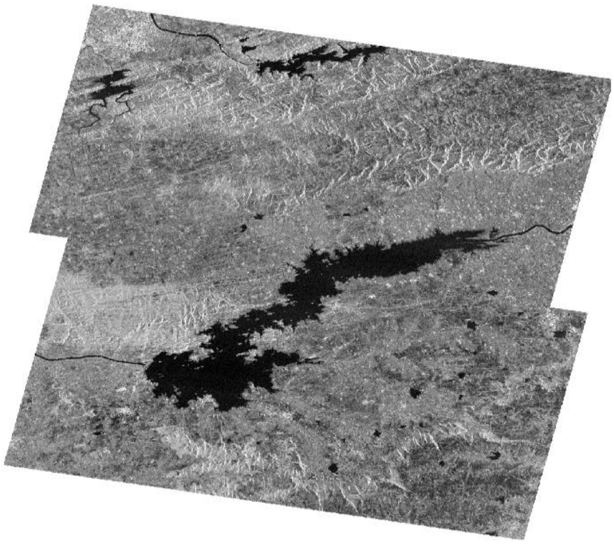
26-June-2020 (96.844 m)



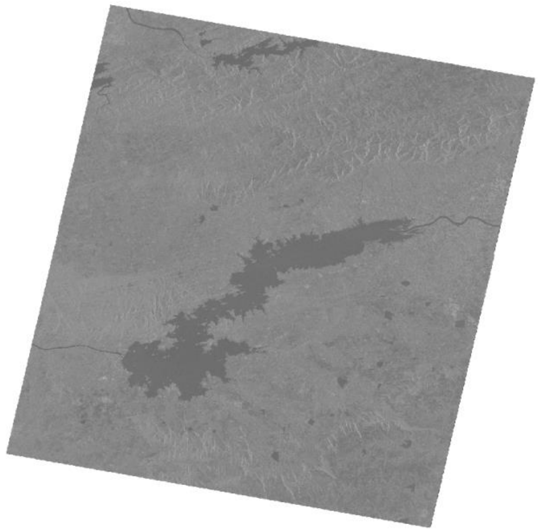
21-May-2020 (98.191 m)



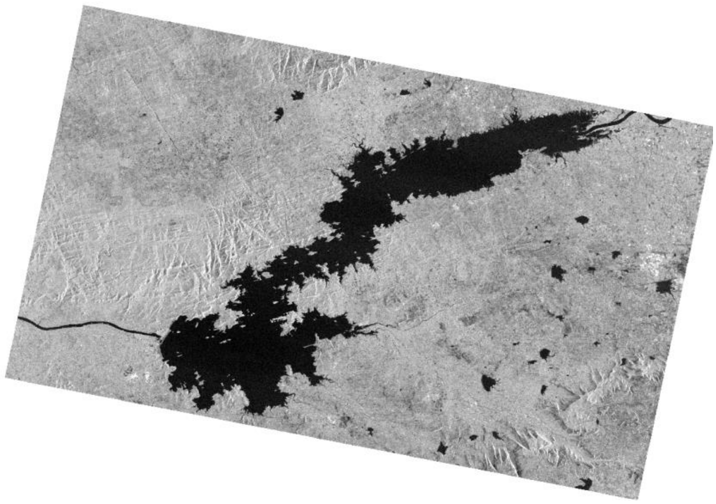
13-Aug-2020 (100.813 m)



27-Feb-2020 (102.513 m)



10-Jan-2020 (104.065 m)



24-Oct-2020 (105.156 m)

