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बालीमेला जलाशय, ओडिशा का अवसादन आंकलन

SEDIMENTATION ASSESSMENT OF BALIMELA RESERVOIR, ODISHA, THROUGH SATELLITE REMOTE SENSING

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Government of India
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SEDIMENTATION ASSESSMENT OF BALIMELA RESERVOIR, ODISHA, THROUGH SATELLITE REMOTE SENSING

Year of Study 2021
Data Used 2019-2021

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 2019-21 in the sedimentation study of Balimela 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 satellites** have been used to estimate water spread area of Balimela 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.

Balimela dam was constructed on the river Machhkund-Sileru of Malkangiri district in Odisha. Balimela Dam project is a joint project of Governments of Andhra Pradesh and Odisha. It is a multipurpose project on river Machhkund, a major tributary of the river Godavari. The reservoir was impounded for the first time on 15th August, 1972. The height and length of the reservoir is 70m and 1823m respectively.

Its Gross storage capacity and live storage capacity is 3610 MCM and 2676 MCM respectively.

After analysis of the satellite data in the present study, it is found that live capacity of Balimela reservoir in 2021 is 2631.856 MCM witnessing a live storage loss of 44.144 MCM (i.e. 1.650%) in a period of 49 years during 1972 to 2021. This accounts for live capacity loss of

0.034% per annum since 1972.

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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 BALIMELA RESERVOIR, ODISHA 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 Balimela reservoir, Odisha 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.

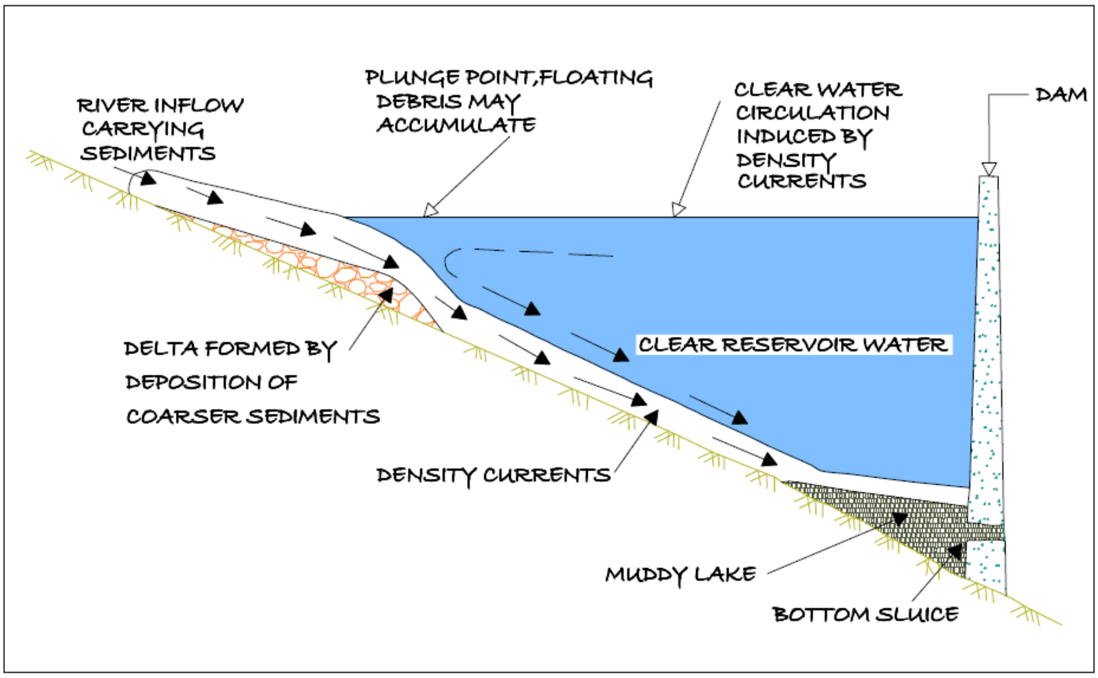


Fig. 1: Conceptual sketch of density currents in a reservoir

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.

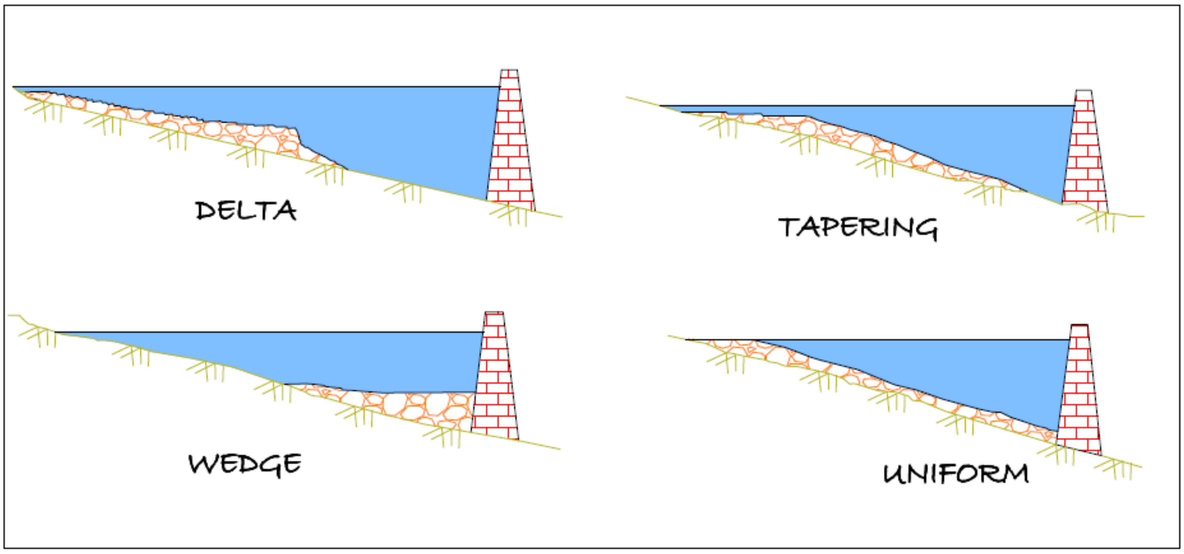


Fig. 2: Longitudinal Patterns of sediment deposition in reservoirs.

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.

