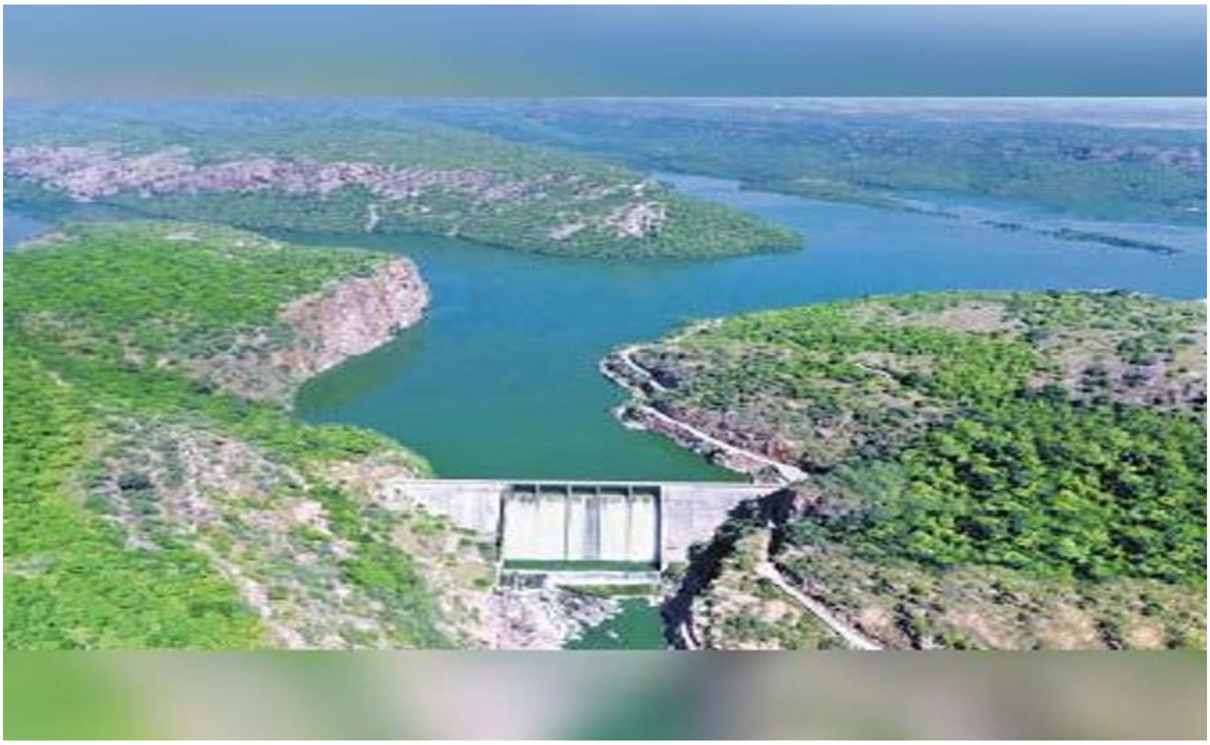
सत्यमेव जयते

उपग्रह दूरस्थ संवेदन द्वारा
जाखम जलाशय राजस्थान का अवसादन आंकलन

SEDIMENTATION ASSESSMENT OF JAKHAM RESERVOIR, RAJASTHAN, THROUGH SATELLITE REMOTE SENSING



भारत सरकार
केन्द्रीय जल आयोग
पर्यावरण प्रबंध संगठन
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Government of India
Central Water Commission
Environment Management Organization
Remote Sensing Directorate

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SEDIMENTATION ASSESSMENT OF JAKHAM RESERVOIR, RAJASTHAN, THROUGH SATELLITE REMOTE SENSING

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

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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 2020, 2021 in the sedimentation study of Jakham reservoir. 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 Jakham 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.

Jakham Dam was constructed in 1986 over river Jakham, which is tributary of river Mahi in Chittorgarh district of Rajasthan. Project has a designed live storage capacity of 132.28 MCM. In 2003-04 Satellite Remote Sensing survey was done that reported the live capacity as 175.451 MCM. The capacity for the project purpose estimated at the time of commissioning in 1986 shows lesser capacity as compared to SRS survey conducted in 1986. This may be due to erroneous survey conducted in 1986 or error in the estimation of original capacity itself. The Reservoir Hydrographic survey has been carried out in year 2021 that reported gross capacity as 168.35 MCM and live Capacity as 162.68 MCM.

After analysis of the satellite data in the present study, it is found that live capacity of Jakham reservoir in 2021 is 159.312 MCM witnessing a live storage loss of 16.139 MCM (i.e. 9.199%) in a period of 18 years during 2003 to 2021. This accounts for live capacity loss of 0.511% per annum since 2003. It may be noted that the recent Reservoir Hydrographic survey conducted in 2021, reported the live capacity as 162.68 MCM having very slight difference with Live Storage assessment using Remote sensing technique in the present study i.e about 3.368 MCM (i.e. 2.07%), which is less than 5% and in acceptable range.

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ABBREVIATIONS

CWC	Central Water Commission
DSL	Dead Storage Level
FRL	Full Reservoir Level
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 JAKHAM RESERVOIR, RAJASTHAN THROUGH 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 more 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 along with efficient management and operation of reservoirs thereby deriving maximum benefits for the society.

This report covers the study of Jakham Reservoir, Rajasthan by Central Water Commission, New Delhi.

2. SOURCES AND MECHANISM OF SEDIMENTATION

The principal sources of sediments are as follows:

- Deforestation
- Excessive erosion in the catchment
- Disposal of industrial and public wastes
- Farming
- Channelisation works
- Human activities
- 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 river bank 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 (Fig 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.

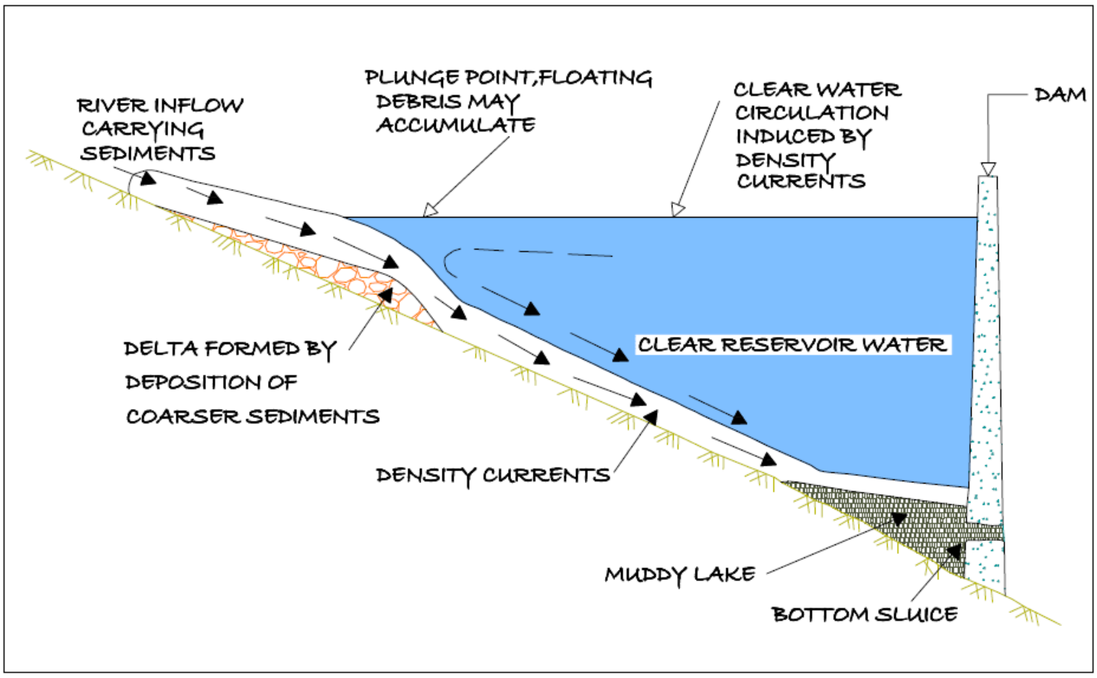


Fig. 1: Conceptual sketch of density currents in a reservoir

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 fig 2.

