सत्यमेव जयते

उपग्रह दूरस्थ संवेदन द्वारा
दमनगंगा जलाशय, गुजरात का अवसादन आंकलन

SEDIMENTATION ASSESSMENT OF DAMANGANGA RESERVOIR, GUJARAT (THROUGH SATELLITE REMOTE SENSING)

भारत सरकार
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Government of India
Central Water Commission
Environment Management Organization
Remote Sensing Directorate

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Year of Study 2021
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 2019-20 in the sedimentation study of Damanganga 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 Damanganga 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.

Damanganga dam, which is also known as Madhuban reservoir was constructed in the year 1983 across Damanganga river in Valsad district of Gujarat state. Project has a designed gross reservoir capacity as 567 MCM, with live capacity as 502 MCM. Hydrographic survey was carried out in the year 1999 and the live capacity was calculated as 464.46 MCM. In 2002 Satellite Remote Sensing survey was done that reported the live capacity as 476.133 MCM.

After analysis of the satellite data in the present study, it is found that live capacity of Damanganga reservoir in 2020 is 451.718 MCM witnessing a live storage loss of 50.282 MCM (i.e. 10.016%) in a period of 37 years during 1983 to 2020. This accounts for live capacity loss of 0.271% per annum since 1983.

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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 DAMANGANGA RESERVOIR, GUJARAT 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 Damanganga reservoir, Gujarat by Central Water Commission, New Delhi.

2. SOURCES AND MECHANISM OF SEDIMENTATION

The principal sources of sediments are as follows:

Deforestation

Excessive erosion in the catchment

Disposal of industrial and public wastes

Farming

Channelisation works

Human activities

Land development, highways, and mining

The sedimentation is a product of erosion in the catchment areas of the reservoir and hence lesser the rate of erosion, smaller is the sediment load entering the reservoir. Various factors govern the erosion, transport and deposition of sediment in the reservoir. Type of soil, drainage density, vegetation, rainfall intensity and duration, shape of catchment and land use /land cover affect the erosion. Sediment transportation depends upon slope of the catchment, channel geometry and nature of 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.

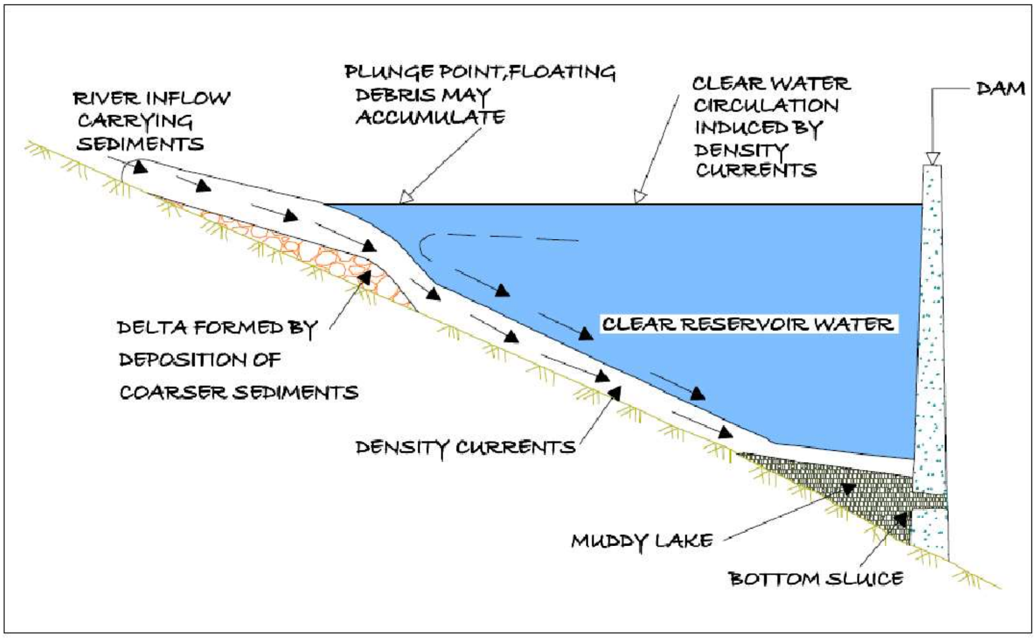


Fig. 1: Conceptual sketch of density currents in a reservoir

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.

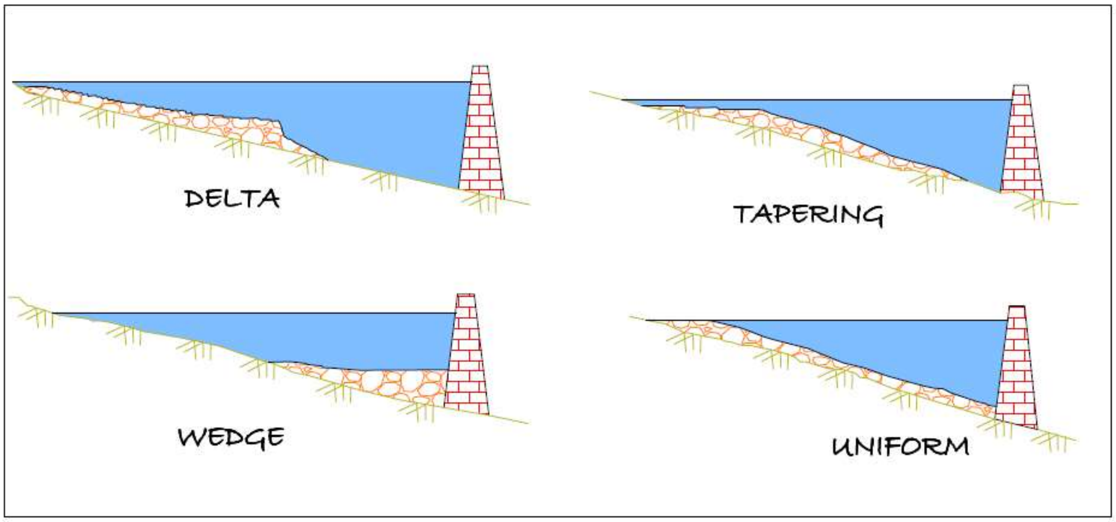


Fig. 2: Longitudinal Patterns of sediment deposition in reservoirs.

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.

