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

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Government of India
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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 Idamalayar 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 Idamalayar 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 Idamalayar reservoir at the time of opening in 1985 were 1090 MCM & 1017.80 MCM respectively. In 1986, Hydrographic survey was conducted for this reservoir that witnessed increased gross and live storage capacities as 1208.23 MCM and 1136.23 MCM. The capacity for the project purpose estimated at the time of commissioning in 1985 shows lesser capacity as compared to hydrographic survey conducted in 1986. This may be due to erroneous survey conducted in 1986 or error in the estimation of original capacity itself. Thereafter, a number of hydrographic and remote sensing surveys were undertaken and all of those showed capacity higher than the capacity at the time of commissioning. This indicates that original capacity estimated in 1985 ought to be wrong. Therefore the base line survey conducted in 1986 has been taken as reference survey for estimation of sedimentation loss in the live storage zone for this study.

After analysis of the satellite data in the present study, it is found that live capacity of the Idamalayar reservoir in 2019 is 1117.93 MCM witnessing a live storage loss of 18.301 MCM (i.e. 1.61 %) in a period of 33 years during 1986 to 2019. This accounts for live capacity loss of 0.049% per annum since 1986.

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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 IDAMALAYAR 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 Idamalayar 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

Characteristics of reservoir sedimentation include amount, distribution, configuration and composition of reservoir deposits. 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". In a general sense, a density current may be defined as a gravity flow, a fluid under, over, or through a fluid or fluids of approximately equal density. From Fig. 1 It may be seen that the depth of the turbid flow increases to the point where the density current is established after which it tends to decrease again (Varshney, 1997).

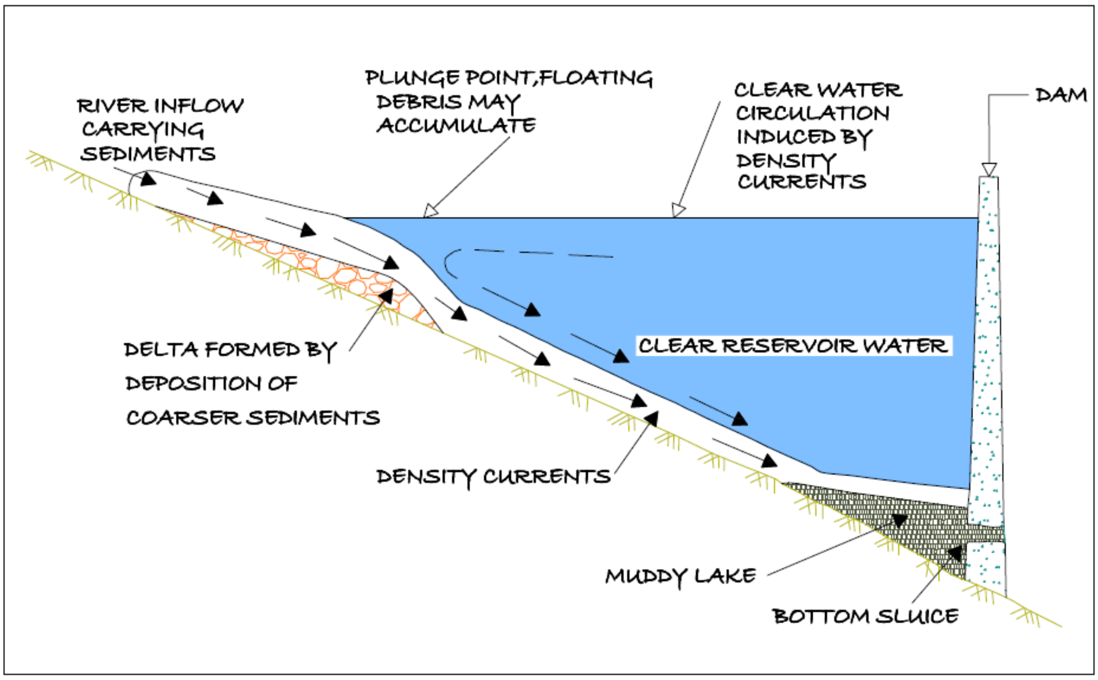


Fig. 1: Conceptual sketch of density currents in a reservoir

The magnitudes of these relative change and their effects upon sediments deposition depend on many factors such as reservoir shape, channel slopes, relation of outflow to inflow and density differences. As a rule, however, conditions are such that density currents move very slowly. In many respects deposits in a reservoir resemble those in a delta, made by stream where it discharges into a lake or sea.

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.

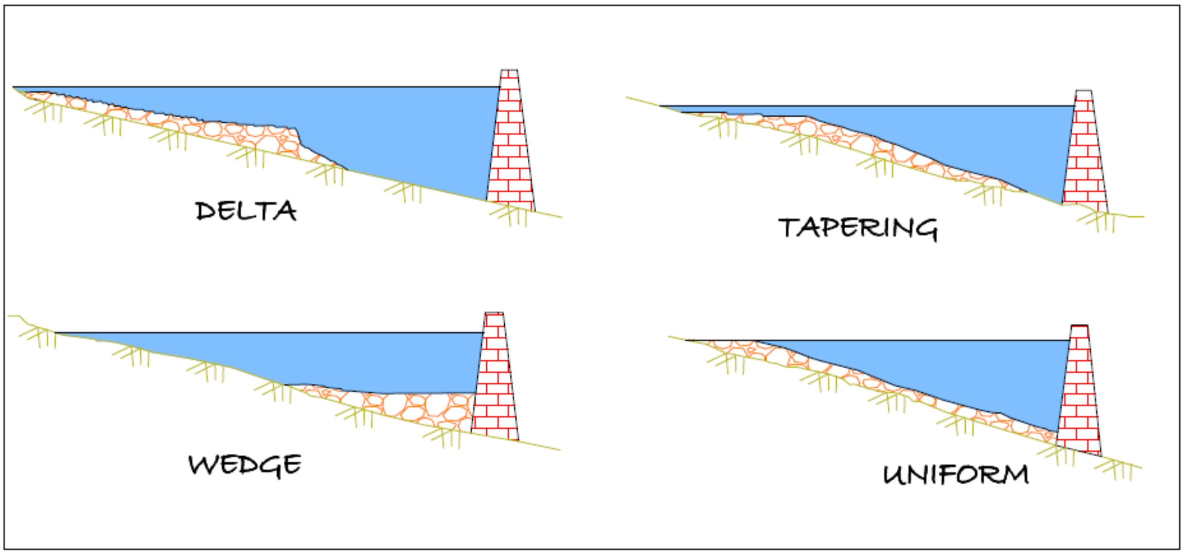


Fig. 2: Longitudinal Patterns of sediment deposition in reservoirs.

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.