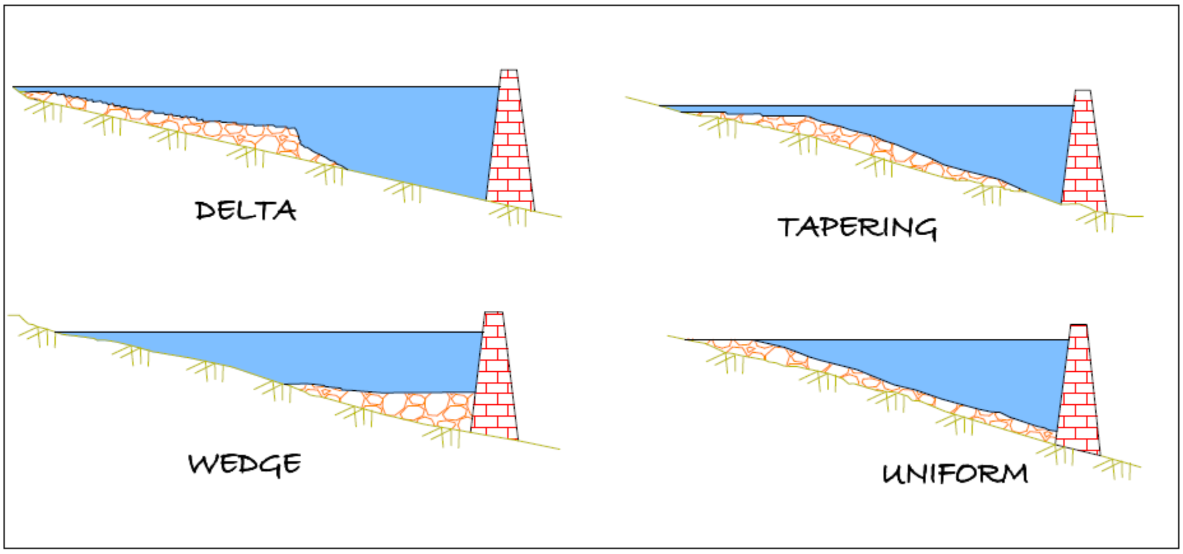


Fig. 2: Longitudinal Patterns of sediment deposition in reservoirs.

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 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 dam level. The storage between these two levels is the live storage as shown in Fig. 3. The storage below MDDL is the dead storage. Water stored along the valley bed is known as valley storage.

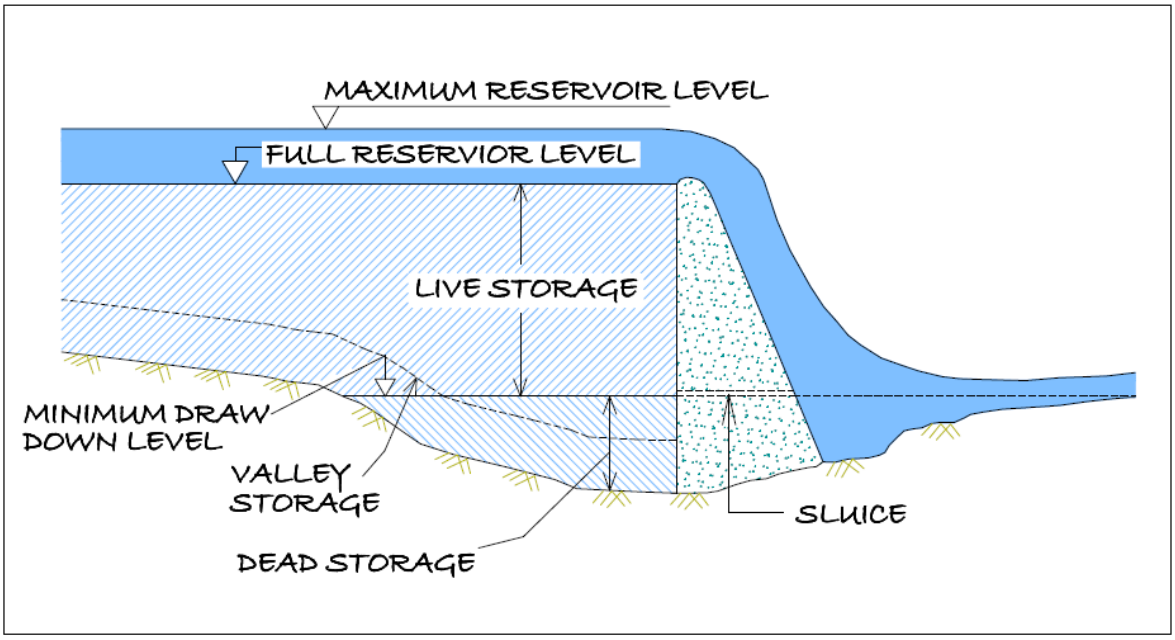


Fig. 3: Conceptual sketch of different levels in a reservoir

3. CONTROL OF SEDIMENTATION

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

- Soil and water conservation measures within the drainage basin include contour ploughing, strip cropping, suitable farming practices, improvement of agricultural land, construction of small dams/ponds/terraces/check dams on gullies
- Revetment and vegetation cover
- Evacuation of sediment
- Reservoir shoreline protection
- Stream bank and flood plain protection
- 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 study is to estimate live capacity loss of Jakham reservoir 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 live storage zone.
- Estimation of storage loss due to Sedimentation.

6. STUDY AREA

Jakham Reservoir is located at 24º10’30”N latitude and 74º35’10” E longitude at village Annupura, tehsil Pratapgarh, district Chittorgarh in Rajasthan. It was constructed in the year 1986 on river Jakham - a tributary of river Mahi. The project provides irrigation benefits to tribal people of area consisting of 104 villages of Dhariawad tehsil and 3 village of Pratapgarh tehsil. The area near the dam is hilly and consists of waste land, hence a pickup weir at Nagada, which is 13 km away from dam is constructed from which main canal emerges. Figure 4 shows index map of Jakham Reservoir.

Project has a catchment area of 1010 sq km with average yield as 212.376 Mcum. It lies in Pratapgarh and Chotisadri tehsils of Chittorgarh in agroclimatic zone IVB. The irrigated area in catchment covers 95.85 sq kms (9.49%) and the unirrigated cultivable area is 366.32 sq km (36.27%). Around 45% of the catchment area has sufficient soil cover for raising crops and this area may contribute to soil erosion to Jakham reservoir. Forest area covers 23.52% of catchment area. Soils in the area vary considerably. The soils are silty loam to clay loam, occaisonally clay, greyish brown to dark greyish brown. Soils are deep and are derived from alluvium of phyllites and limestone.

Study area falls in typical sub-tropical, sub-humid to humid climate conditions, characterized by mild winter and moderate summer with high relative humidity during the month of July-September. Mean monthly minimum temperature ranges from 11ºC (Jan) to 26ºC (June) and mean monthly maximum temperature ranges from 21.8ºC (Jan) to 43.8ºC (May). Average annual rainfall varies between 800-900 mm.

Length of Dam is 253.0 m with maximum height as 81.0 m. two main canal with length as 23.76 km of RMC and 39.00 km of LMC emerge from pick up weir. The lined canals have design discharge of 3.533 cumecs (RMC) and 7.92 cumecs (LMC).

Salient features of the Jakham project are given in Annexure 1.

7. APPROACH FOR PRESENT STUDY

Remote Sensing technique makes use of water-spread of the reservoir between maximum and minimum operating level during the observation period. Since the reservoir levels generally do not go below the MDDL, water spread observations are not possible below MDDL. The same are to be extrapolated from observed elevation-area curve to find out capacity below MDDL. In the case of Jakham reservoir, the height difference between FRL (359.50 m) and MDDL (332.00 m) is 27.50 m.