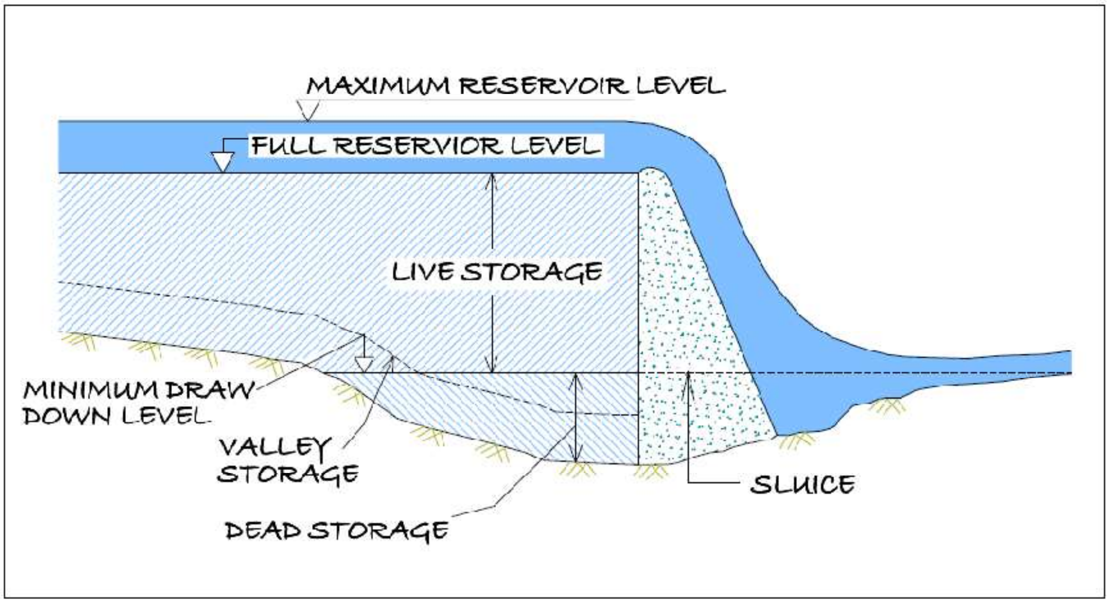


Fig. 3: Conceptual sketch of different levels in a reservoir

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:

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

Revetment and vegetation cover

Evacuation of sediment

Reservoir shoreline protection

Stream bank and flood plain protection

Ridge plantation such as pasture development and reservoir shoreline protection

Silting not only occurs in the dead storage but also encroaches into the live storage zone, which impairs the intended benefits from the reservoirs. Therefore, the problem of sedimentation needs careful consideration. Adequate provision has to be made in the reservoir for accumulation of anticipated quantities of silt. Steps are also required to be taken to ensure that the storage capacities available are not lost or get reduced by accelerated sedimentation.

4. REMOTE SENSING IN RESERVOIR SEDIMENTATION

Remote sensing is the art and science of collecting information about earth's feature without being in physical contact with it. Various features on earth surface reflect or emit electromagnetic energy depending upon their characteristics. The reflected radiation depends upon physical properties of the terrain and emitted radiation depends upon temperature and emissivity. The radiations are recorded by the sensor on-board satellite and then are transmitted back to earth. Difference between features depends on the fact that response from different features like vegetation, soil, water is different and discernable. Data received at ground stations, is digitally or visually interpreted to generate thematic maps.

The data from satellites such as Landsat, SPOT and IRS are useful for mapping and monitoring the surface water bodies and other land resources based on which, better water management strategies could be planned. Data from microwave remote sensing technique such as SENTINEL-1 is more useful as it is an imaging radar mission providing continuous all-weather, day-and-night imagery at C-band. The SENTINEL-1 constellation provides high reliability, improved revisit time, geographical coverage and rapid data dissemination to support operational applications in the priority areas of marine monitoring, land monitoring and emergency services.
Spectral response of water is affected by variables like time of the year, sun elevation angle, water vapour content in the atmosphere, roughness of water surface, water colour, turbidity, type and concentration of suspended particles, depth of water, characteristics of bottom material and submerged or emergent vegetation.

Reservoir sedimentation surveys are essentially based on mapping of water-spread area at the time of satellite over pass. Multi-date satellite data is needed which covers the operating level of reservoir at close interval. Water spread area is nothing but water level contour at that level. Using different contours, capacity between them is calculated. With the sedimentation, the water spread area of the reservoir reduces at different levels. The water spread area and the elevation information is used to calculate the volume of water stored between different levels. These capacity values are then compared with the previously calculated capacity values to find out the change in capacity between different levels.

Remote Sensing based reservoir capacity estimation has certain limitations. The capacity estimation works between MDDL and FRL only as these are the levels between which reservoir operates. Thus changes can be estimated only in live capacity of reservoir. For capacity estimation below MDDL corresponding to dead storage other methods like hydrographic survey are to be used. Availability of cloud free data throughout reservoir operations that was a limitation in earlier optical analysis has been taken care of by using microwave datasets that are not affected by weather or illumination conditions. This technique gives accurate estimates for fan shaped reservoir where there is a considerable change in water spread area with change in water level.

5. OBJECTIVES

The objective of the study is to estimate live capacity loss of Damanganga reservoir due to sedimentation through Satellite Remote Sensing. Following objectives will be achieved in the study.

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

6. STUDY AREA

River Damanganga (one of the river of composite basin consisting of West Flowing Rivers between Tapi to Tadri) originates in Sahyadri hill ranges in Nasik district of Maharashtra at 930.5m elevation above mean sea level (MSL). Two major distributaries Daman and Vag, after travelling through a course of 79 km and 61.1 km resepectively meet near village Matunji to form main river Damanganga. For its major course it runs through Maharashtra, then enters Dadra and Nagar Haveli (U.T.) and finally enters Gujarat to join Arabian sea near Daman (U.T.). The gross catchment area of the river Damanganga at the dam site is 1813 Mm^2. Figure 4 and

Figure 5 show the Damanganga basin and the index map of Damanganga reservoir respectively.

Damanganga dam was constructed in the year 1983 on the river Damaganga near village Madhuban of Valsad district of Gujarat. The dam site is 30 km away from Vapi and 60km from Valsad. The dam is designed to impound gross storage of 567MCM at FRL 79.86m. the length of masonry dam is 352m and length of earthen dam is 2376m. The maximum height of dam above river bed on ground is 57.50m. The original water spread area of the reservoir at FRL is 46.6 Mm^2 (now as per present study 41.429 Mm^2) which mainly lies in Gujarat State and Dadra and Nagar Haveli (U.T.).