Figure 6 : Sentinel 1 SAR imageries showing water spreads on 9 different dates

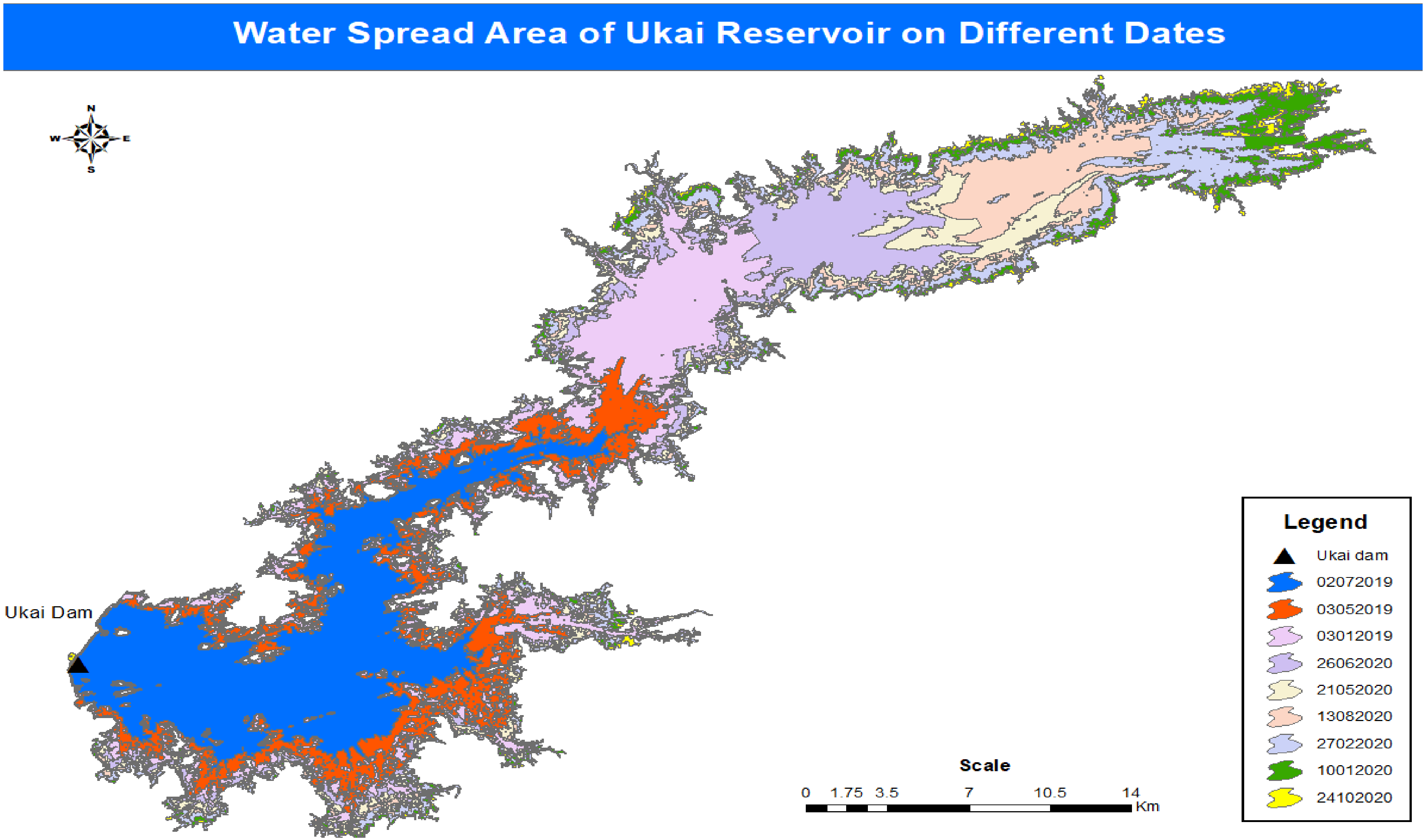


Figure 7: Water Spread Area of Ukai Reservoir on different dates

The Satellite Images for the Ukai reservoir have been obtained from Copernicus Open Access Hub that provides complete, free and open access to all sentinel mission data. The analysis has been carried out using **Sentinel Application Platform** (SNAP) and Digital Image Processing software Arc GIS. The digitally processed images of Ukai Reservoir showing its water spread area for nine overpass dates such as *02 July 2019, 03 May 2019, 03 Jan, 2019, 26 June 2020, 21 May 2020, 13 Aug 2020, 27 Feb, 2020, 10 Jan 2020 and 24 Oct 2020 are shown in figure 7.*

During the study period, Ukai reservoir reached the Full Reservoir Level (FRL) of 105.156 m on 24-Oct-2020. The lowest water elevation of 84.063 m was achieved on 02-July-2019, which is about 1.76 m above the Minimum Drawdown Level (MDDL) of 82.296 m .

9.3 ESTIMATION OF RESERVOIR CAPACITY

The Area-Elevation curve has been plotted using these above nine (09) water-spread areas for different water levels in the reservoir and the *best-fit polynomial equation* of second order as given below have been derived:

$Y = 0.314 X^2 + 10.26X + 101.69$

$R^2 = 0.9958$

Where,

X is Elevation in meters

Y is Water Spread Area in Mm^2

The Elevation-area curve using the above best-fit polynomial equation has been plotted and shown in Figure 8. Water spread areas derived from satellite data for various dates are also marked on the curve. Further, the computation of the reservoir capacity at various elevations was made using following formula:

$V = h/3\{A1+A2 + sqrt. (A1*A2)\}$

Where,

'V' is the reservoir capacity between two successive elevations h1 and h2,

'h' is the elevation difference (h1-h2), and

'A1 & A2' are the areas of reservoir water spread at elevations h1 & h2.

