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

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Government of India
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Remote Sensing Directorate

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

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 Malampuzha 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 Malampuzha 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 Malampuzha reservoir at the time of opening in 1955 were 226 MCM & 221.174 MCM respectively. In 1977, 1990 and 2006 Hydrographic surveys were conducted for this reservoir that witnessed storage capacities as 220.153 MCM, 208.130 and 195.328 respectively. In 2004-05 Satellite Remote Sensing survey was done that reported the live capacity as 203.955 MCM. After analysis of the satellite data in the present study, it is found that live capacity of the Malampuzha reservoir in 2019 is 186.566 MCM witnessing a live storage loss of 34.608 MCM (i.e. 15.647 %) in a period of 64 years during 1955 to 2019. This accounts for live capacity loss of 0.244% per annum since 1955.

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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 MALAMPUZHA 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 Malampuzha 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.

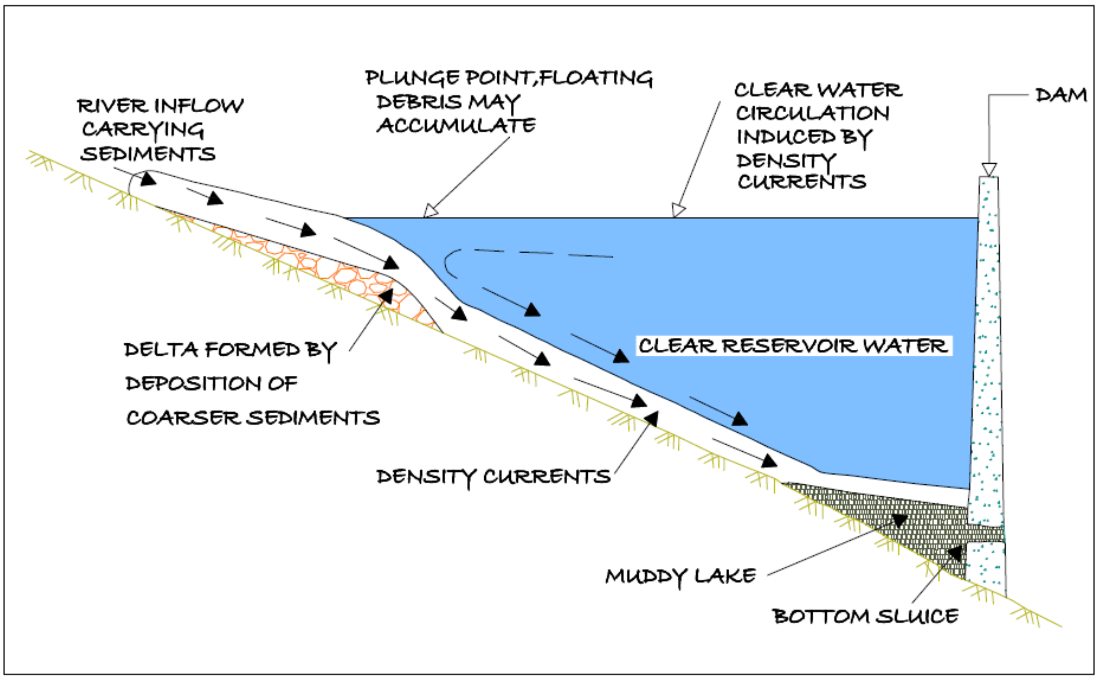


Fig. 1: Conceptual sketch of density currents in a reservoir

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.

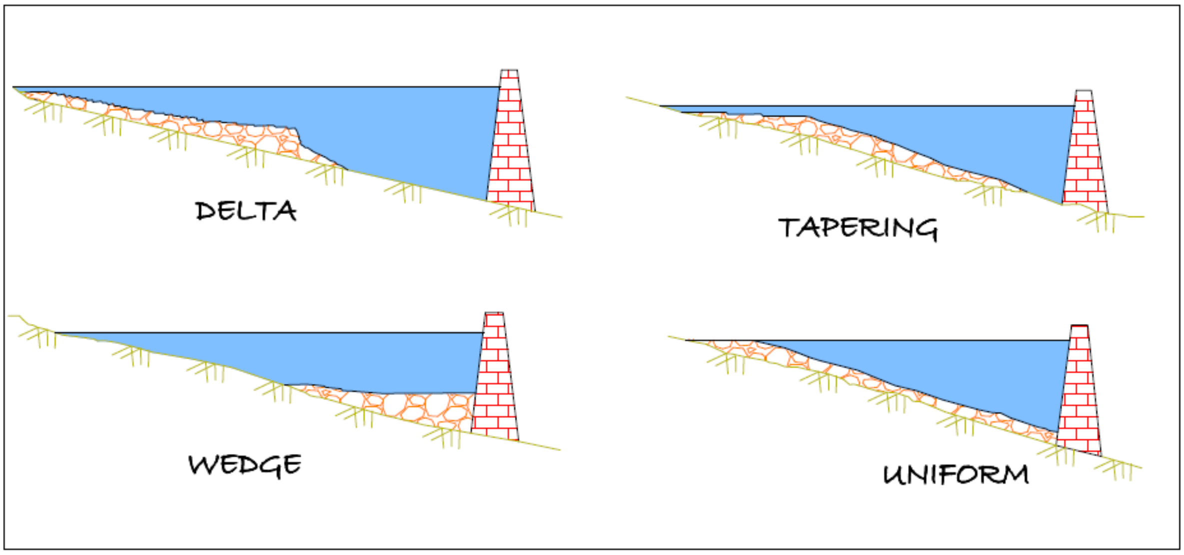


Fig. 2: Longitudinal Patterns of sediment deposition in reservoirs.

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.

