सत्यमेव जयते

# उपग्रह दूरस्थ संवेदन द्वारा इंदिरा सागर डैम जलाशय, मध्य प्रदेश का अवसादन आंकलन

# SEDIMENTATION ASSESSMENT OF INDIRA SAGAR DAM RESERVOIR, MADHYA PRADESH (THROUGH SATELLITE REMOTE SENSING)


भारत सरकार
केन्द्रीय जल आयोग
पर्यावरण प्रबंध संगठन
दूरस्थ संवेदन निदेशालय

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


March 2024

# SEDIMENTATION ASSESSMENT OF
# INDIRA SAGAR DAM RESERVOIR, MADHYA PRADESH
# (THROUGH SATELLITE REMOTE SENSING)

**Year of Study 2024**
**Data Used 2021-23**

## STUDY TEAM


### OVERALL GUIDANCE

| | |
|---|---|
| Sh. Rishi Srivastava | Chief Engineer (EMO),<br>CWC, New Delhi |

### SUPERVISION

| | |
|---|---|
| Sh. Avanti Verma | Director (RS Directorate),<br>CWC, New Delhi |
| Smt. Karishma Bhatnagar Malhotra | Deputy Director (RS Directorate),<br>CWC, New Delhi |

### PRINCIPAL INVESTIGATOR

| | |
|---|---|
| Sh. Devendro Moirangthem | Assistant Director (RS Directorate),<br>CWC, New Delhi |

# 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 2021-23 in the sedimentation study of Indira Sagar Dam 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 Satellite and EOS-4 (RISAT-1A)** have been used to estimate water spread area of Indira Sagar Dam 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.

EOS-04 is a Low Earth Orbit (LEO) satellite to be operated in a Sun Synchronous Polar Orbit (SSPO) with 6 AM-6 PM Equatorial Crossing Time (ECT) at an altitude of 524.87 km carrying a Synthetic Aperture Radar (SAR) payload. SAR payload of EOS-04 operates in C-Band frequency range (5.4G Hz) having repetivity cycle of 377 orbits in 25 days and Side-Looking Radar mode with performance parameters.

The Indira Sagar Dam on the Narmada River in Khandwa District, Madhya Pradesh is operated and maintained by Narmada Hydroelectric Development Corporation Ltd, a Joint Venture of NHPC Ltd & Govt. of M.P. The project is mainly used for hydroelectric power generation with a total capacity of 1000MW (8 x 125 MW). The foundation stone of the project was laid by the then Prime Minister of India, Late Smt. Indira Gandhi on 23.10.1984 and it was commissioned in 2005.

Originally, the project had a designed gross reservoir capacity of 12212 MCM, with live capacity of 9745 MCM.

After analysis of the satellite data in the present study, it is found that the live capacity of Indira Sagar Dam reservoir in 2024 is 9585.091 MCM witnessing a live storage loss of 159.909 MCM (i.e.1.64%) in a period of 18 years during 2005 to 2023. This accounts for live capacity loss of 0.09% per annum since 2005.

***

# CONTENTS

## LIST OF TABLES



## LIST OF FIGURES

## 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 $m^3$ or MCM | million cubic metre |
| Ha | Hectare |
| Sq Km | Square Kilometre |
| mm/a | millimetre per annum |

# SEDIMENTATION ASSESSMENT OF INDIRA SAGAR DAM RESERVOIR, MADHYA PRADESH 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/a, 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 murkier due to topographical and other constraints. Due to this, the total utilisable water resources in the country are about 1126 BCM (690 BCM of surface water and 436 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 industrialization, urbanization 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 is 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 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. Realizing 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 alongwith efficient management and operation of reservoirs thereby deriving maximum benefits for the society.

This report covers the study of Linganamakki Dam Reservoir, Karnataka 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.