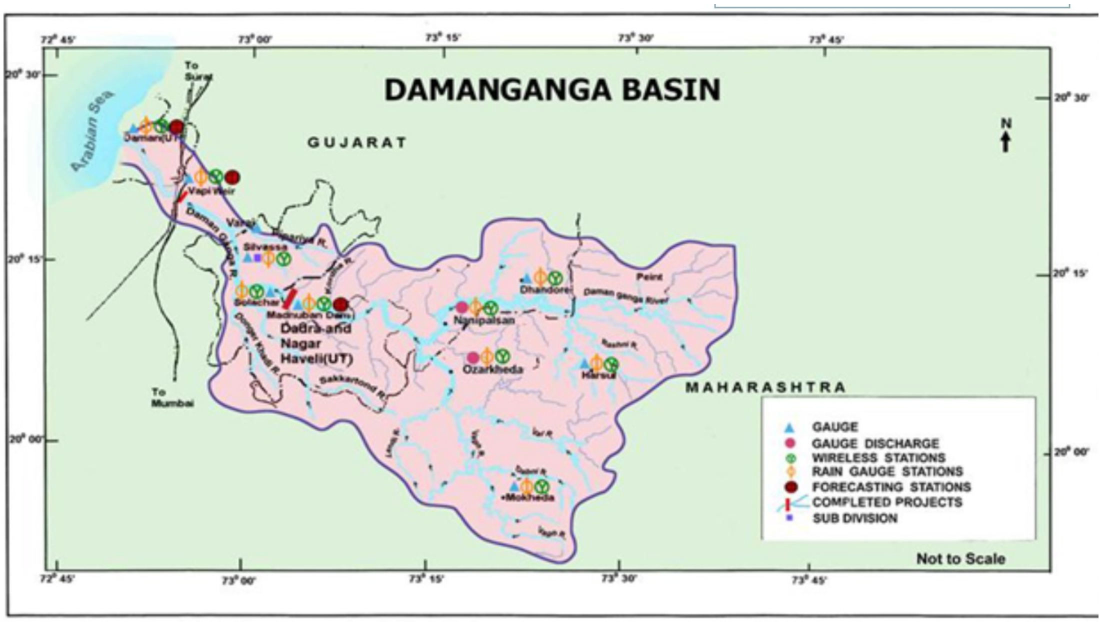


Fig-4: Basin Map of Damanganga river

Average rainfall in the area is 220.2 cm with maximum being 378.0 cm. The spillway length is 191.11 m. Ten radial gates of size 15.55mm x 14.02mm are provided. Salient features of the Damanganga 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 Damanganga reservoir, the height difference between FRL (79.86 m) and MDDL (61.60 m) is 18.26 m.

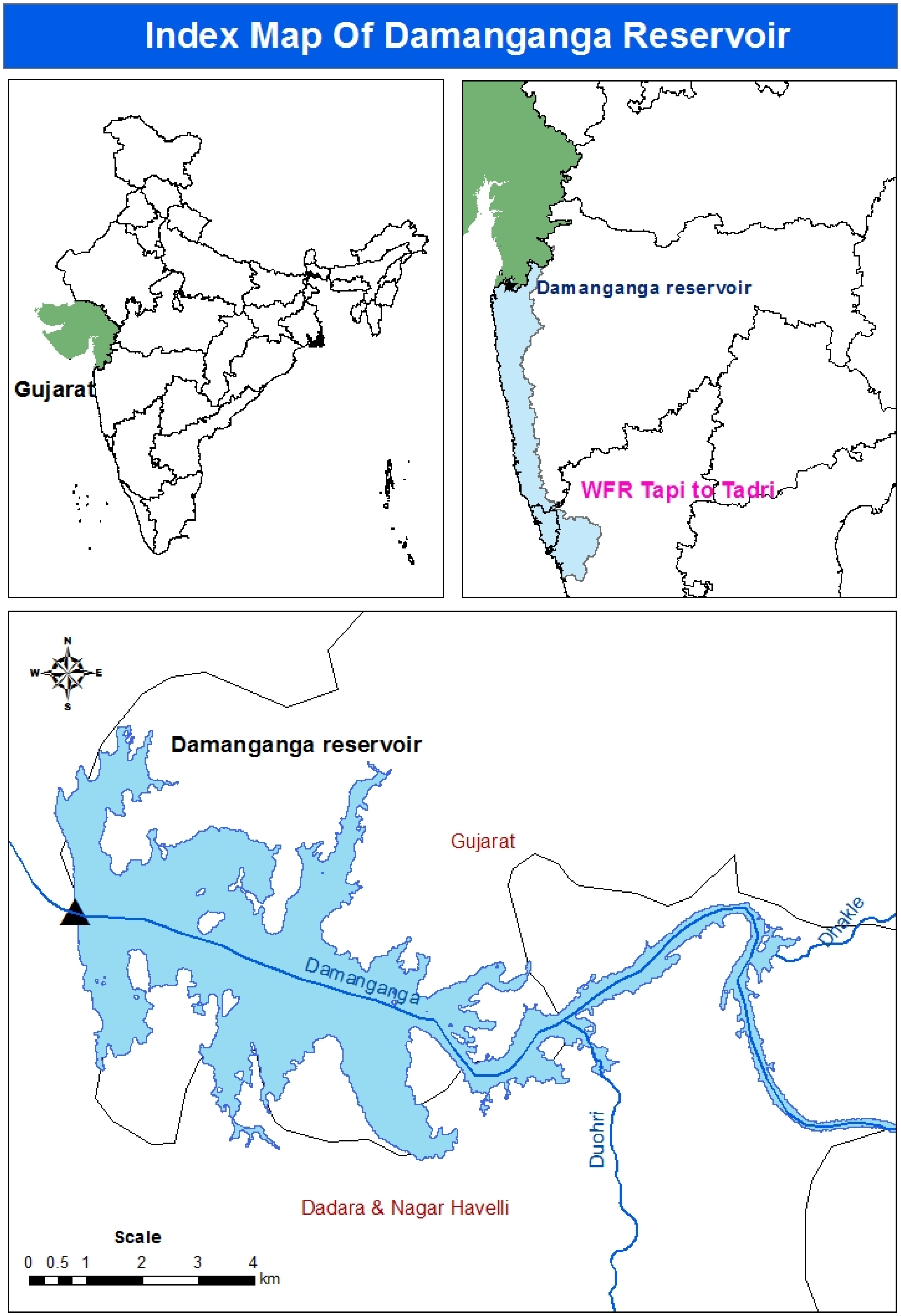


Fig. 5: Index map of the Damanganga Reservoir

8. DATA USED

8.1. SATELLITE DATA

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

Table – 1: Date of pass for satellite data

Satellite	Date of pass	Elevation (m)
Sentinel 1A	12-10-2020	79.860
Sentinel 1A	06-09-2020	77.850
Sentinel 1A	13-08-2020	75.550
Sentinel 1A	01-08-2020	72.100
Sentinel 1A	08-07-2020	70.550
Sentinel 1A	14-06-2020	68.800
Sentinel 1A	15-05-2019	65.800
Sentinel 1A	08-06-2019	64.150

8.2. FIELD DATA

The following field data have been obtained from project authorities:

Elevation - Capacity data

Salient features of Damanganga 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 Damanganga 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 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 represents the flowchart of methodology, Fig. 7 shows Sentinel 1A/1B images of different dates and Fig. 8 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)
12-10-2020	79.860	41.77
06-09-2020	77.850	38.703
13-08-2020	75.550	34.154
01-08-2020	72.100	29.026
08-07-2020	70.550	25.374
14-06-2020	68.800	23.34
15-05-2019	65.800	13.6
08-06-2019	64.150	10.62