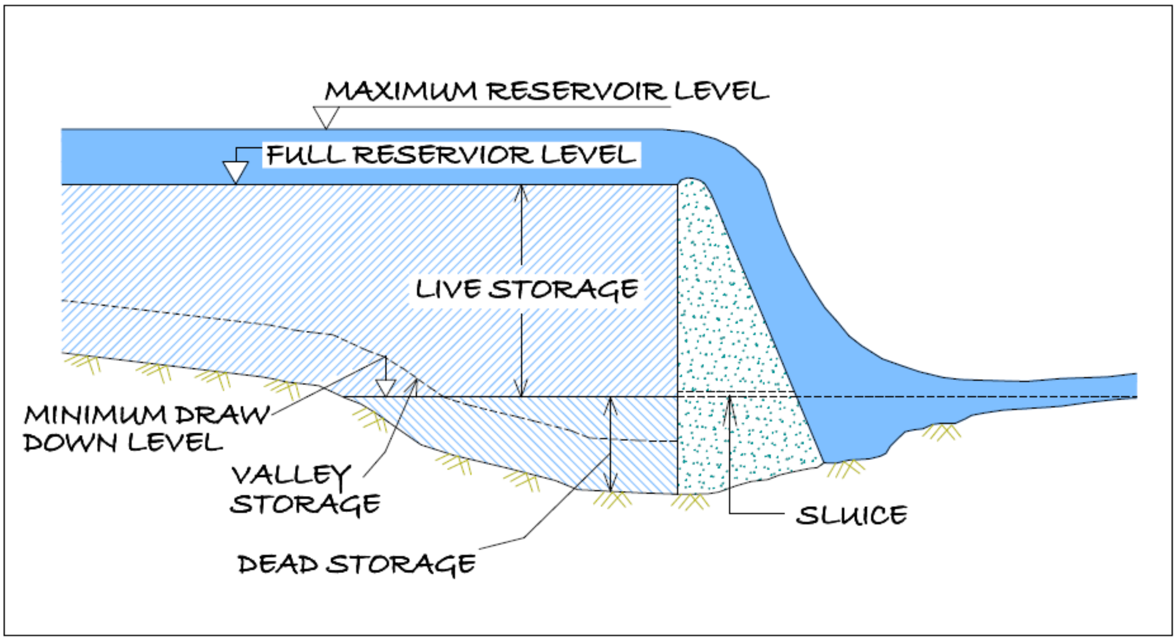


Fig. 3: Conceptual sketch of different levels in a reservoir

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 Idamalayar 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

Idamalayar Reservoir is a reservoir, located near Kothamangalam city in Kerala, India. It is one of the major hydroelectric project under Kerala State Electricity Board (KSEB). The project work was started in 1976 and completed in 1985. Full reservoir level (FRL) is 169 meters and Minimum Drawdown level is 115 meters above sea level. The dam lies at 10° 13′ 15″ North Latitude and, 76° 42′ 30″ East Longitude.

The catchment area of the project is 380.79 Sq Km. The height of the dam above lowest foundation is 91m while the length is 373 m. The original gross capacity of the dam is 1089.80 MCM and live storage capacity is 1017.80 MCM. However, in 1986, Hydrographic survey was conducted for this reservoir that witnessed increased gross and live storage capacities as 1208.23 MCM and 1136.23 MCM as compared to capacity estimated at the time of commissioning in 1985. This may be due to erroneous survey conducted in 1986 or error in the estimation of original capacity itself. Thereafter, a number of hydrographic and remote sensing surveys were undertaken and all of those showed capacity higher than the capacity at the time of commissioning. This indicates that original capacity estimated in 1985 ought to be wrong. Therefore the base line survey conducted in 1986 has been taken as reference survey for estimation of sedimentation loss in the live storage zone for this study.

Fig-4 is the index map showing the location of the Idamalayar reservoir.

Salient features of the project are given at Annexure-I.

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 Idamalayar reservoir, the height difference between FRL (169 m) and MDDL (115 m) is 54 m.