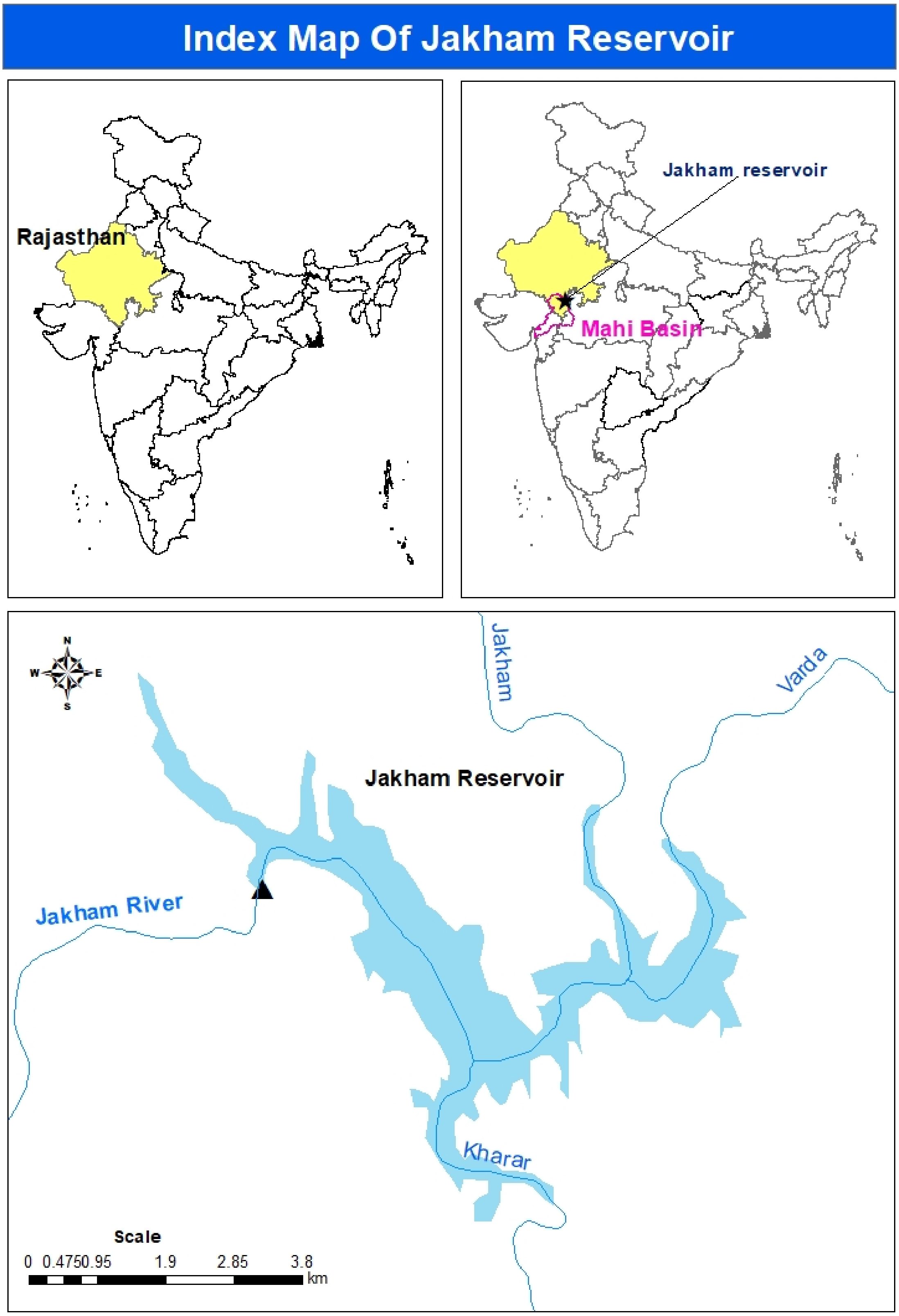


Fig. 4: Index map of the Jakham Reservoir

8. DATA USED

8.1. SATELLITE DATA

Microwave data from Sentinel 1A/1B for Eight (08) dates has been used in the analysis. Table 1 depicts the date of pass of satellite along with elevation observed on that date.

Table – 1: Date of pass for satellite data

Satellite	Date of pass	Elevation (m)
Sentinel 1A	03-07-2021	344.45
Sentinel 1A	05-03-2021	347.00
Sentinel 1A	21-02-2021	349.00
Sentinel 1A	09-02-2021	350.65
Sentinel 1A	28-01-2021	352.20
Sentinel 1A	04-01-2021	354.70
Sentinel 1A	06-12-2020	356.85
Sentinel 1A	05-11-2020	359.45

8.2. FIELD DATA

The following field data have been obtained from project authorities:

Elevation - Capacity data

Salient features of Jakham reservoir levels and capacity data on specified dates.

9. METHODOLOGY

Digital analysis has an edge over visual analysis in identifying water spread and turbidity levels in detail and more accurately because of minimizing human error or subjectivity. For Jakham reservoir studies, multi-date Sentinel 1A (08 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 estimation.
- Estimation of reservoir capacity.
- Comparison with original capacity.

9.1. DATA BASE

The satellite data from Sentinel 1 satellite corresponding to reservoir area obtained 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 capacity of reservoir at different levels is depicted by reduction in water-spread area (WSA) at different water levels. 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. Fig. 6 shows Sentinel 1A/1B images of different dates and Fig. 7 shows the superimposed reservoir water spreads for different dates. Water spread area has been calculated by multiplying number of pixels with area of each pixel i.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

Sl No	Date of pass of Satellite	Water level in Meter	Water spread area (by SRS) in M m2
1	03-07-2021	344.45	4.059
2	05-03-2021	347.00	6.203
3	21-02-2021	349.00	6.835
4	09-02-2021	350.65	7.532
5	28-01-2021	352.20	8.583
6	04-01-2021	354.70	10.437
7	06-12-2020	356.85	12.183
8	05-11-2020	359.45	14.350