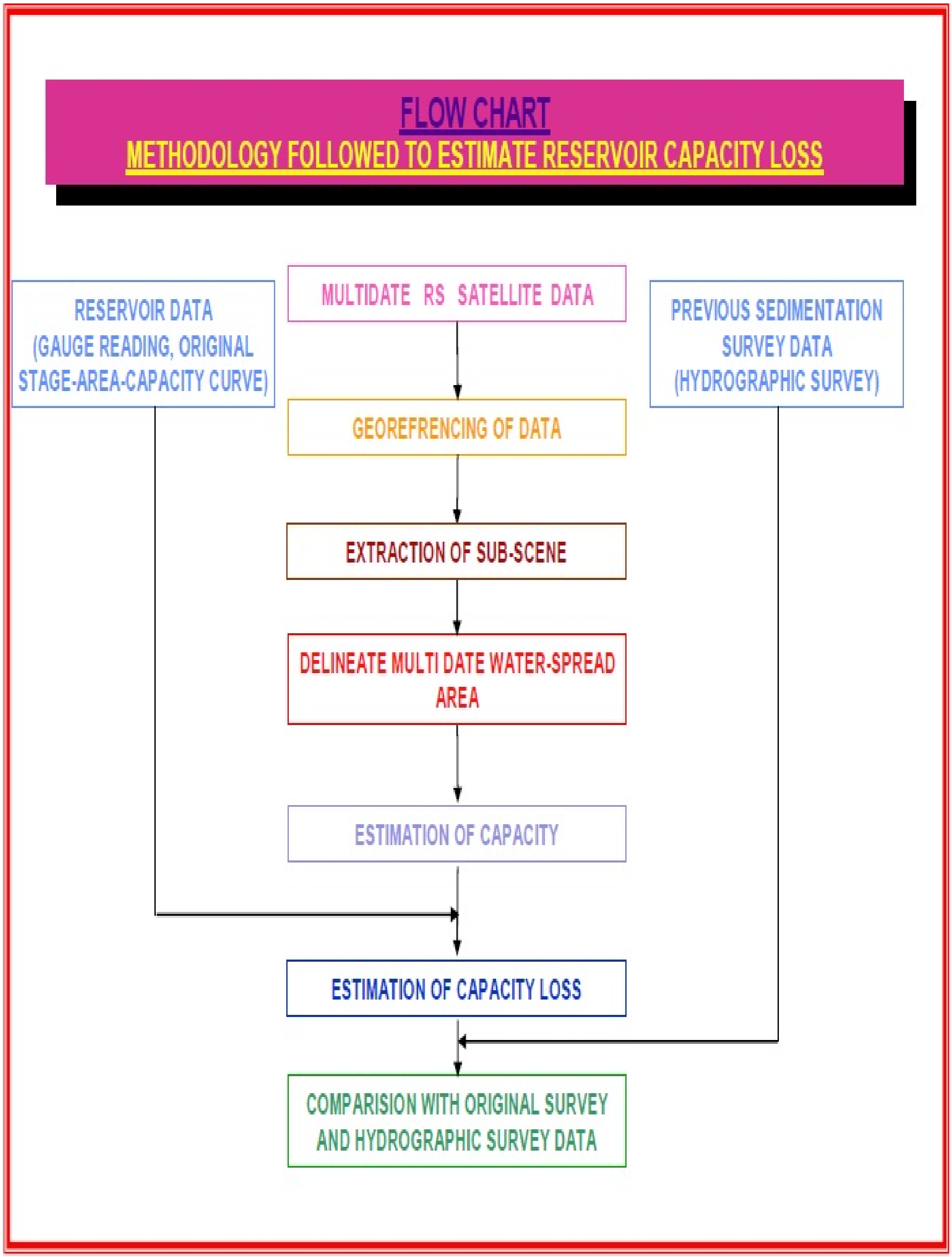


Fig 6 : Flow chart showing methodology followed to estimate reservoir capacity loss

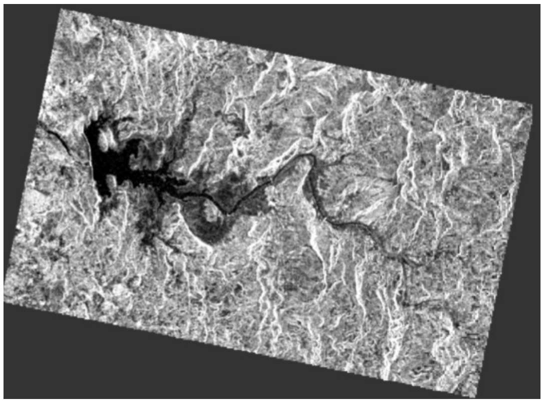
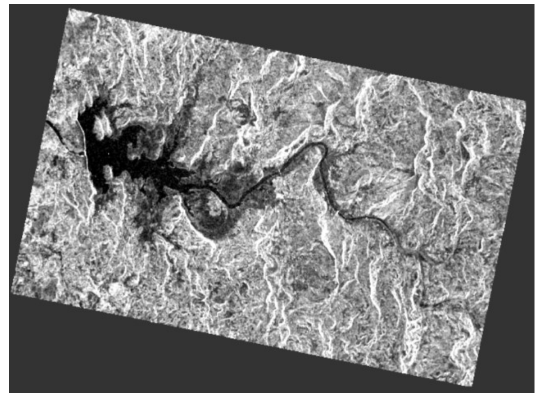
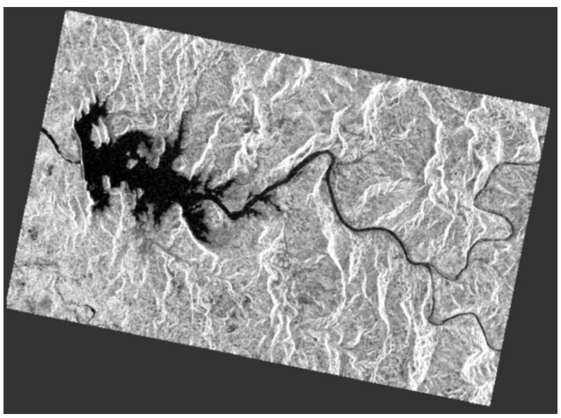
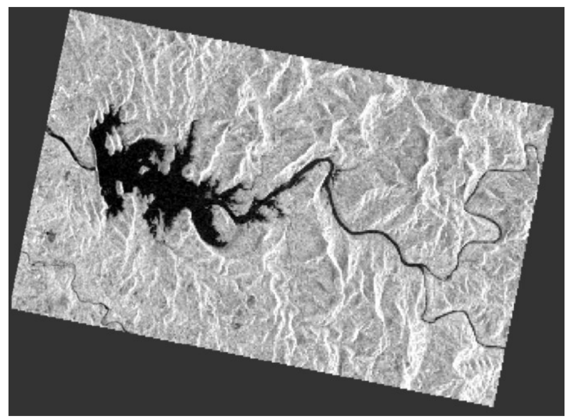
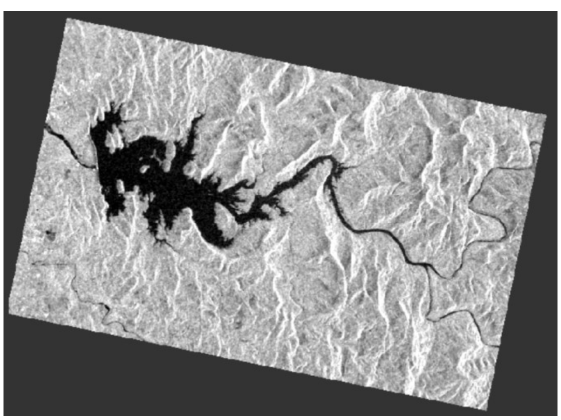
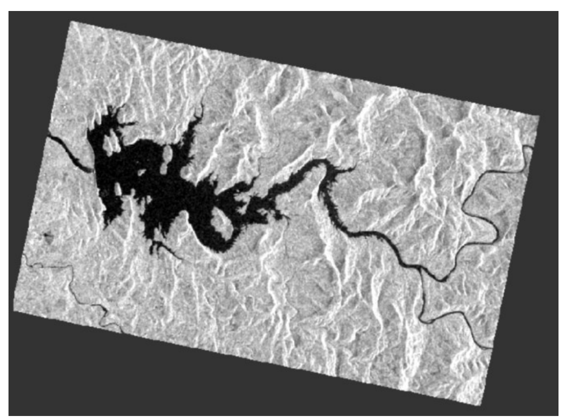
	