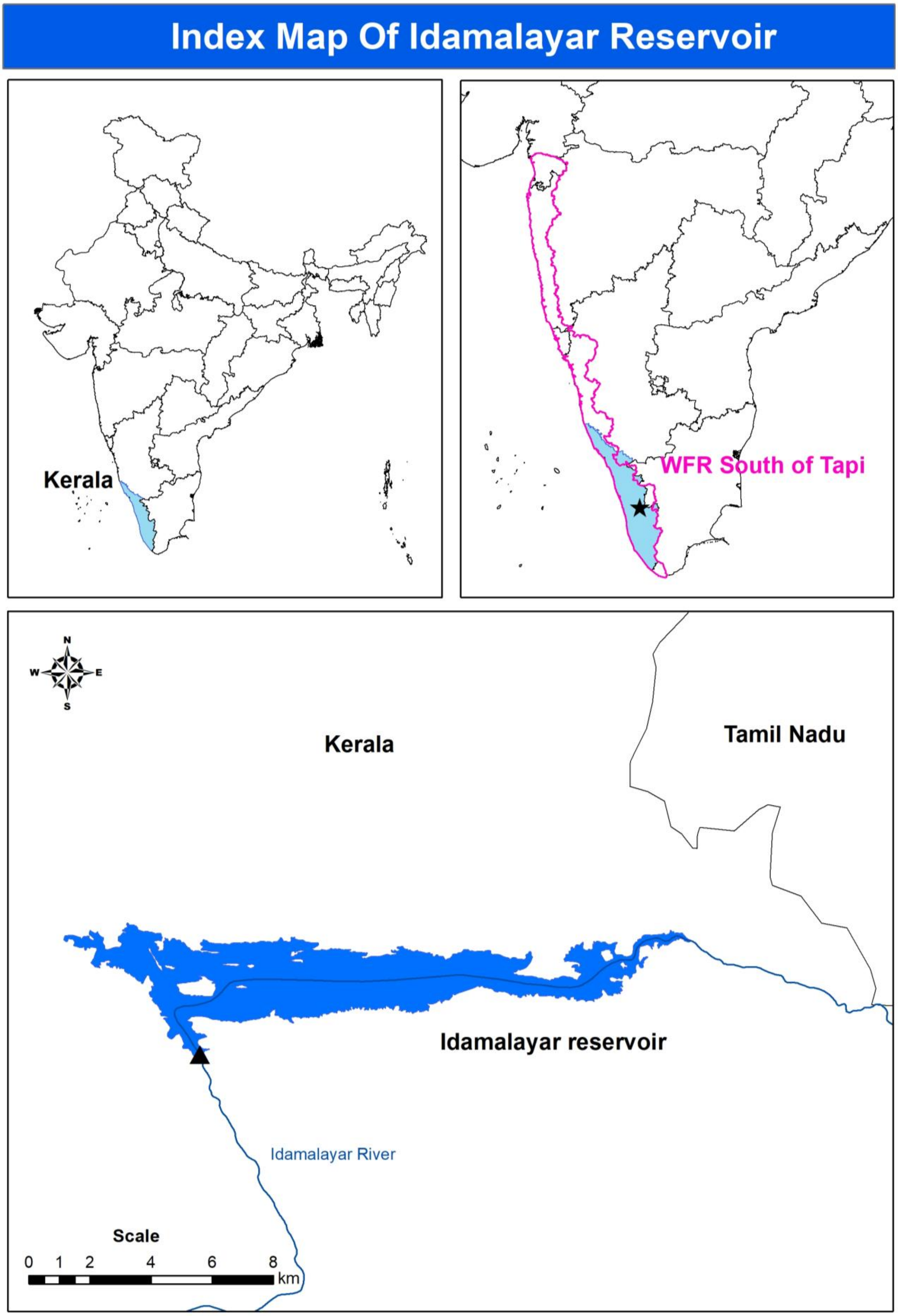


Fig. 4: Index map of the Idamalayar Reservoir

8. DATA USED

8.1. SATELLITE DATA

Microwave data from Sentinel 1A/1B for eleven (11) 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	09/08/2018	169.950 (above FRL)
Sentinel 1A	14/09/2018	162.501
Sentinel 1A	26/09/2018	160.840
Sentinel 1B	15/09/2019	158.868
Sentinel 1A	12/01/2019	154.320
Sentinel 1B	23/02/2019	148.748
Sentinel 1B	19/03/2019	144.259
Sentinel 1B	12/04/2019	138.937
Sentinel 1B	29/07/2019	133.618
Sentinel 1B	18/05/2019	130.019
Sentinel 1B	23/06/2019	124.078

8.2. FIELD DATA

The following field data have been obtained from project authorities:

Elevation - Capacity data

Salient features of Idamalayar 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 Idamalayar reservoir studies, multi-date Sentinel 1 (11 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)
09/08/2018	169.950 (above FRL)	29.554
14/09/2018	162.501	28.631
26/09/2018	160.840	27.735
15/09/2019	158.868	27.191
12/01/2019	154.320	26.614
23/02/2019	148.748	25.662
19/03/2019	144.259	24.273
12/04/2019	138.937	22.076
29/07/2019	133.618	18.911
18/05/2019	130.019	15.277
23/06/2019	124.078	12.171

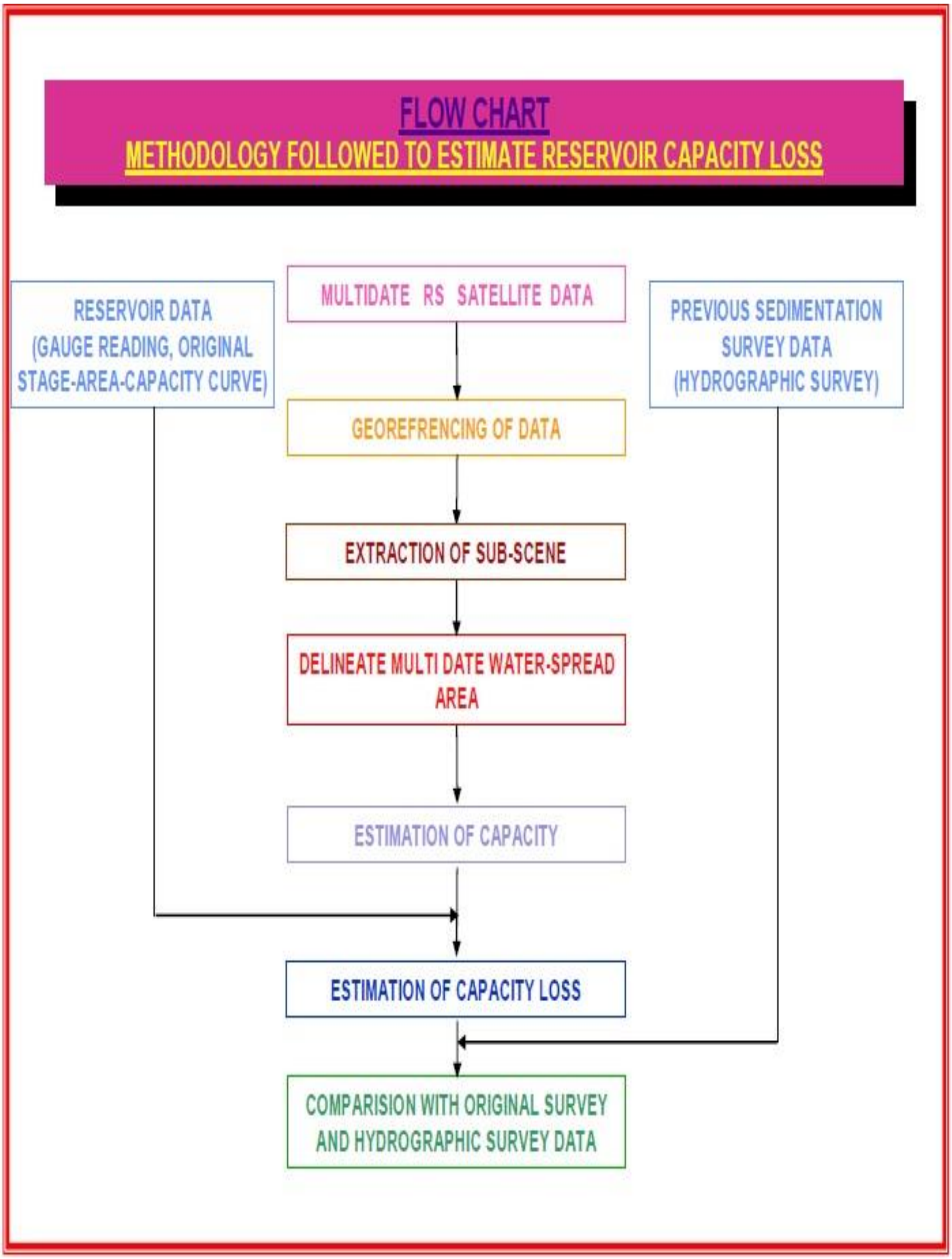


Fig 5 : Flow chart showing methodology followed to estimate reservoir capacity loss