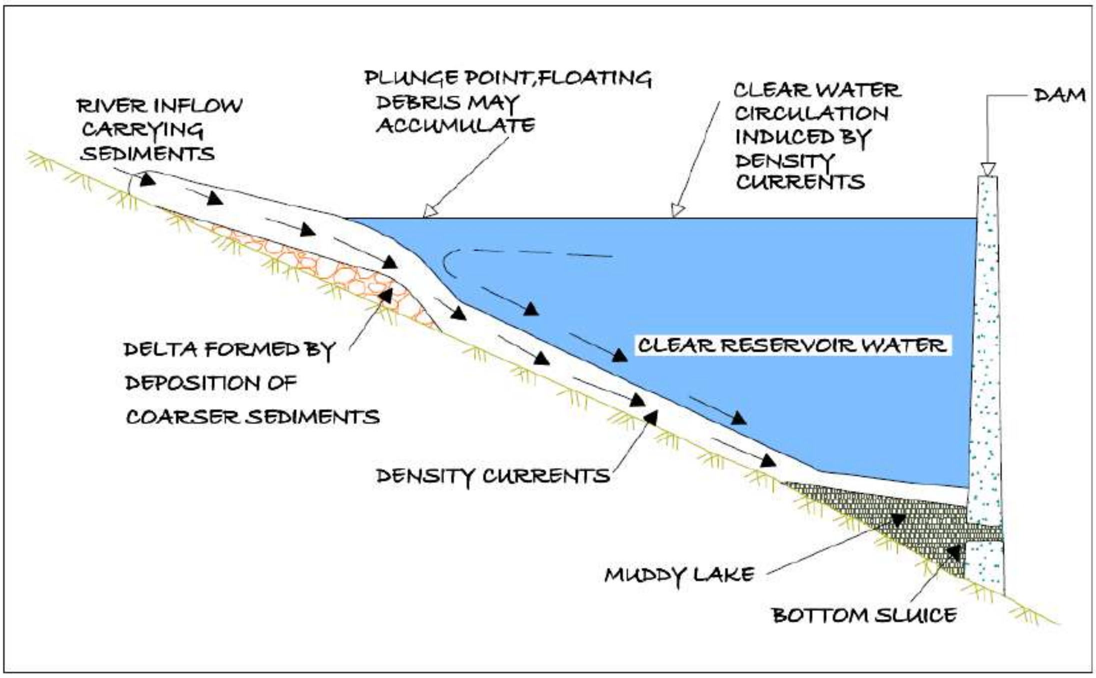



**Fig. 1: Conceptual sketch of density currents in a reservoir**

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.

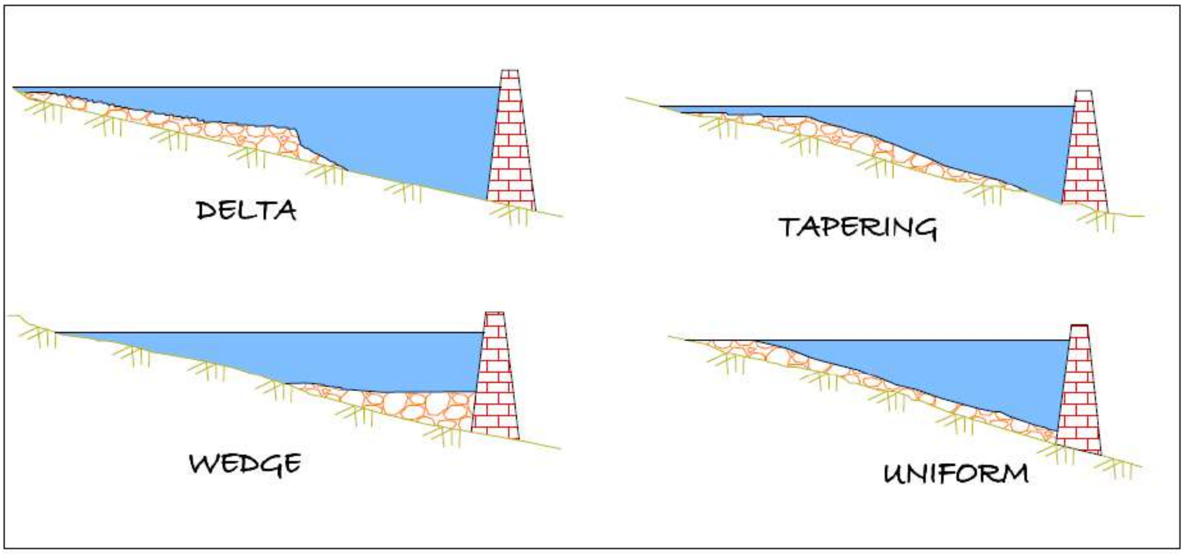



**Fig.2: Longitudinal Patterns of sediment deposition in reservoirs.**

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.