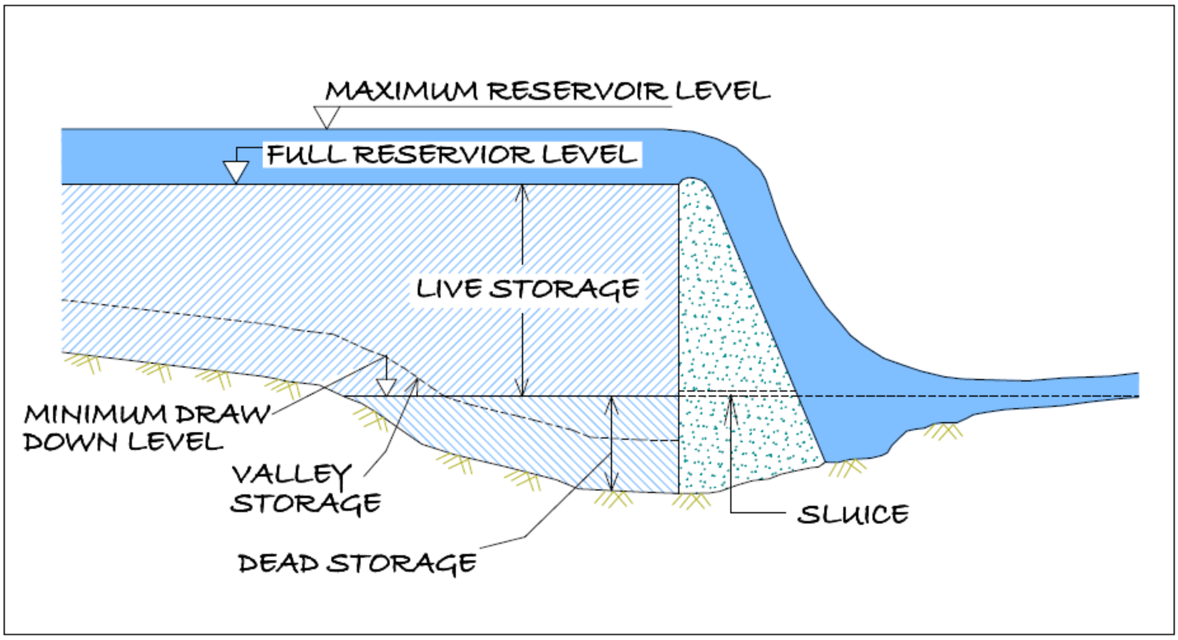


Fig. 3: Conceptual sketch of different levels in a reservoir

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 Balimela 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

Balimela Dam project is a joint project of Governments of Andhra Pradesh and Orissa. It is a multipurpose project on river Machhkund, a major tributary of the river Godavari.

The Water is tapped in four stages, at Machhkund and Balimela in Orissa State and Upper Sileru and Dhonkara in Andhra Pradesh for hydropower generation. The reservoir was impounded for the first time on 15th August, 1972. The total catchment upto Balimela Dam is 4908 Sq. km. out of which 1955 Sq. km. is intercepted by Jalaput Dam. The reservoir submergence at FRL is 167.09 sq. km. Fig:4 shows the Index map of Balimela Reservoir.

Main Features: The main levels of the reservoir are as under:

Reservoir levels	Elevation
MDDL	438.91m
FRL	462.07m
MWL	462.62m

The latitude and longitude of study area are 18°8′25” N and 82°7′22” E respectively.

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 Balimela reservoir, the height difference between FRL (462.07 m) and MDDL (438.91 m) is 23.16m.

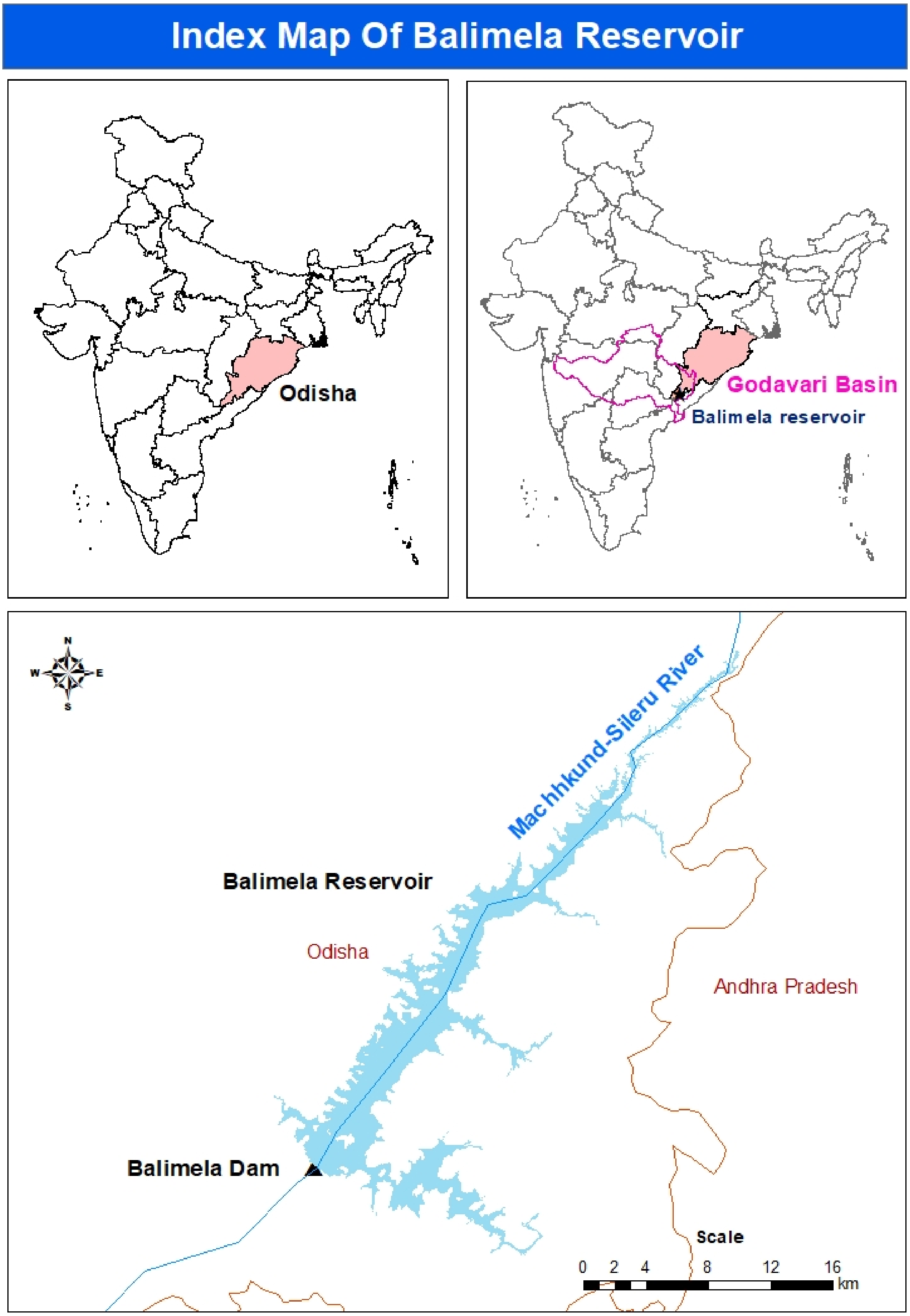


Fig. 4: Index map of the Balimela Reservoir

7. DATA USED

8.1. SATELLITE DATA

Microwave data from Sentinel 1A for seven (07) 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	01-07-2019	443.545
Sentinel 1A	12-08-2020	446.010
Sentinel 1A	20-05-2020	448.605
Sentinel 1A	04-03-2021	452.200
Sentinel 1A	27-01-2021	454.884
Sentinel 1A	04-11-2020	458.175
Sentinel 1A	10-11-2019	461.680

8.2. FIELD DATA

The following field data have been obtained from project authorities:

Elevation - Capacity data

Salient features of Balimela 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 Balimela reservoir studies, multi-date Sentinel 1 (08 nos. imageries) is used for the analysis. Image processing with SNAP software and Arc GIS software was used for the analysis. The analysis comprised,

- Geo-referenced Data base.
- Water spread area estimation.