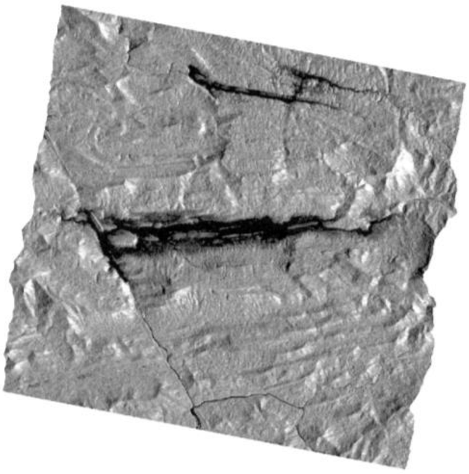
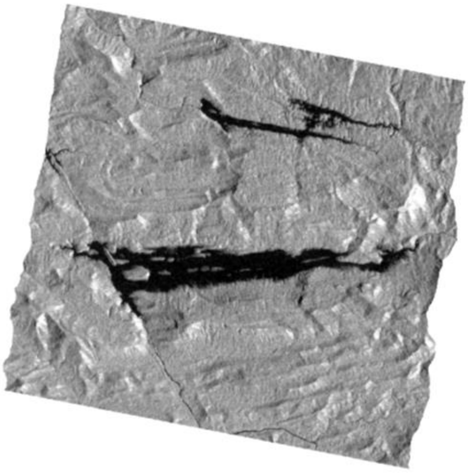
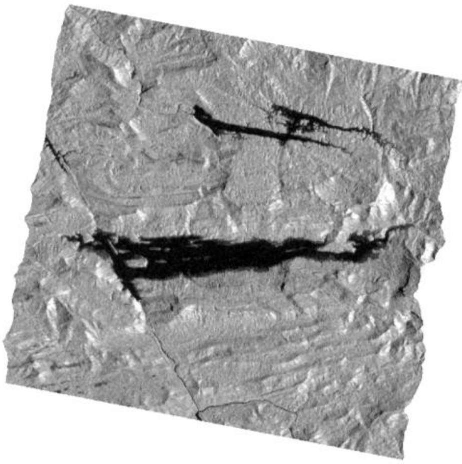
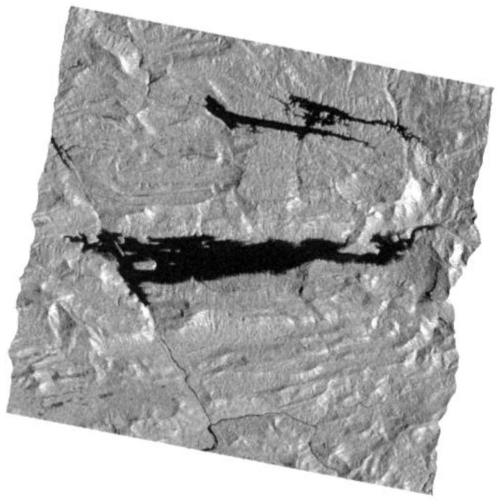
	
23-June-2019 (124.078 m)	**18-May-2019 (130.019 m)**
	
29-July-2019 (133.618 m)	**12-April-2019 (138.937 m)**
	
19-Mar-2019 (144.259 m)	**23-Feb-2019 (148.748 m)**

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

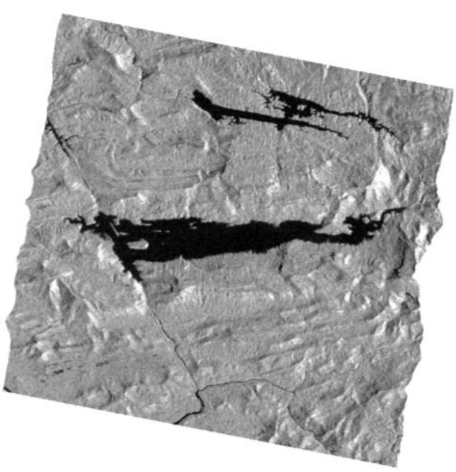
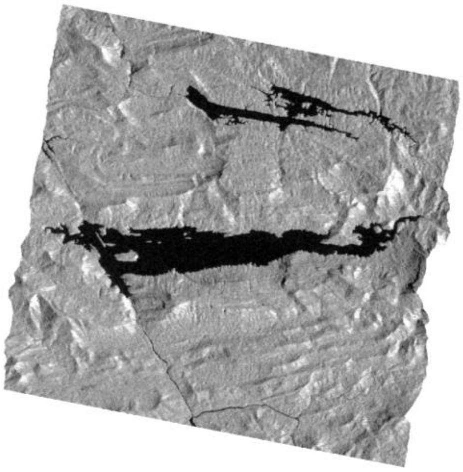
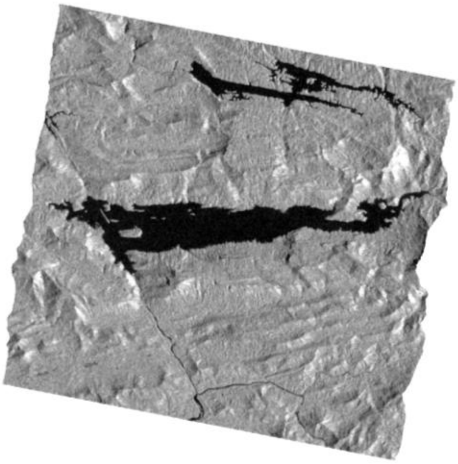
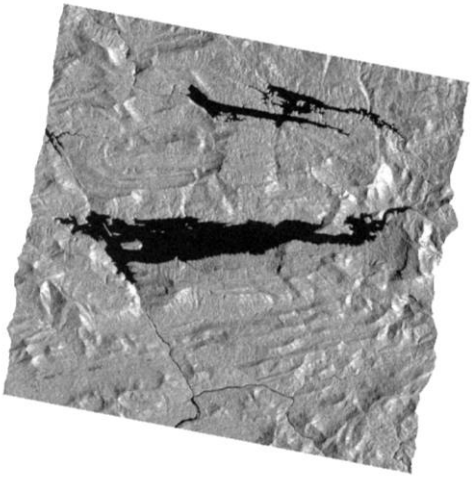
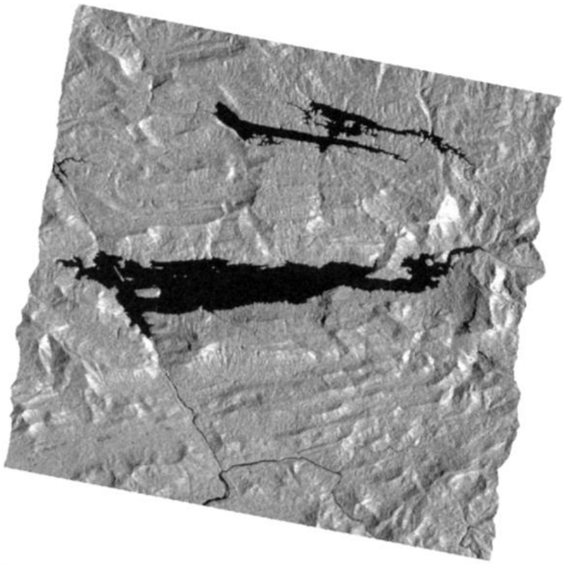
	
12-Jan-2019 (154.320 m)	**15-Sept-2019 (158.868 m)**
	
26-Sept-2018 (160.840 m)	**14-Sept-2018 (162.501 m)**
	
09-Aug-2018 (169.950 m)	

