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SEDIMENTATION ASSESSMENT OF IDUKKI RESERVOIR, KERALA, THROUGH SATELLITE REMOTE SENSING

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Government of India
Central Water Commission
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Remote Sensing Directorate

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सत्यमेव जयते

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Year of Study 2020
Data Used 2018-2019

STUDY TEAM

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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 2018-19 in the sedimentation study of Idukki 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 Idukki 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.

The original gross and live storage capacities of Idukki reservoir at the time of opening in 1974 were 1998.57 MCM & 1461.81 MCM respectively. In 1999, Hydrographic survey was conducted for this reservoir that witnessed loss in gross and live storage capacities as 1972.72 MCM and 1453.04 MCM. After analysis of the satellite data in the present study, it is found that live capacity of the Idukki reservoir in 2019 is 1449.907 MCM witnessing a live storage loss of 11.903 MCM (i.e. 0.814 %) in a period of 45 years during 1974 to 2019. This accounts for live capacity loss of 0.018% per annum since 1974.

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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 IDUKKI RESERVOIR, KERALA 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 1122 BCM (690 BCM of surface water and 432 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 Idukki reservoir, Kerala 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 (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.

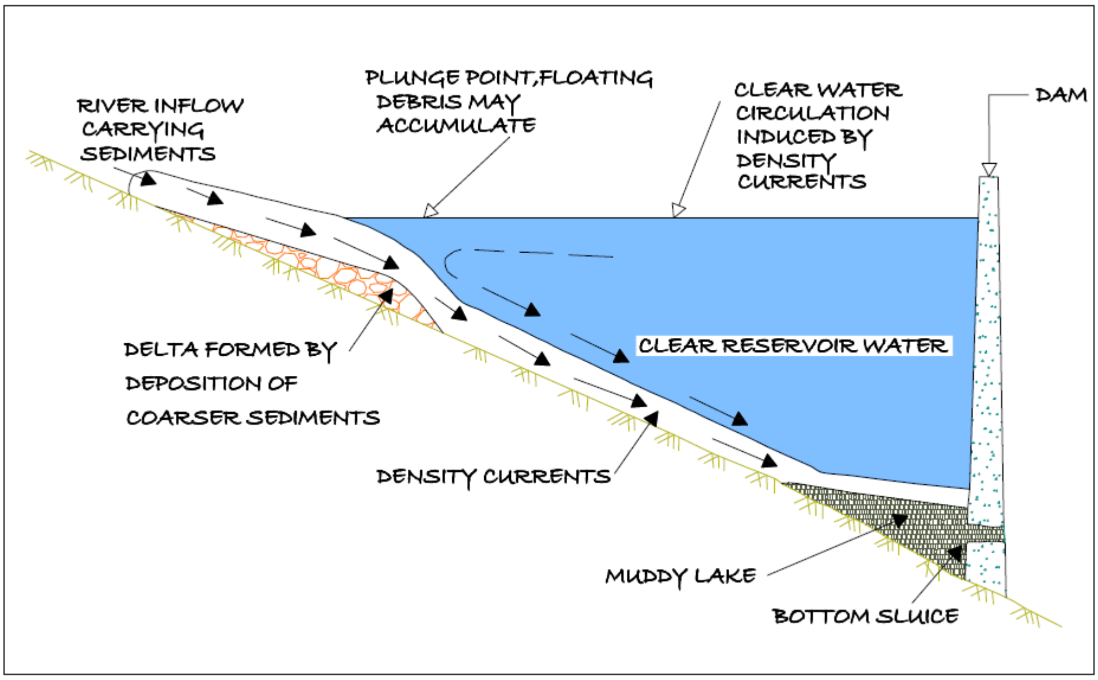


Fig. 1: Conceptual sketch of density currents in a reservoir

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.

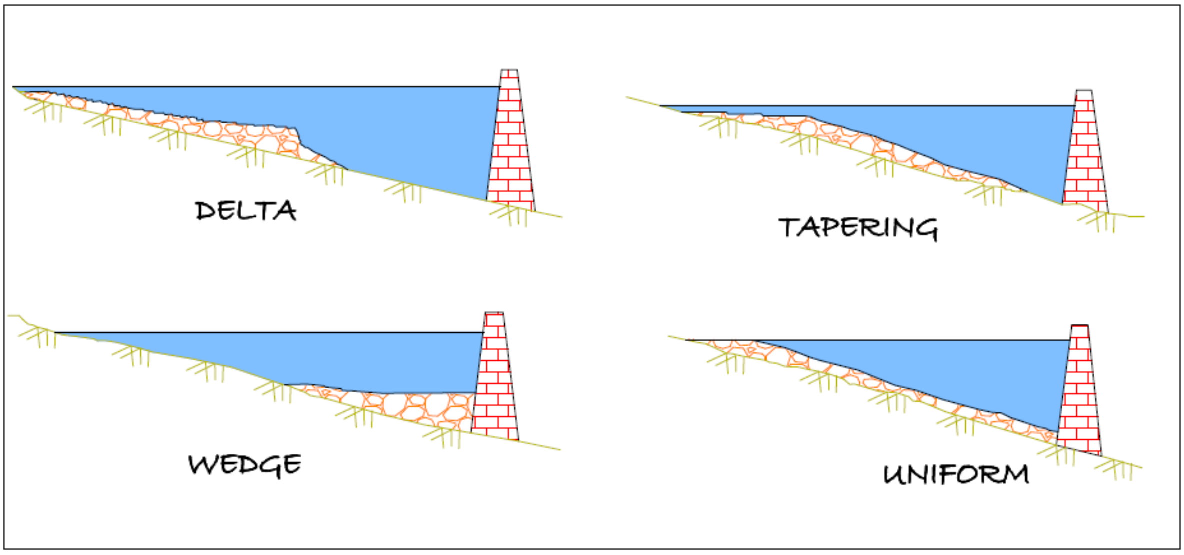


Fig. 2: Longitudinal Patterns of sediment deposition in reservoirs.

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.