- Estimation of reservoir capacity.
- Comparison with original capacity.

9.1. DATA BASE

The satellite data from Sentinel 1 satellite corresponding to reservoir area obtained from Copernicus open access hub was loaded on the system. The Sentinel-1 mission is a constellation of two polar-orbiting satellites (Sentinel-1A), 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 5 shows the flowchart of methodology, Fig. 6 shows Sentinel 1A 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)
01-07-2019	443.545	86.309
12-08-2020	446.010	93.069
20-05-2020	448.605	108.584
04-03-2021	452.200	120.93
27-01-2021	454.884	133.153
04-11-2020	458.175	143.255
10-11-2019	461.680	158.662

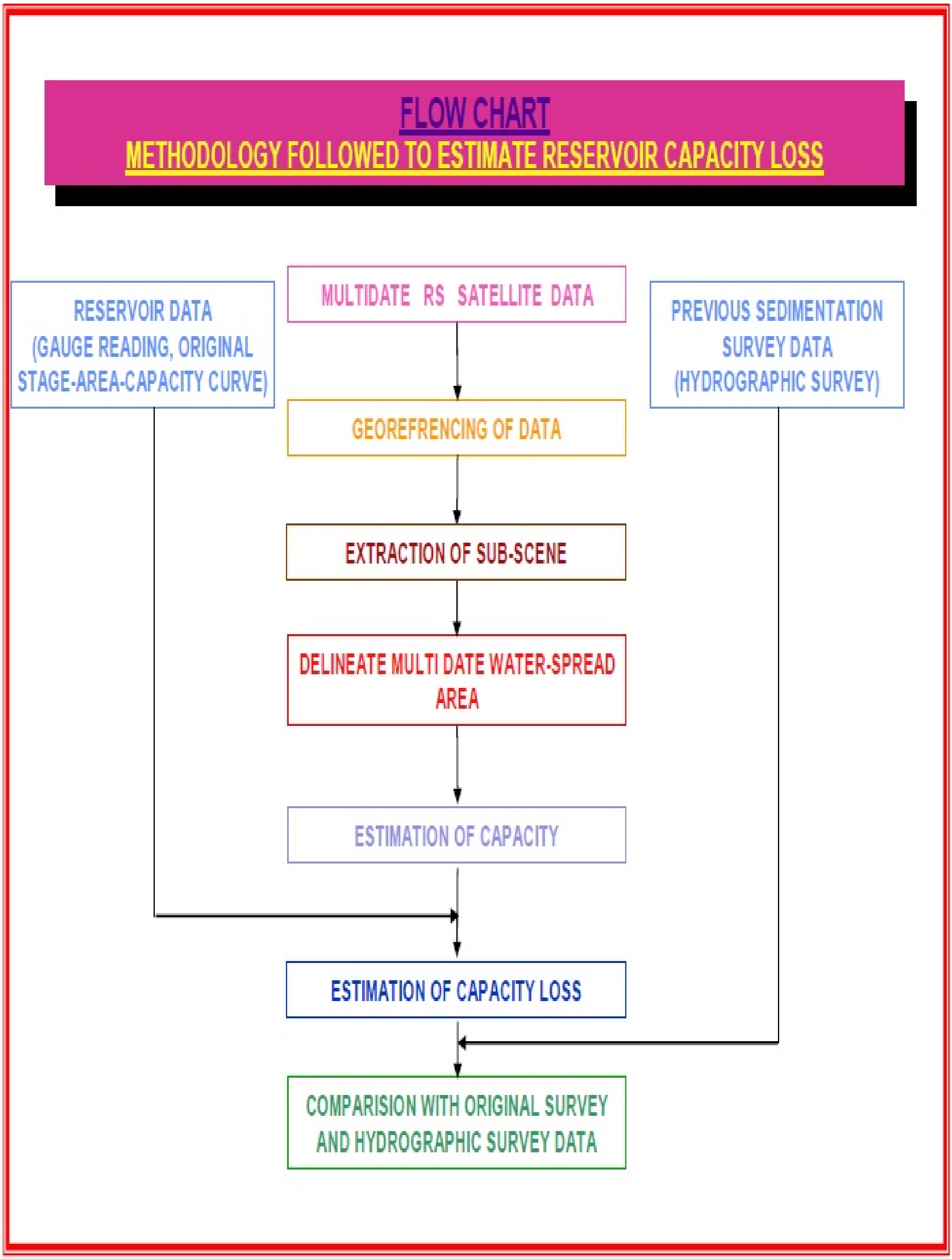


Fig 5 : Flow chart showing methodology followed to estimate reservoir capacity loss