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

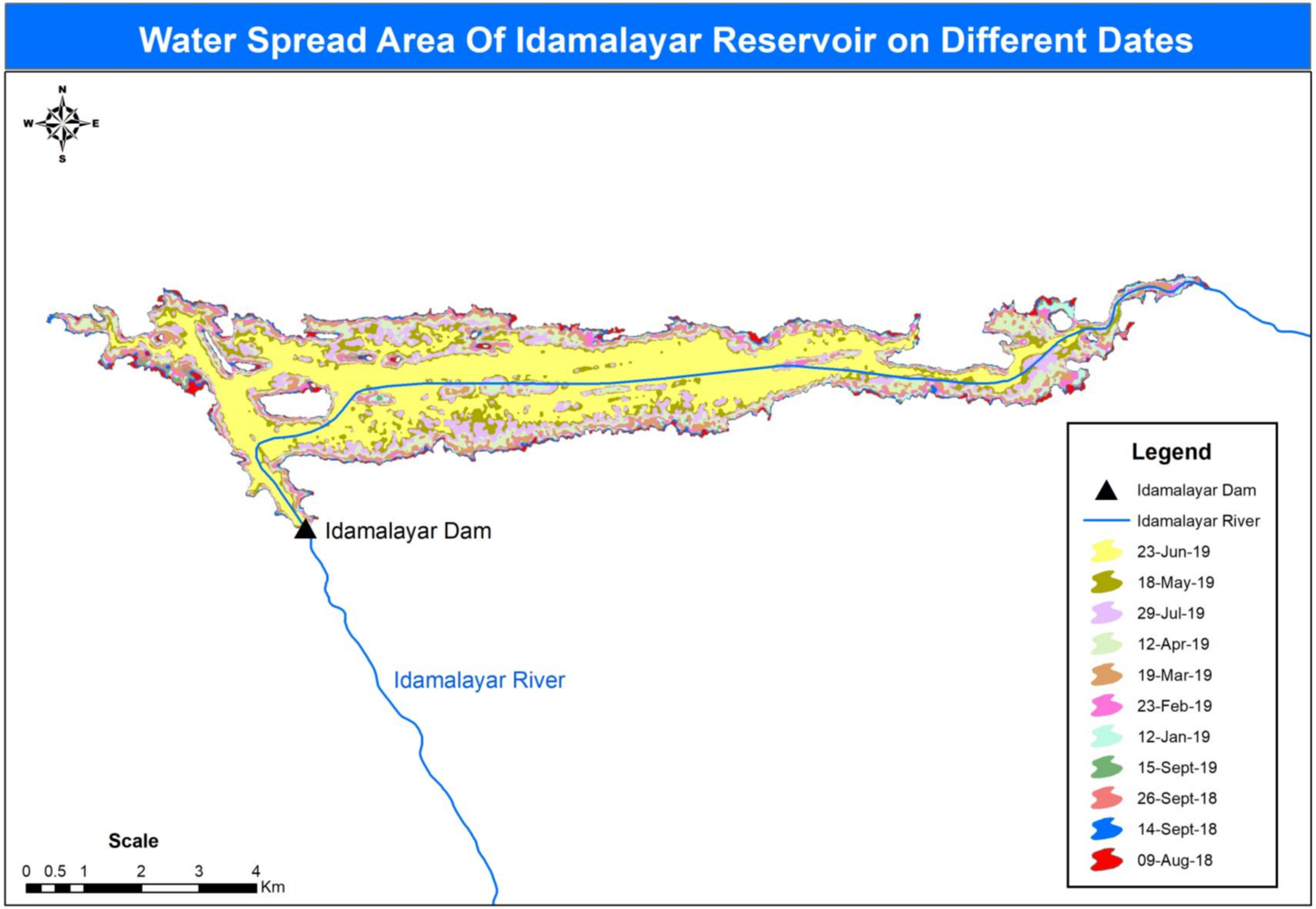


Fig. 7: Water Spread Area of Idamalayar Reservoir on different dates

The Satellite Images for the Idamalayar 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 Idamalayar Reservoir showing its water spread area for eleven overpass dates such as 23-June-19, 18-May-19, 29-July-19, 12-Apr-19, 19-Mar-19, 23-Feb-19, 12-Jan-19, 15-Sept-19, 26-Sept-18, 14-Sept-18 and 09-Aug-18 are shown in fig. 7.

The water elevation 169.950 m for 09-Aug-18 is above the Full Reservoir Level (FRL) of 169 m during Kerala floods of 2018. The Water elevation 124.078 m for 23-June-19 is above the Minimum Drawdown Level (MDDL) of 115 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.

$Y = -0.0082*X^2 + 0.8875 * X + 4.7671$

$R^2 = 0.9889$

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

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

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.