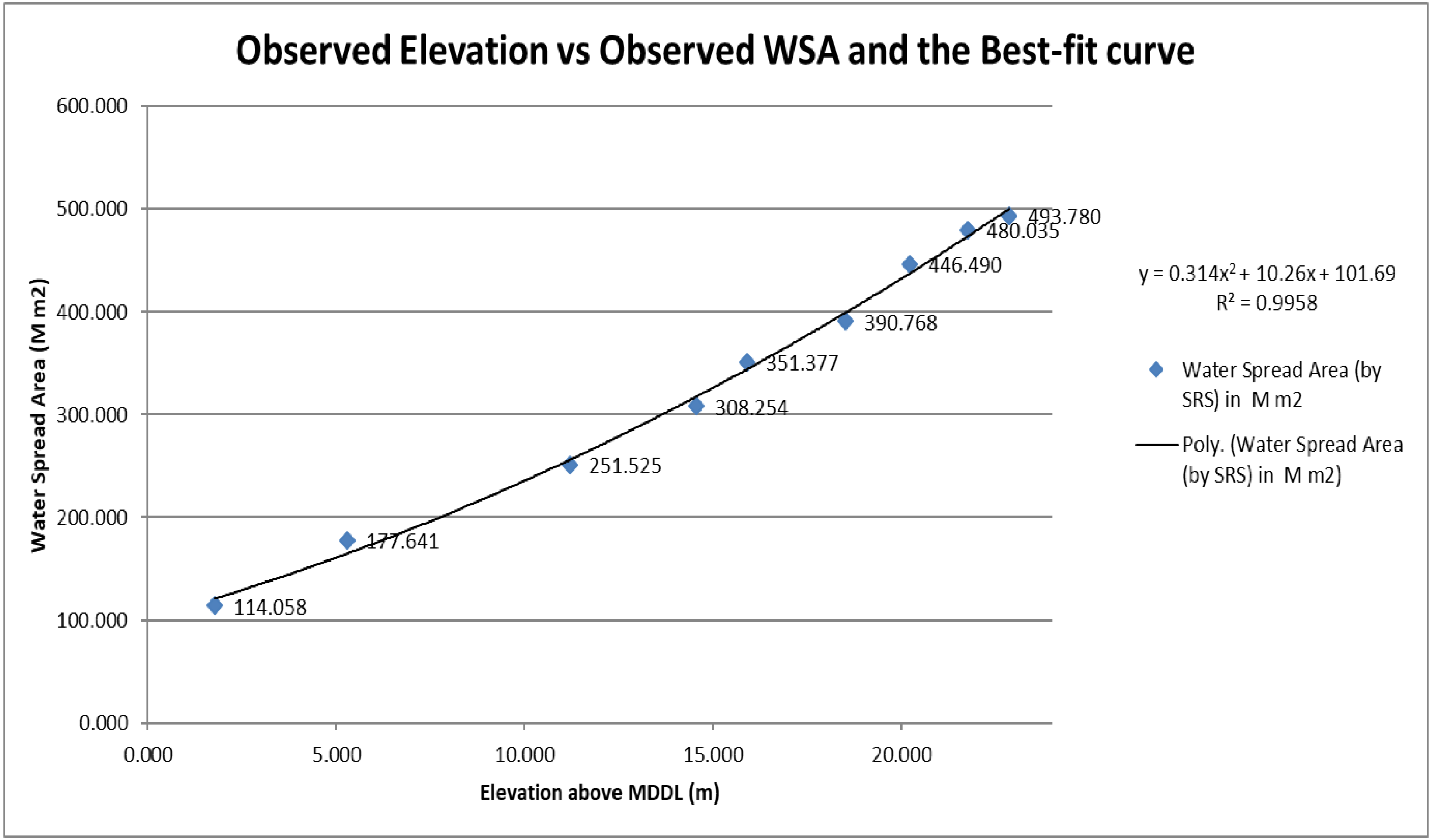


Figure 8: Observed elevation vs Observed WSA of Ukai Reservoir

Table 3 gives the values of Live storage capacity and submergence areas at a regular interval of 1.5 m have been worked out using the best-fit polynomial equation at different elevations.

The Modified live capacity - elevation curve and modified elevation – area –capacity curves are plotted and shown in Figure 9 and Figure 10 respectively.