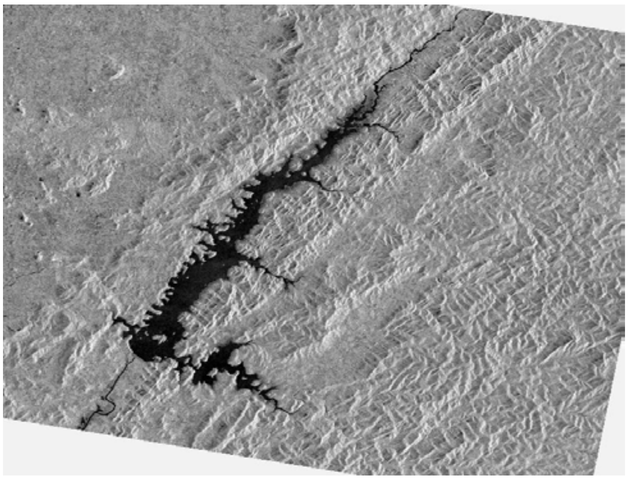
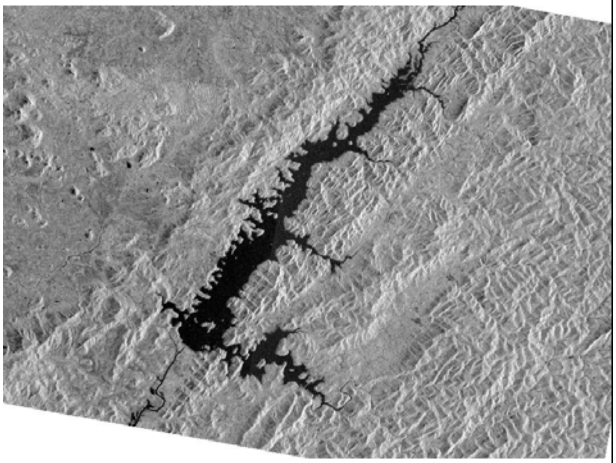
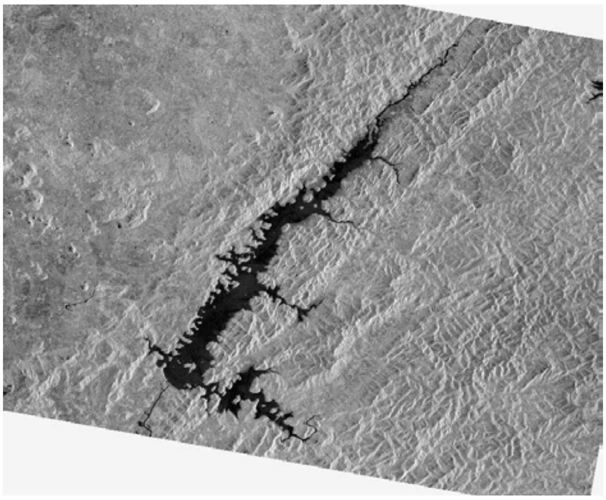
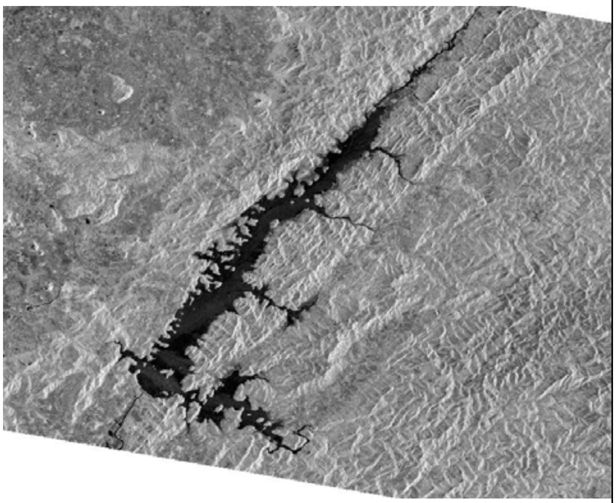
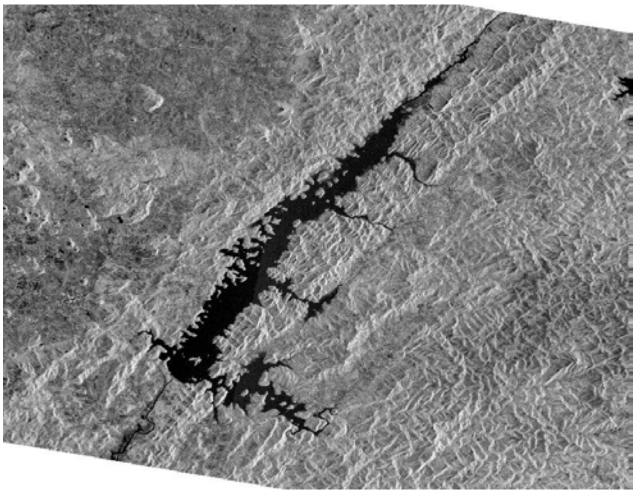
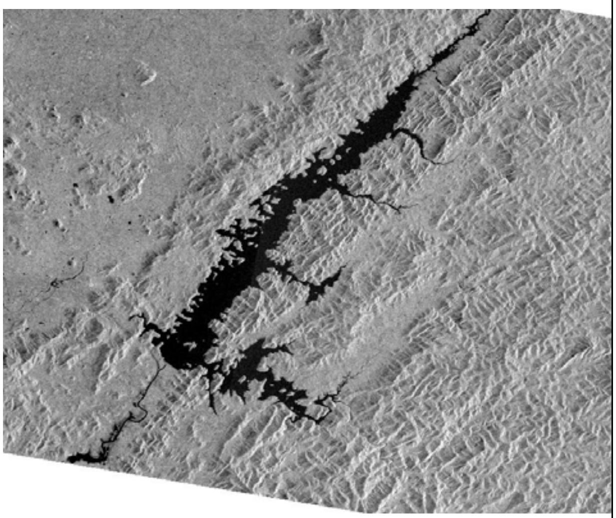
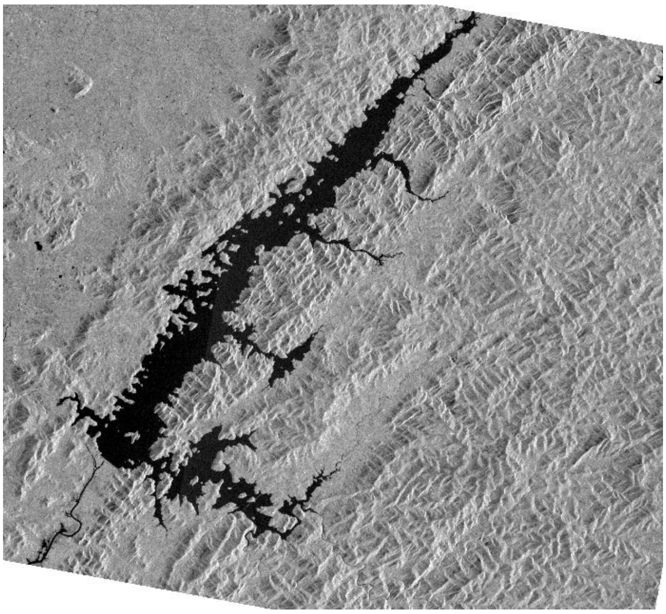
	
1-July-2019 (443.545m)	**12-Aug-2020 (446.010m)**
	
20-May-2020 (448.605m)	**04-March-2021 (452.200m)**
	
27-Jan-2021 (133.153m)	**04-Nov-2020 (458.175m)**

Fig 6 : Sentinel 1 SAR imageries showing water spreads at different dates (Balimela Reservoir)



10-Nov-2019 (461.680m)

Fig 6 : Sentinel 1 SAR imageries showing water spreads at different dates (Balimela Reservoir)