08-June-2019 (64.15 m)	**15-May-2019 (65.80 m)**
	
14-June-2020 (68.80 m)	**08-July-2020 (70.55 m)**
	
01-Aug-2020 (72.10 m)	**13-Aug-2020 (75.55 m)**

Fig 7 : Sentinel 1 SAR imageries showing water spreads at different dates

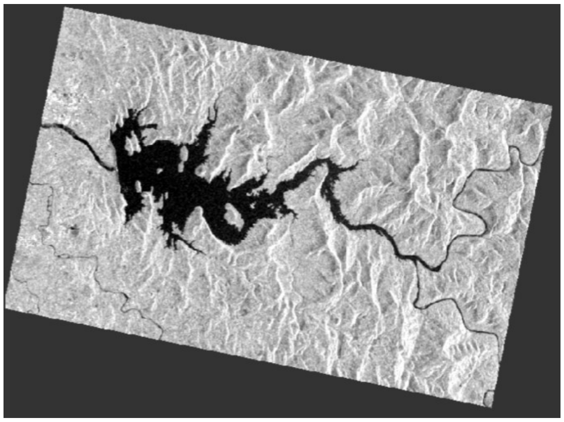
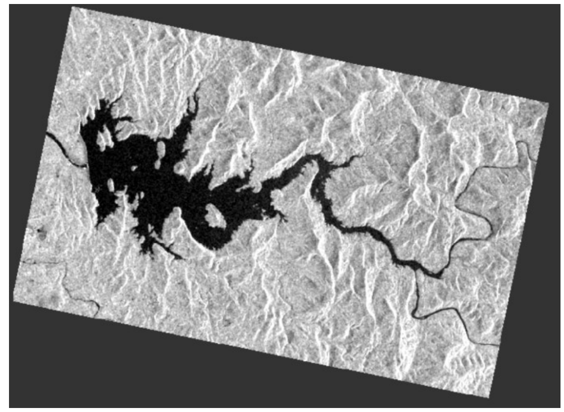
	
06-Sept-2020 (77.85 m)	**12-Oct-2020 (79.86 m)**

Fig 7 : Sentinel 1 SAR imageries showing water spreads at different dates

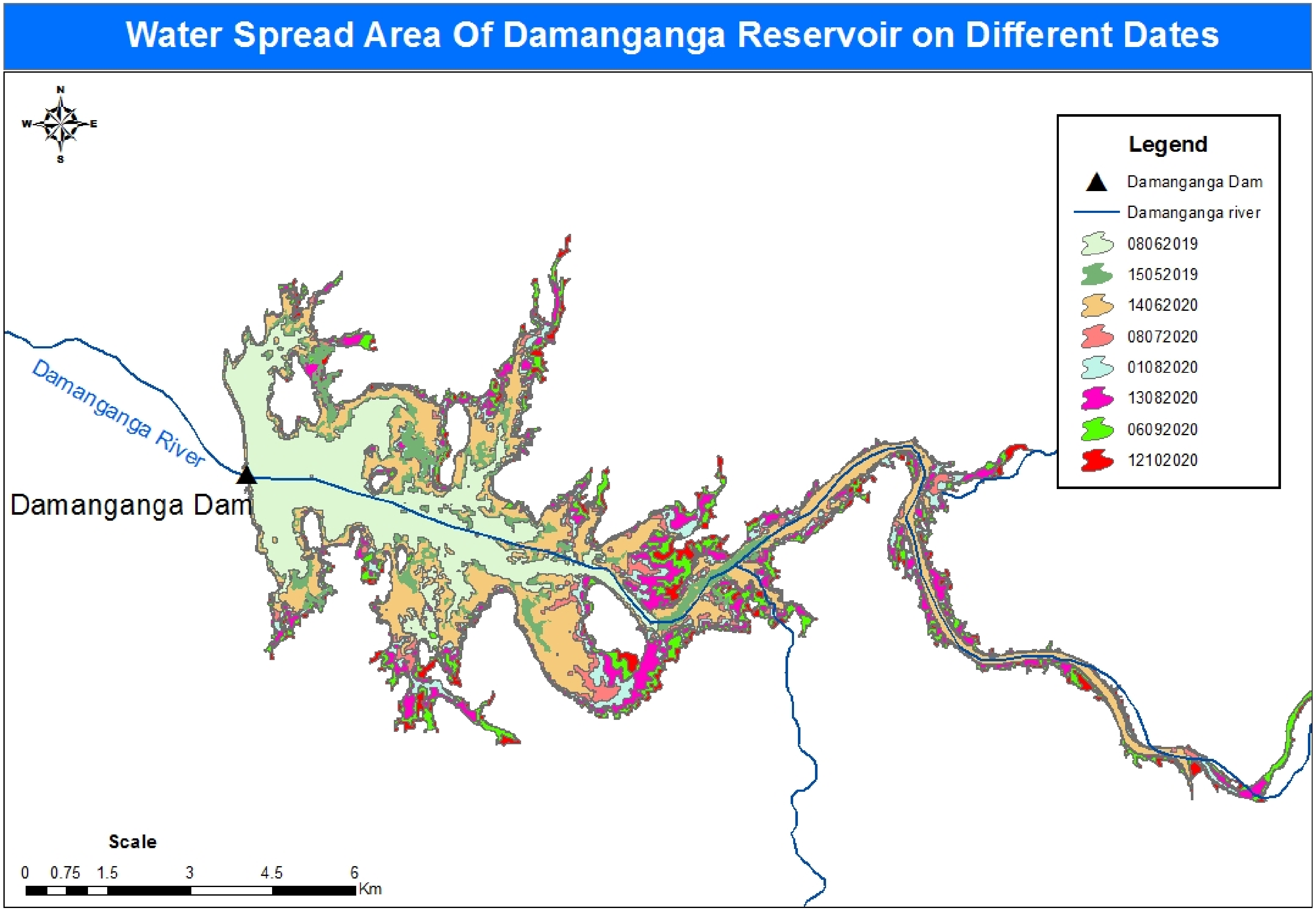


Fig. 8: Water Spread Area of Damanganga Reservoir on different dates

The Satellite Images for the Damanganga 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 Damanganga Reservoir showing its water spread area for eight overpass dates such as 12-Oct-2020, 06-Sept-2020, 13-Aug-2020, 01-Aug-2020, 08-July-2020, 14-Jun-2020, 15-May-2019 and 08-June-2019 are shown in fig. 8.

The water elevation 79.86 m for 12-Oct-2020 is at the Full Reservoir Level (FRL). The Water elevation 64.150 m for 08-June-2019 is near the Minimum Drawdown Level (MDDL) 61.60m .

9.3. ESTIMATION OF RESERVOIR CAPACITY

Area elevation curve has been plotted using these above eight (8) water-spread areas for different water level in the reservoir and best-fit polynomial equation of second order as given below have been derived.