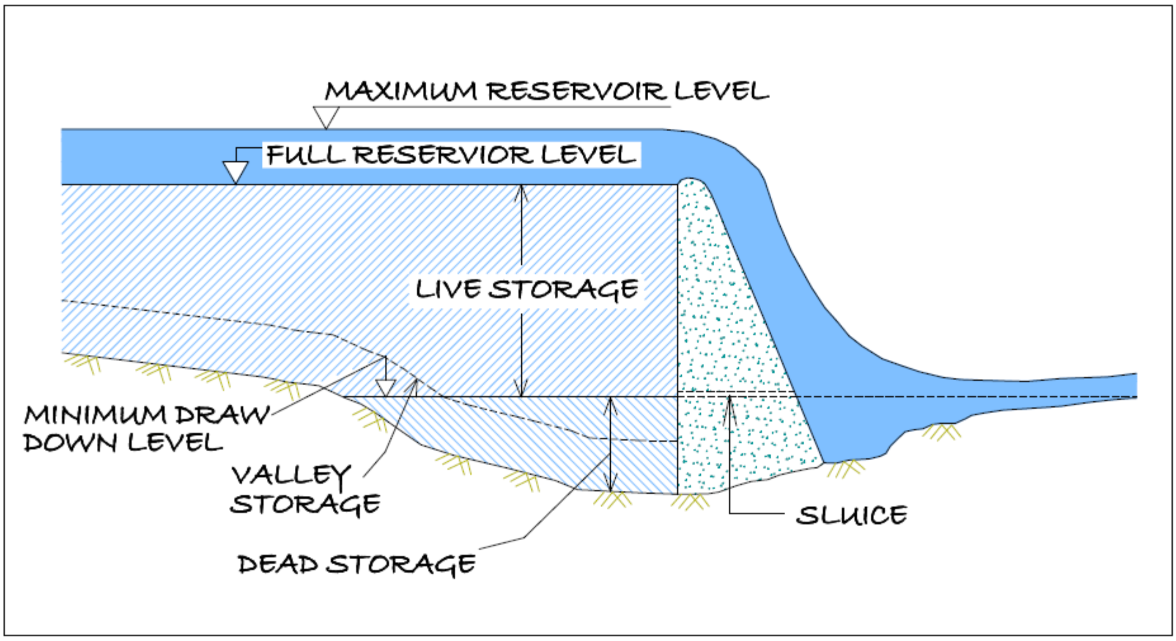


Fig. 3: Conceptual sketch of different levels in a reservoir

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:

1. Soil and water conservation measures within the drainage basin, 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 study is to estimate live capacity loss of Idukki reservoir due to sedimentation through Satellite Remote Sensing. Following objectives will be achieved in the study.

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

6. STUDY AREA

The Idukki reservoir in the Idukki district of Kerala State is located at 9° 50′ 30″ North Latitude and 76° 58′ 40″ East Longitude on the western Ghats of the Indian Peninsula at an altitude of 695 meters above MSL. The reservoir is formed in 1974 by construction of three high dams; the one across Periyar river is a thin arch dam at very narrow gorge known as Idukki arch dam, the next located nearby is across Cheruthoni river, a major tributary meeting Periyar a mile lower down and the third one is across Kikivallithodu at Kulamavu, a river flowing to the adjoining Muvattupuzha basin. The index map showing the location of the Idukki reservoir is given in Fig-4. The Idukki project is a hydroelectric project envisaging diversion of impounded water into the adjacent basin of the river Muvattupuzha to enable generation of hydroelectric power. Salient features of the Idukki project are given in Annexure 1.

The catchment area of the Idukki reservoir which is about 649 sq km. is generally hilly with deep valleys and is covered with rich vegetation consisting of reserve forests interspersed with tea, coffee, pepper and cardamom estates. Since the soil is hghly productive, crops are grown with traditional methods and in this area mixed cropping pattern is observed. The soil is clayey loam in nature, originated from lateritic rock. They are dark brown to reddish in colour varying from sandy loam to clay texture. The geomorphology of the area consists of pediment, buried pediments, shallow pediment and rocky outcrops. The catchment receives rainfall mainly during the southwest monsoon between June and September.

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 Idukki reservoir, the height difference between FRL (732.43 m) and MDDL (694.94m) is 37.49 m.

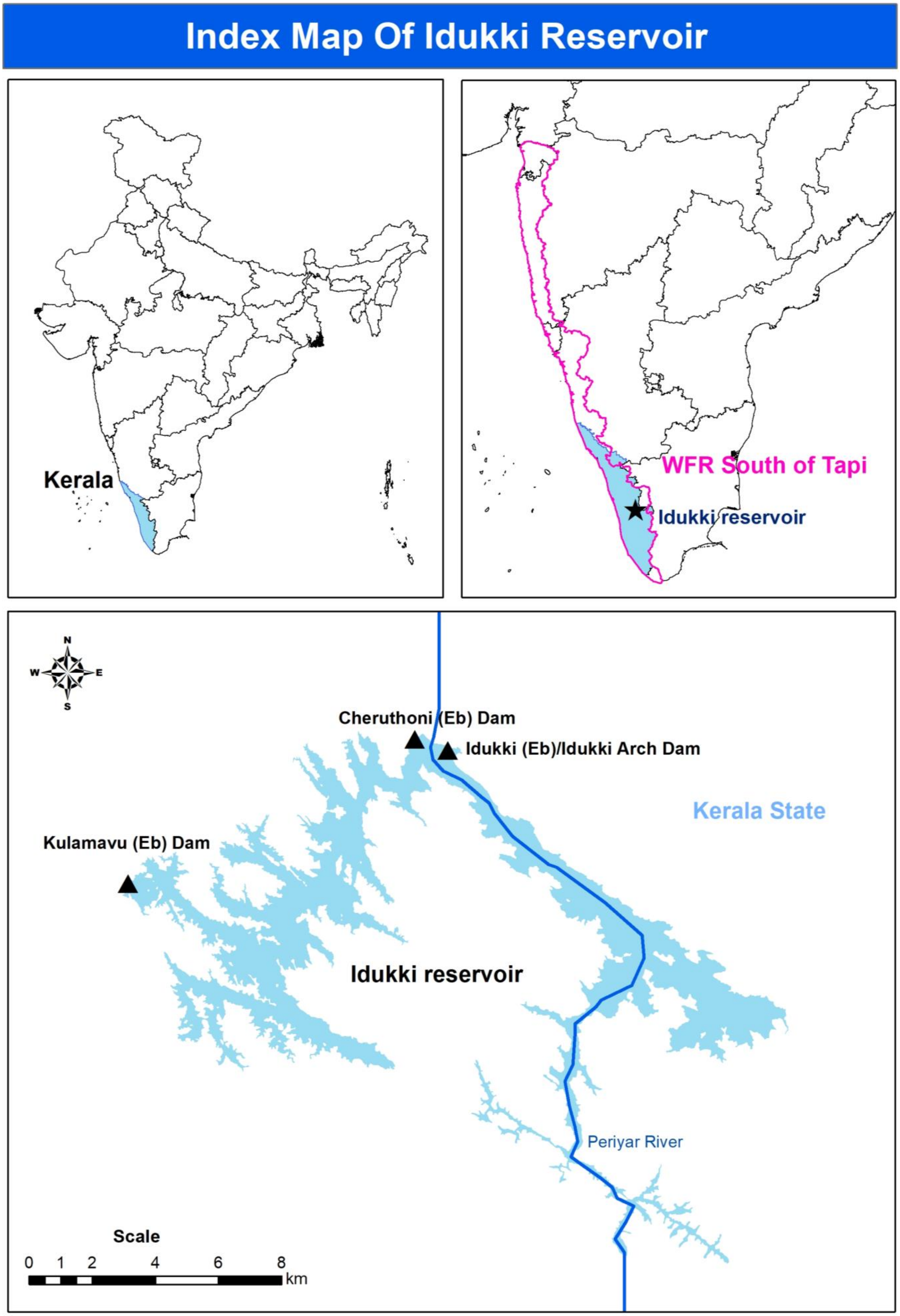


Fig. 4: Index map of the Idukki Reservoir

8. DATA USED

8.1. SATELLITE DATA

Microwave data from Sentinel 1A/1B for ten (10) 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	21/08/2018	731.831
Sentinel 1A	02/09/2018	729.844
Sentinel 1B	20/12/2019	726.74
Sentinel 1B	15/09/2019	723.15
Sentinel 1B	03/09/2019	719.675
Sentinel 1B	31/03/2019	716.304
Sentinel 1B	10/08/2019	711.970
Sentinel 1B	18/05/2019	708.300
Sentinel 1B	11/06/2019	703.881
Sentinel 1B	17/07/2019	702.143