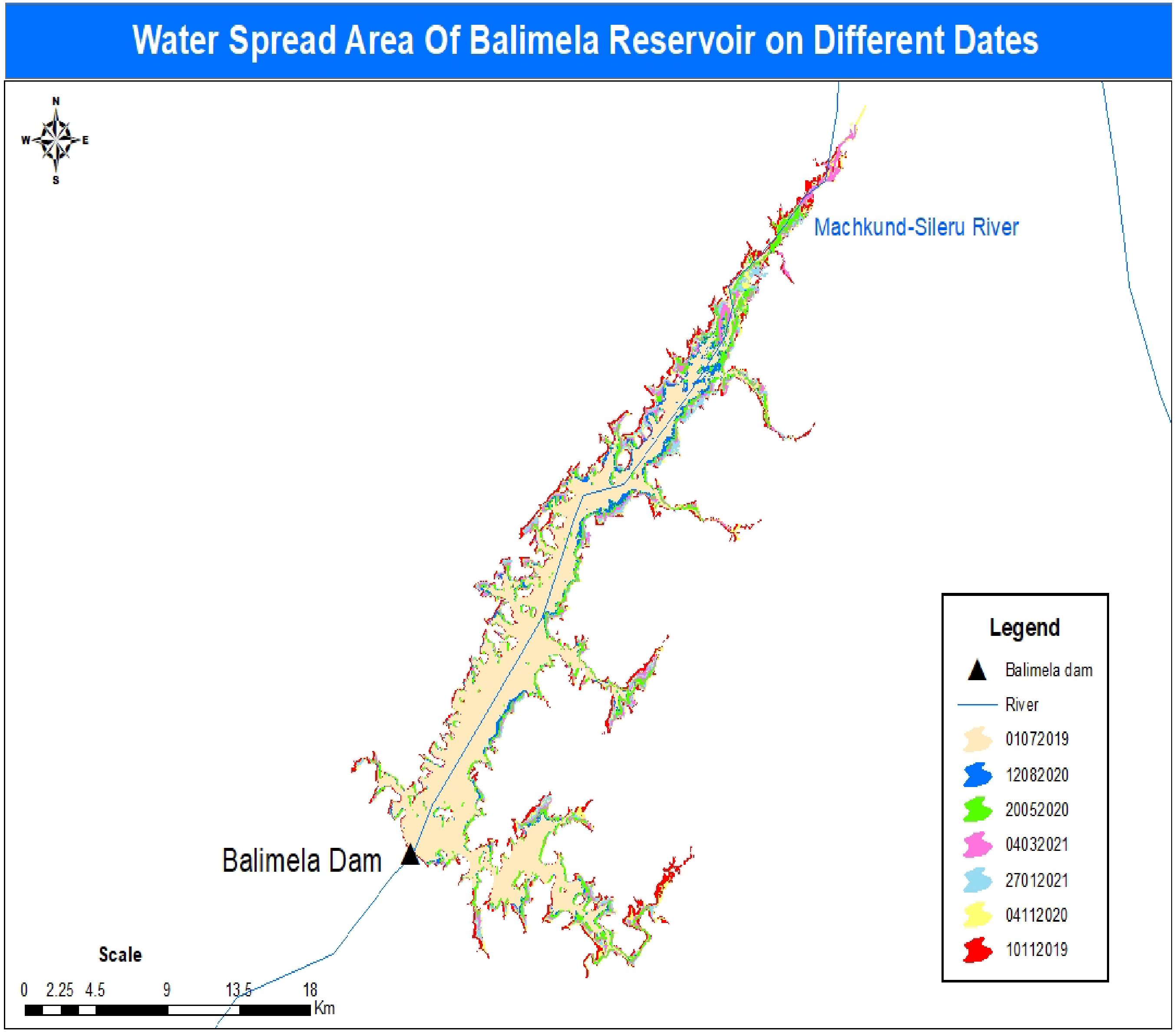


Fig 7: Water Spread Area of Balimela Reservoir on different dates

The Satellite Images for the Balimela 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 Balimela Reservoir showing its water spread area for seven overpass dates such as 1-July-2019, 12-Aug-2020, 20-May-2020, 04-March-2021, 27-Jan-2021, 04-Nov-2020, 10-Nov-2019 are shown in fig. 7.

The water elevation 461.680 m for 10-Nov-2019 is at the Full Reservoir Level (FRL). The Water elevation 443.545 m for 01-July-2019 is at the Minimum Drawdown Level (MDDL). 1

9.3. ESTIMATION OF RESERVOIR CAPACITY

Area elevation curve has been plotted using these above seven (7) water-spread areas for different water level in the reservoir and best-fit polynomial equation of second order as given below have been derived.

$Y = -0.0155*X^2 + 4.4402 * X + 65.001$

$R^2 = 0.9961$

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.

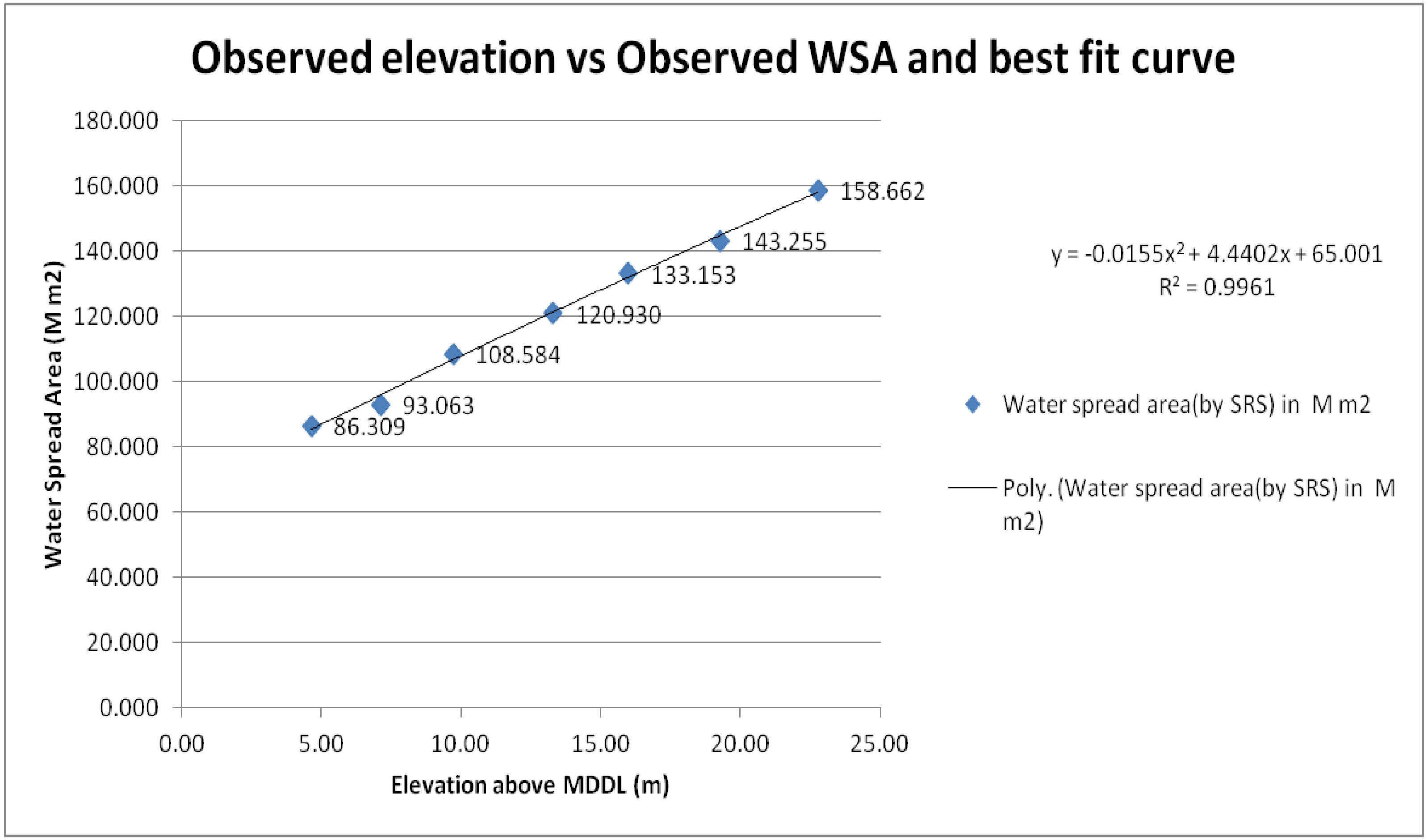


Fig. 8: Observed elevation vs Observed WSA of Balimela Reservoir

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 Observed water level versus observed water spread area is at Fig-8. Modified live capacity - elevation curve and modified elevation – area –capacity curves are plotted and shown in Fig-9 and Fig-10 respectively.