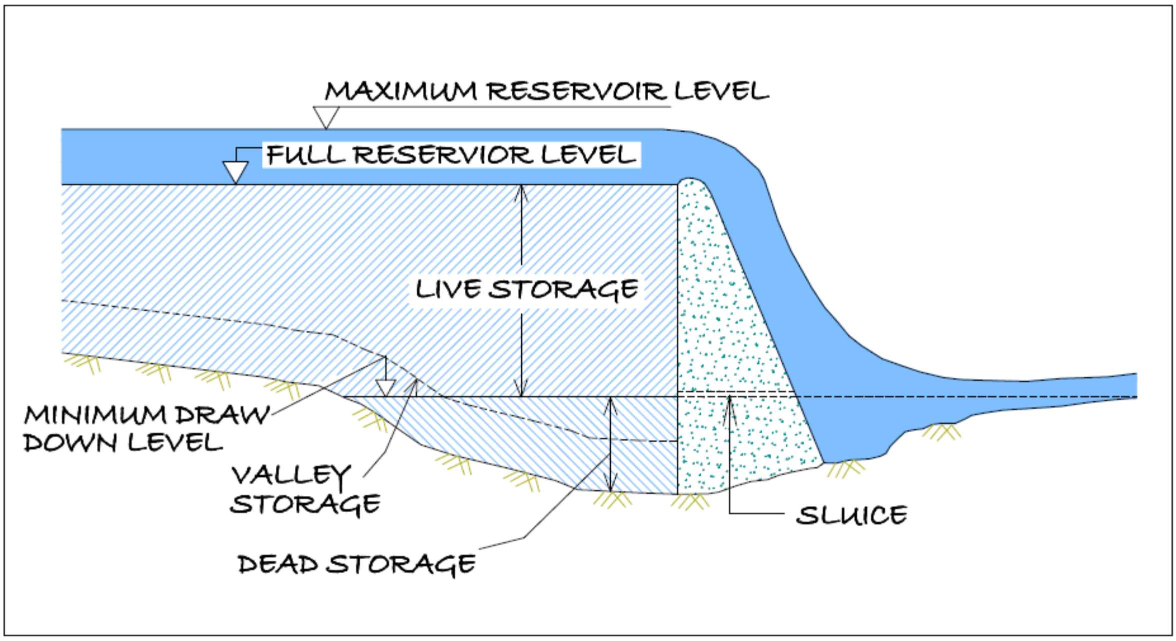


Fig. 3: Conceptual sketch of different levels in a reservoir

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 Malampuzha 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

Malampuzha reservoir was completed in the year 1955 on Malampuzha river at Malampuzha which is 13 km from Palakkad in Kerala state. Malampuzha River is a tributary of the river Bharatpuza. Malampuzha reservoir was under consideration of the erstwhile Madras Presidency since 1914. The preliminary investigation report and the detailed investigation report of the project were prepared in 1925 and 1947 respectively. The Malampuzha irrigation project is one of the major completed projects of Kerala having a net ayacut of 21045 hectares. The reservoir is formed by construction of gravity type masonry dam across the Malampuzha river. The reservoir lies between 76^0 39' to 76^0 42' E longitudes and 10^0 48' to 10^0 55' N latitudes.

The catchment area of the reservoir is 147.63 sq. km. and comprises of number of folded hills one behind the other. The major portion of the catchment is forest land. The mean annual rainfall in the watershed is 2169.16 mm which yields an estimated mean annual runoff of 207 MCM. The type of the dam is straight gravity rubble dam. Gross storage capacity of the dam in 1955 was 221.17 MCM at FRL of 115.06 m. Minimum Drawdown Level (MDDL) of the reservoir is 91.44m. Salient features of the Malampuzha 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 Malampuzha reservoir, the height difference between FRL (115.06 m) and MDDL (91.44 m) is 23.62 m.

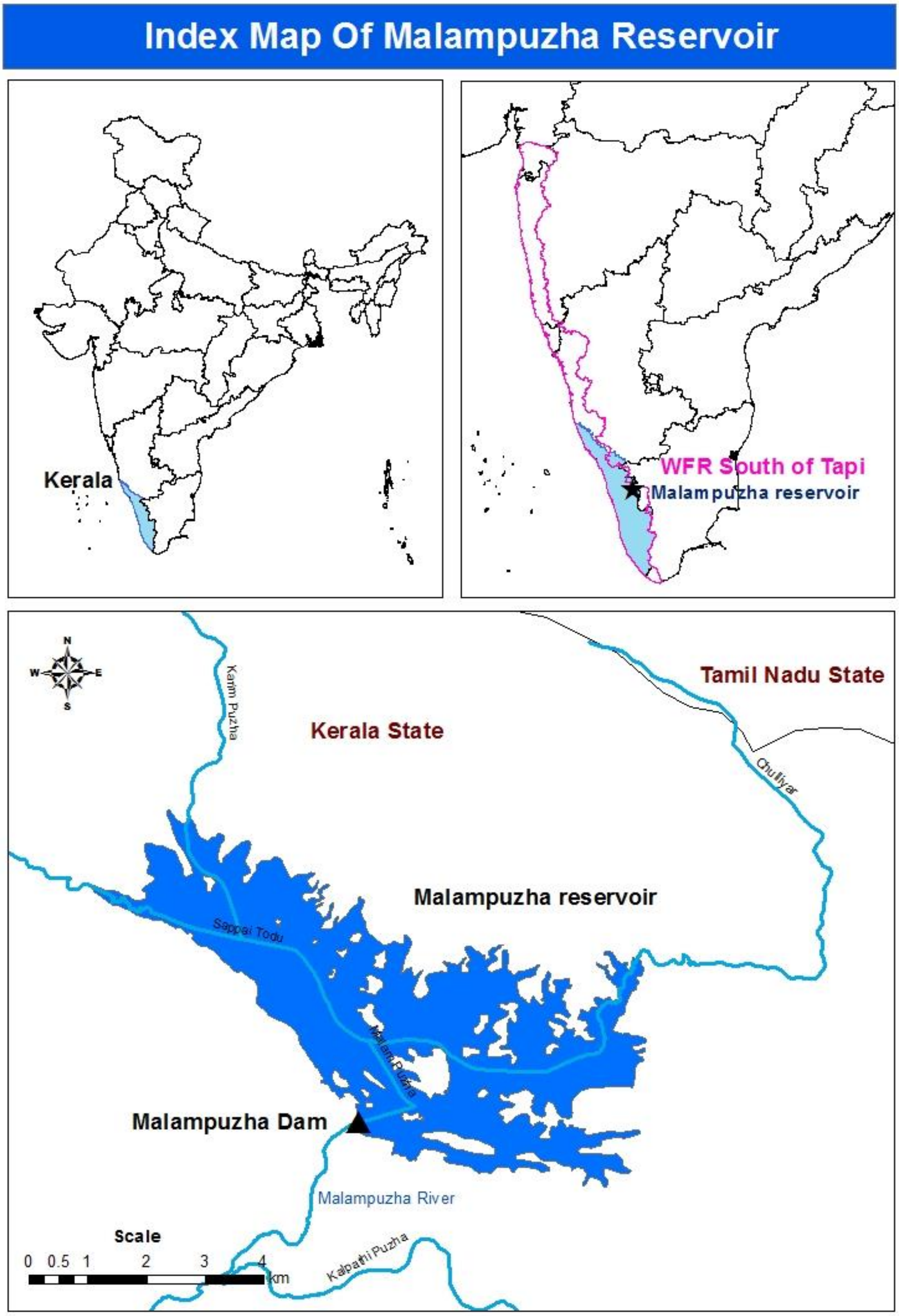


Fig. 4: Index map of the Malampuzha Reservoir

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	20/11/2019	114.94
Sentinel 1A	14/12/2019	113.78
Sentinel 1B	01/01/2020	112.53
Sentinel 1A	19/01/2020	110.54
Sentinel 1A	31/01/2020	109.09
Sentinel 1A	12/02/2020	107.41
Sentinel 1A	24/02/2020	105.49
Sentinel 1B	17/07/2019	103.83
Sentinel 1B	05/07/2019	102.41
Sentinel 1B	11/06/2019	101.41