$Y = -0.0446*X^2 + 2.9051 * X + 3.253$

$R^2 = 0.9948$

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.

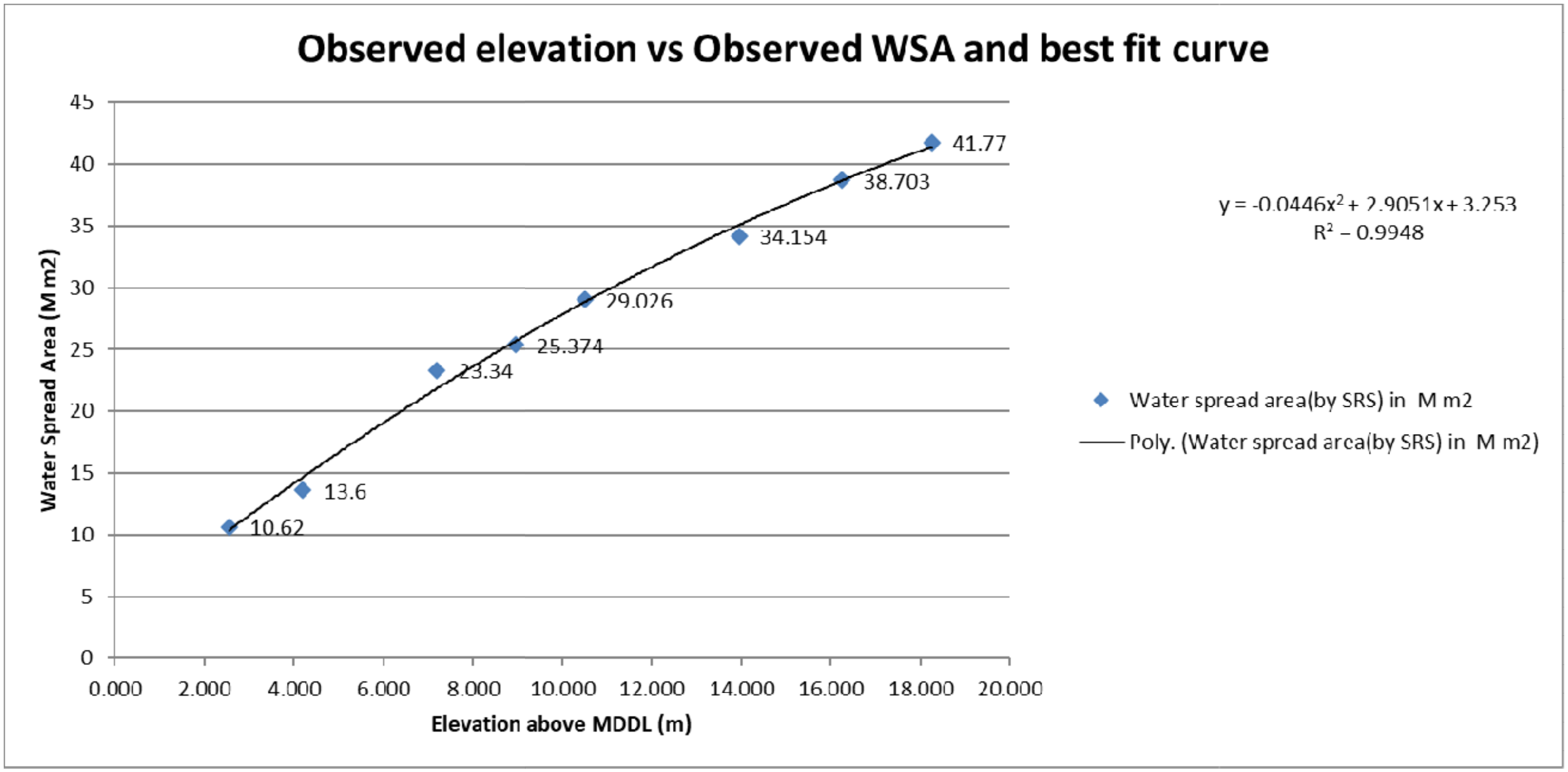


Fig. 9: Observed elevation vs Observed WSA of Damanganga Reservoir

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-10 and Fig-11 respectively.

Table-3: Aerial extent of reservoir at regular interval (1.0m) using SRS Survey 2020

	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 2020**
MDDL	61.60	3.253	0.000	0.000
	63.00	7.233	7.157	7.157
	65.00	12.615	19.600	26.757
	67.00	17.640	30.115	56.871
	69.00	22.308	39.857	96.728
	71.00	26.620	48.865	145.594
	73.00	30.575	57.149	202.743
	75.00	34.173	64.715	267.457
	77.00	37.414	71.563	339.020
FRL	79.86	41.429	112.697	**451.718**