Table-3: Aerial extent of reservoir at regular interval (1.5 m) using SRS Survey 2020

	Reservoir water level (in m)	Water spread area by trend line (in M m^2)	Segmental Live Capacity by SRS technique (in MCM)	Cumulative Live Capacity by SRS technique 2020 (in MCM)
MDDL	**82.296**	101.690	0.000	0.000
	83.820	118.056	167.291	167.291
	85.344	135.880	193.340	360.631
	86.868	155.162	221.612	582.242
	88.392	175.904	252.107	834.349
	89.916	198.103	284.826	1119.175
	91.440	221.762	319.768	1438.943
	92.964	246.879	356.933	1795.876
	94.488	273.454	396.321	2192.197
	96.012	301.489	437.933	2630.130
	97.536	330.981	481.767	3111.898
	99.060	361.933	527.825	3639.722
	100.584	394.342	576.105	4215.827
	102.108	428.211	626.609	4842.436
	103.632	463.538	679.335	5521.771
FRL	**105.156**	500.324	734.284	**6256.055**

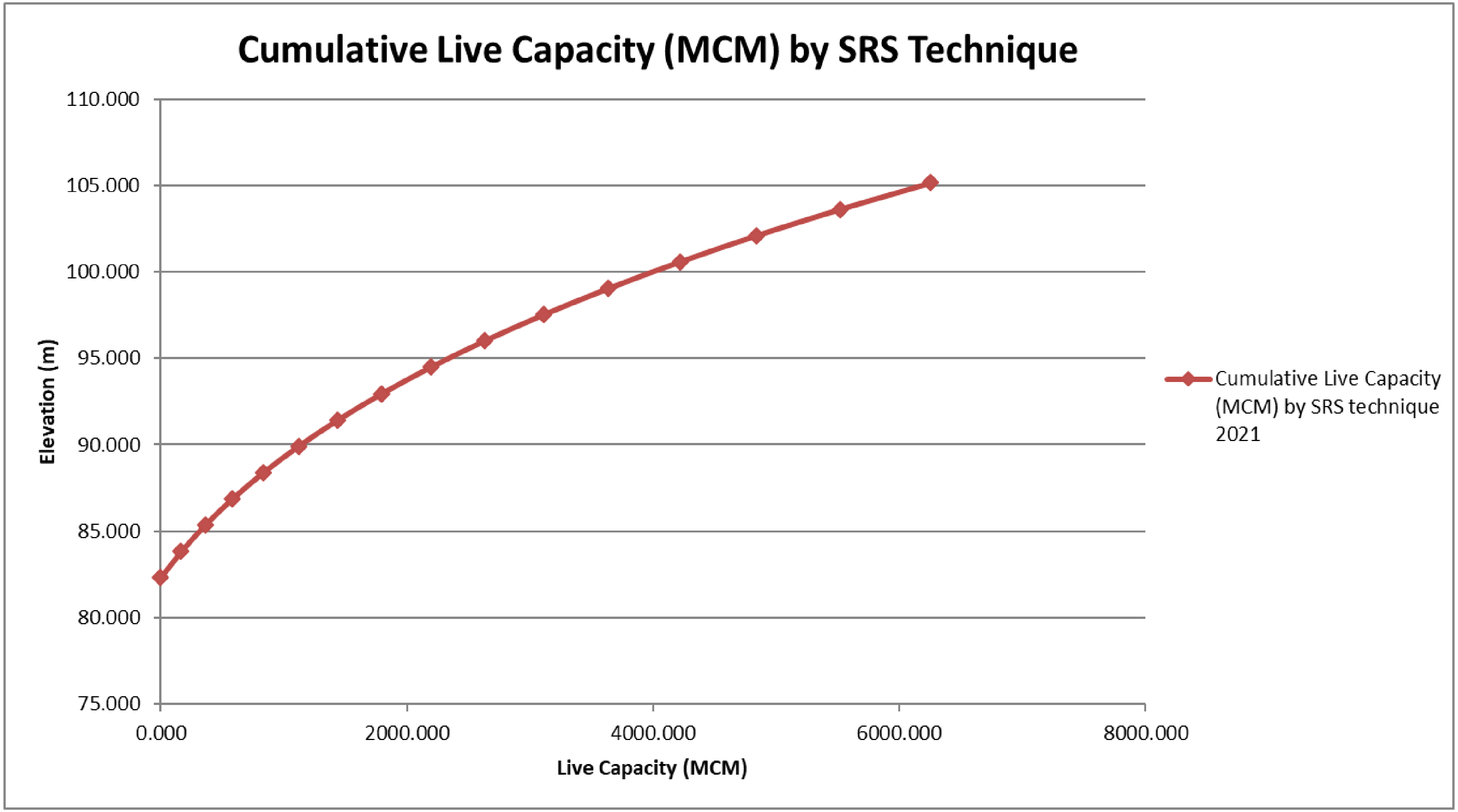


Figure 9: Modified live Capacity - Elevation curve (SRS technique)-Ukai reservoir, Gujarat