8.2. FIELD DATA

The following field data have been obtained from project authorities:

Elevation - Capacity data

Salient features of Malampuzha 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 Malampuzha 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 of:

- 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)
20/11/2019	114.94	18.192
14/12/2019	113.78	17.931
01/01/2020	112.53	17.307
19/01/2020	110.54	15.904
31/01/2020	109.09	14.850
12/02/2020	107.41	12.380
24/02/2020	105.49	10.191
17/07/2019	103.83	8.811
05/07/2019	102.41	6.669
11/06/2019	101.41	5.590

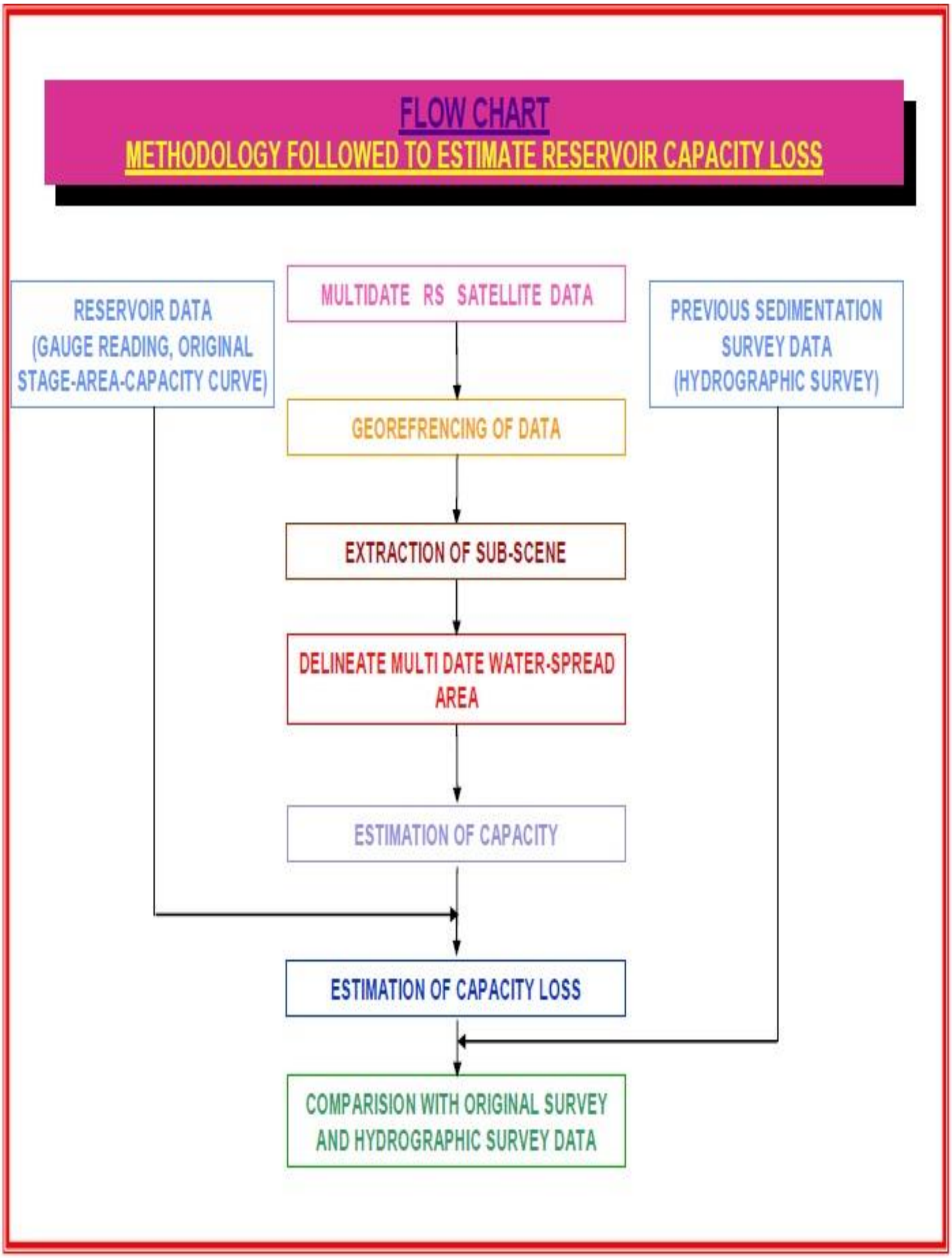


Fig 5 : Flow chart showing methodology followed to estimate reservoir capacity loss