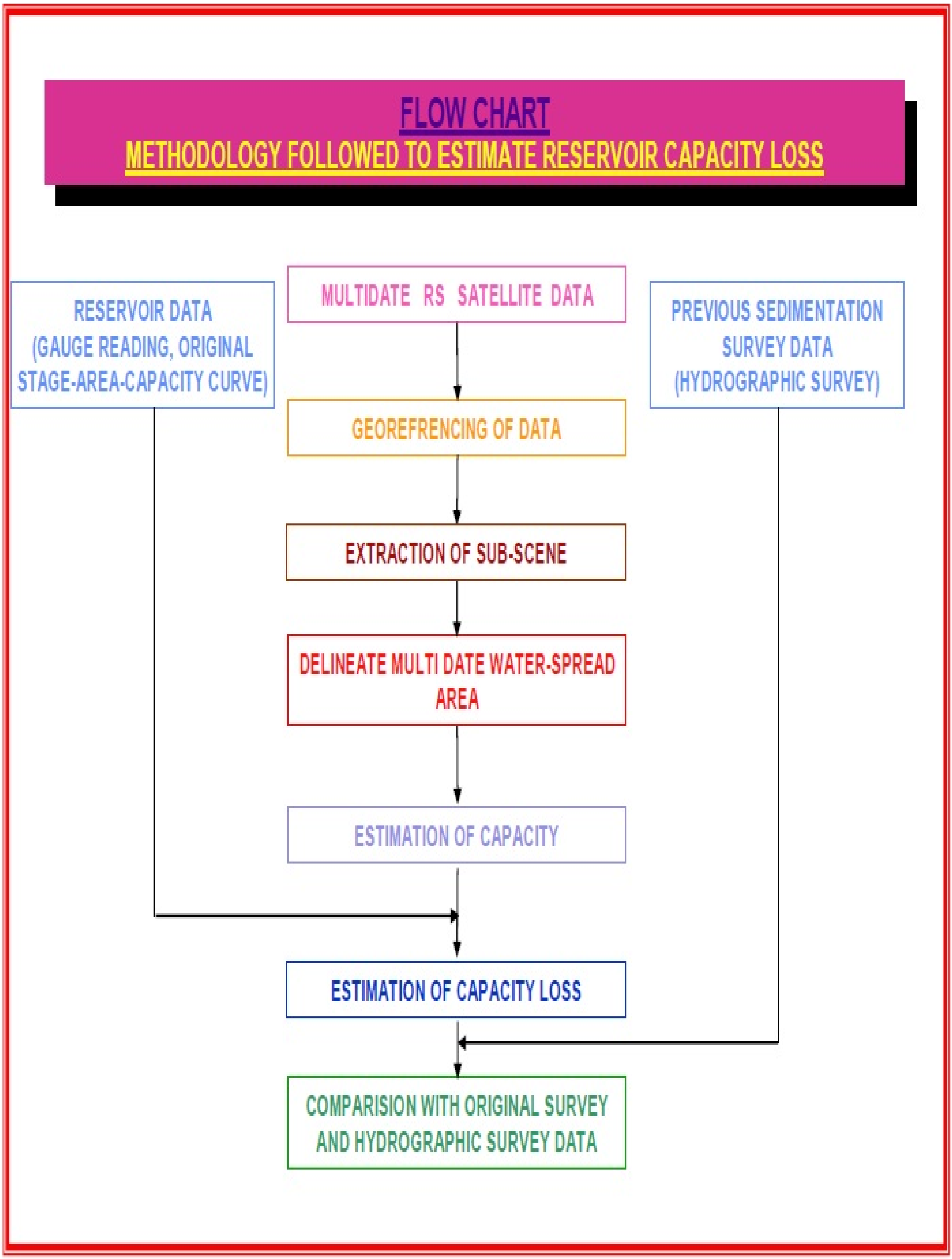
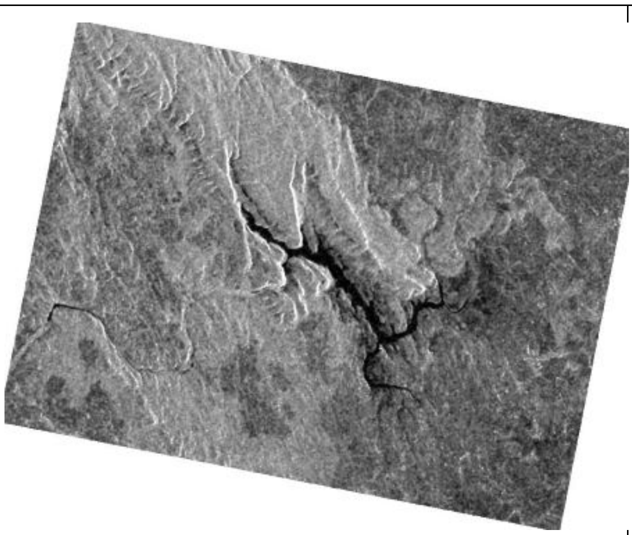
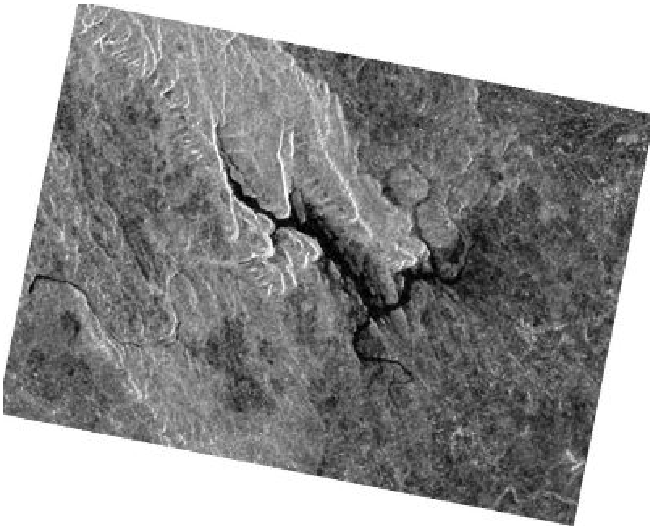
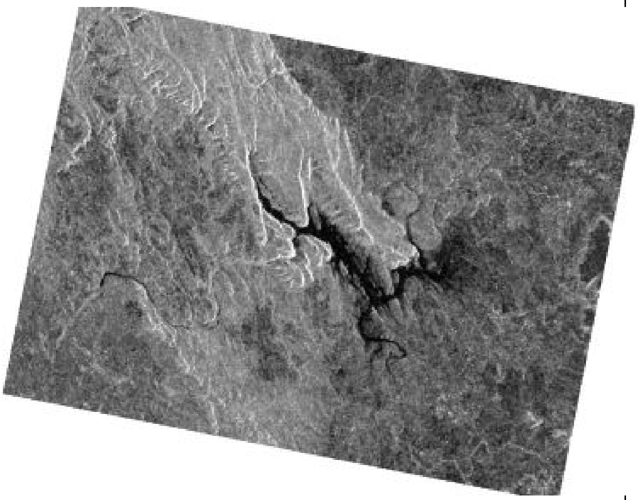
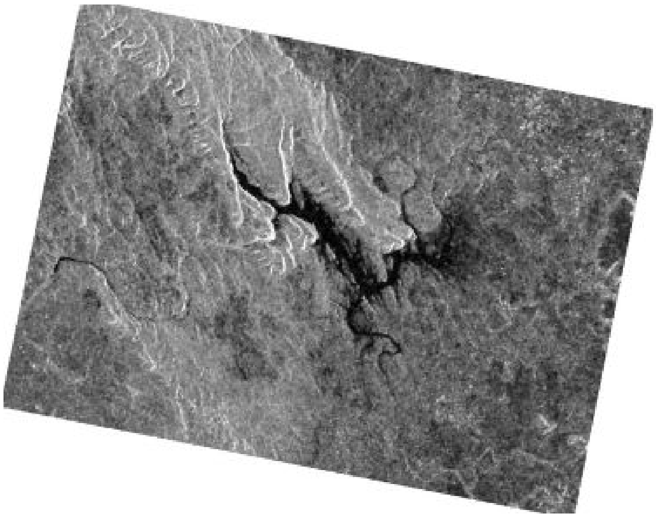
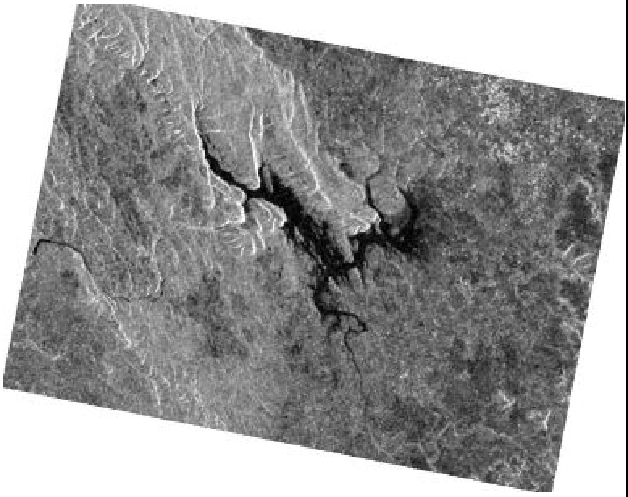
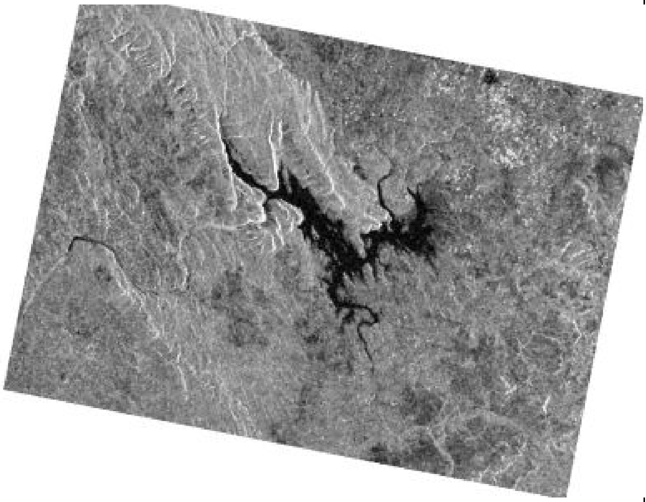


Fig 5 : Flow chart showing methodology followed to estimate reservoir capacity loss