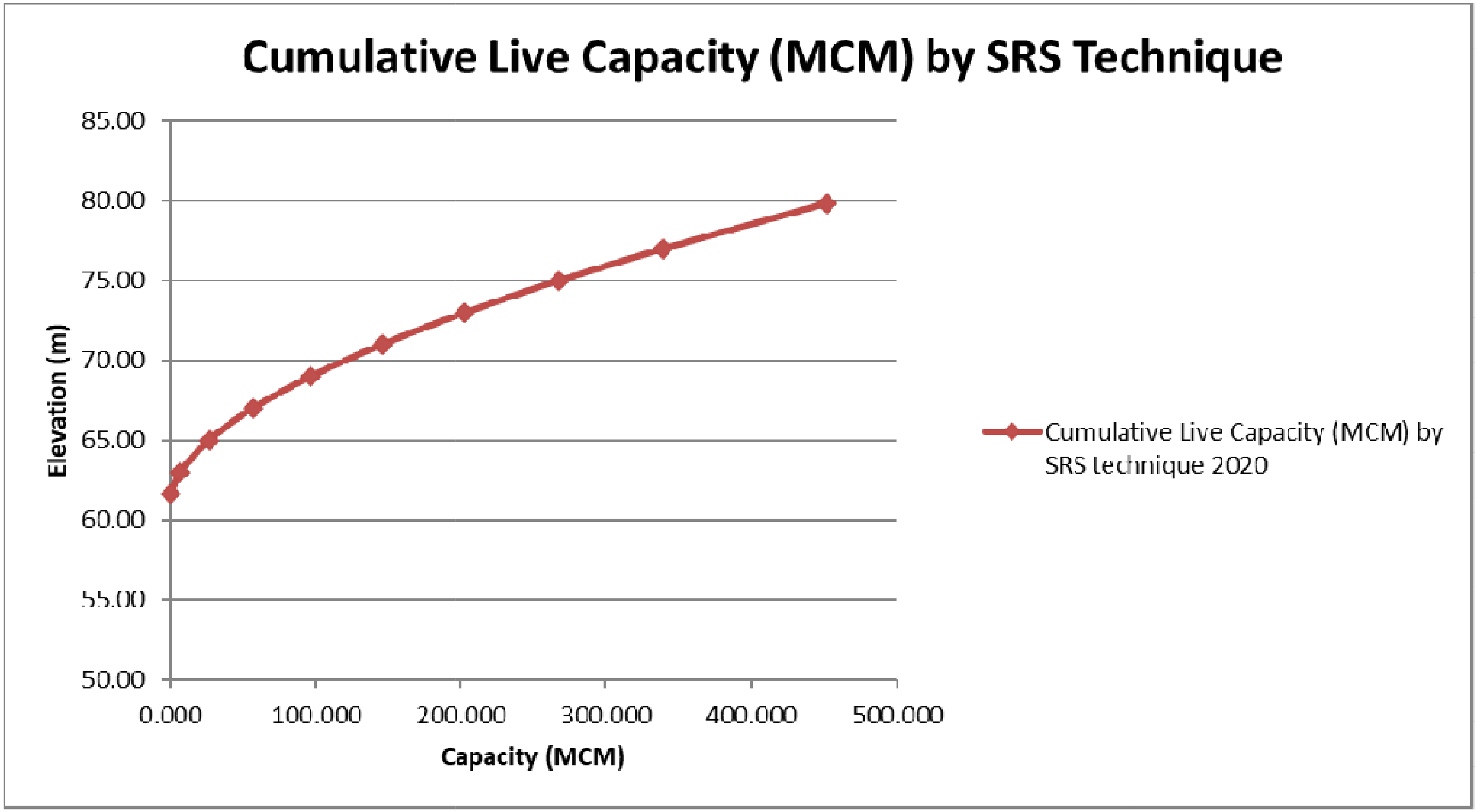


Fig. 10: Modified live capacity - elevation curve (SRS technique)

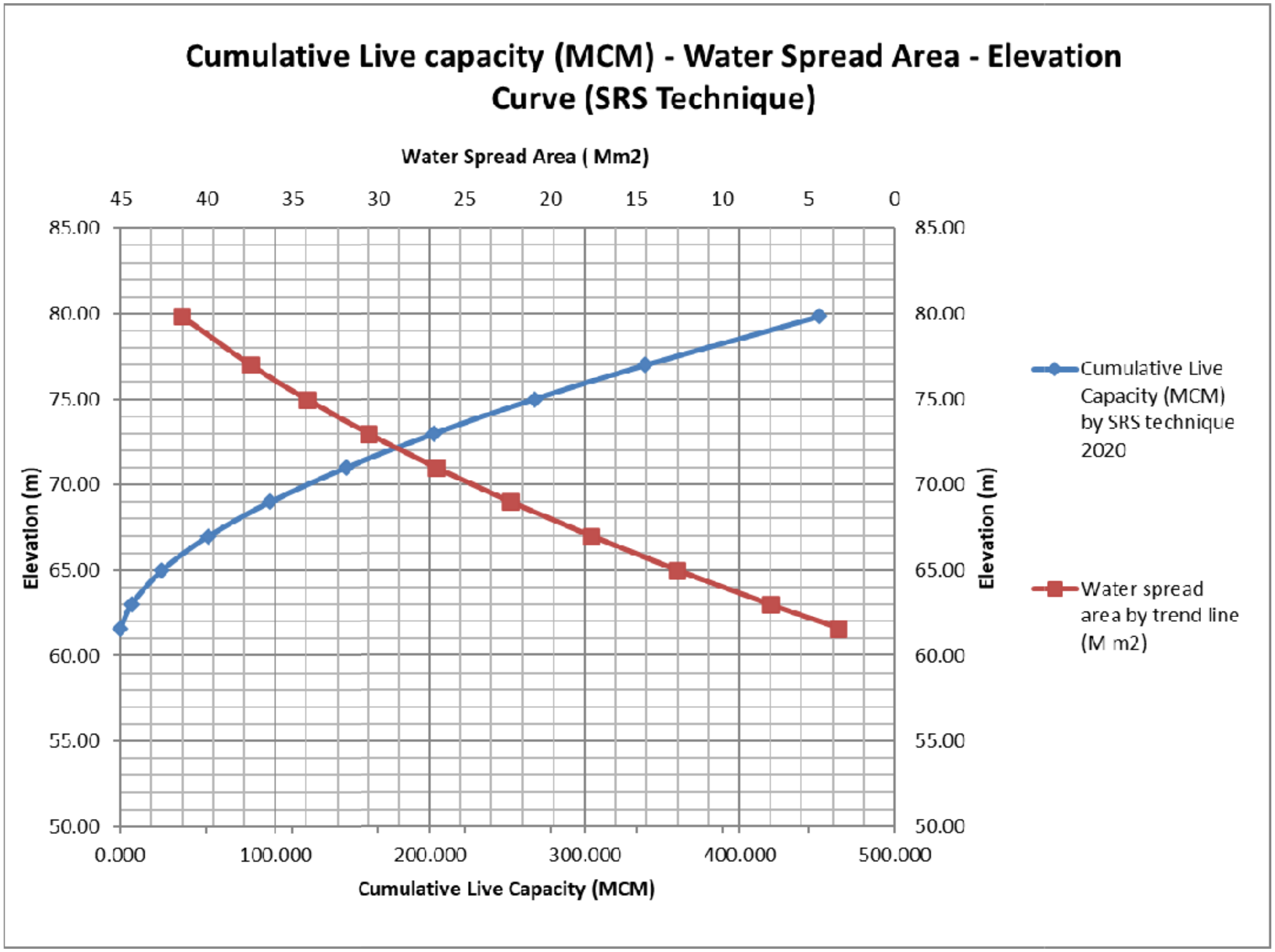


Fig. 11: Elevation – Area- Capacity Curve

9.4. Comparison with Original and Previous Surveys

Comparison of live storage capacity of SRS survey with original survey 1983, and SRS survey 2003 at various elevations is given below in table 4. Curve showing comparison of live capacity is drawn in figure 12.

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

	Reservoir water level in Metre	Cumulative Live Capacity (MCM) by SRS technique 2020	Cumulative Live Capacity (MCM) by SRS technique 2002	Cumulative Live Capacity (MCM) by HS 1999	Original Live Capacity 1983
MDDL	61.60	0.000	0.000	0.000	0
	63.00	7.157	7.561	15.793	23
	65.00	26.757	28.471	43.553	57
	67.00	56.871	60.519	77.867	97
	69.00	96.728	102.855	119.792	141
	71.00	145.594	154.639	169.144	189
	73.00	202.743	215.034	225.810	245
	75.00	267.457	283.204	288.524	309
	77.00	339.020	358.317	357.547	382
FRL	79.86	451.718	476.133	464.460	502

The original gross and live storage capacity of Damanganga reservoir in 1983 were reported as 567 MCM & 502 MCM respectively. In 1999, a Hydrographic survey was conducted which reported a live storage capacity of 464.460 MCM. In 2002 a Satellite Remote Sensing Survey was conducted using optical imageries that indicated a live storage capacity of 476.133 MCM.

In the present study, it is found that live capacity of the Damanganga reservoir in 2020 is 451.718 MCM witnessing a live storage loss of 50.282 MCM (i.e. 10.016 %) in a period of 37 years during 1983 to 2020. This accounts for live capacity loss of 0.271% per annum since 1983.