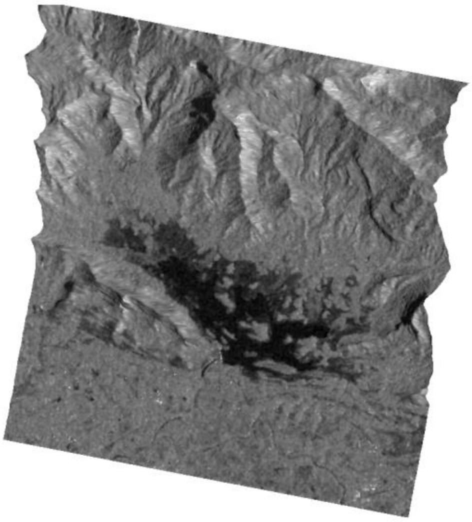
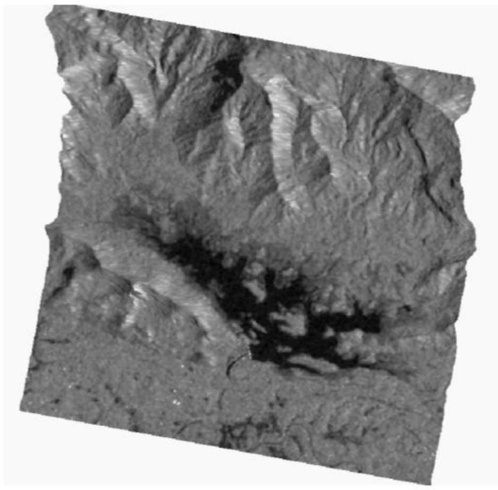
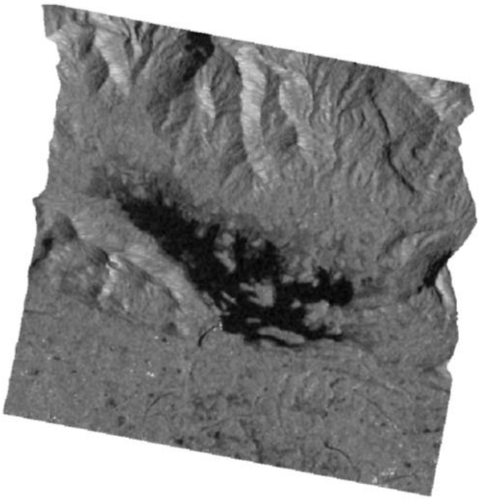
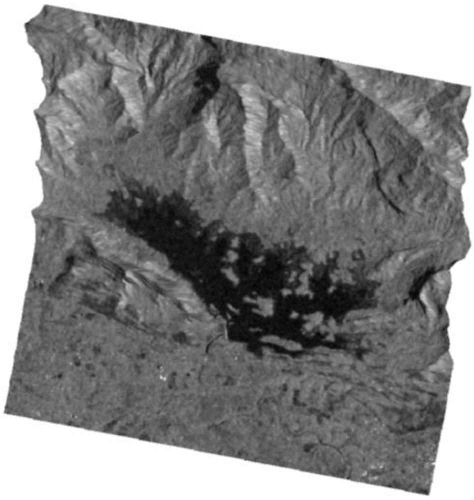
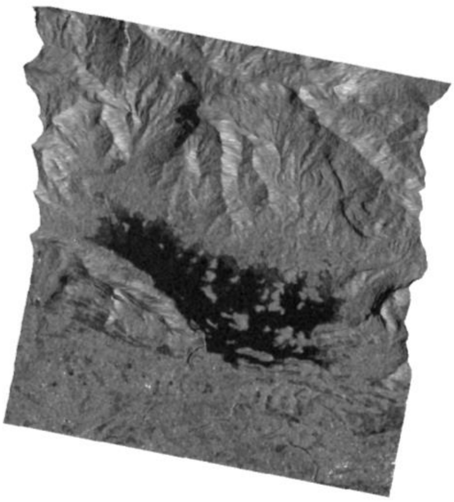
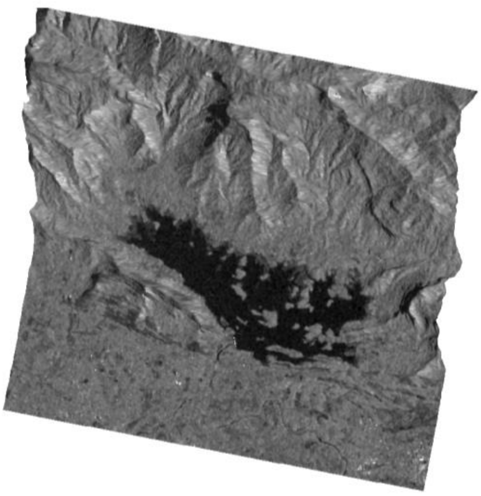
	
11-June-2019 (101.41 m)	**05-July-2019 (102.41 m)**
	
17-July-2019 (103.83 m)	**24-Feb-2020 (105.49 m)**
	
12-Feb-2020 (107.41 m)	**31-Jan-2020 (109.09 m)**

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

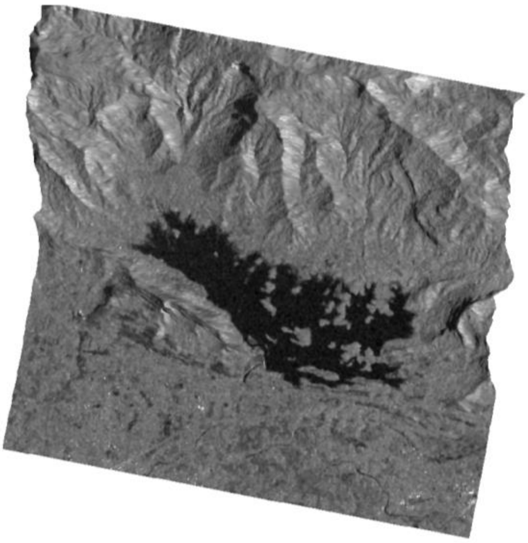
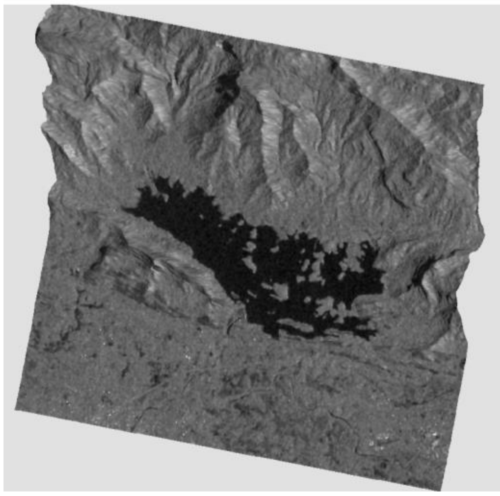
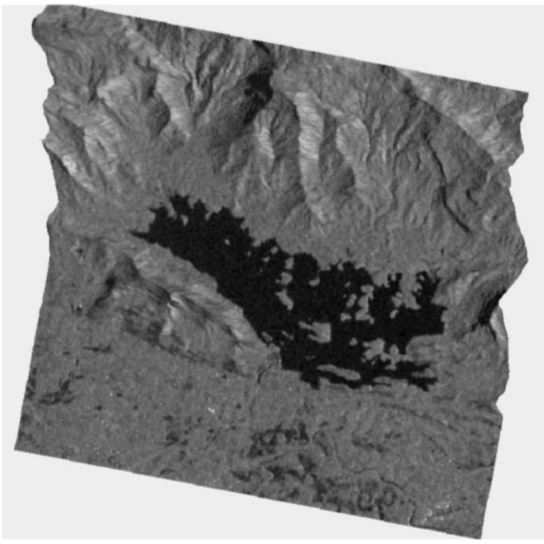
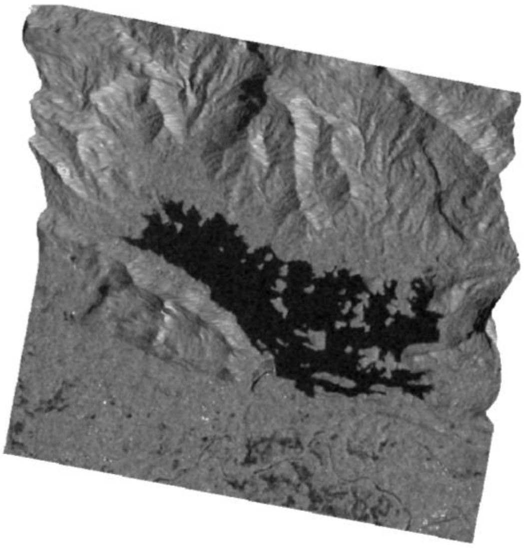
	