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

	Reservoir water level in Metre	Water spread area by trend line (M m2)	Segmental Live Capacity (MCM) by SRS technique	Cumulative Live Capacity (MCM) by SRS technique 2021
MDDL	438.91	65.001	0.000	0.000
	439.00	65.400	5.868	5.868
	440.00	69.822	67.599	73.467
	441.00	74.213	72.007	145.474
	442.00	78.573	76.383	221.857
	443.00	82.902	80.728	302.585
	444.00	87.200	85.042	387.627
	445.00	91.467	89.325	476.952
	446.00	95.703	93.577	570.529
	447.00	99.908	97.798	668.327
	448.00	104.082	101.988	770.314
	449.00	108.225	106.146	876.461
	450.00	112.337	110.274	986.735
	451.00	116.417	114.371	1101.106
	452.00	120.467	118.437	1219.542
	453.00	124.486	122.471	1342.014
	454.00	128.474	126.475	1468.489
	455.00	132.431	130.448	1598.936
	456.00	136.357	134.389	1733.326
	457.00	140.252	138.300	1871.625
	458.00	144.116	142.179	2013.805
	459.00	147.949	146.028	2159.833
	460.00	151.751	149.846	2309.678
	461.00	155.522	153.632	2463.311
	462.00	159.261	157.388	2620.698
FRL	462.07	159.522	11.157	2631.856

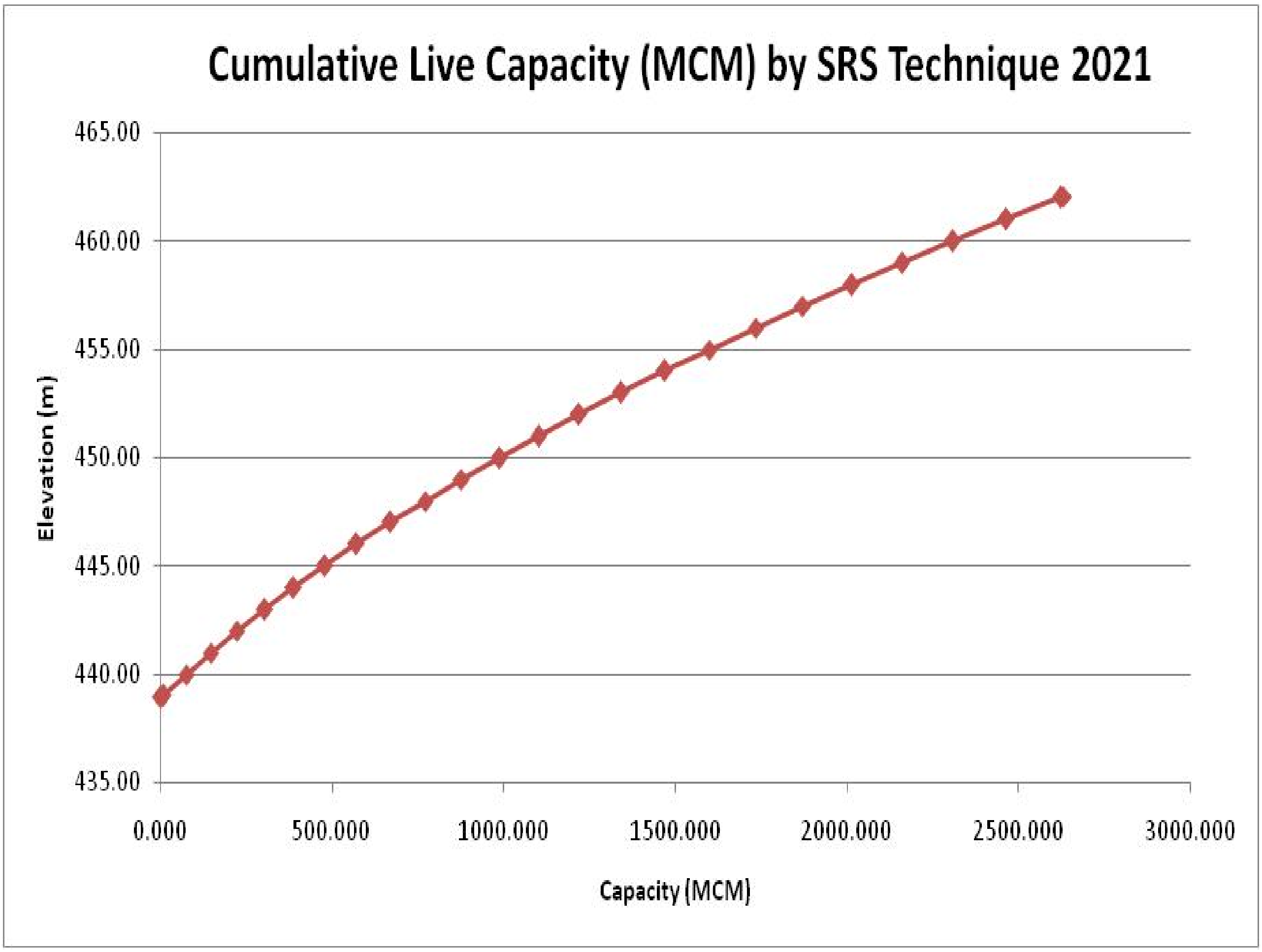


fig. 9: Modified live capacity - elevation curve (SRS technique) : Balimela Reservoir