Fig.3 shows different levels in the reservoir where-in the capacity is affected. Reservoirs operate between Minimum Draw Down Level (MDDL) and Full Reservoir Level (FRL). The storage between these two levels is the live storage. The storage below MDDL is the dead storage. Water stored along the valley bed is known as valley storage.

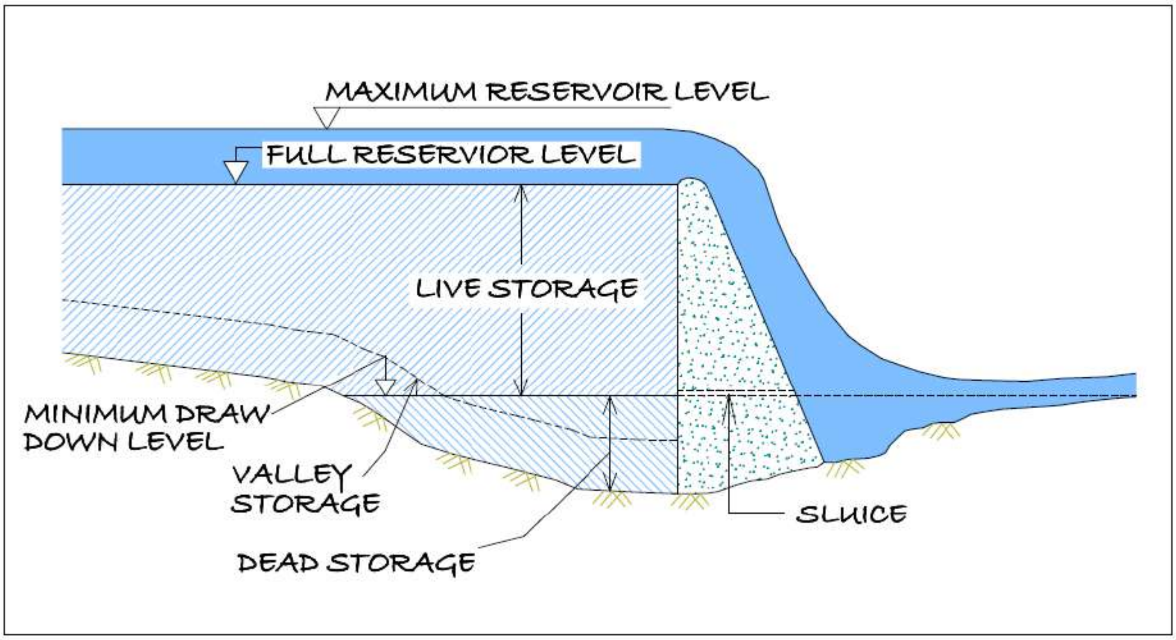



**Fig.3: Conceptual sketch of different levels in a reservoir**

## 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 and EOS-4 (RISAT-1A) are more useful as it is an imaging radar mission providing continuous all-weather, day-and-night imagery at C-band. The SENTINEL-1 and EOS-4 (RISAT-1A) 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, 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 Linganamakki Dam 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

The Indira Sagar Dam on the Narmada River which is located in Khandwa District, Madhya Pradesh is operated and maintained by Narmada Hydroelectric Development Corporation Ltd, a Joint Venture of NHPC Ltd & Govt. of M.P.

For location of the dam please refer Figure 4 - Index Map. The dam is located at a Latitude 22° 17’ 00” – N and Longitude 76° 28’ 00” – E. The nearest railway station is Khandwa Railway Station.

The salient features of Indira Sagar Dam project are listed as Annexure I. Multi date satellite data of the water year 2021-23 between maximum to minimum reservoir stages is utilized in the present study.

As per CWC (2020), the whole country has been classified into 7 regions based on several factors which affect the rate of sedimentation such as hydrometeorology, physiography, climate etc. The zone-wise average rate of siltation of reservoirs is given in Annexure III. In the present study, the Indira Sagar Dam reservoir in Madhya Pradesh lies in Sedimentation zone – 5 *i.e.* region of Narmada and Tapi having an average siltation rate of 2.84 Th.cu.m./sq.km/year and a median siltation rate of 0.65 Th.cu.m./sq.km/year.