8.2. FIELD DATA

The following field data have been obtained from project authorities:

Elevation - Capacity data

Salient features of Idukki 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 Idukki reservoir studies, multi-date Sentinel 1 (10 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 USGS Earth Explorer 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

Date of pass	Elevation (m)	Area (Mm^2)
21/08/2018	731.831	47.604
02/09/2018	729.844	46.590
20/12/2019	726.740	45.626
15/09/2019	723.150	43.775
03/09/2019	719.675	41.370
31/03/2019	716.304	39.994
10/08/2019	711.970	37.634
18/05/2019	708.300	35.761
11/06/2019	703.881	33.931
17/07/2019	702.143	32.984

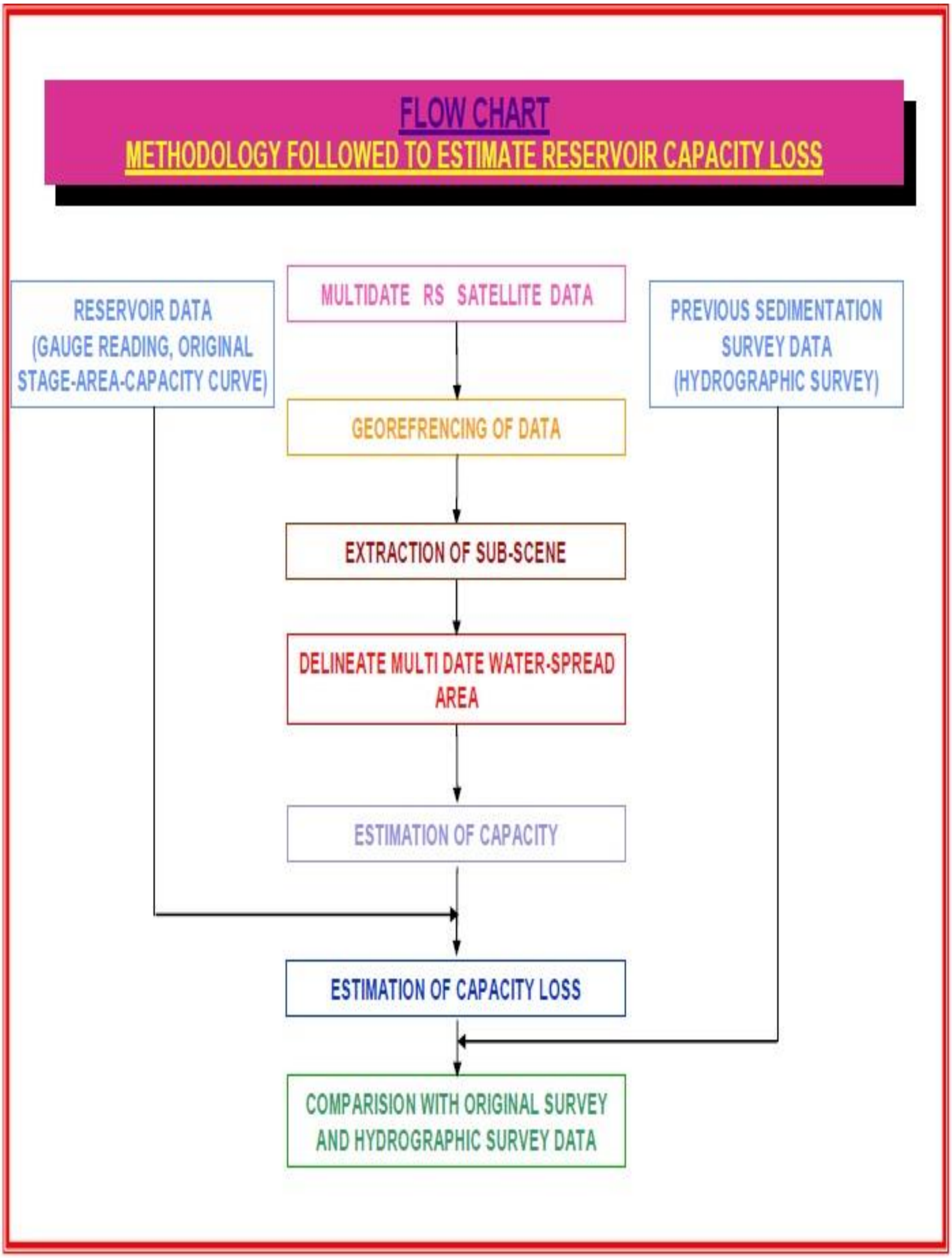


Fig 5 : Flow chart showing methodology followed to estimate reservoir capacity loss

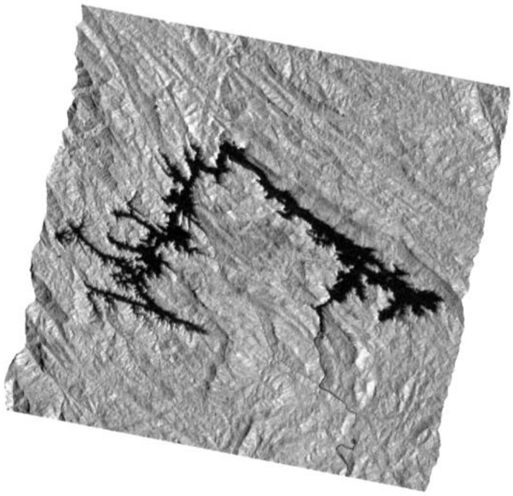
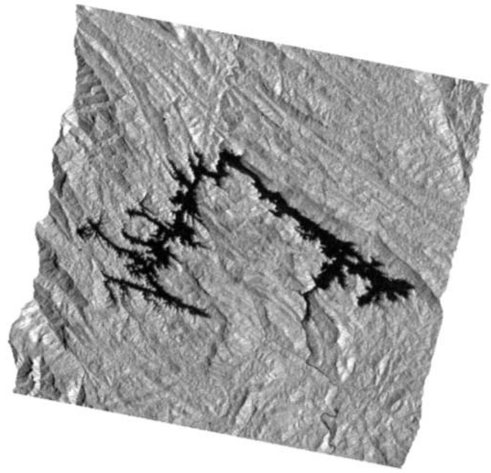
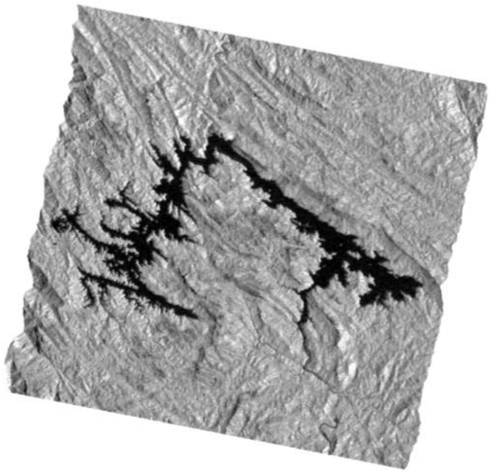
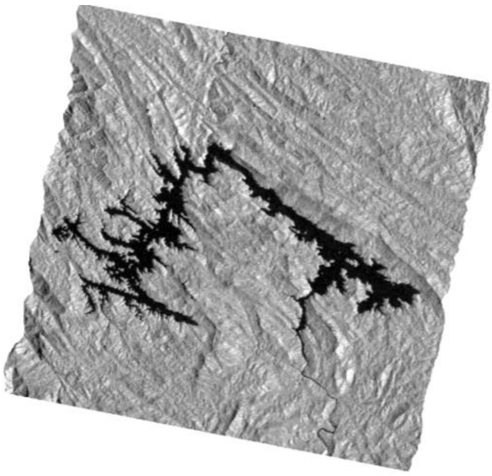
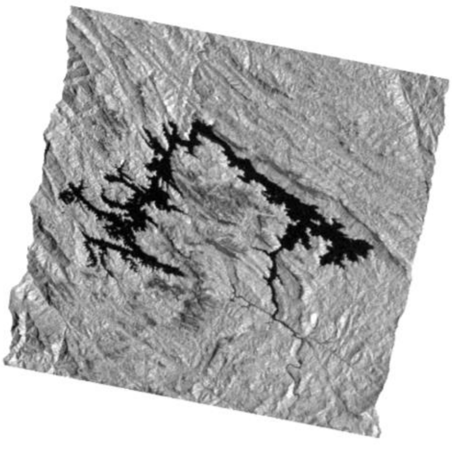
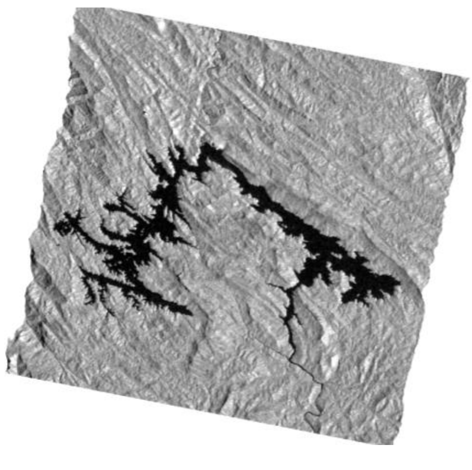
	