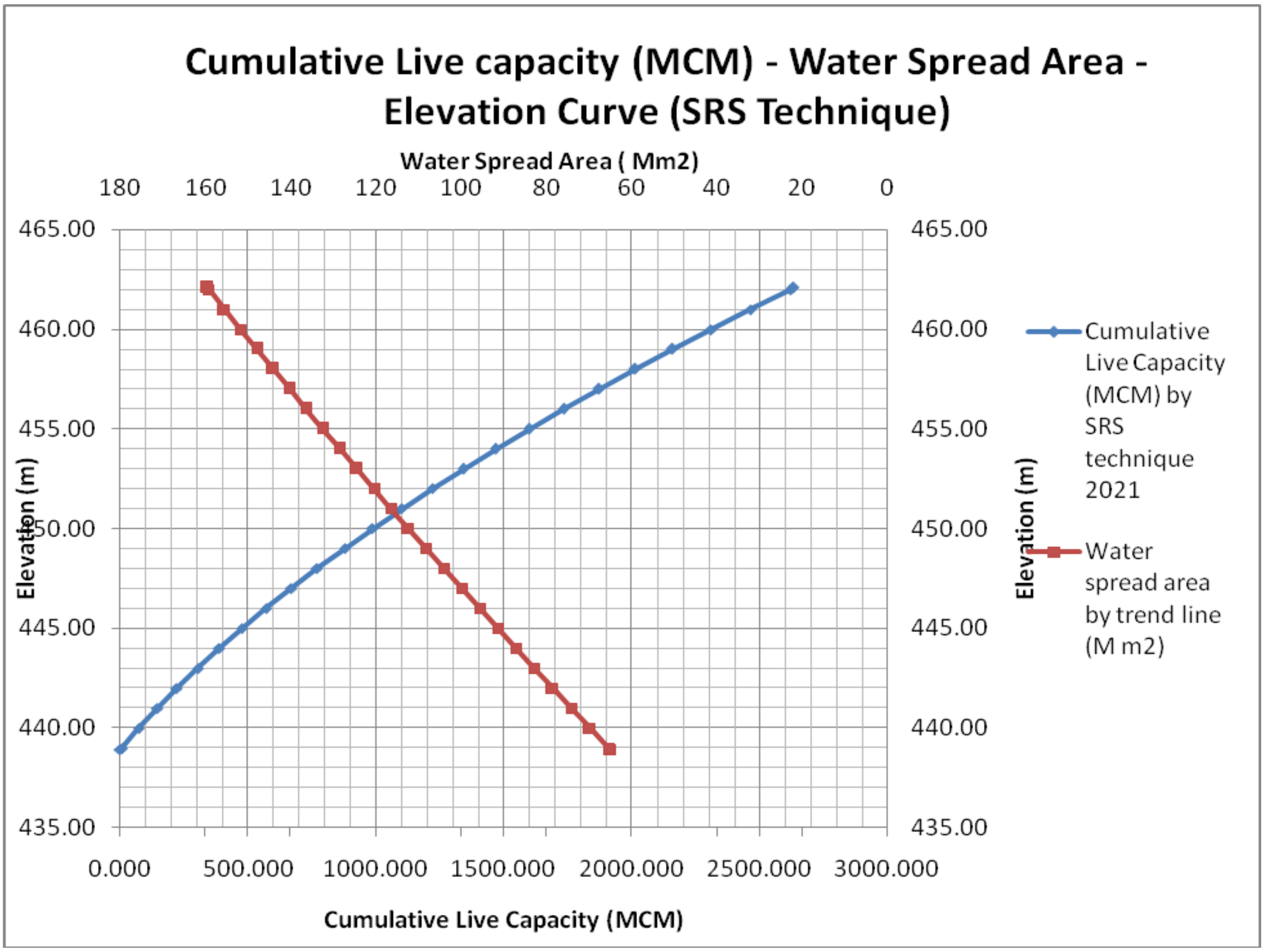


Fig 10: Elevation-Area-Capacity curve (Balimela Reservoir)

9.4 Comparison with Original and Previous Surveys

Comparison of live storage capacity of SRS survey with original survey 1972, Hydrographic survey 1999 and SRS survey 2003 and 2021 at various elevations is given below in table 4. Curve showing comparison of live capacity is drawn in figure 11.

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

Reservoir water level in metre	Original Live Capacity 1972	Live Capacity of reservoir as per Hydrographic Survey of 1999	Cumulative Live Capacity (MCM) by SRS technique 2003	Cumulative Live Capacity (MCM) by SRS technique 2021
438.91	0.000	0.000	0.000	0.000
439.00	6.830	6.780	6.200	5.868

440.00	76.260	78.910	77.450	73.467
441.00	148.550	155.220	153.120	145.474
442.00	222.970	235.280	233.140	221.857
443.00	299.400	318.690	317.470	302.585
444.00	380.040	405.160	406.060	387.627
445.00	463.480	494.580	498.860	476.952
446.00	551.700	586.900	595.840	570.529
447.00	643.210	681.920	696.930	668.327
448.00	738.250	779.900	802.090	770.314
449.00	840.330	880.880	911.180	876.461
450.00	946.340	984.960	1024.450	986.735
451.00	1056.160	1092.050	1141.540	1101.106
452.00	1177.630	1202.310	1262.510	1219.542
453.00	1302.720	1315.740	1387.320	1342.014
454.00	1435.070	1432.490	1515.920	1468.489
455.00	1563.560	1552.620	1648.520	1598.936
456.00	1693.560	1676.310	1784.280	1733.326
457.00	1828.270	1803.840	1923.950	1871.625
458.00	1966.690	1935.280	2067.210	2013.805
459.00	2113.460	2071.250	2214.030	2159.833
460.00	2281.660	2212.630	2364.340	2309.678
461.00	2464.170	2362.550	2518.110	2463.311
462.00	2661.520	2525.130	2674.780	2620.698
462.07	2676.000	2537.060	2682.170	2631.856

The original gross and live storage capacity of Balimela reservoir in 1972 were reported as 3610 MCM & 2676 MCM respectively. In 1999, Hydrographic survey the live capacity was worked out as 2537.060 MCM. In 2003 Remote sensing survey, the live capacity was worked out as 2682.170 MCM, which was even more than the original live storage at the time of first impoundment.

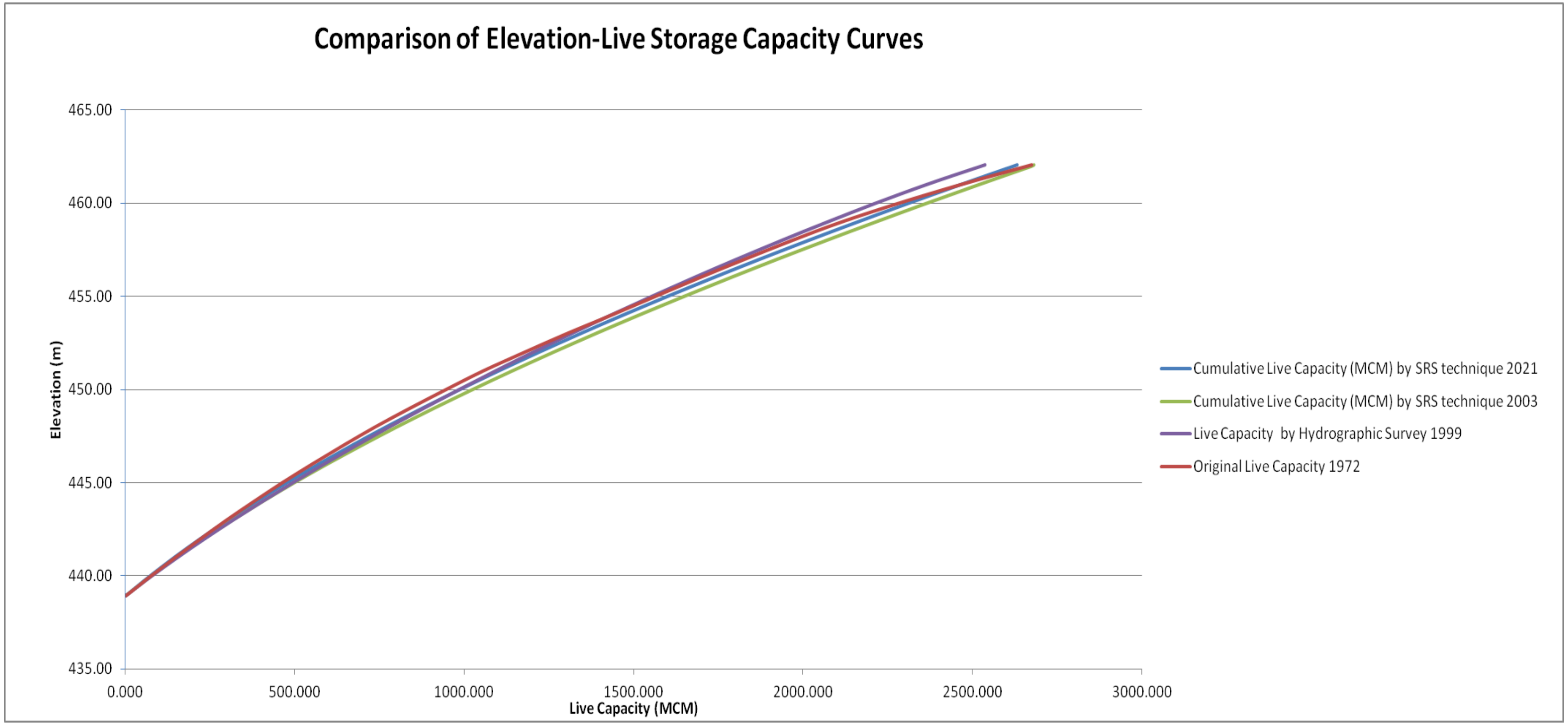


Fig. 11: Comparison of Elevation-Live Storage Capacity Curves (MCM): Balimela Reservoir

In the present study, it is found that live capacity of the Balimela reservoir in 2021 is 2631.856 MCM witnessing a live storage loss of 44.144 MCM (i.e. 1.650 %) in a period of 49 years during 1972 to 2021. This accounts for live capacity loss of 0.034% per annum since 1972.