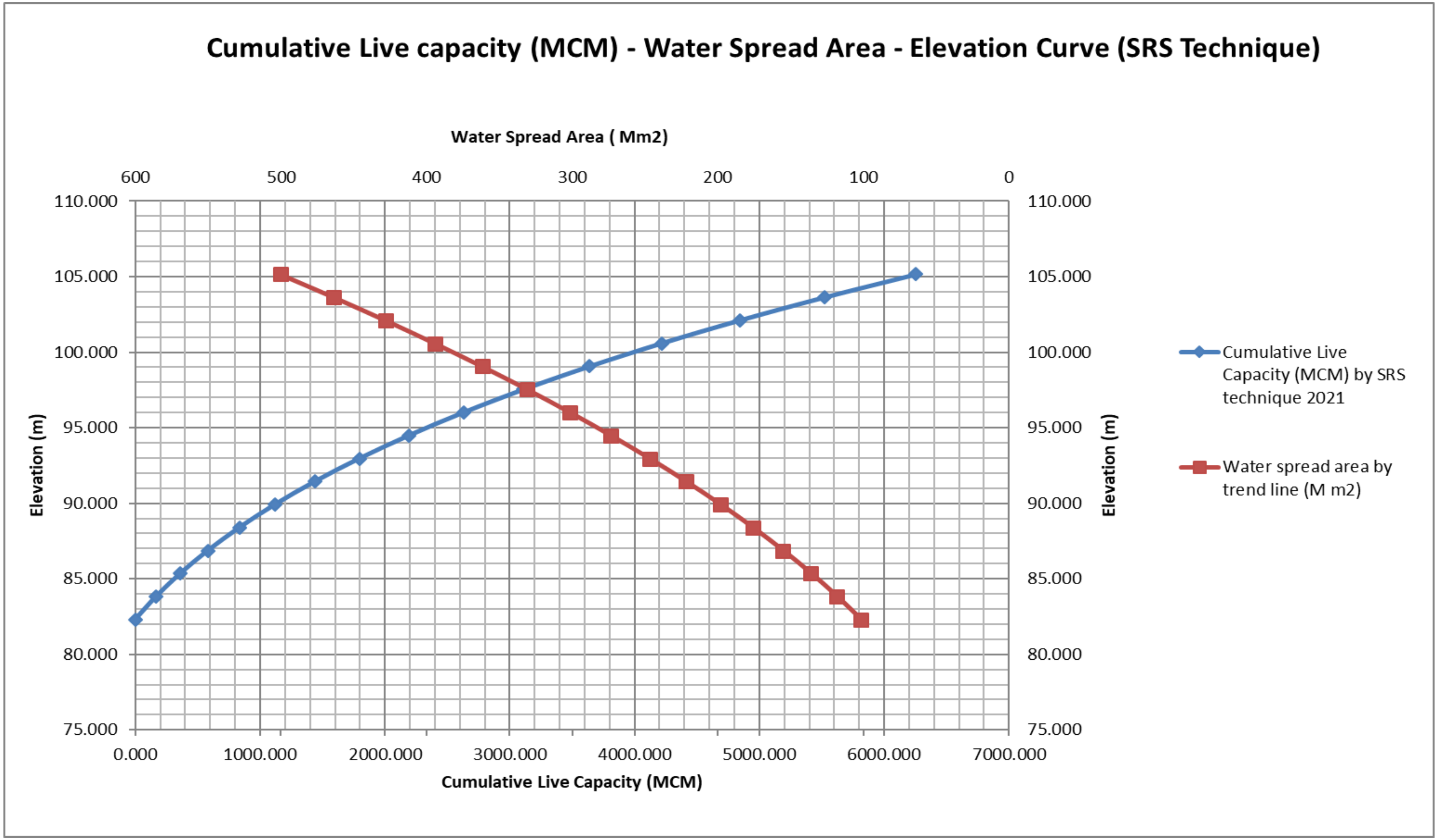


Figure 10: Elevation- Area- Capacity Curve- Ukai reservoir, Gujarat

9.4. Comparison of Live Storage Capacity with Original and Previous Surveys

The comparison of the live storage capacity of the current SRS assessment with the original survey of 1972, the Hydrographic Survey of 1992 and Remote Sensing technique Survey of 2005 at various elevations is given below in table 4. The curves showing the comparison of the live capacity is presented in figure 11:

Table-4: Comparison of the Live Storage Capacity (MCM) of Ukai Reservoir, Gujarat