19-Jan-2020 (110.54 m)	**01-Jan-2020 (112.53 m)**
	
14-Dec-2019 (113.78 m)	**20-Nov-2019 (114.94 m)**

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

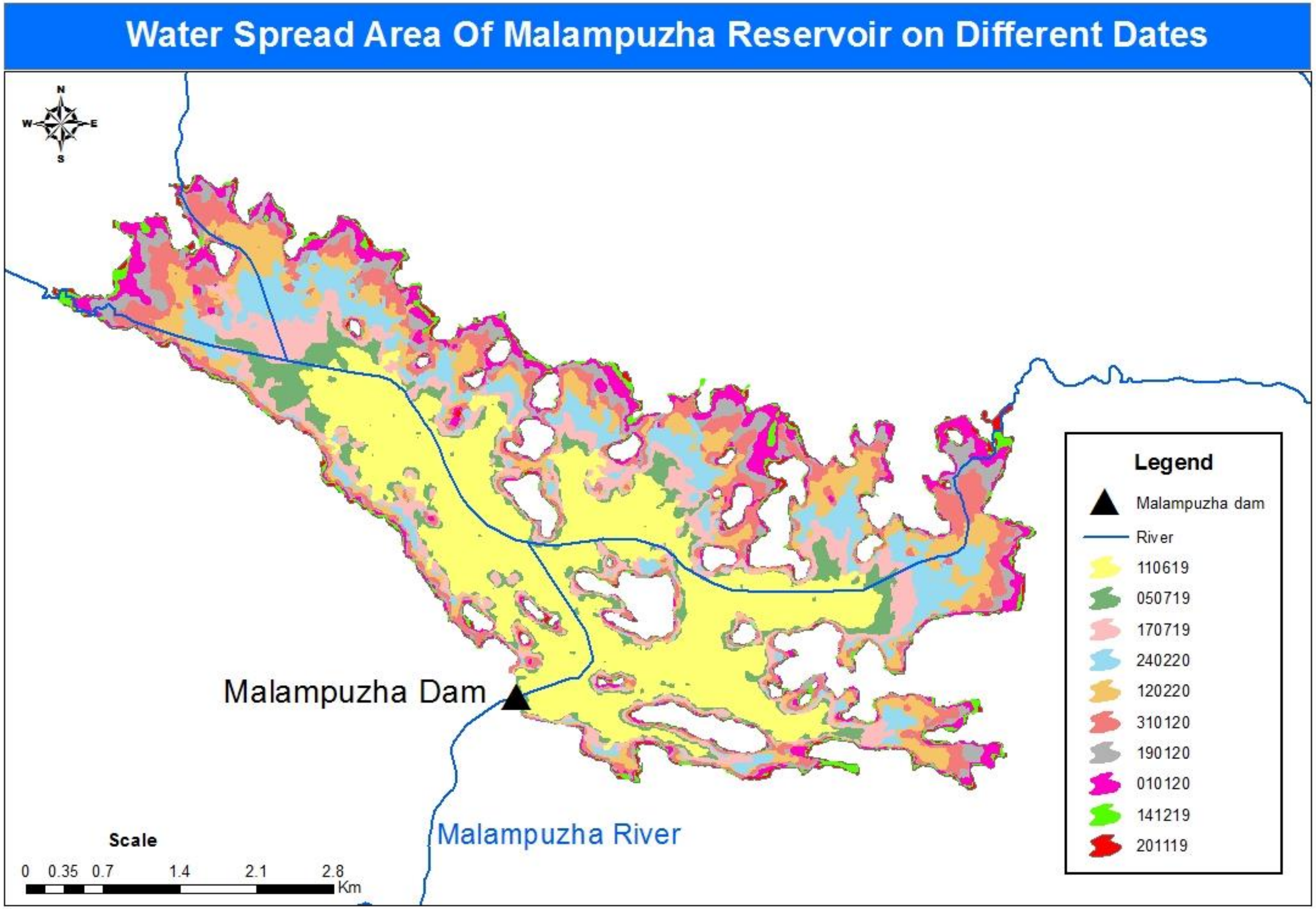


Fig. 7: Water Spread Area of Malampuzha Reservoir on different dates

The Satellite Images for the Malampuzha 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 Malampuzha Reservoir showing its water spread area for ten overpass dates such as 20-Nov-19, 14-Dec-19, 01-Jan-20, 19-Jan-20, 31-Jan-20, 12-Feb-20, 24-Feb-20, 17-July-19, 05-July-19 and 11-Jun-19 are shown in fig. 7.

The water elevation 114.94 m for 20-Nov-19 is near the Full Reservoir Level (FRL) of 115.06 m. The Water elevation 101.41 m for 11-Jun-19 is above the Minimum Drawdown Level (MDDL) of 91.44 m.

9.3. ESTIMATION OF RESERVOIR CAPACITY

Area elevation curve has been plotted using these above ten(10) water-spread areas for different water level in the reservoir and best-fit polynomial equation of second order as given below have been derived.

$Y = -0.0358*X^2 + 2.1701 * X – 12.73$

$R^2 = 0.9956$

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

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

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.