10. RESULTS AND DISCUSSIONS

The loss in live storage capacity of the reservoir due to sedimentation since original survey (1972), and remote sensing survey (2021) is given in Table –5.

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

	Original Survey (1972)	Hydrographic Survey(1999)	SRS (2003)	SRS (2021)
Live Capacity (MCM)	2676.00	2537.060	2682.170	2631.856
Loss in Capacity (MCM) (since 1972)	-	138.94	-	44.144
% Live capacity loss (since impoundment in 1972)	-	5.192%	-	1.65%
Annual % live capacity loss	-	0.192%	-	0.04%

The live storage capacity of Balimela reservoir as per present study is found to be 2631.856 MCM for the year 2021. As per original survey conducted in 1972 the live storage capacity was 2676.00 MCM. In 1999, Hydrographic survey the capacity was worked out as 2537.060 MCM. In 2003 Remote sensing survey, the capacity was worked out as 2682.170 MCM. In 2021 Remote sensing survey, the capacity was worked out to be 2631.856 MCM. In view of above, this is to mention that the various surveys conducted since its first impoundment have not shown any definite trend of siltation (2003 survey has reported figures even higher than the original survey), and it is recommended that the capacities may be re-checked with hydrographic survey as well.

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 Balimela reservoir has been found to be 2631.856 MCM in 2021.
2. Live storage loss of 44.144 MCM (i.e. 1.650%) was observed since original survey (1972) i.e. in a period of 49 years. This accounts for live capacity loss of 0.034% per annum since 1972.
3. As per original survey conducted in 1972 the live storage capacity was 2676.00 MCM. In 1999, Hydrographic survey the capacity was worked out as 2537.060 MCM. In 2003 Remote sensing survey, the capacity was worked out as 2682.170 MCM. In view of above, this is to mention that the various surveys conducted since its first impoundment have not shown any definite trend of siltation (2003 survey has reported figures even higher than the original survey), and it is recommended that the capacities may be re-checked with hydrographic survey as well.
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 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.

13. SALIENT FEATURES OF BALIMELA RESERVOIR

Name of Dam	Balimela Dam Joint Project between Orissa & Andhra Pradesh
General	
Location	State Orissa– Distt. Malkangiri
	Latitude 18° 8’ 25” N Longitude 82° 7’.22” E
Nearest City/Town	Jeypore (Koraput) Orissa
Village	Chitrakonda
Purpose	Multipurpose river valley scheme, mainly intended for Hydro-electric power generation
Altitude	Chitrakonda 441.96 m (1500 ft.)
River	Machhkund – Sileru
Year of Impoundment	August 1972 Main Basin - Godavari Sub Basin- Sabari
Year of First Impoundment	1972
Height of Dam	Maximum 70m (230 ft.)
Length of Dam	1821 m (597 ft.)
Hydrology	
Catchment Area	4908 sq. km out of which 1955 sq. km. is intercepted by Jalaput dam – free catchment is 2953 sq km
Nature of Catchment	Hilly with dense vegetation
Design	14300 m/sec
FRL	462.07m (1516)
Dead storage level	438.91 m (1440 ft.)
Water spread area at FRL	169.08 Sq.km
Gross capacity at FRL	3610 M.cum
Live Storage capacity	2676.00 M.cum
Storage capacity at DSL	934 M.cum

Rainfall	Maximum observed : 2400 mm Mean Annual : 1600 mm Minimum Annual : 1280 mm (1971)
Temperature	Highest 1972-1992 14.4° C (from 1972) Lowest 7.8° C
Installed capacity of Power Generation	6x60 MW + 2x75 MW

PHOTOGRAPH OF RESERVOIR

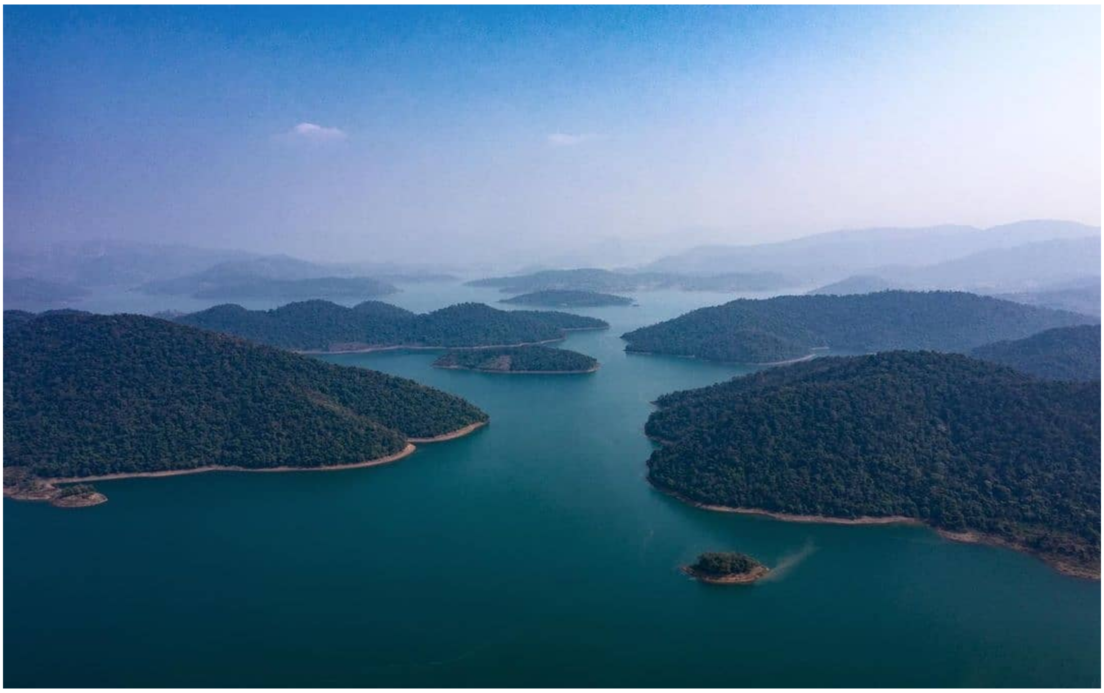


Photo 1: Balimela Reservoir

Photo 2: Balimela Dam

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 Periyar river through Satellite Remote Sensing, Remote Sensing Dte, CWC, February 2020, pp 1-27.
6. Sentinel-1 SAR Technical Guide, <https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-1-sar.>

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