## 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 Indira Sagar Dam reservoir, the height difference between FRL (262.130 m) and MDDL (243.250 m) is 18.88 m.

However, the minimum and maximum level upto which satellite data/imagery can be obtained is 245.80 m and 262.130 m respectively. Moreover, the storage covered by the selected levels between 245.80 m and 262.130 m is 88.18% of the live storage capacity (> 80%).

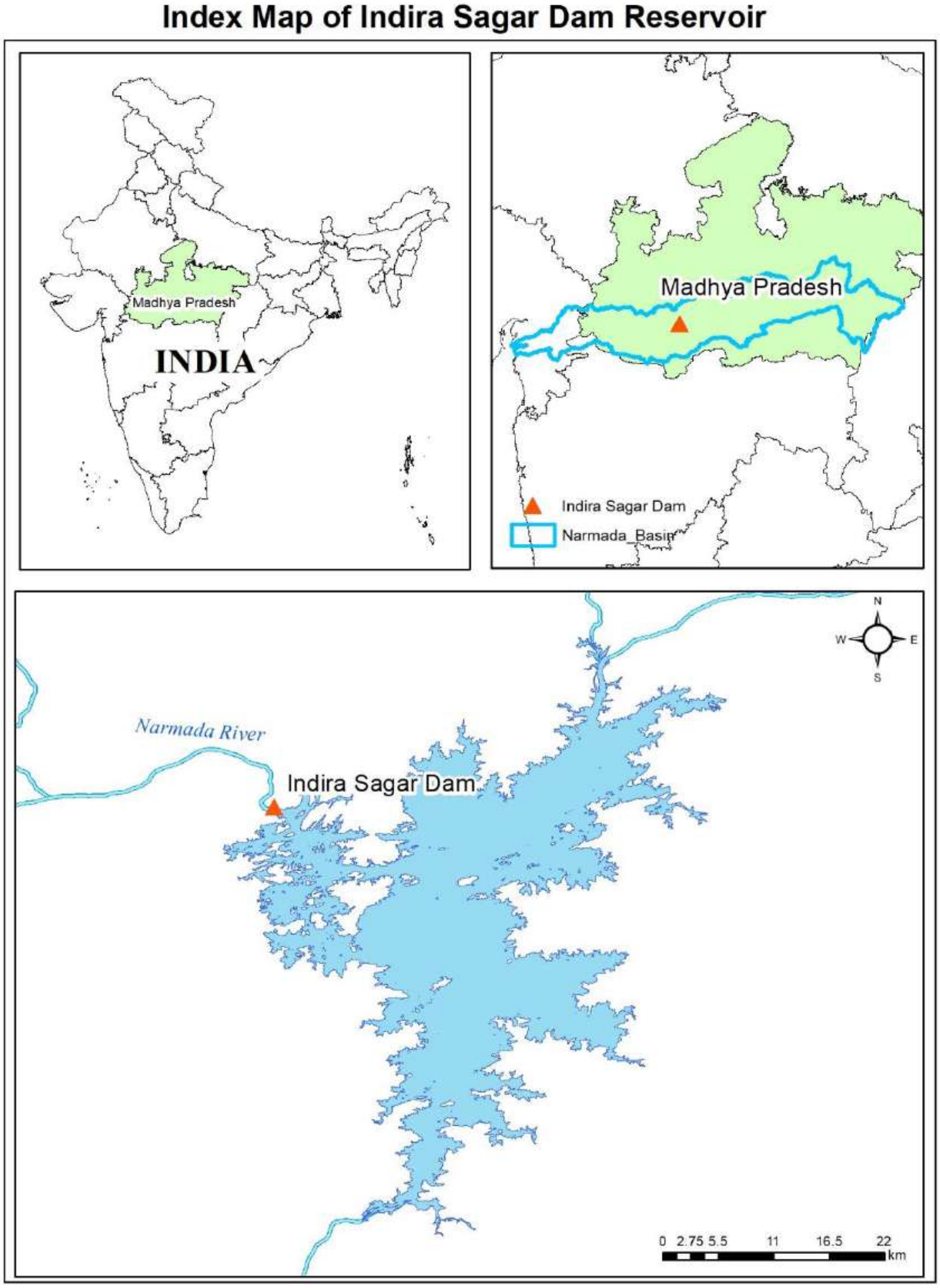



**Fig. 4: Index map of the Indira Sagar dam Reservoir**

# 8. DATA USED

## 8.1. Satellite Data

Microwave data from Sentinel-1A and EOS-4 (RISAT-1A) for ten (10) dates have been used in the analysis. Table – 1 depicts the date of pass of satellite along with elevation observed on that date. The reservoir has FRL (262.130 m) and MDDL (243.250 m).

**Table – 1: Date of pass for satellite data**

| Sl. No. | Satellite | Date of pass | Elevation (m) |
|---|---|---|---|
| 1. | Sentinel 1A | 22-09-2022 | 262.13 |
| 2. | Sentinel 1A | 27-12-2022 | 260.35 |
| 3. | EOS-4 (RISAT-1A) | 04-02-2023 | 258.14 |
| 4. | Sentinel 1A | 13-01-2022 | 256.50 |
| 5. | EOS-4 (RISAT-1A) | 10-03-2023 | 254.22 |
| 6. | Sentinel 1A | 26-03-2022 | 252.60 |
| 7. | Sentinel 1A | 10-08-2021 | 251.01 |
| 8. | Sentinel 1A | 06-06-2022 | 248.30 |
| 9. | Sentinel 1A | 23-06-2021 | 246.60 |
| 10. | Sentinel 1A | 17-07-2021 | 245.80 |

The predominant water year for which satellite images are considered is 2022-23. The above satellite images are taken at well distributed water levels within the live storage region. The live storage capacity covered between the maximum and minimum water levels for which satellite images have been taken is 88.18% (>80%).

## 8.2. Field Data

The following field data have been obtained from project authorities:

1. Elevation- Capacity data