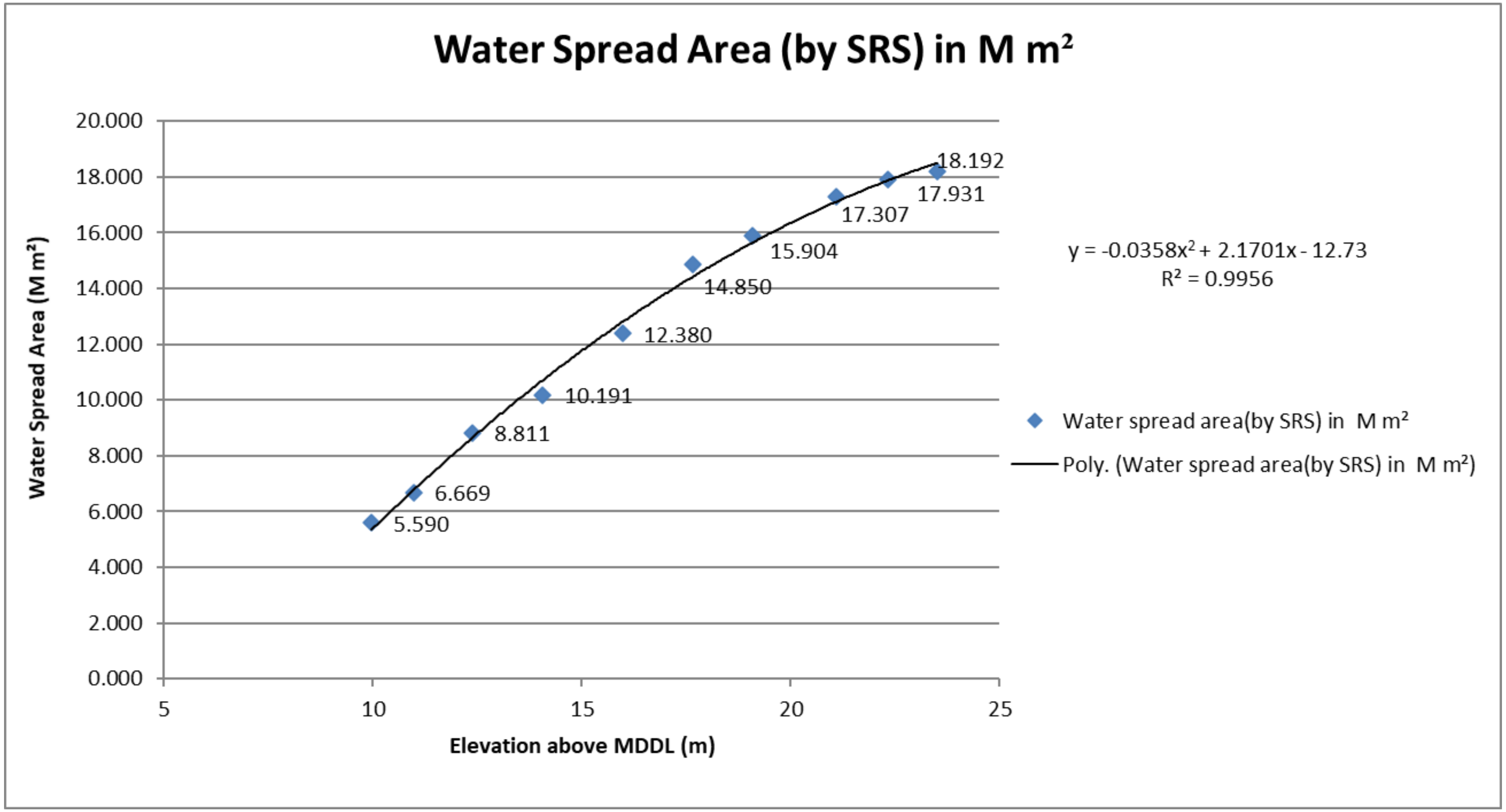


Fig. 8: Observed elevation vs Observed WSA of Malampuzha Reservoir

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	**91.44**	0.000	-	-
	92.00	0.000	0.000	0.000
	93.00	0.000	0.000	0.000
	94.00	0.000	0.000	0.000
	95.00	0.000	0.000	0.000
	96.00	0.000	0.000	0.000
	97.00	0.000	0.000	0.000
	98.00	0.000	0.000	0.000
	99.00	1.630	0.000	0.000
	100.00	3.223	2.382	2.382
	101.00	4.744	3.959	6.341
	102.00	6.194	5.453	11.794
	103.00	7.572	6.872	18.665
	104.00	8.879	8.217	26.882
	105.00	10.114	9.490	36.372
	106.00	11.277	10.690	47.062
	107.00	12.369	11.819	58.881
	108.00	13.389	12.876	71.757
	109.00	14.338	13.861	85.618
	110.00	15.215	14.774	100.392
	111.00	16.020	15.616	116.008
	112.00	16.754	16.386	132.394
	113.00	17.416	17.084	149.478
	114.00	18.007	17.711	167.189
FRL	**115.06**	18.555	19.377	**186.566**

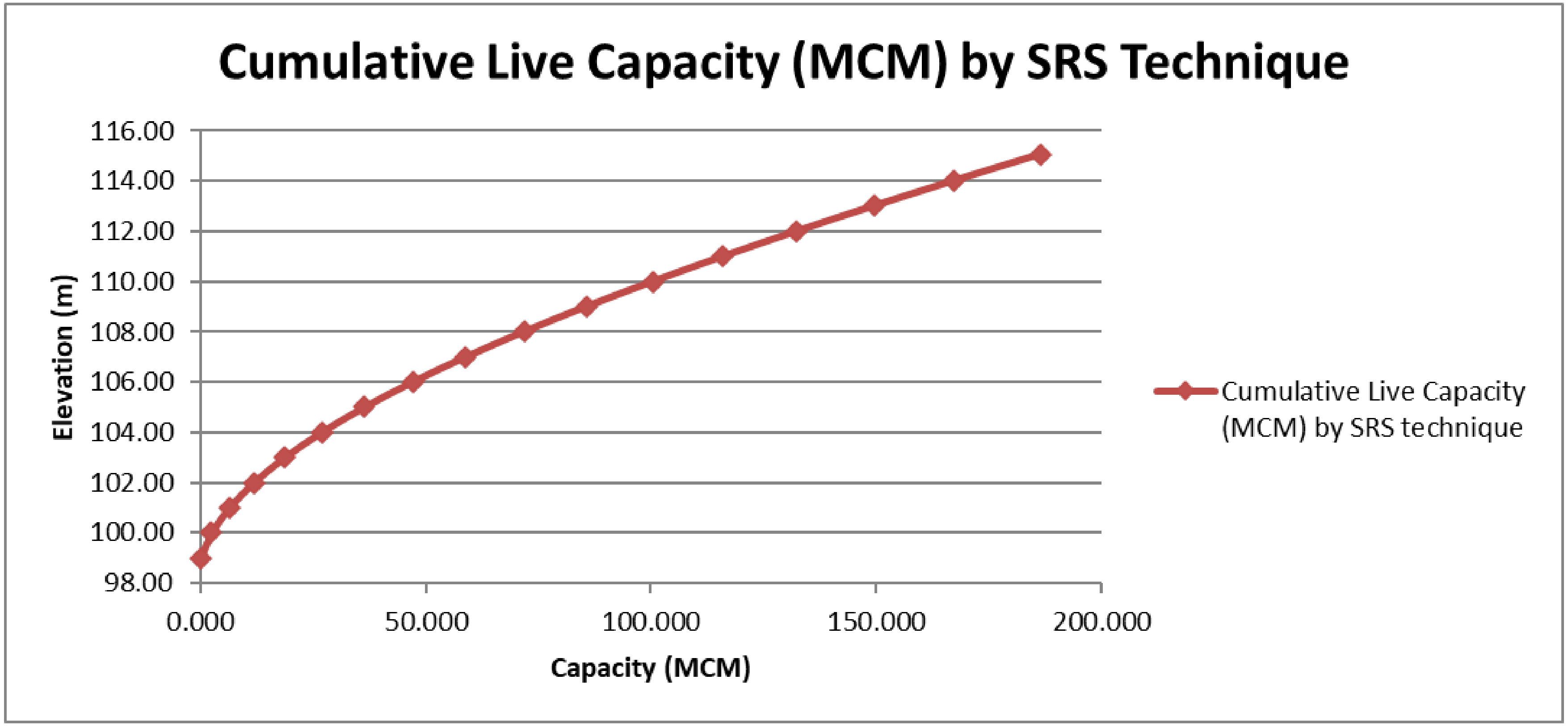


Fig. 9: Modified live capacity - elevation curve (SRS technique)