17-July-2019 (702.143 m)	**11-June-2019 (703.881 m)**
	
18-May-2019 (708.300 m)	**10-Aug-2019 (711.970 m)**
	
31-Mar-2019 (716.304 m)	**03-Sept-2019 (719.675 m)**

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

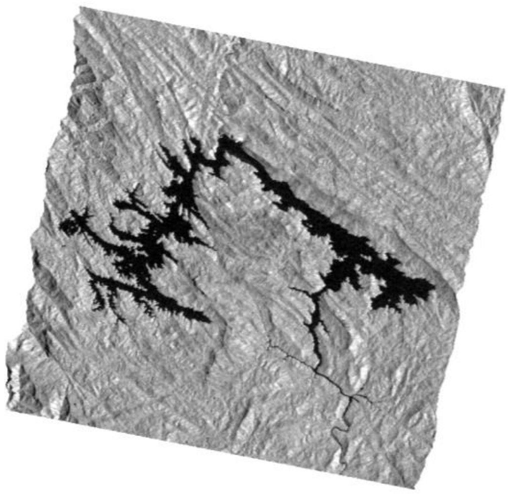
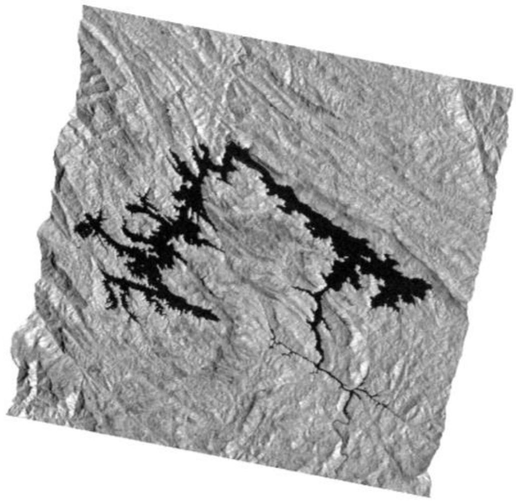
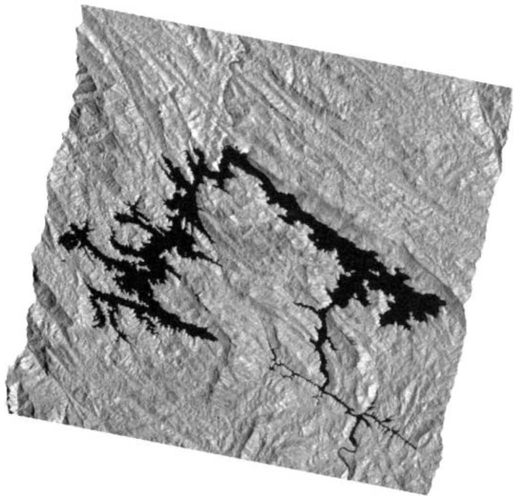
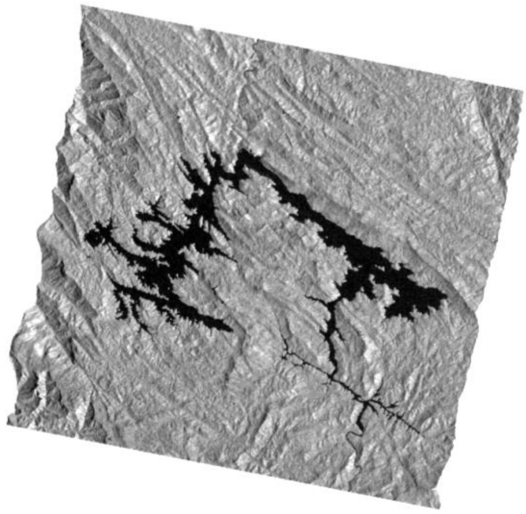
	