	
03-July-2021 (344.45 m)	**05-Mar-2021 (347.00 m)**
	
21-Feb-2021 (349.00 m)	**09-Feb-2021 (350.65 m)**
	
28-Jan-2021 (352.20 m)	**04-Jan-2021 (354.70 m)**

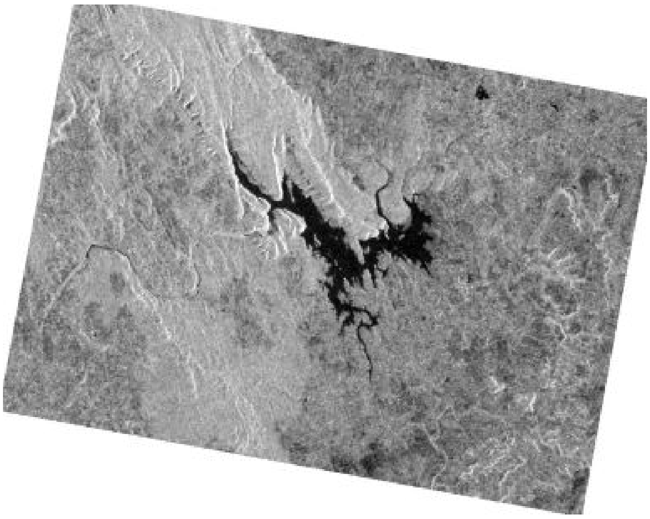
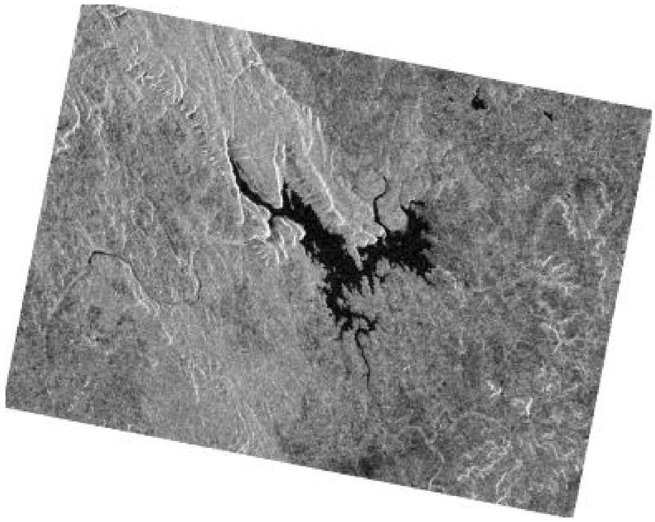
	
06-Dec-2020 (356.85 m)	**05-Nov-2020 (359.45 m)**

Fig 6 : Sentinel 1 SAR imageries showing water spreads at different dates

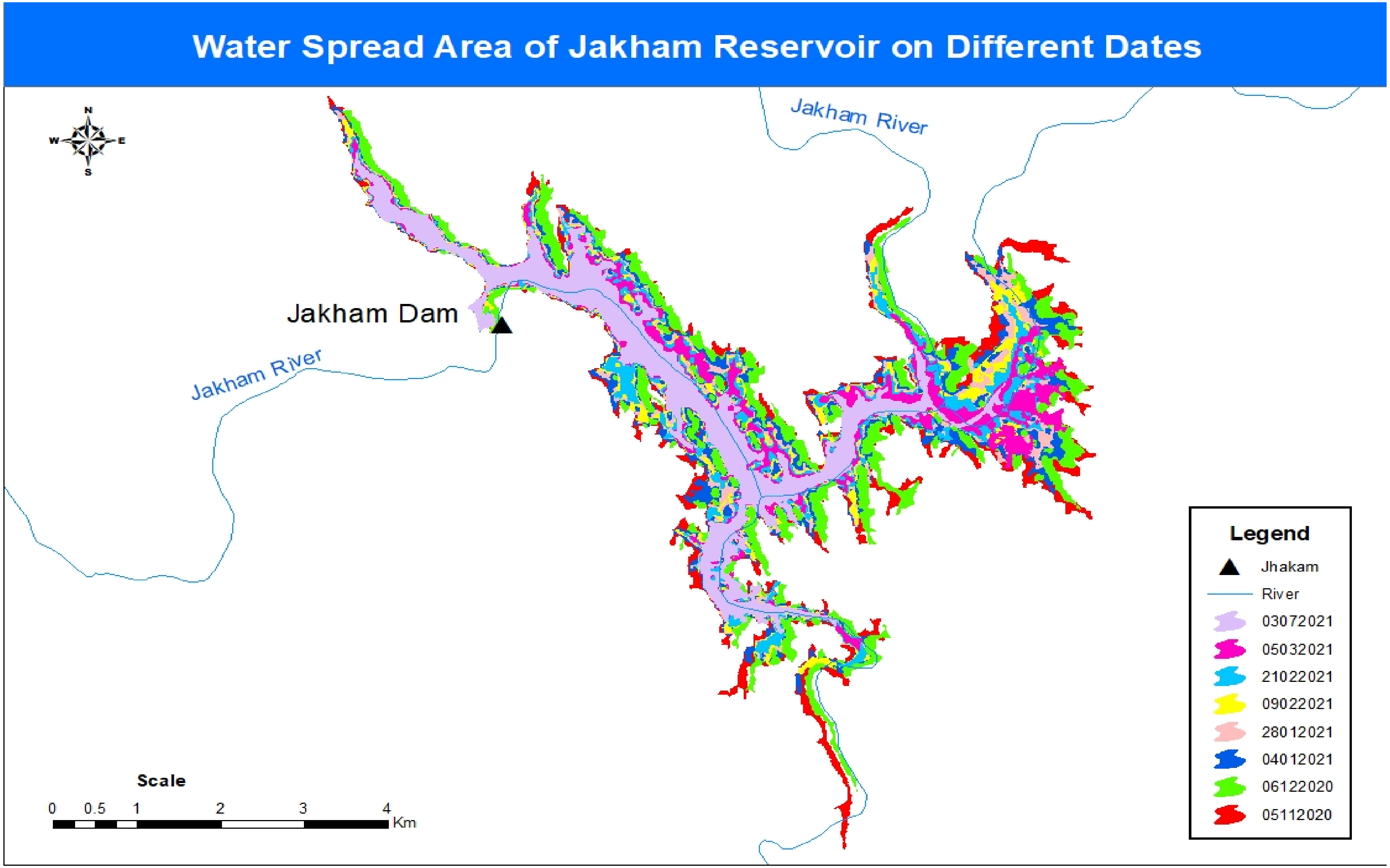


Fig. 7: Water Spread Area of Jakham Reservoir on different dates

The Satellite Images for the Jakham 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 Jakham Reservoir showing its water spread area for eight overpass dates such as 03-July-2021, 05-Mar-2021, 21-Feb-2021, 09-Feb-2021, 28-Jan-2021, 04-Jan-2021, 06-Dec-2020 and 05-Nov-2020 are shown in fig. 7.

The water elevation 359.45 m for 05-Nov-2020 is almost at the Full Reservoir Level (FRL) of 359.50 m. The lowest achieved Water elevation 344.45 m for 03-July-2021 is more than 12 metres above the Minimum Drawdown Level (MDDL) of 332.00 m .

9.3. ESTIMATION OF RESERVOIR CAPACITY

Area elevation curve has been plotted using these above Eight (08) water-spread areas for different water level in the reservoir and best-fit polynomial equation of second order as given below have been derived.

Y = 0.013x2 +0.123x +0.748

R^2 = 0.993

Where, X is Elevation in meters

Y is Water Spread Area in Mm^2

Elevation - area curve using this equation has been plotted and shown in Fig-8. Water spread areas derived from satellite data for various dates are also marked on the curve. 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),