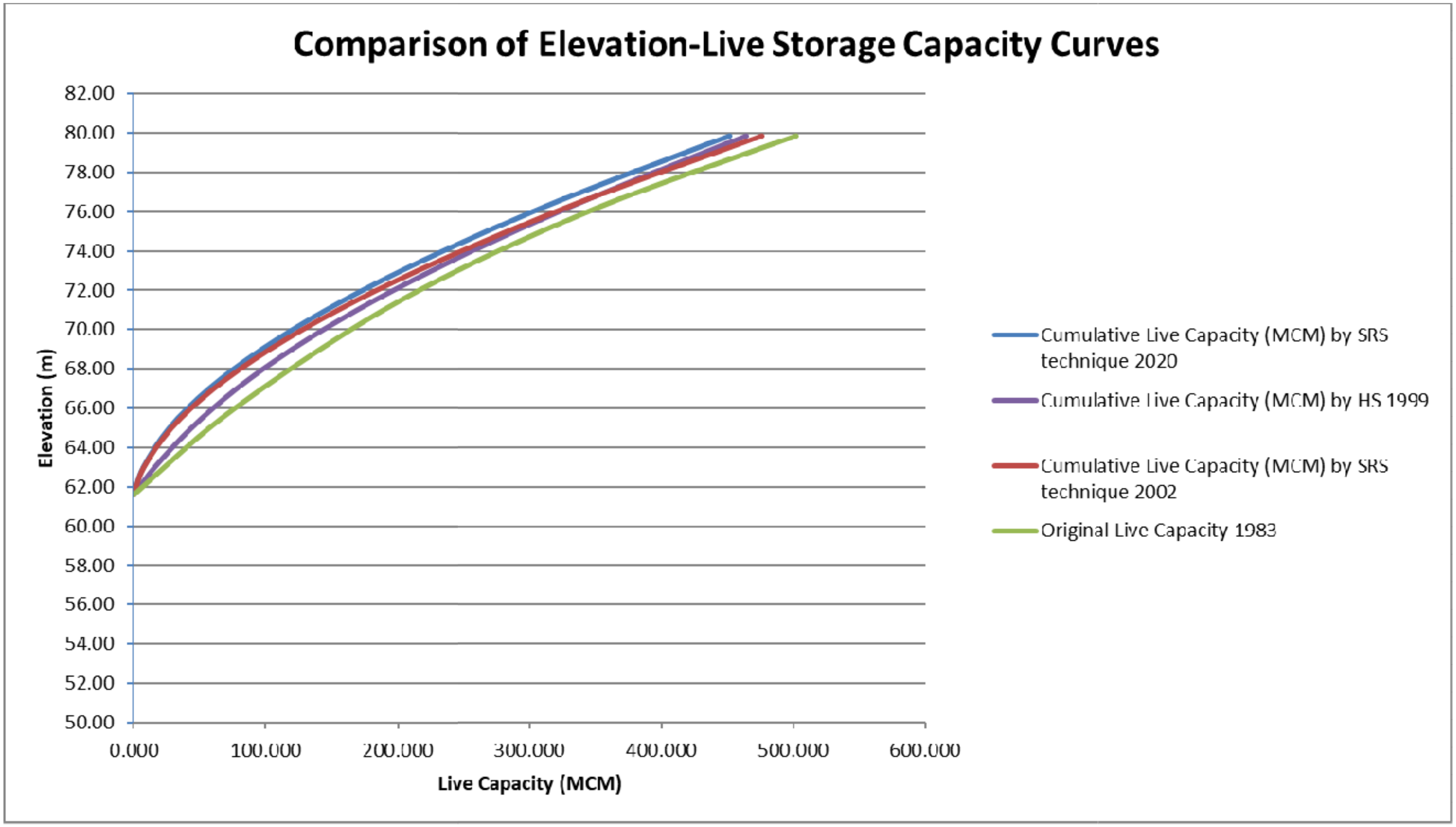


Fig. 12: Comparison of Elevation-Live Storage Capacity Curves (MCM)

10. RESULTS AND DISCUSSIONS

The loss in live storage capacity of the reservoir due to sedimentation since original survey (1983), and remote sensing survey (2003) is given in Table –5.

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

	Original Survey (1983)	Hydrographic Survey (1999)	SRS (2002)	SRS (2020)
Live Capacity (MCM)	502	464.460	476.133	451.718
Loss in Capacity (MCM) (since 1983)	-	37.54	25.867	50.282
% Live capacity loss between two consecutive surveys (of the original capacity)	-	7.48%	Error	2.54%
% Live capacity loss (since impoundment in 1983)	-	7.48%	Error	10.016%
Annual % live capacity loss	-	0.467%	Error	0.271%

The live storage capacity of Damanganga reservoir as per present study is found to be 451.718 MCM for the year 2020. As per original survey conducted in 1983 the live storage capacity was 502 MCM. In 1999 hydrographic survey the live capacity was calculated to be 464.460 MCM. In 2002 Remote sensing survey the capacity was worked out as 476.133 MCM (an increase over the hydrographic survey 1999).
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 Damanganga reservoir has been found to be 451.718 MCM in 2020.
2. Live storage loss of 50.282 MCM (i.e. 10.016%) was observed since

original survey (1983) i.e. in a period of 37 years. This accounts for live capacity loss of 0.271% per annum since 1983.

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.

Annexure-I

LOCATION

1. Name of River	Damanganga
2. Nearest Village	Madhuban
3. Taluka	Dharampur
4. District	Valsad
5. State	Gujarat
6. Location of dam	Latitude $20^{o}10'$N Longitude $73^{o}5'$E
7. Distance of dam from Vapi (Gujarat)	30 km
8. Distance of dam from Valsad (Gujarat)	60 km

Hydrology

1. Catchment Area	1813 Mm^2
2. Average rainfall	2202 mm
3. Maximum rainfall	3780 mm
4. Design flood	26856 cumec

Reservoir

1. MDDL	61.6 m
2. FRL	79.86 m
3. Spillway crest	65.83 m
4. MWL	82.4 m
5. Top of dam	86.6 m
6. Submergence at FRL (original)	46.60 Mm^2
7. Dead Storage (original)	65 Mm^3
8. Submergence Area at MDDL	11.3 Mm^2
9. Gross storage (original)	567 Mm^3
10. Live storage (original)	502 Mm^3

Dam

1. Type of dam	Composite
2. Length of masonry dam	352 m
3. Length of Earthen dam	2376 m
4. Height of masonry from foundation	48.74 m
5. Height of earthen dam from foundation	57.5 m
6. Freeboard above MWL	4.2 m

Spillway

1. Type	Masonry with gates
2. Location	Main gorge
3. Length	191.11 m
4. Shape of Crest	Ogee
5. No. of gates	Ten

Canals

1. RBC length	45.54 km
2. LBC length	33.4 km
3. Vapi branch length	19.4 km
4. Type	Lined
5. Capacity	39.35 cumec

BENEFITS

1. Irrigation	
a. Gujarat	410.23 Mm^2
b. Dadra and Nagar Haveli	70.44 Mm^2
c. Daman	30.71 Mm^2
2. Water Supply	
a. Gujarat	40 MGD
b. Dadra and Nagar Haveli	12.75 MGD
c. Daman	5.25 MGD
3. Power	1000 MW

PHOTOGRAPH OF RESERVOIR

Photo 1: Damanganga Dam

Photo 2: Damanganga Dam

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