15-Sept-2019 (723.150 m)	**20-Dec-2019 (726.740 m)**
	
02-Sept-2018 (729.844 m)	**21-Aug-2018 (731.831 m)**

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

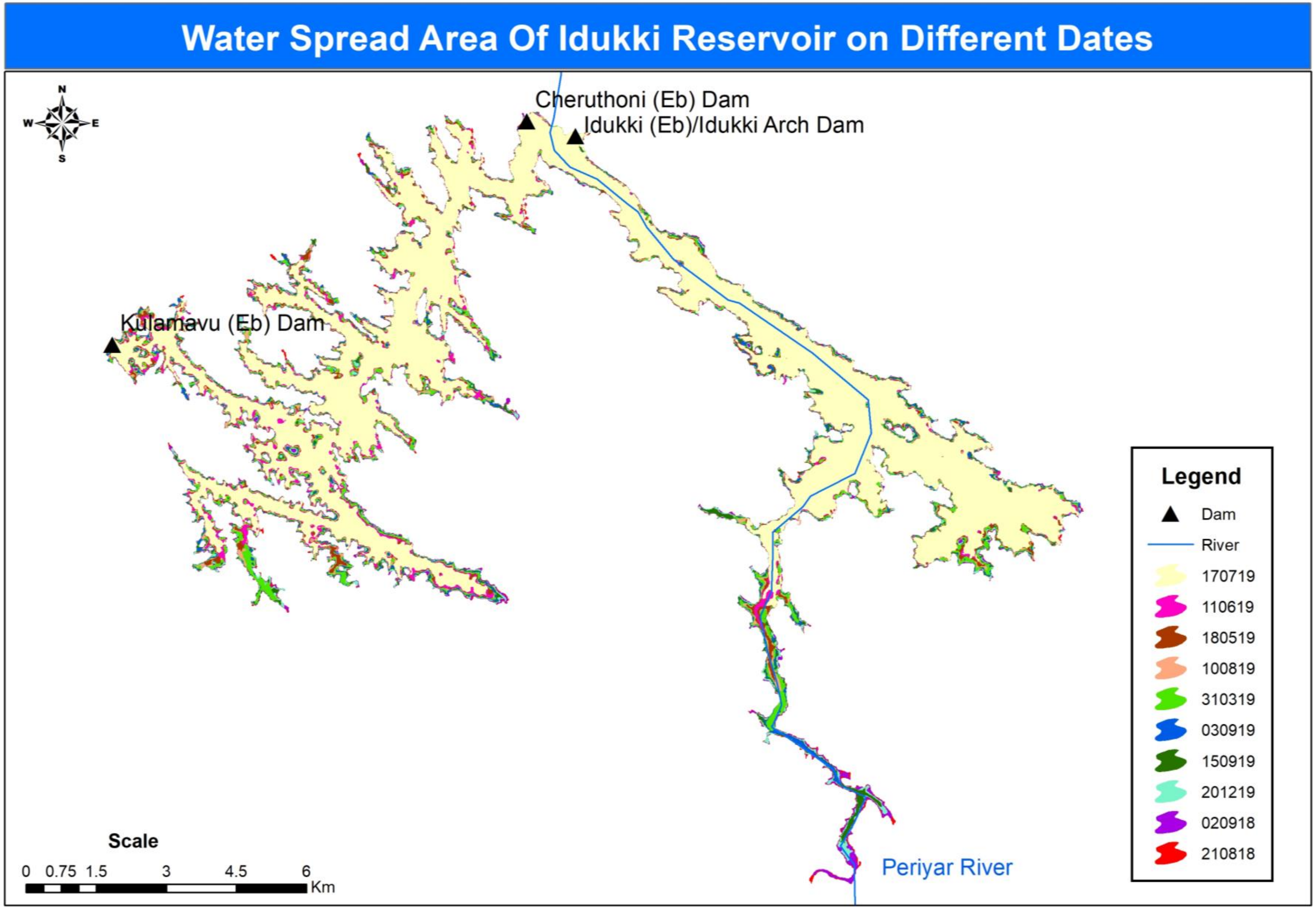


Fig. 7: Water Spread Area of Idukki Reservoir on different dates

The Satellite Images for the Idukki 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 Idukki Reservoir showing its water spread area for ten overpass dates such as 21-Aug-18, 02-Sept-18, 20-Dec-19, 15-Sept-19, 03-Sept-19, 31-Mar-19, 10-Aug-19, 18-May-19, 11-Jun-19 and 17-July-19 are shown in fig. 7.

The water elevation 731.831 m for 21-Aug-18 is near the Full Reservoir Level (FRL) of 732.43 m. The Water elevation 702.143 m for 17-July-19 is above the Minimum Drawdown Level (MDDL) of 694.94 m.

9.3. ESTIMATION OF RESERVOIR CAPACITY

Area elevation curve has been plotted using these above eleven(11) water-spread areas for different water level in the reservoir and best-fit polynomial equation of second order as given below have been derived.

$Y = 0.0002*X^2 + 0.4916 * X + 29.366$

$R^2 = 0.9978$

Where, X is Elevation in meters

Y is Water Spread Area in M Sqm

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

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

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.