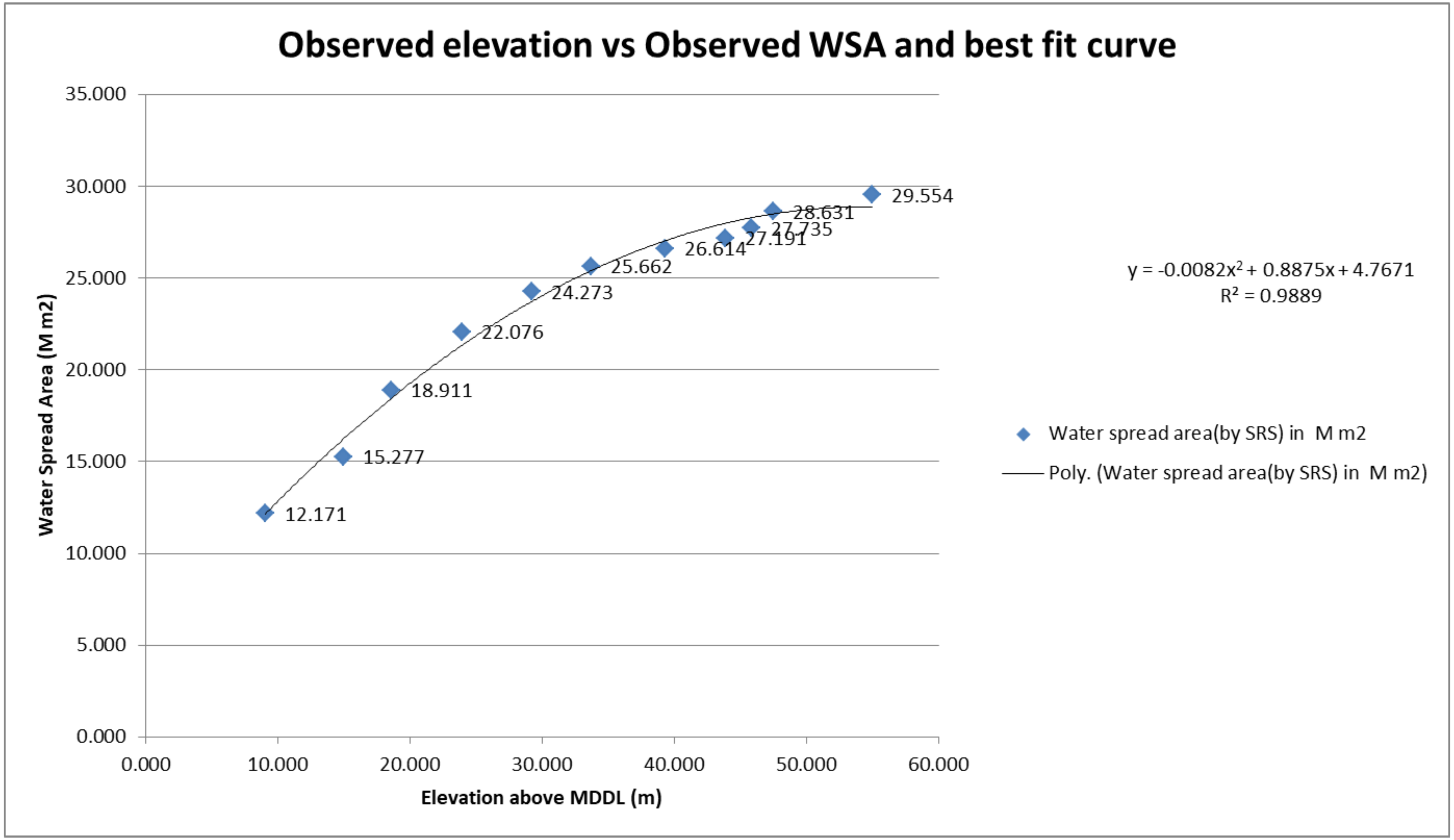


Fig. 8: Observed elevation vs Observed WSA and best fit curve of Idamalayar Reservoir

Table 3 gives the values of Live storage capacity and submergence areas at a regular interval of 5.0 m have been worked out using the best-fit polynomial equations 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 (5.0m) using SRS Survey 2019

Reservoir water level in Metre		Water spread area by trend line (Mm^2)	Segmental Live Capacity (MCM) by SRS technique	Cumulative Live Capacity (MCM) by SRS technique
MDDL	115	4.767	0.000	0.000
	120	9.000	33.861	33.861
	125	12.822	54.273	88.134
	130	16.235	72.474	160.608
	135	19.237	88.573	249.182
	140	21.830	102.598	351.780
	145	24.012	114.561	466.341
	150	25.785	124.465	590.806
	155	27.147	132.315	723.121
	160	28.100	138.110	861.231
	165	28.642	141.852	1003.083
FRL	169	28.781	114.846	**1117.929**

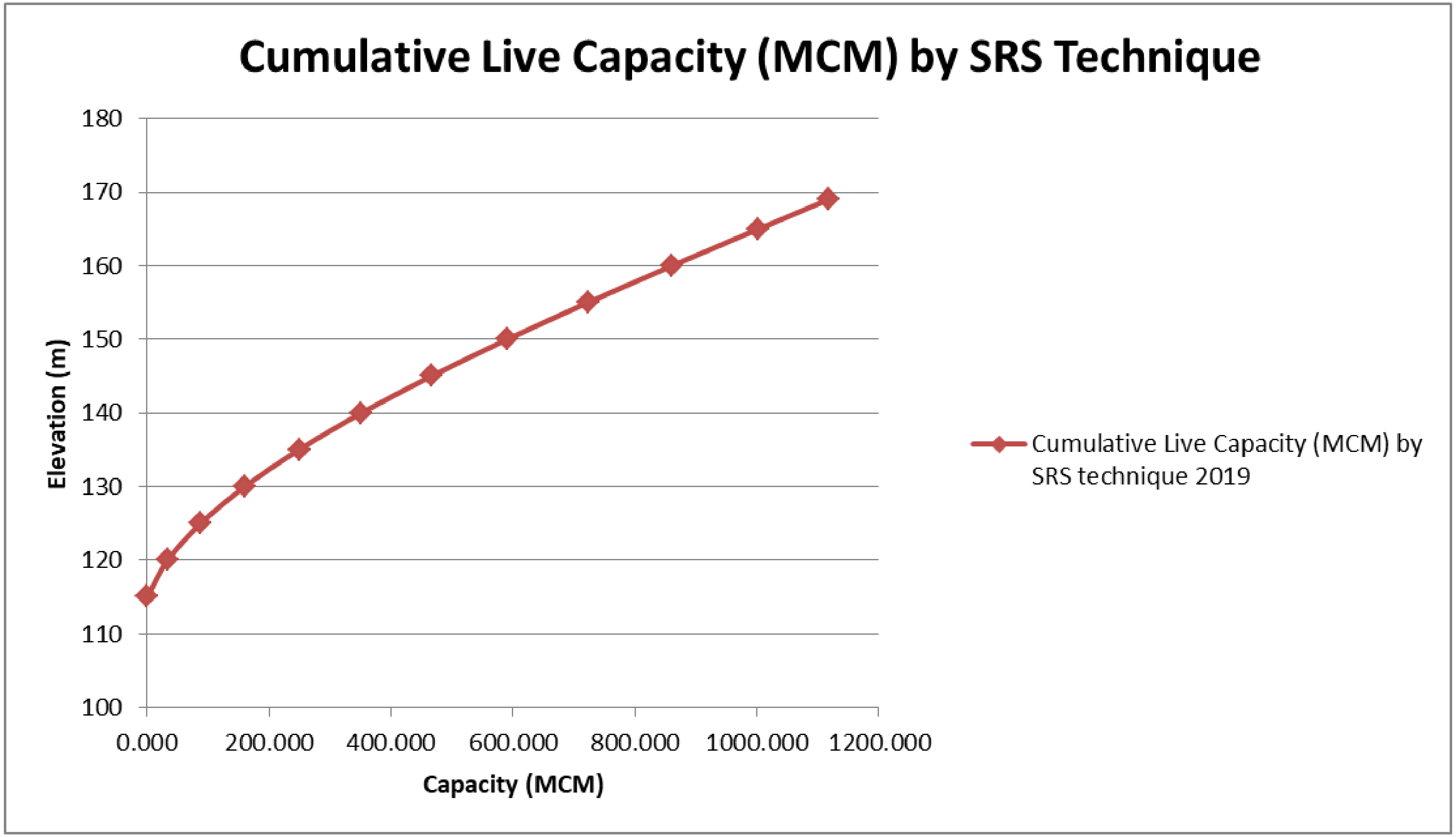


Fig. 9: Modified live capacity - elevation curve (SRS technique)