Elevation (m)	Original Live Capacity (MCM) 1972	Cumulative Live capacity by Hydrographic survey (MCM) 1992	Cumulative Live capacity by SRS survey (MCM) 2005	Cumulative live capacity by SRS survey (MCM) 2020
82.296	0.000	0.000	0.000	0.000
83.820	269.271	187.480	135.630	167.291
85.344	411.368	376.210	301.630	360.631
86.868	678.416	536.700	499.969	582.242
88.392	971.368	853.540	732.214	834.349
89.916	1287.385	1166.870	1000.066	1119.175
91.440	1634.363	1543.080	1305.129	1438.943
92.964	2019.826	1967.380	1649.107	1795.876
94.488	2417.623	2433.640	2033.671	2192.197
96.012	2867.843	2948.010	2460.505	2630.130
97.536	3330.949	3507.290	2931.280	3111.898
99.060	3839.949	4066.770	3447.637	3639.722
100.584	4440.530	4884.750	4011.259	4215.827
102.108	5211.455	5313.830	4623.836	4842.436
103.632	6081.058	5956.480	5287.017	5521.771
105.156	7092.512	6615.150	6002.504	6256.055

The original gross and live storage capacity of the Ukai Reservoir (in 1972) were reported as 8511.0 MCM and 7092.5 MCM, with a dead storage capacity of 1408.5 MCM. The results of the cumulative live storage capacity of the original survey and other subsequent surveys are given in Table 4 above.

In the current SRS study of Ukai Reservoir, it is found that the live storage capacity of the reservoir in 2020 is 6256.05 MCM witnessing a loss in the live storage of about 836 MCM during the 48 year period from 1972 to 2020; amounting to an annual loss of 17.47 MCM during this period. With respect to the 1992 Hydrographic survey results, the current study indicates a loss of about 359 MCM of live storage capacity in the 28 year period from 1992 to 2020; amounting to an annual loss of 12.81 MCM. With respect to the 2003-05 SRS study, it is found that the current study shows a higher or enhanced live storage capacity, an increase of 254 MCM in 15 years. It is pertinent to note here that the 2005 SRS study was done using optical images having a resolution of 23.5m x 23.5 m, whereas the current SRS study has been done using the Microwave data having a much better resolution of 10m x 10m.

Overall it is observed that the live storage capacity of Ukai reservoir as per the present study is found to be **6256.055 MCM** for the year 2020, which reflects **11.79% loss (836.445 MCM**) in the original live storage capacity (*at an annual rate of loss of 0.24% since 1972*).