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

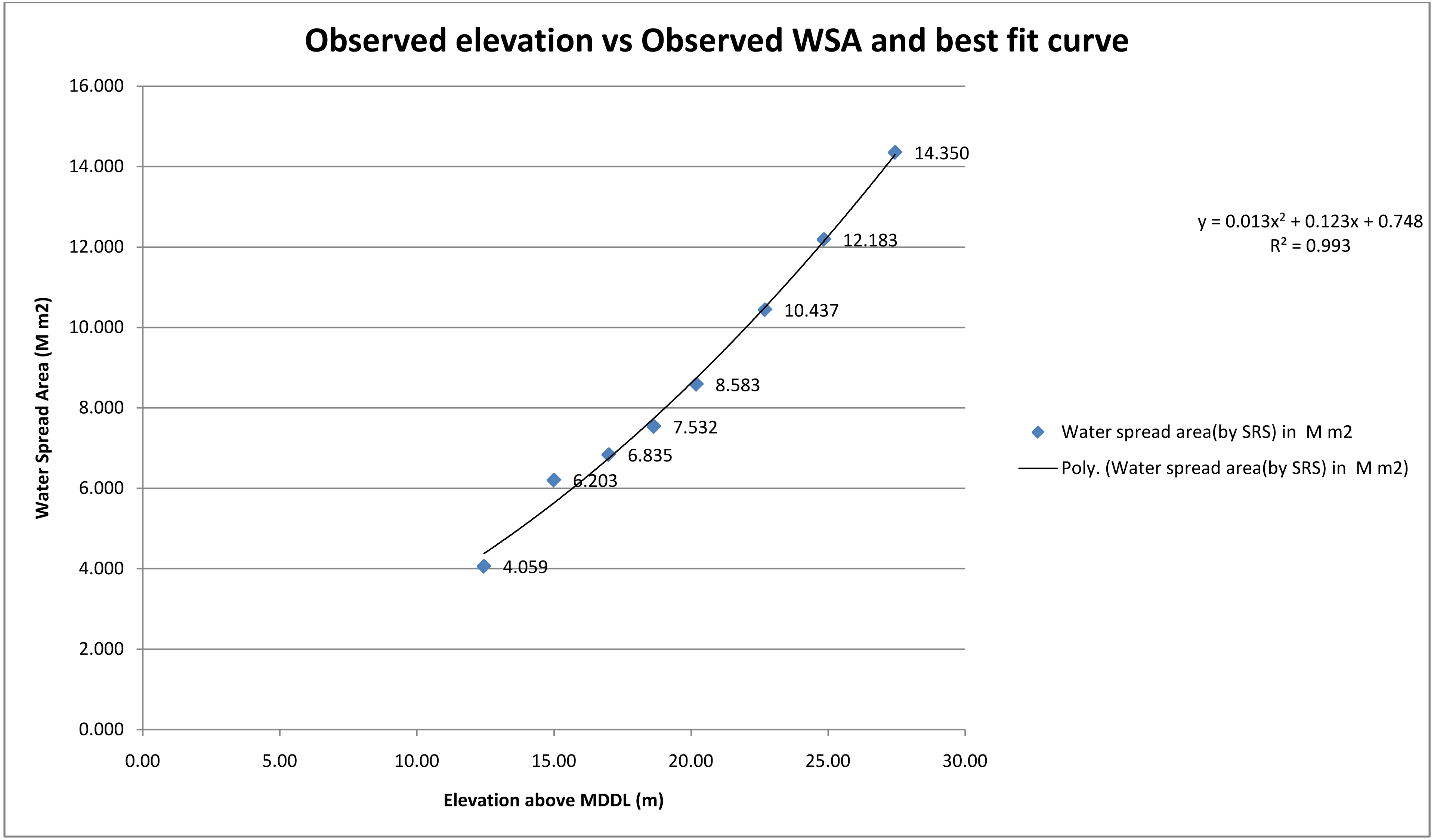


Fig.8: Observed elevation vs Observed WSA of Jakham Reservoir

Table 3 gives the values of Live storage capacity and submergence areas at a regular interval of 1.0 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 Fig-9 and Fig-10 respectively.

Table-3: Aerial extent of reservoir at regular interval (1.0m) using SRS Survey 2021

	Reservoir water level in Metre	**Water spread area by trend line (M m2)**	**Segmental Live Capacity (MCM) by SRS technique**	**Cumulative Live Capacity (MCM) by SRS technique 2021**
MDDL	332.00	0.748	0.000	0.000
	333.00	0.884	0.815	0.815
	334.00	1.046	0.964	1.779
	335.00	1.234	1.139	2.918
	336.00	1.448	1.340	4.257
	337.00	1.688	1.566	5.824
	338.00	1.954	1.819	7.643
	339.00	2.246	2.098	9.741
	340.00	2.564	2.403	12.145
	341.00	2.908	2.734	14.879
	342.00	3.278	3.091	17.970
	343.00	3.674	3.474	21.444
	344.00	4.096	3.883	25.327
	345.00	4.544	4.318	29.645
	346.00	5.018	4.779	34.424
	347.00	5.518	5.266	39.690
	348.00	6.044	5.779	45.469

	349.00	6.596	6.318	51.787
	350.00	7.174	6.883	58.670
	351.00	7.778	7.474	66.144
	352.00	8.408	8.091	74.235
	353.00	9.064	8.734	82.969
	354.00	9.746	9.403	92.372
	355.00	10.454	10.098	102.470
	356.00	11.188	10.819	113.289
	357.00	11.948	11.566	124.855
	358.00	12.734	12.339	137.194
	359.00	13.546	13.138	150.332
FRL	359.45	14.088	8.980	159.312

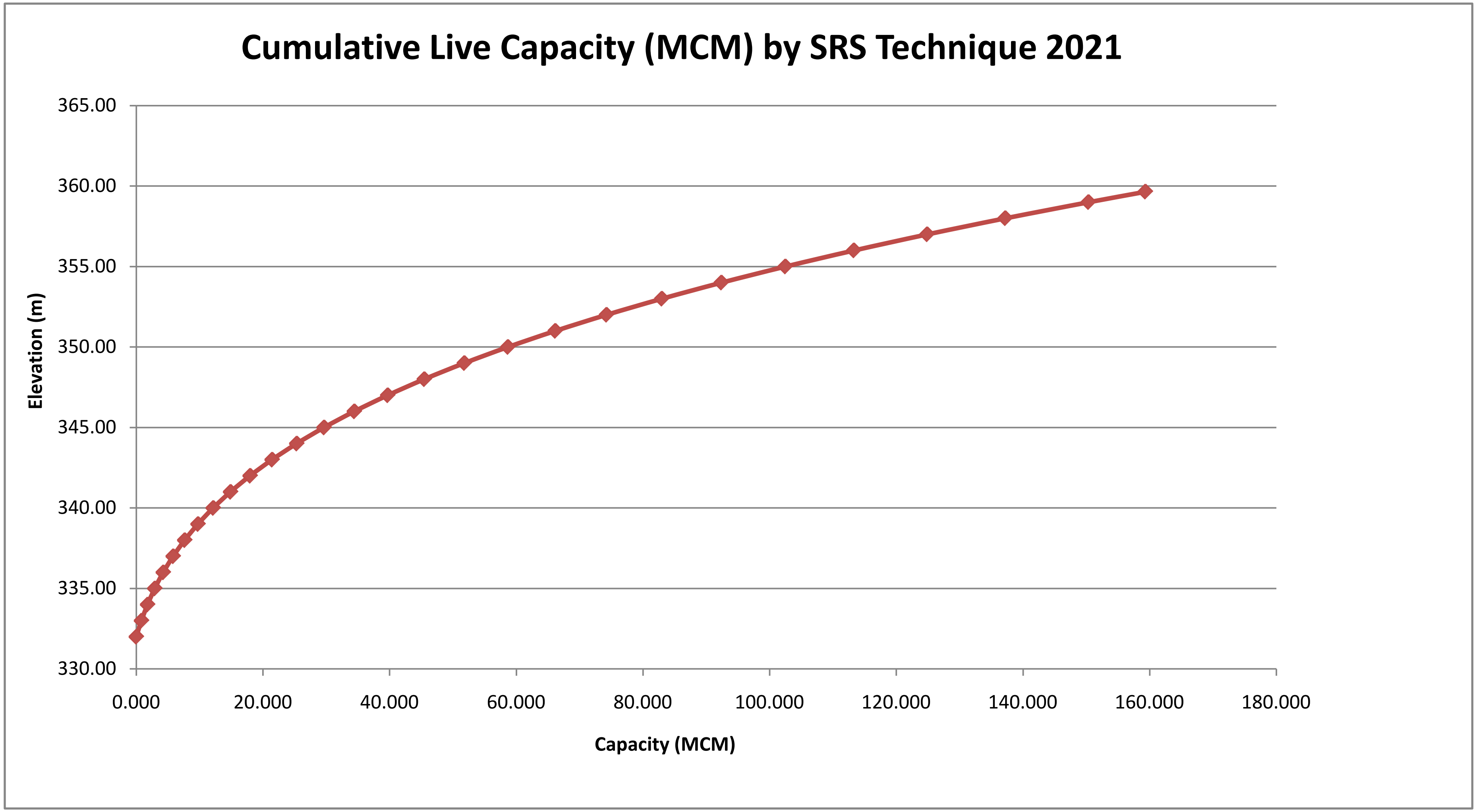


Fig. 9: Modified live capacity - elevation curve (SRS technique)-Jakham reservoir, Rajasthan