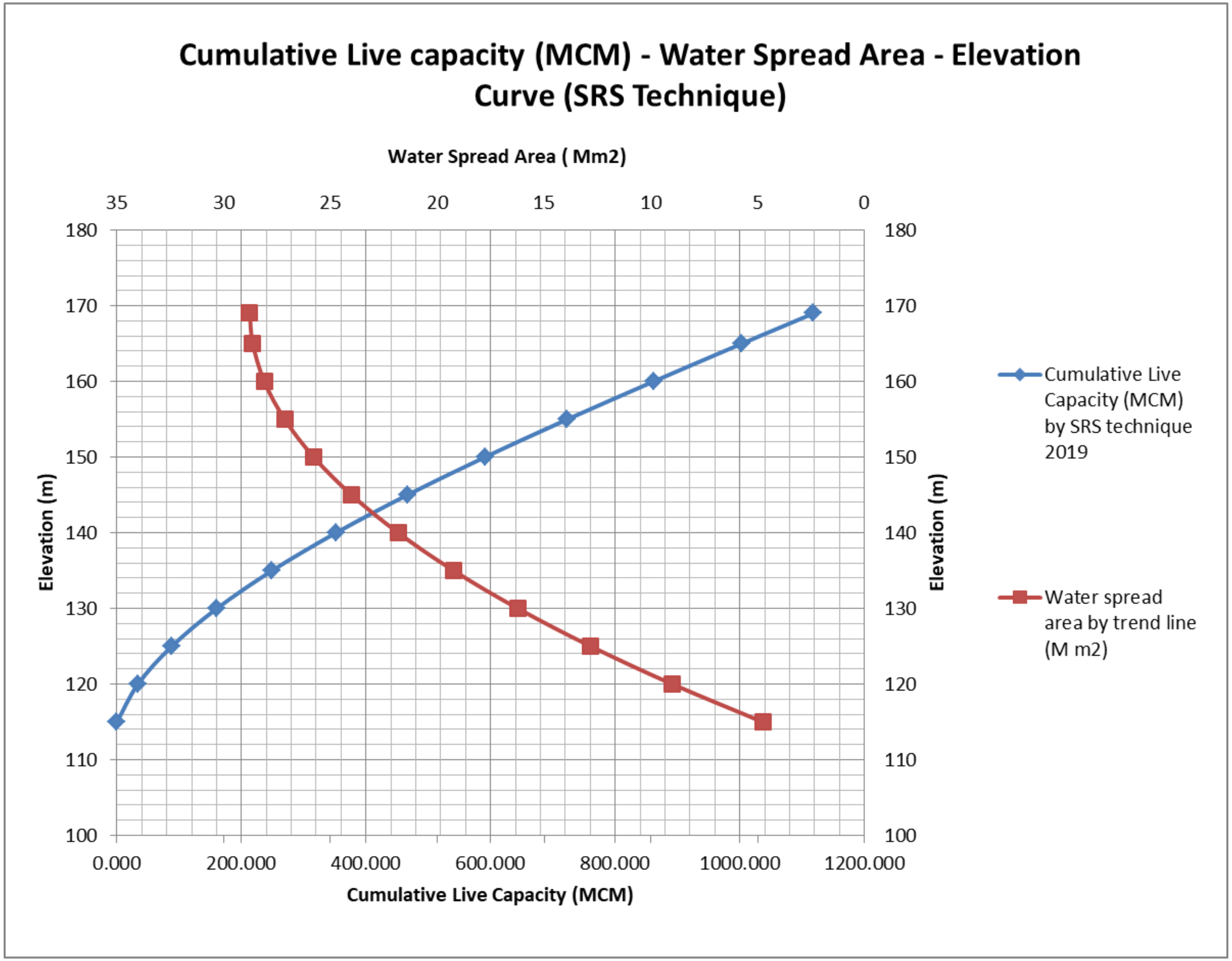


Fig. 10: Elevation – Area- Capacity Curve

9.4. Comparison with Original and Previous Surveys

Comparison of live storage capacity of SRS survey with original survey 1985 and SRS survey 2007 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)

Reservoir water level in Meter		Original Live Capacity 1985 (MCM)	Live Capacity (MCM) by SRS technique 2007	Live Capacity (MCM) by SRS technique 2019
MDDL	**115**	0.00	0.00	0.000
	120	38.00	86.95	33.861
	125	86.50	181.43	88.134
	130	147.00	283.11	160.608
	135	220.00	391.67	249.182
	140	309.00	506.79	351.780
	145	407.00	628.12	466.341
	150	515.34	755.35	590.806
	155	632.24	888.15	723.121
	160	760.00	1026.19	861.231
	165	903.22	1169.14	1003.083
FRL	**169**	**1017.80**	**1286.81**	**1117.929**

Idamalayar reservoir was completed in 1985 and its original gross and live storage capacity were reported as 1090 MCM & 1017.80 MCM respectively.

The first hydrographic capacity survey was conducted immediately after in 1986. The gross capacity and live storage capacity were worked out to 1208.23 MCM and 1136.23 MCM. The capacity for the project purpose estimated at the time of commissioning in 1985 shows lesser capacity as compared to hydrographic survey conducted in 1986. This may be due to erroneous survey conducted in 1986 or error in the estimation of original capacity itself. Thereafter, a number of hydrographic and remote sensing surveys were undertaken and all of those showed capacity higher than the capacity at the time of commissioning. This indicates that original capacity estimated in 1985 ought to be wrong. Therefore the base line survey conducted in 1986 has been taken as reference survey for estimation of sedimentation loss in the live storage zone for this study.

In 2007 a Satellite Remote Sensing Survey was conducted using optical imageries that indicated a live storage capacity of 1286.81 higher than the previous capacities and recommended to conduct hydrographic survey for the reservoir.

Another hydrographic survey was conducted in 2011 for the reservoir that reported live storage capacity as 1135.227 MCM.

In the present study, it is found that live capacity of the Idamalayar reservoir in 2019 is 1117.93 MCM witnessing a live storage loss of 18.30 MCM (i.e. 1.61 %) in a period of 33 years during 1986 to 2019. This accounts for live capacity loss of 0.049% per annum since 1986.