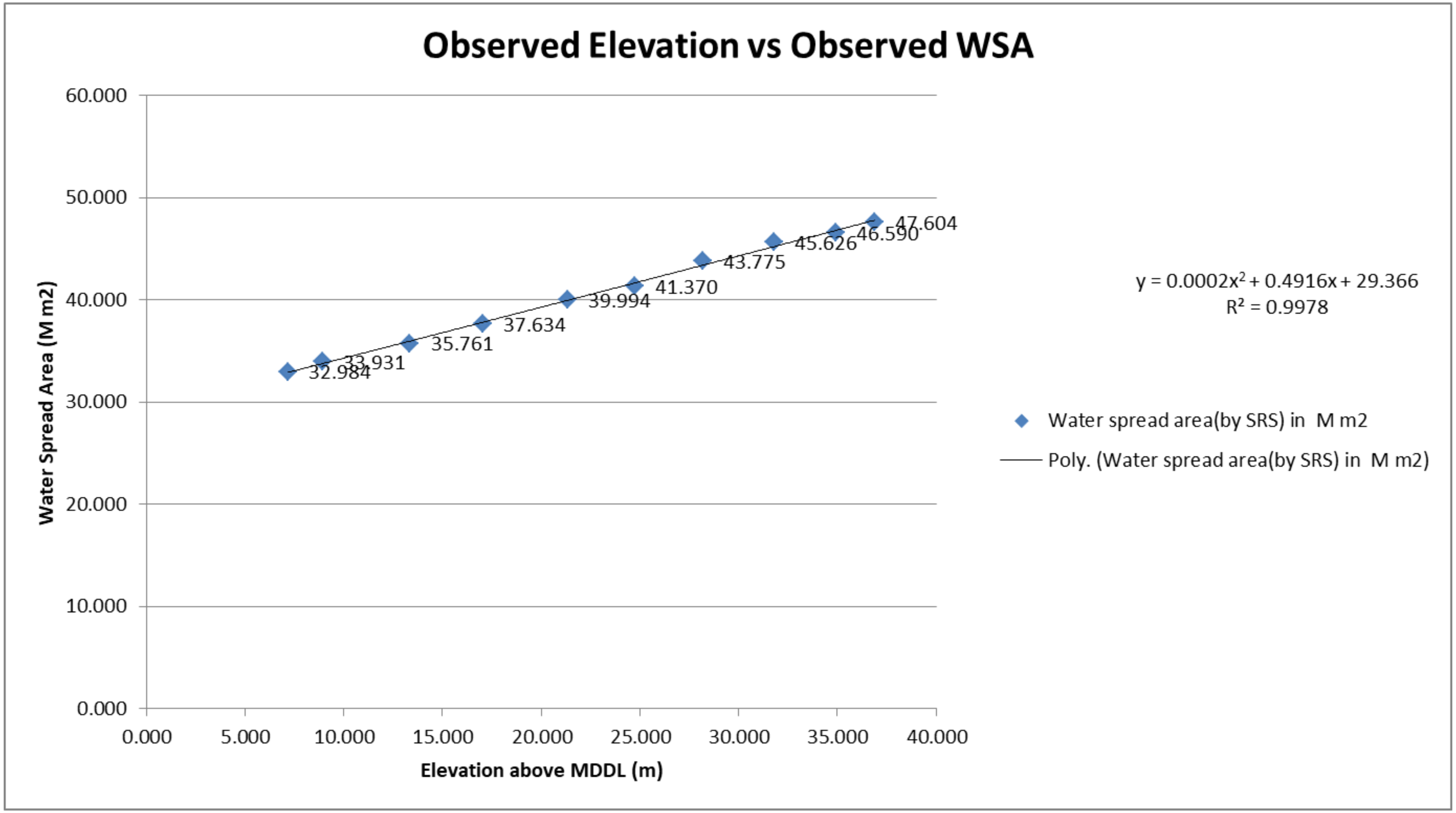


Fig. 8: Observed elevation vs Observed WSA of Idukki Reservoir

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 2019

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 2019
MDDL	**694.94**	29.366	0.000	0.000
	695	29.395	1.763	1.763
	696	29.887	29.641	31.404
	697	30.380	30.133	61.537
	698	30.872	30.626	92.163
	699	31.365	31.118	123.281
	700	31.859	31.612	154.892
	701	32.352	32.105	186.998
	702	32.847	32.599	219.597
	703	33.341	33.094	252.691
	704	33.836	33.588	286.279
	705	34.332	34.084	320.363
	706	34.828	34.579	354.942
	707	35.324	35.075	390.018
	708	35.820	35.572	425.589
	709	36.317	36.069	461.658
	710	36.815	36.566	498.224
	711	37.313	37.063	535.287
	712	37.811	37.562	572.849
	713	38.310	38.060	610.909
	714	38.809	38.559	649.468
	715	39.308	39.058	688.526
	716	39.808	39.558	728.083
	717	40.308	40.058	768.141
	718	40.809	40.558	808.699
	719	41.310	41.059	849.758
	720	41.811	41.560	891.318
	721	42.313	42.062	933.380
	722	42.815	42.564	975.944
	723	43.318	43.066	1019.010
	724	43.821	43.569	1062.579
	725	44.324	44.072	1106.651

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 2019
	726	44.828	44.576	1151.227
	727	45.332	45.080	1196.307
	728	45.837	45.584	1241.891
	729	46.342	46.089	1287.980
	730	46.847	46.594	1334.575
	731	47.353	47.100	1381.675
	732	47.859	47.606	1429.281
FRL	**732.43**	48.077	20.626	**1449.907**

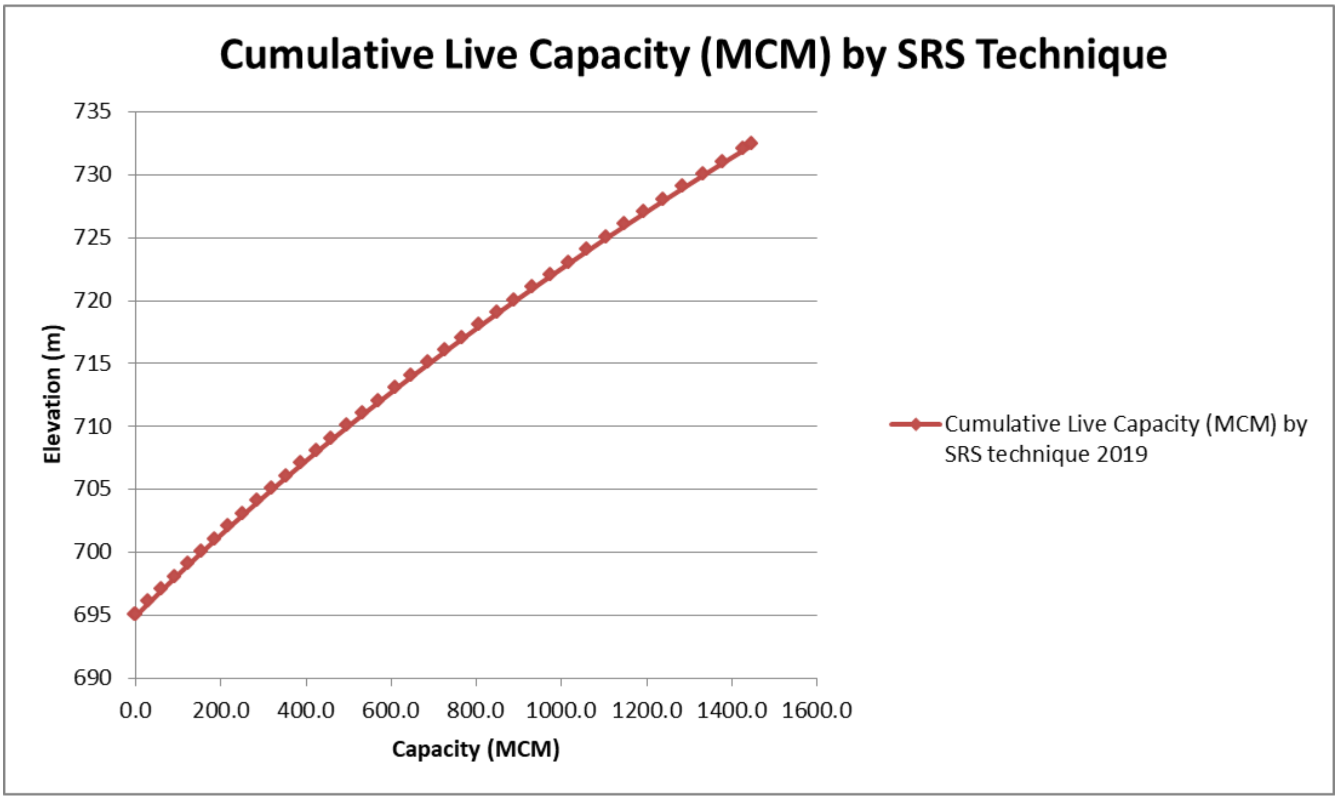


Fig. 9: Modified live capacity - elevation curve (SRS technique)