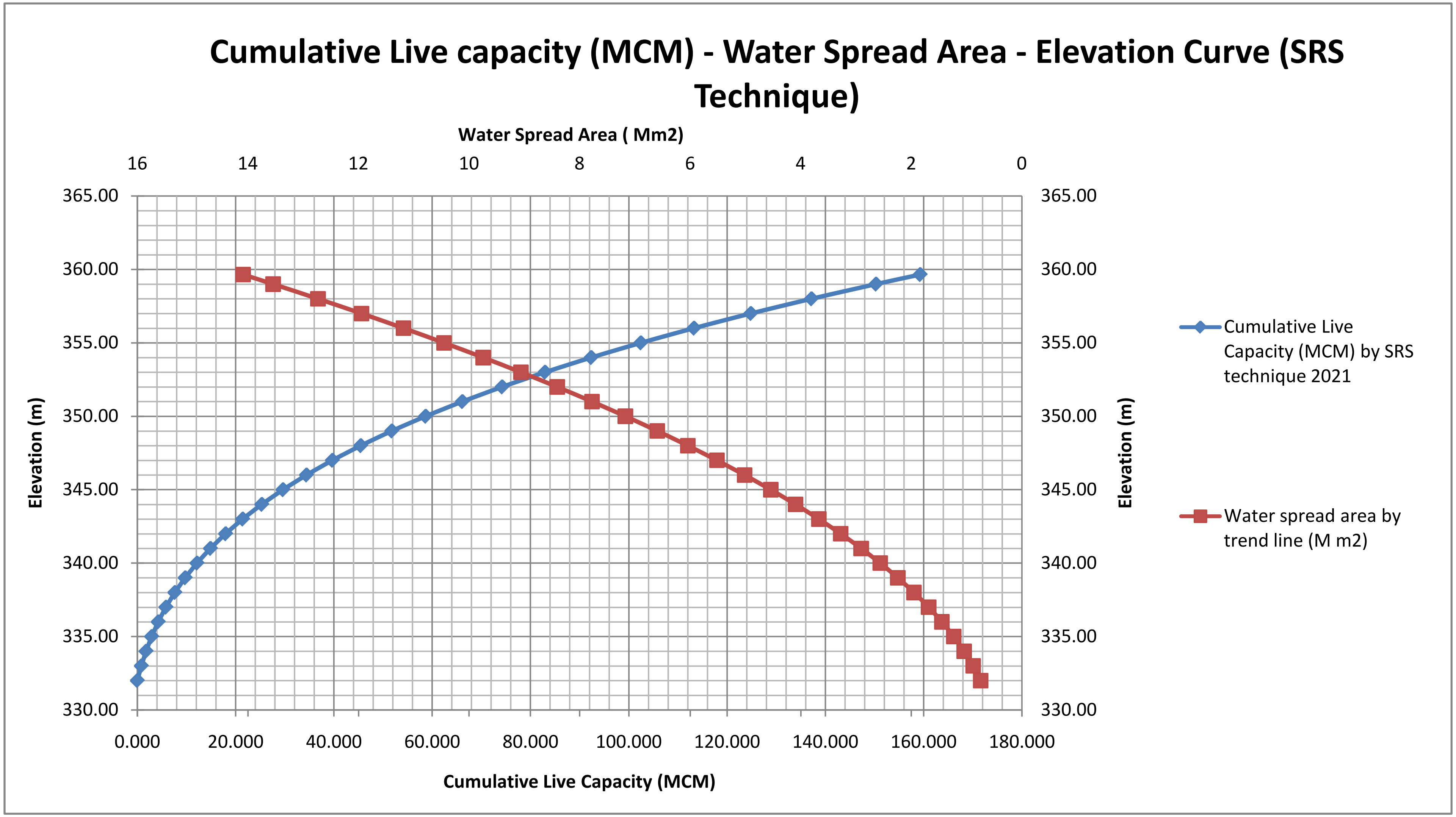


Fig. 10: Elevation – Area- Capacity Curve- Jakham reservoir, Rajasthan

9.4. Comparison with Original and Previous Surveys

Comparison of live storage capacity of SRS survey with original survey 1986, SRS survey 2003 and Hydrographic Survey 2021 at various elevations is given below in table 4. Curve showing comparison of live capacity is drawn in figure 11.

Table-4: Comparison of Live Storage Capacity (MCM)

Elevation (m)	Original Live Capacity (MCM) 1986	Cumulative live capacity by SRS survey (MCM) 2003	Cumulative live capacity by Hydrographic survey (MCM) 2021	Cumulative live capacity by SRS survey (MCM) 2021
332.00	0.000	0.000	0.000	0.000
333.00	1.300	1.545	1.110	0.815
334.00	2.700	3.208	2.370	1.779
335.00	4.200	5.018	3.810	2.918
336.00	5.900	7.004	5.460	4.257
337.00	7.700	9.196	7.320	5.824
338.00	9.700	11.622	9.410	7.643
339.00	11.800	14.311	11.750	9.741
340.00	13.700	17.293	14.360	12.145
341.00	16.600	20.596	17.290	14.879
342.00	19.200	24.249	20.580	17.970
343.00	21.700	28.282	24.280	21.444
344.00	25.700	32.724	28.410	25.327
345.00	29.700	37.603	33.130	29.645
346.00	34.100	42.948	38.460	34.424
347.00	38.700	48.789	44.320	39.690
348.00	43.500	55.154	50.670	45.469
349.00	48.400	62.074	57.480	51.787
350.00	54.000	69.575	64.780	58.670
351.00	59.700	77.689	72.590	66.144
352.00	67.700	86.443	81.010	74.235
353.00	75.100	95.867	90.040	82.969

354.00	82.700	105.990	99.640	92.372
355.00	90.300	116.840	109.790	102.470
356.00	97.900	128.447	120.540	113.289
357.00	106.700	140.840	131.870	124.855
358.00	116.500	154.048	143.780	137.194
359.00	126.600	168.100	156.250	150.332
359.45	131.700	175.451	162.680	159.312

The original gross and live storage capacity of Jakham reservoir in 1986 were reported as 142.02 MCM & 132.28 MCM respectively. Results of present survey and previously conducted surveys are given in Table-4.

In the present study, it is found that live capacity of the Jakham reservoir in 2021 is 159.312 MCM witnessing a live storage loss of 16.139 MCM (i.e. 9.199 %) in a period of 18 years during 2003 to 2021. This accounts for live capacity loss of 0.511% per annum since 2003.