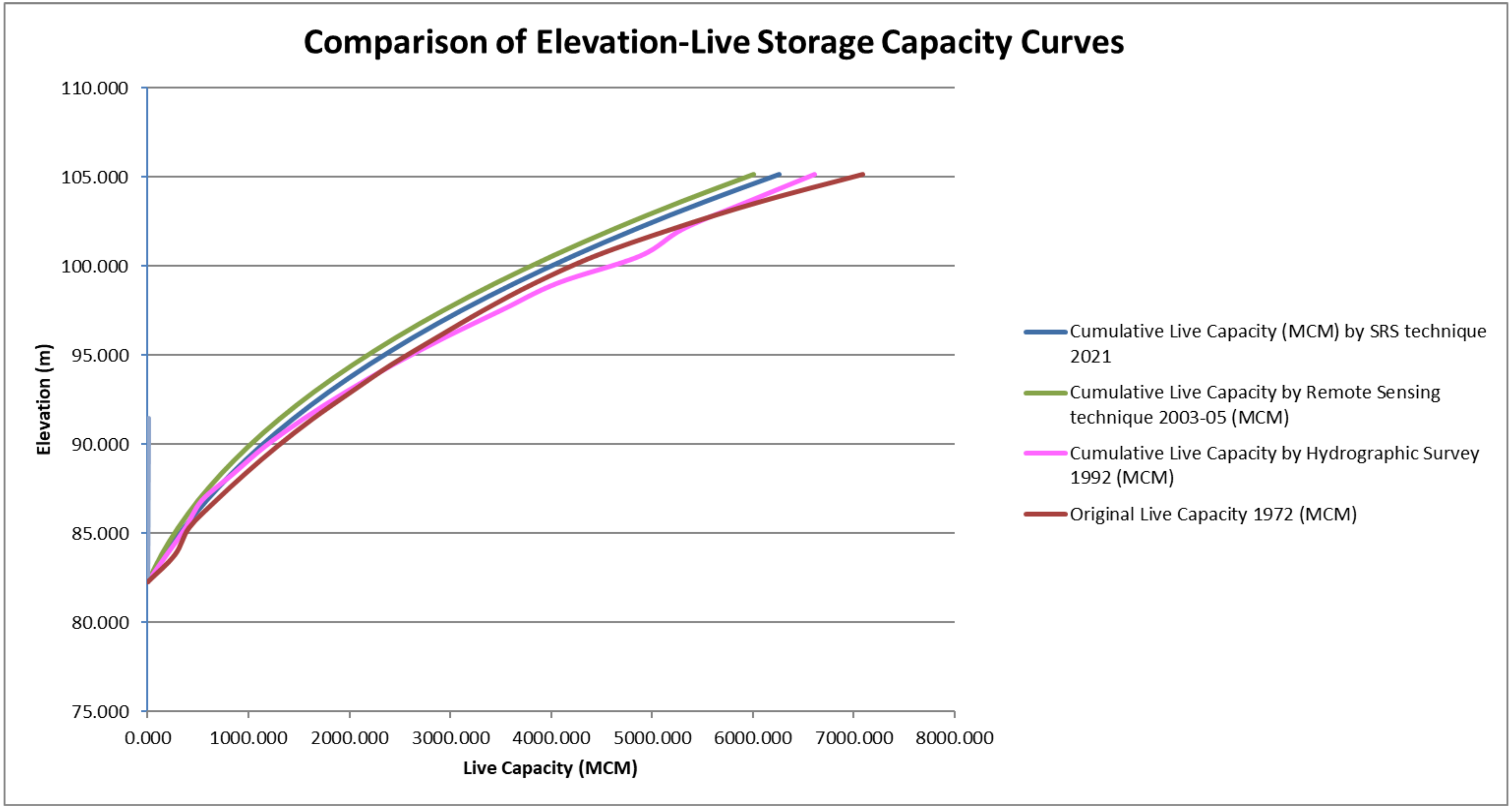


Figure 11: Comparison of Elevation-Live Storage Capacity Curves (MCM) - Ukai reservoir, Gujarat

10. RESULTS AND DISCUSSIONS

Table 5 shows the summary of the sedimentation assessment analysis done for Ukai reservoir. The loss in live storage capacity of the reservoir due to sedimentation as per previous studies/surveys is given below:

Table – 5: Live Storage Capacity loss due to sedimentation as per previous surveys

	Original Survey (1972)	HS (1979)	HS (1983)	HS (1992)	HS (2001)	HS (2003)	SRS (2005)	SRS (2020)
Live Capacity (MCM)	7092.5	6852.0	6803.0	6615.15	7144.2	6729.9	6002.5	6256.055
Loss in Live Capacity (MCM) (since 1972)	--	240.5	289.5	477.362	--	--	--	836.445
% Live capacity loss (since 1972)	--	3.39	4.08	6.73	--	--	--	11.79
% Annual live capacity loss (since 1972)	--	0.48	0.37	0.3365	--	--	--	0.24
% Live Capacity loss between two consecutive surveys (of the original capacity)	--	3.39	0.69	2.65	--	--	--	5.06
Annual % loss between 2 consecutive surveys	--	3.39	0.18	0.29	--	--	--	0.19

As per the original survey conducted for Ukai Reservoir in 1972, the original live storage capacity was 7092.5 MCM. Further, the Hydrographic survey of 1979 revealed a fall of in live storage capacity by 240.5 MCM in 7 years at an annual rate of loss of capacity of 0.48%. Further, the 1983 Hydrographic survey reflected loss of live capacity by another 49 MCM in 4 years. The subsequent Hydrographic Survey of 1992 showed the live capacity to be 6615.15 MCM which is a 477.462 MCM loss from the original capacity in a period of 20 years. Further, the live storage capacity of Ukai reservoir as per the present study is found to be **6256.055 MCM** for the year 2020, which reflects **11.79% loss (836.445 MCM**) in the original live storage capacity (*at an annual rate of loss of 0.24% since 1972*).

In the intermediate years between 1992 and 2020, hydrographic surveys were conducted for Ukai reservoir in the years 2001 and 2003 and a remote based survey was done in the year 2005, which provided the available live storage capacities for the reservoir to be 7144.2 MCM (HS-2001), 6729.90 MCM (HS-2003) & 6002.5 MCM (SRS-2005). Here, it may be observed that a rise of about 529 MCM (7.4% jump in original live capacity) in the live capacity in 9 year time frame from 1992 to 2001 does not seem reasonable and practically feasible. However, the subsequent 2003 HS study reveals a live storage capacity of 6729.90 MCM which seems much acceptable and realistic based upon the previous siltation trends.

Further, the study for the live capacity estimation of Ukai reservoir was done using the SRS technique in 2005 that reflected the live capacity to be 6002.5 MCM. This values seems to be slightly lower than the estimates of the current study and also out of sync with the earlier trends. In view of this, it is pertinent to note here that the 2005 SRS study was done using optical images having a resolution of 23.5 m x 23.5 m, whereas the current SRS study has been done using the Microwave data having a much better resolution of 10m x 10m. The optical image approach (used in 2005) has an inherent limitation due to low resolution images, making the identification difficult for the edge pixels as to whether they are land or water. So, the imageries used in 2005 were not of the same quality as in 2020. Therefore, outcome of SRS 2005 is expected to have a lesser reliability as compared to SRS 2020 survey using the microwave imageries.