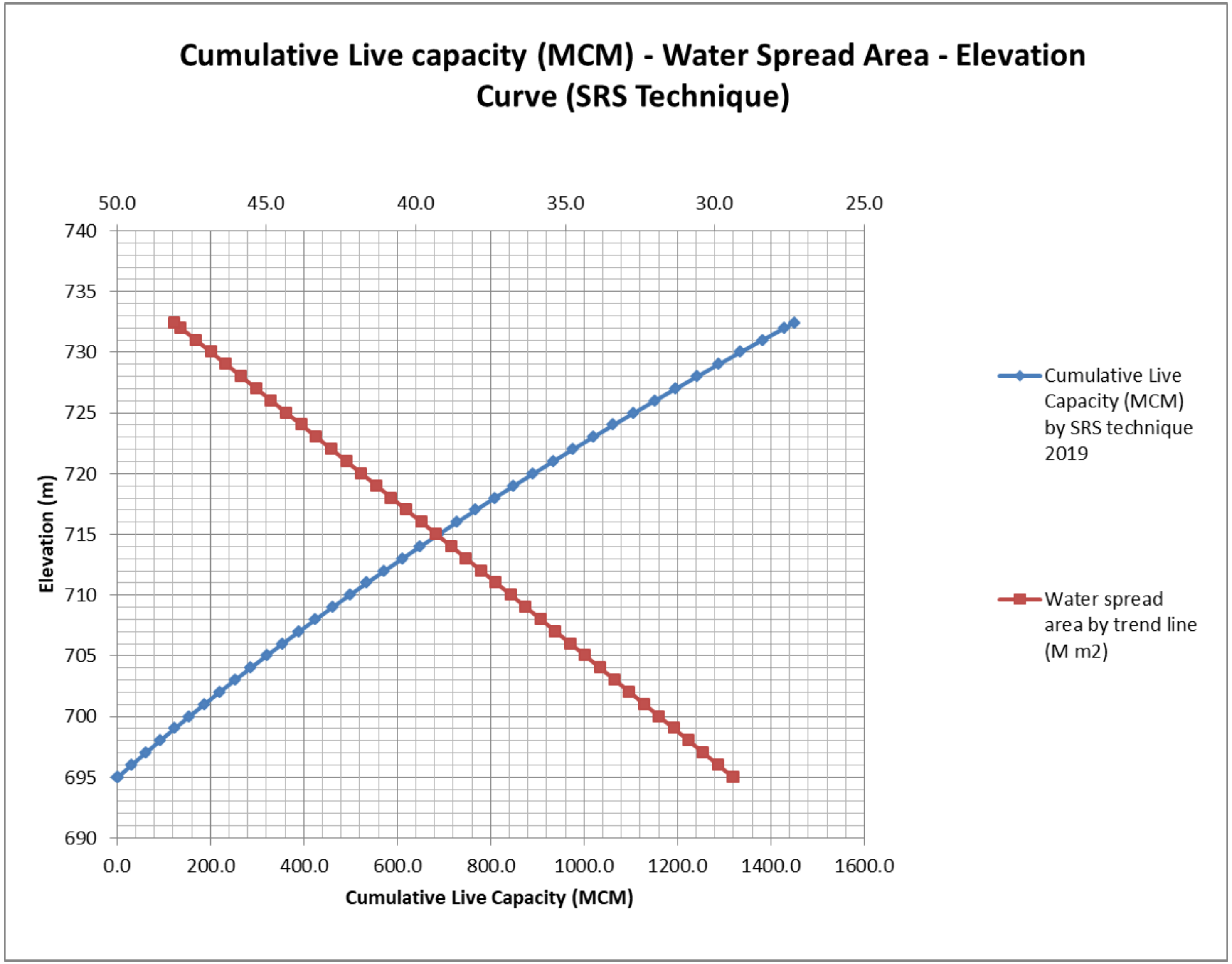


Fig. 10: Elevation – Area- Capacity Curve

9.4. Comparison with Original and Previous Surveys

Comparison of live storage capacity of SRS survey with original survey 1974, hydrographic survey 1999 and SRS survey 2003 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) 1974	Live Capacity hydrographic survey (MCM) 1999	Cumulative live capacity by SRS survey (MCM) 2003	Cumulative live capacity by SRS survey (MCM) 2019
694.940	0.000	0.000	0.000	0.000
695.000	1.420	1.640	1.659	1.763
696.000	26.140	22.580	29.593	31.404
697.000	50.600	44.270	58.035	61.537
698.000	75.580	66.800	86.994	92.163
699.000	100.310	90.190	116.479	123.281
700.000	125.030	118.410	146.500	154.892
701.000	153.830	139.720	177.064	186.998
702.000	182.640	165.910	208.181	219.597
703.000	211.450	193.120	239.859	252.691
704.000	240.260	221.360	272.107	286.279
705.000	269.070	250.570	304.933	320.363
706.000	301.910	278.510	338.347	354.942
707.000	334.740	306.210	372.357	390.018
708.000	367.580	334.840	406.971	425.589
709.000	400.420	364.410	442.199	461.658
710.000	433.260	395.600	478.050	498.224
711.000	470.160	426.550	514.532	535.287
712.000	507.060	459.160	551.653	572.849
713.000	543.960	492.860	589.423	610.909
714.000	580.870	527.670	627.850	649.468
715.000	617.770	561.980	666.943	688.526

716.000	658.910	613.750	706.711	728.083
717.000	700.060	665.040	747.162	768.141
718.000	741.210	716.320	788.305	808.699
719.000	782.350	767.600	830.149	849.758
720.000	823.500	818.240	872.703	891.318
721.000	870.090	864.000	915.975	933.380
722.000	916.680	912.540	959.975	975.944
723.000	963.270	961.090	1004.710	1019.010
724.000	1009.860	1009.630	1050.189	1062.579
725.000	1056.450	1061.470	1096.423	1106.651
726.000	1110.100	1121.000	1143.418	1151.227
727.000	1163.740	1174.470	1191.184	1196.307
728.000	1217.390	1227.950	1239.729	1241.891
729.000	1271.040	1281.430	1289.062	1287.980
730.000	1324.690	1338.540	1339.193	1334.575
731.000	1381.120	1388.180	1390.129	1381.675
732.000	1437.550	1436.030	1441.880	1429.281
732.430	**1461.810**	**1454.680**	**1464.385**	**1449.907**

Idukki reservoir was completed in 1974 and its original gross and live storage capacity were reported as 1998.57 MCM & 1461.81 MCM respectively.

The first hydrographic capacity survey was conducted in 1999. The gross capacity and live storage capacity were worked out to 1972.72 MCM and 1453.04 MCM.

In 2003 a Satellite Remote Sensing Survey was conducted using optical imageries that indicated a live storage capacity of 1464.385 higher than the original capacity.

In the present study, it is found that live capacity of the Idukki reservoir in 2019 is 1449.907 MCM witnessing a live storage loss of 11.903 MCM (i.e. 0.814 %) in a period of 45 years during 1974 to 2019. This accounts for live capacity loss of 0.018% per annum since 1974.