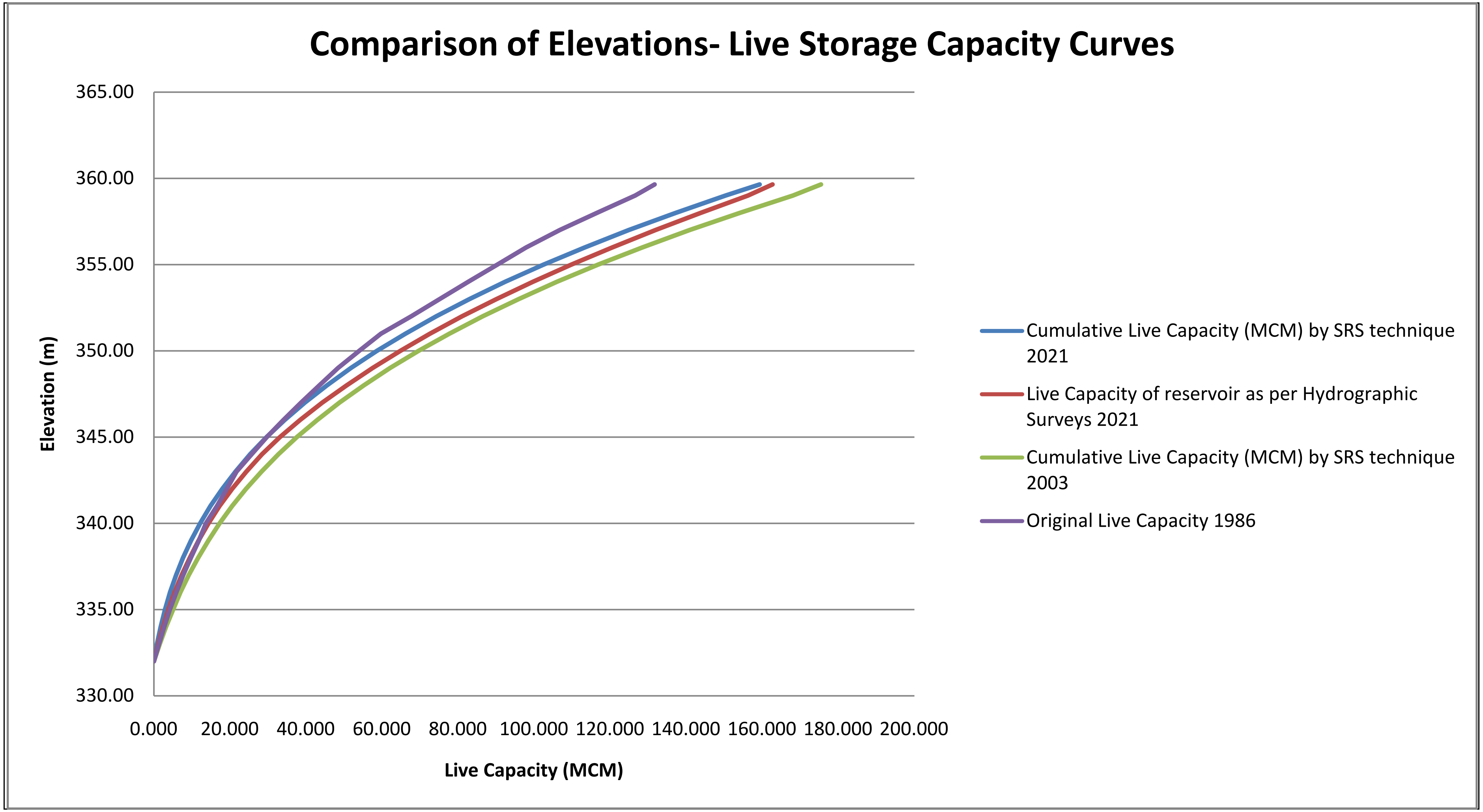


Fig. 11: Comparison of Elevation-Live Storage Capacity Curves (MCM)- Jakham reservoir, Rajasthan

10. RESULTS AND DISCUSSIONS

Table 10 shows the summary of the analysis done for Jakham reservoir.

The loss in live storage capacity of the reservoir due to sedimentation since SRS Survey (2003) and remote sensing survey 2021 is given in Table –5.

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

	Original Survey (1986)	SRS (2003)	SRS 2021
Live Capacity (MCM)	131.7	175.451	159.312
Loss in Capacity (MCM) (since 2003)	-	-	16.139
% Live capacity loss (since 2003)	-	-	9.199%
% Live Capacity loss between two consecutive surveys (of the original capacity)	-	-	9.199%
Annual % live capacity loss	-	-	0.511%
Annual % live capacity loss between two consecutive surveys	-	-	0.511%

As per original survey conducted in 1986 the live storage capacity was 142.02 MCM, which has some error and In 2003, Remote Sensing survey the capacity was found out as 175.451 MCM which was 132.6% of the original capacity, much more than the original survey. In 2021 hydrographic Survey was done and Gross capacity was worked out as 168.35 MCM and Live Capacity as 162.68 MCM. **The live storage capacity of Jakham reservoir as per present study is found to be 159.312 MCM for the year 2021.** It may be noted that variation from recently conducted Hydrographic Survey 2021 is 3.368 MCM (i.e. 2.07%), which is less than 5% and in acceptable range. 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 following paragraphs.

1. The live storage capacity of Jakham reservoir has been found to be 159.312 MCM in 2021. It may be noted that as per Reservoir Hydrographic survey 2021 live capacity assessed as 162.68 MCM which has not much difference to the present SRS study (159.312 MCM). However, variation in live storage capacity of Jakham Reservoir from recently conducted Hydrographic Survey 2021 is 3.368 MCM (i.e. 2.07%).which is less than 5% and in acceptable range.
2. Live storage loss of 16.139 MCM (i.e. 9.199%) was observed since SRS survey (2003) i.e. in a period of 18 years. This accounts for live capacity loss of 0.511% per annum since 2003.
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

Details	As per original approval (1961)	As per 3rd Revision (1996)
General		
Reservoir Location		
State	Rajasthan	Rajasthan
District	Chittorgarh	Chittorgarh
Tehsil	Pratapgarh	Pratapgarh
River	Jakham	Jakham
Latitude	24°10'-0"N	24°10'-30"N
Longitude	74°34'-0"E	74°35'-30"E
1. Total Catchment Area :	1010 sq. km.	1010 sq. km
2. 75% dependable Rainfall 1981:	28 inch	860 mm
3. 75% dependable yield:	129.30 M.C.M.	200 MCM
4. Designed spillway peak discharge	4032.40 Cumecs	11944 Cumecs
5. Maximum Flood lift	5.79 m	12.15 m
6. Maximum Water Level	360.57 m	371.65 m
7. Reservoir crest level	354.78 m	359.50 m
8. Minimum Drawdown Level	-	332.00 m
9. Irrigation sluice sill level	-	328.50 m
10. Type of non-overflow	-	Straight gravity masonry
11. Reservoir Capacity Data : Mcum (Original)		
i. Gross storage @ F.R.L. :	121.75	142.02
ii. Dead storage :	9.63	9.74
iii. Live storage :	112.14	132.28
12. Length of overflow dam	142.65 m	90.00 m
13. Top width of non-overflow dam	8.23 m	4.5 m
14. Submergence area at FRL	-	10.1470 sq km

SADDLE DAM

1.	Type of Dam	Rock fill with impervious core of clay
2.	No. of saddle dam	2
3.	Total length of saddle dam at top	507.00 m
4.	Top width of saddle dam	8.00 m
5.	Top Elevation	374.00 m
6.	Maximum height above NSL	10 m

AUXILLIARY SPILLWAY

1.	Type of spillway	-	
2.	Length of overflow portion	-	93.00 m
3.	TBL	-	374.00 m
4.	MWL	-	371.65 m
5.	Crest Level	-	367.00 m
6.	Type of silting Basin	-	
7.	Maximum Peak discharge	-	1360.00 Cumecs
8.	Flood lift	-	4.65 m

PICK UP WEIR AT NAGLA

1.	Location		
	a. Latitude	$24^{o}8'$-N	$24^{o}8'$-N
	b. Longitude	$75^{o}31'$-E	$75^{o}31'$-E
2.	Total Catchment Area	1103 sq.km	1103 sq.km.
3.	Designed maximum discharge	4270.60 cumecs	8070 cumecs
4.	Maximum flood lift	6.04 m	8.79 m
5.	Crest Level of overflow	231.71 m	232.21 m
6.	Top level of non-overflow	239.00 m	242.50 m
7.	Maximum Water Level	-	241.00 m
8.	Length of non- overflow of left and right	24.40 m	81.50 m
9.	Length of overflow weir	152.40 m	150.00 m

10. Sill level of right main canal head sluice	229.41 m	229.41 m
11. Sill level of right main canal head sluice	229.41 m	229.41 m
12. FSL of right main canal	230.89 m	231.11 m
13. FSL of right main canal	231.01 m	231.11 m

CANALS

GCA:RMC	64.18 sq km	118.50 sq km
GCA:LMC	342.65 sq km	270.51 sq km
Total	**406.83 sq km**	**389.01 sq km**

1. GCA:RMC	53.56 sq km	87.90 sq km
GCA:LMC	212.02 sq km	195.29 sq km
2. Annual proposed irrigation		
a. RMC	32.14 sq km	72.96 sq km
b. LMC	127.21 sq km	162.09 sq km
3. Pattern of irrigation		
a. Rabi	60%	59%
b. Kharif	20%	24%
4. Length of main canals: RMC	41.90 km	34.12 km
Length of main canals: LMC	49.70 km	39.90 km
5. Discharge at head: RMC	11.217 cumecs	7.53 cumecs
6. Total length of distributaries & Minors	-	325 km

PHOTOGRAPH OF RESERVOIR

Photo 1:Jakham Dam

Photo 2: Downstream side of Jakham

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