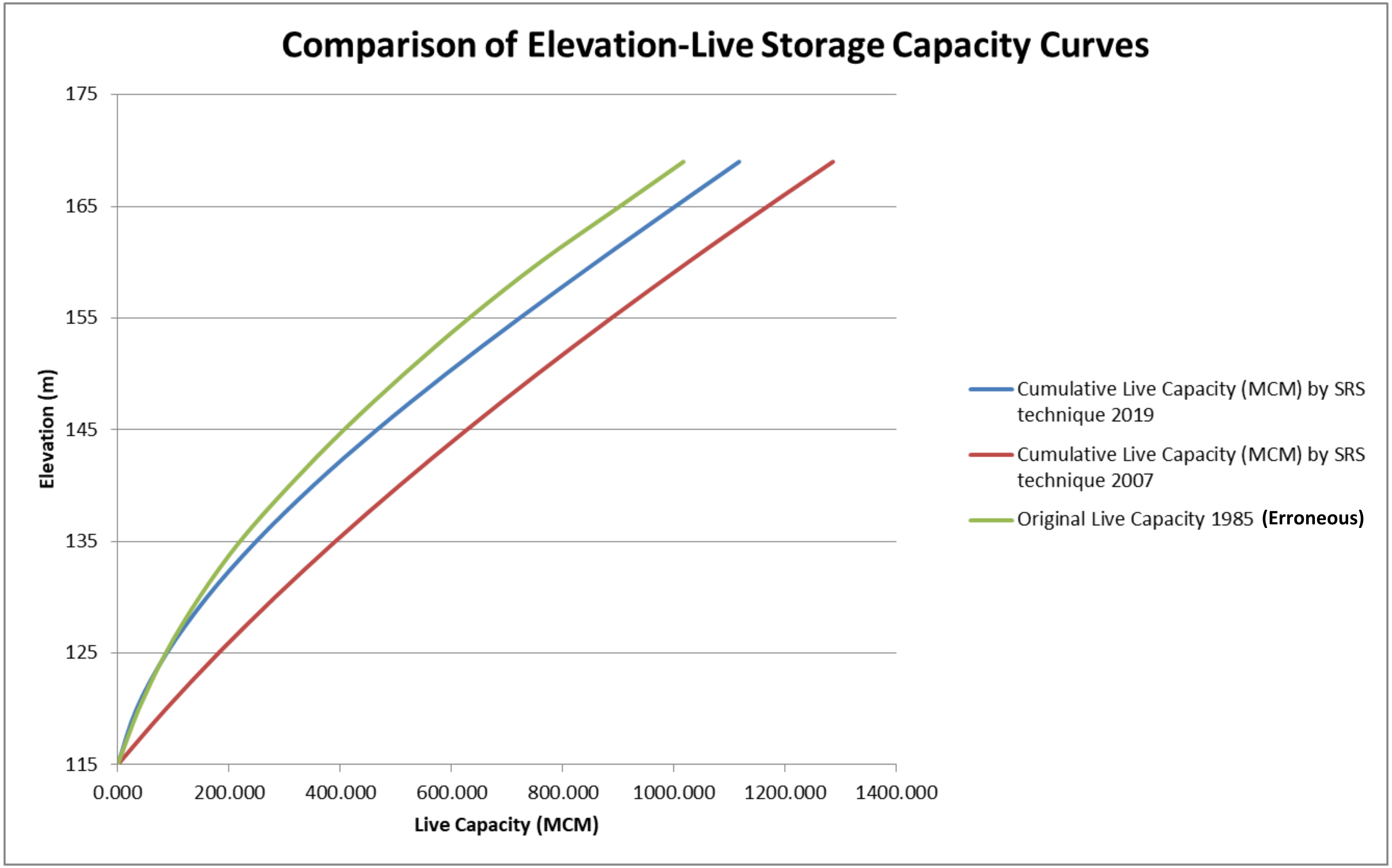


Fig. 11: Comparison of Elevation-Live Storage Capacity Curves (MCM)

10. RESULTS AND DISCUSSIONS

The loss in live storage capacity of the reservoir due to sedimentation since original survey (1985), hydrographic survey (1986 & 2011) and remote sensing survey (2007) is given in Table –5.

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

	Original Survey (1985)	Hydrographic Survey (1986)	SRS (2007)	Hydrographic Survey (2011)	SRS (2019)
Live Capacity (MCM)	1017.80	1136.23	1286.81	1135.227	1117.93
Loss in Capacity (MCM)	-	-	-	1.003	18.30
% Live capacity loss (since 1986)	-	-	-	0.088	1.61
Annual % live capacity loss	-	-	-	0.0035	0.049

The live storage capacity of Idamalayar reservoir as per present study is found to be 1117.93 MCM for the year 2019. As per original survey conducted in 1985 the live storage capacity was 1017.80 MCM and as per hydrographic survey conducted in 1986 the live storage capacity was 1136.23 MCM. In 2007 Remote sensing survey the capacity was worked out as 1286.81 MCM. In 2011 another hydrographic survey was conducted that computed live storage capacity as 1135.227 MCM. 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 Idamalayar reservoir has been found to be 1117.93 MCM in 2019.
2. Live storage loss of 18.30 MCM (i.e. 1.61 %) was observed since hydrographic survey (1986) i.e. in a period of 33 years during 1986 to 2019.

This accounts for live capacity loss of 0.049% per annum since 1986.

3. A number of hydrographic and remote sensing surveys were undertaken for Idamalayar reservoir and all of those showed capacity higher than the capacity at the time of commissioning in 1985. This indicates that original capacity estimated in 1985 ought to be wrong. Therefore the base line survey conducted in 1986 has been taken as reference survey for estimation of sedimentation loss in the live storage zone for the study.
4. 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.
5. 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.
6. **Capacity estimation using Microwave remote sensing technology has the advantage that cloud-free imageries are available throughout the year at frequent inetrval 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.

Annexure-I

SALIENT FEATURES OF IDAMALAYAR DAM RESERVOIR

1.	**Name of Project**		Idamalayar Dam
2.	**Location**:		
		a. Nearest city	Kothamangalam
		b. State	Kerala
		c. Longitude	76^0 42' 30" E
		d. Latitude	10^0 13'15" N
4.	**Type**		Concrete Gravity dam with height of 91 m above deepest foundation level
5.	**River** Tributary on which located		Idamalayar river
6.	**Year of Completion**		Work started in 1976 & completed in 1985
7.	**Total catchments** up to dam site		380.79 sq. Km + 101 sq Km of Nirar
8.	**Salient Levels**:		
		i. Maximum Water Level	171.20 m
		ii. FRL	169 m
		iii MDDL	115 m
9.	**Designed storage capacity**		
		i. Gross Storage	1090 MCM
		ii. Live Storage	1017.80 MCM
		iii. Dead Storage	72 MCM
13	(i) **Dam**		
	Bed Level		81 m
	Deepest Foundation Level		70.40 M
	Height at Bed Level		91.00 M
	Length at Dam Top		373.00 M

Top width	8.50 M
Bottom width	85.00 M
(ii) **Spillway**	
Crest level	161.00 M
Width	60.0 M
Maximum discharge	4063.50 M /Sec
(iii) **Head Race Tunnel**	
Shape Type and Size	Circular, Concrete, 5.20m dia
Length	1564.00 M
Slope	1/250
Max. flow	80m per sec
Velocity of flow	3.77 m/sec
Power House Capacity	37.50 MWx2 Nos. Francis Turbine (BHEL Make)
(iv) **Power Intake**	
Size of opening	3100 mmx4746.73mm
Size of intake	4.20m dia
(v) **Surge shaft**	
Height	89.116m
Size	21.70m dia & 18.85m dia
(vi) Low Pressure Pipe	
Length	114.40m
Diameter	4.20m

PHOTOGRAPH OF RESERVOIR

Photo 1: Idamalayar Reservoir

Photo 2: Idamalayar Reservoir

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