The modified elevation-area-capacity table worked out by the present study is given at Table 3.

11. CONCLUSION

The following conclusions emerge from the present study, subject to the limitations stated in the following paragraphs:

1. The live storage capacity of Ukaireservoir has been found to be **6256.055 MCM** in 2020.

2. This study reflects a loss of**11.79% (836.445 MCM**) in the original live storage capacity at an annual rate of loss of 0.24% since the first impoundment in 1972.

3. Satellite Remote Sensing (SRS) based survey gives the information on the capacities in the water level fluctuation zone only, which generally lies between MDDL and FRL of the reservoir. Use of Satellite Remote Sensing technique enables a fast and economical estimation of live storage capacity loss due to sedimentation.

4. Capacity estimation by this technique at regular time interval can give important parameters like annual rate of sedimentation and sediment deposition pattern in the live storage zone of reservoir and provide new elevation - area - capacity curve for optimal operation of the reservoir.

5. Capacity estimation using Microwave remote sensing technology has the advantage that cloud-free imageries are available throughout the year at frequent interval as they are not affected by weather or illumination conditions.

12. LIMITATIONS/OBSERVATIONS

- As the reservoir operates between MDDL and FRL, the satellite data is generally available for this range only. The satellite remote sensing based reservoir capacity estimation works between MDDL and FRL in live storage.

- Remote Sensing techniques give accurate estimate for fan shaped reservoir where there is considerable change in water-spread area with change in water level.

- Ground truth verification of boundary pixels is not possible due to continuous variation in reservoir levels,that prevents correlating field observation of reservoir boundary with satellite data.

Annexure-I

Salient Feature of Ukai Reservoir, Gujarat		
1	*Name of the Reservoir:*	Ukai Reservoir
2	*General Location:*	Ukai village in Songarh Taluka of Tapi District of Gujarat State
3	*Nearest City:*	Surat, Gujarat
4	*Village:*	Ukai
5	*River:*	Tapi
6	*Year of Impoundment:*	1972
7	*Total catchment area at dam site:*	62225 sq km
8	*Average rainfall in the catchment:*	785 mm
9	*Average yield at the dam site:*	17269 Mcum
10	*Design flood:*	49,490 cumecs
11	*Reservoir levels:* *i. River bed level:* *ii. Crest level of spillway:* *iii. FRL:* *iv. MWL:* *v. Top of Dam:* *vi. Dead storage level:*	 42.673 m 91.135 m 105.156 m 106.985 m 111.253 m 82.296 m
12	*Reservoir Capacity Data: (Original):* *i. Gross storage @ F.R.L.* *ii. Dead storage:* *iii. Live Storage:*	(in MCM) 8511.0 1418.50 7092.50

13	*Total area of submergence at F.R.L.*	60095 Ha
14	*Dam Details:* *i.* *Height of dam above the deepest bed level:* *ii.* *Length of dam at crest:* *iii.* *Crest level of spillway:* *iv.* *Spillway length:* *v.* *Type & No. of spillway gates:*	 68.58 m 4926.83 m 91.135 m 425.196 m Radial 22 Nos. (Gate size – 15.45 m x 14.78 m)
15	*Project Benefits:*	Irrigation, Hydropower, Partial Flood Control

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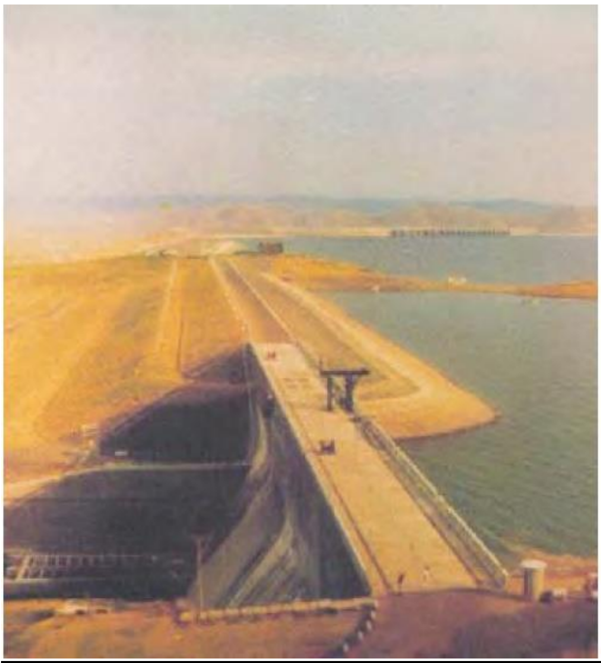
Annexure-II

PHOTOGRAPHS OF UKAI RESERVOIR, GUJARAT



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