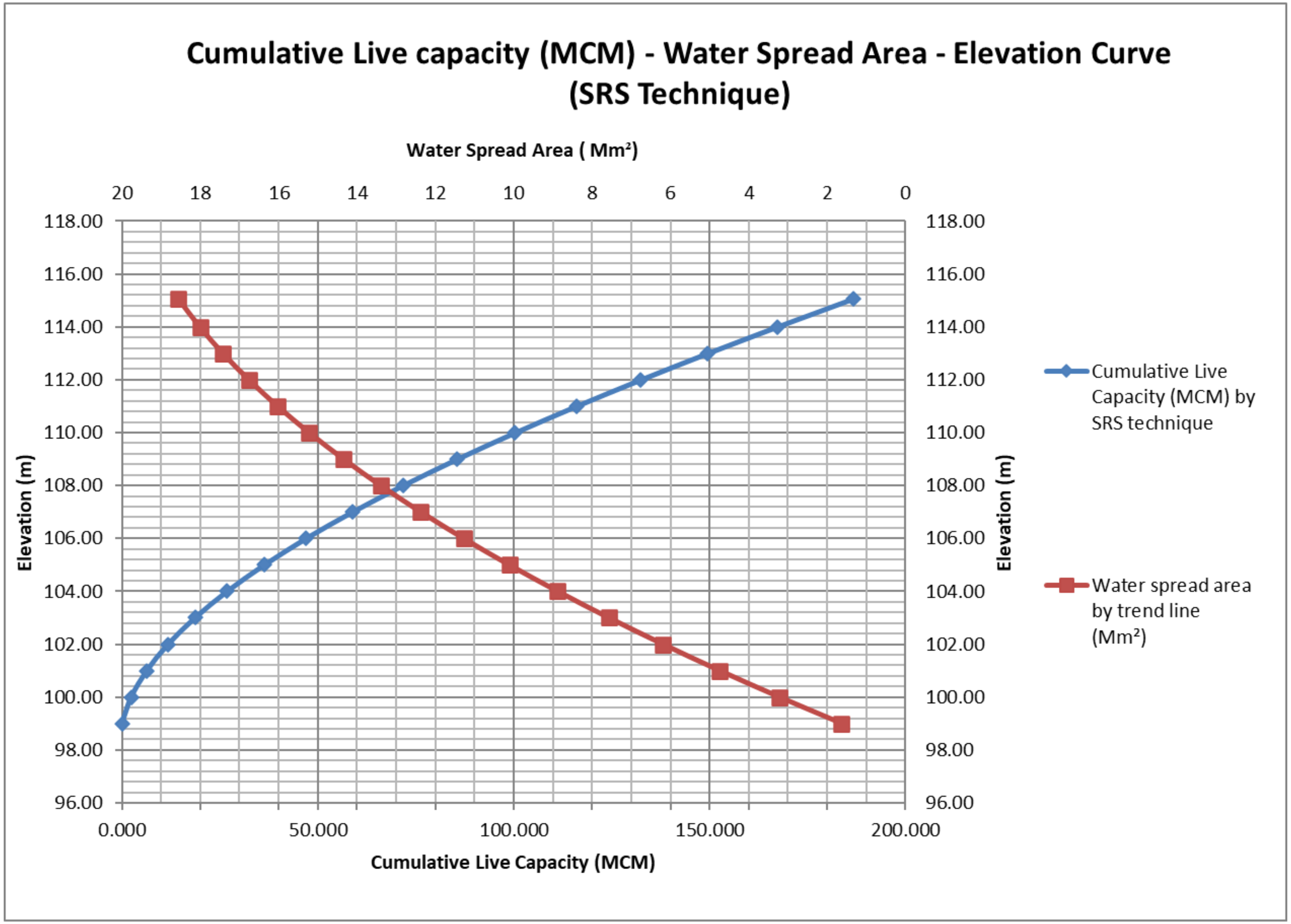


Fig. 10: Elevation – Area- Capacity Curve

9.4. Comparison with Original and Previous Surveys

Comparison of live storage capacity of SRS survey with original survey 1955, hydrographic survey 1977 and SRS survey 2004 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) 1955	Live Capacity hydrographic survey (MCM) 1977	Cumulative live capacity by SRS survey (MCM) 2004	Cumulative live capacity by SRS survey (MCM) 2019
91.440	0.000	0.000	0.000	0.000
92.000	0.343	0.129	0.000	0.000
93.000	0.956	0.358	0.000	0.000
94.000	1.569	0.985	0.031	0.000
95.000	2.844	1.613	0.257	0.000
96.000	2.747	3.134	0.924	0.000
97.000	6.651	4.655	2.196	0.000
98.000	9.539	7.125	4.262	0.000
99.000	13.565	10.915	7.352	0.000
100.000	17.592	15.500	11.368	2.382
101.000	22.844	20.857	16.310	6.341
102.000	29.818	27.188	22.288	11.794
103.000	36.791	34.757	29.323	18.665
104.000	44.974	43.563	37.431	26.882
105.000	55.236	53.186	46.630	36.372
106.000	65.498	64.281	59.939	47.062
107.000	76.827	76.276	68.376	58.881
108.000	90.420	90.125	80.958	71.757
109.000	104.014	104.308	94.705	85.618
110.000	118.260	120.875	109.634	100.392
111.000	135.763	137.716	125.763	116.008
112.000	154.720	156.813	143.111	132.394

113.000	174.506	176.168	161.696	149.478
114.000	197.160	197.625	181.535	167.189
115.060	**221.174**	**220.153**	**203.955**	**186.566**

The original gross and live storage capacity of Malampuzha reservoir in 1955 were reported as 226 MCM & 221.174 MCM respectively.

The first hydrographic capacity survey was conducted in 1977. The storage capacity were worked out to 220.153 MCM. Another hydrographic survey was conducted in 1990 wherein the storage capacity was reported as 208.130 MCM.

In 2004 a Satellite Remote Sensing Survey was conducted using optical imageries that indicated a live storage capacity of 203.955.

In 2006 yet another hydrographic survey was conducted and the storage capacity was found to be 195.328 MCM.

In the present study, it is found that live capacity of the Malampuzha reservoir in 2019 is 186.566 MCM witnessing a live storage loss of 34.608 MCM (i.e. 15.647 %) in a period of 64 years during 1955 to 2019. This accounts for live capacity loss of 0.244% per annum since 1955.