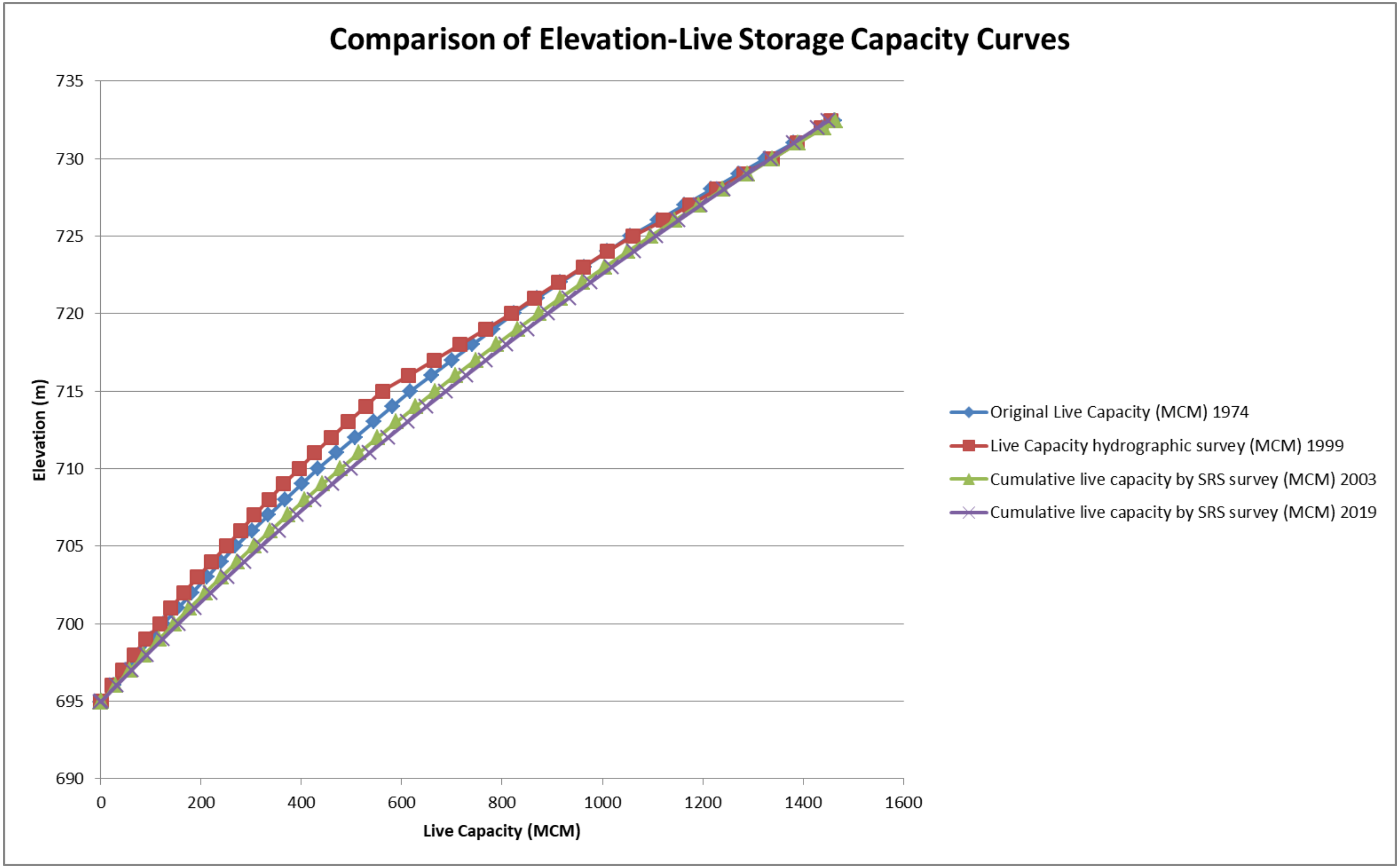


Fig. 11: Comparison of Elevation-Live Storage Capacity Curves (MCM)

10. RESULTS AND DISCUSSIONS

The loss in live storage capacity of the reservoir due to sedimentation since original survey (1974), hydrographic survey (1999) and remote sensing survey (2003) is given in Table –5.

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

	Original Survey (1974)	Hydrographic Survey (1999)	SRS (2003)	SRS (2019)
Live Capacity (MCM)	1461.81	1453.04	1464.385	1449.907
Loss in Capacity (MCM)	-	8.770	-	11.903
% Live capacity loss (since 1974)	-	0.6	-	0.814
Annual % live capacity loss	-	0.024	-	0.018

The live storage capacity of Idukki reservoir as per present study is found to be 1449.907 MCM for the year 2019. As per original survey conducted in 1974 the live storage capacity was 1461.81 MCM and as per hydrographic survey conducted in 1999 the live storage capacity was 1453.04 MCM. In 2003 Remote sensing survey the capacity was worked out as 1464.385 MCM higher than the original capacity. The result of SRS study in 2003 may be erroneous due to inability to cover the entire live storage zone of the reservoir due to non-availability of cloud free satellite data at FRL and MDDL, the study was taken up with only 61.5% of original live storage capacity covered by the available cloud free date of satellite pass on maximum and minimum reservoir levels.

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 Idukki reservoir has been found to be 1449.907 MCM in 2019.
2. Live storage loss of 11.903 MCM (i.e. 0.814%) was observed since original survey (1974) i.e. in a period of 45 years. This accounts for live capacity loss of 0.018% per annum since 1974.
3. Satellite remote sensing 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 reservoir area 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

1. As the reservoir operates between MDDL and FRL, the satellite data is available for this range only. The satellite remote sensing based reservoir capacity estimation works between MDDL and FRL in live storage.
2. Remote sensing techniques give accurate estimate for fan shaped reservoir where there is considerable change in water-spread area with change in water level.
3. 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.

SALIENT FEATURES OF IDUKKI DAM RESERVOIR

I LOCATION

1	State	-	Kerala
2.	District	-	Idukki
3.	Tehsil		
	Idukki Dam	-	Across the River Periyar, forming the boundary of Udumbunchola Taluk and Thodupuzha Taluk of Idukki district.
	Cheruthoni Dam, Kulamavu Dam, Tunnel Power House etc.	-	Thodupuzha Taluk of Idukki District
4.	Rivers	-	Periyar, its tributary Cheruthoni and Kilivally Thodu, a tributary of Muvattupuzha river
5.	Site of Dams		
	Idukki Dam		On the River Periyar about 54.706 kms downstream of the existing Periyar Dam and about 2.413 km upstream of the confluence of Periyar and Cheuthoni at latitude 9°50'30" N and longitude 76°58'40"E.
	Cheruthoni Dam		On the river Cheruthoni, a tributary of Periyar about 2.413 kms upstream of its confluence with the Periyar and not far from Idukki Dam at latitude 9°50'48" N and longitude 76°58'E.
	Kulamavu Dam		At the head of Kilivally Thodu stream-let of Muvattupuzha river, near Kulamavu about 35.398 kms southeast of Thodupuzha at Latitude 9°48'05" N and longitude 76°53'E
6	Site of Power House		At Moolamattam about 24.135 kms south of Thodumuzha at the foot of Naddukani hills, by the side of Nachar at latitude 9°47'18" N and longitude 76°51'22"E.

II Reservoir

1	Full Reservoir Level	+ 732.43 m
2	Gross Storage at F.R.L	1998.568 M.cu.m
3.	Dead Storage below MDDL 694.94 m	536.76 M.cu.m
4.	Live Storage	1461.81 M.cu.m
5.	Water Spread area at F.R.L	60.63 sq.km
6.	Maximum water level	+ 734.11 m
7.	Gross storage at M.W.L	2092.61 M.cu.m
8.	Water spread area at M.W.L	63.39 sq.km
9.	Top level of Dams	
	(a) Idukki & Cheruthoni	+736.092 m
	(b) Kulamavu Dam	+736.092 m

PHOTOGRAPH OF RESERVOIR

Photo 1: Idukki Arch Dam

Photo 2: Idukki Reservoir

Photo 3: Idukki Reservoir

Photo 4: Idukki Reservoir

References

1. Muley M V. Application of Remote Sensing in the study of reservoir Sedimentation, SAC, Ahemedabad, June 2001.
2. Linsley R K and Franzini J B Reservoirs. Water resources Engineering, II ed. Mc Graw Hill Kogakusha ltd, 1972,pp.161-185
3. Borland W M and Miller C R (1960), Distribution of sediment in large reservoirs. Transactions of American Society of civil engineers, vol.125, 1960
4. Compendium on silting of reservoirs in India (2015), WS&RS directorate, Environment Management Organization, WP&P wing, CWC, pp1-194.
5. Technical report on Sedimentation Assessment of Idukki Reservoir, Kerala on Idukki river through Satellite Remote Sensing, Remote Sensing Dte, CWC, August 2009, pp 1-27.
6. Sentinel-1 SAR Technical Guide, <https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-1-sar.>

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