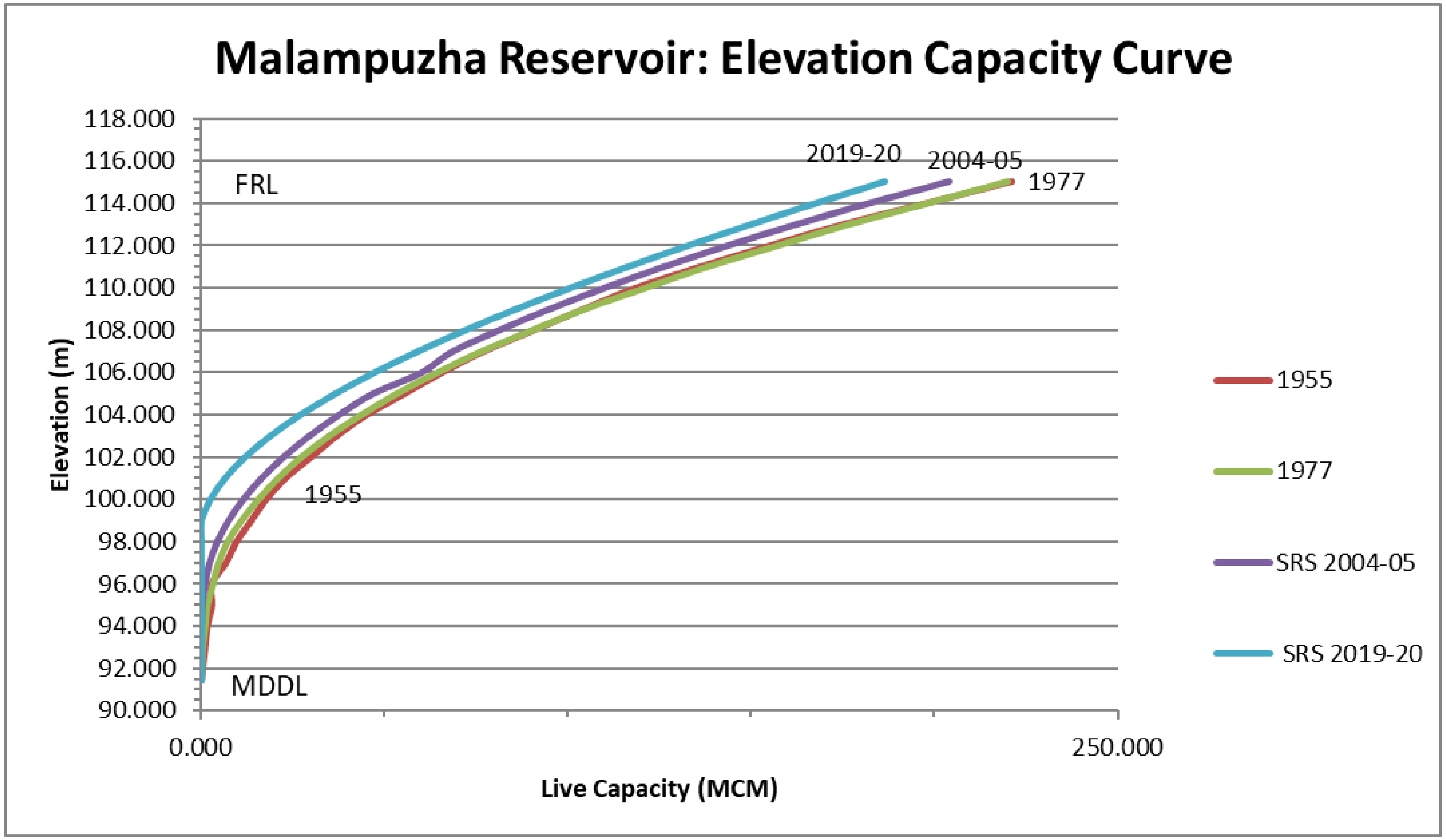


Fig. 11: Comparison of Elevation-Live Storage Capacity Curves (MCM)

10. RESULTS AND DISCUSSIONS

The loss in live storage capacity of the reservoir due to sedimentation since original survey (1955), hydrographic surveys (1977, 1990 & 2006) and remote sensing survey (2004) is given in Table –5.

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

	Original Survey (1955)	Hydrographic Survey (1977)	Hydrographic Survey (1990)	SRS (2004)	Hydrographic Survey (2006)	SRS (2019)
Live Capacity (MCM)	221.174	220.153	208.130	203.955	195.328	186.566
Loss in Capacity (MCM) (since 1955)	-	1.021	13.044	17.219	25.846	34.608
% Live capacity loss (since 1955)	-	0.462	5.898	7.785	11.686	15.647
Annual % live capacity loss	-	0.021	0.169	0.159	0.229	0.244

The live storage capacity of Malampuzha reservoir as per present study is found to be 186.566 MCM for the year 2019. As per original survey conducted in 1955 the live storage capacity was 221.174 MCM and as per hydrographic survey conducted in 1977,1990 and 2006 the live storage capacity was 220.153 MCM, 208.13 MCM, 195.328 MCM respectively. In 2004 Remote sensing survey the capacity was worked out as 203.955 MCM.

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

The loss in live storage capacity of the reservoir due to sedimentation since previous survey (1955), hydrographic surveys (1977, 1990 & 2006) is given in Table –6.

Table – 6 : Live Storage Capacity loss due to sedimentation since previous survey

	Original Survey (1955)	Hydrographic Survey (1977)	Hydrographic Survey (1990)	Hydrographic Survey (2006)	SRS (2019)
Live Capacity	221.174	220.153	208.13	195.328	186.566
Loss since last survey	-	1.021	12.023	12.802	8.762
% Loss since last survey	-	0.462	5.461	6.151	4.486
Annual % loss since last survey	-	0.021	0.420	0.384	0.346

From Table 6, it emerges that the annual % loss is gradually reducing since 1977 (i.e. the first hydrographic survey. However, the annual % loss is very less in the initial period i.e. 1955-77 and that is unusual. It may be due to error in original capacity estimation.

11. CONCLUSION

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

1. The live storage capacity of Malampuzha reservoir has been found to be 186.566 MCM in 2019.
2. Live storage loss of 34.608 MCM (i.e. 15.647%) was observed since original survey (1955) i.e. in a period of 64 years. This accounts for live capacity loss of 0.244% per annum since 1955.
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 MALAMPUZHA DAM RESERVOIR

GENERAL
Name of the project : Malampuzha Reservoir Project
Purpose of project : Irrigation
Name of the Dam : Malampuzha
First filling : 1955
Irrigation potential : 21,045 ha

LOCATION OF DAM
Latitude : 10^{o} 49’ North
Longitude : 76^{o} 41’ East
Village : Malamuza
State : Kerala

CATCHMENT
Catchment area : 147.63 Sq. Km
Average annual rainfall : 216.92 cm
Design flood adopted : 30,000 Cusecs

RESERVOIR
Full Reservoir Level (FRL) : EL +115.06 m
Minimum Draw Down Level (MDDL): EL +91.44 m
Reservoir submergence at FRL : 23.37 Sq.km (computed from the elevation-capacity table of 1955)
Dead storage capacity : 2.4 MCM
Live storage capacity : 221.174 MCM (computed from the elevation-capacity table of 1955)
Gross storage at FRL : 226 MCM (as per the report)

DAM DATA

Normal Bed Level :	85.65m
Deepest Foundation Level:	83.65m
Road Level at Top :	120.27m
Length of the Masonry Dam:	1626.71m
Width of the Road at Top :	4.87m
Top width including operation Platform:	8.99m
Maximum Width:	21.336m

PHOTOGRAPH OF RESERVOIR

Photo 1: Malampuzha Dam

Photo 2: Malampuzha Reservoir

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