2. Salient features of Linganamakki Dam 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 Indira Sagar Dam reservoir studies, multi-date Sentinel 1A and EOS-4 (RISAT-1A) (10 nos.of imageries) are used for the analysis. Image processing was done with SNAP software, QGIS and ArcGIS software. The analysis comprised,

- Geo-referenced Database.
- Water spread area estimation.
- Estimation of reservoir capacity.
- Comparison with original capacity.

## 9.1. Database

The satellite data of Sentinel – 1A corresponding to reservoir are obtained from Copernicus open access hub. Satellite data of EOS-4 (RISAT-1A) are obtained from Bhoonidhi Portal, ISRO's EO data hub.

## 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 techniques adopted for water-spread area estimation are as follows:

- SAR data Pre-processing using Sentinel Application Platform (SNAP) and QGIS
- Thresholding using ARC-GIS

### 9.2.1 SAR DATA pre-processing using SNAP and QGIS

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 corrections 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.

The SAR data of EOS-4 (RISAT-1A) are processed using a combination of SNAP and QGIS. SNAP is used for speckle filtering (Lee-Sigma single product speckle filter with a window size of 7 by 7). QGIS is used for Void filling and Radiometric Calibration.

### 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/ EOS-4 (RISAT-1A) 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**

| Sl. No. | Satellite | Date of pass | Elevation (m) | Area ($Mm^2$) |
|---|---|---|---|---|
| 1. | Sentinel 1A | 22-09-2022 | 262.13 | 844.966 |
| 2. | Sentinel 1A | 27-12-2022 | 260.35 | 768.810 |
| 3. | EOS-4 | 04-02-2023 | 258.14 | 691.502 |
| 4. | Sentinel 1A | 13-01-2022 | 256.50 | 617.877 |
| 5. | EOS-4 | 10-03-2023 | 254.22 | 563.388 |
| 6. | Sentinel 1A | 26-03-2022 | 252.60 | 480.266 |
| 7. | Sentinel 1A | 10-08-2021 | 251.01 | 431.537 |
| 8. | Sentinel 1A | 06-06-2022 | 248.30 | 357.646 |
| 9. | Sentinel 1A | 23-06-2021 | 246.60 | 315.820 |
| 10. | Sentinel 1A | 17-07-2021 | 245.80 | 292.712 |

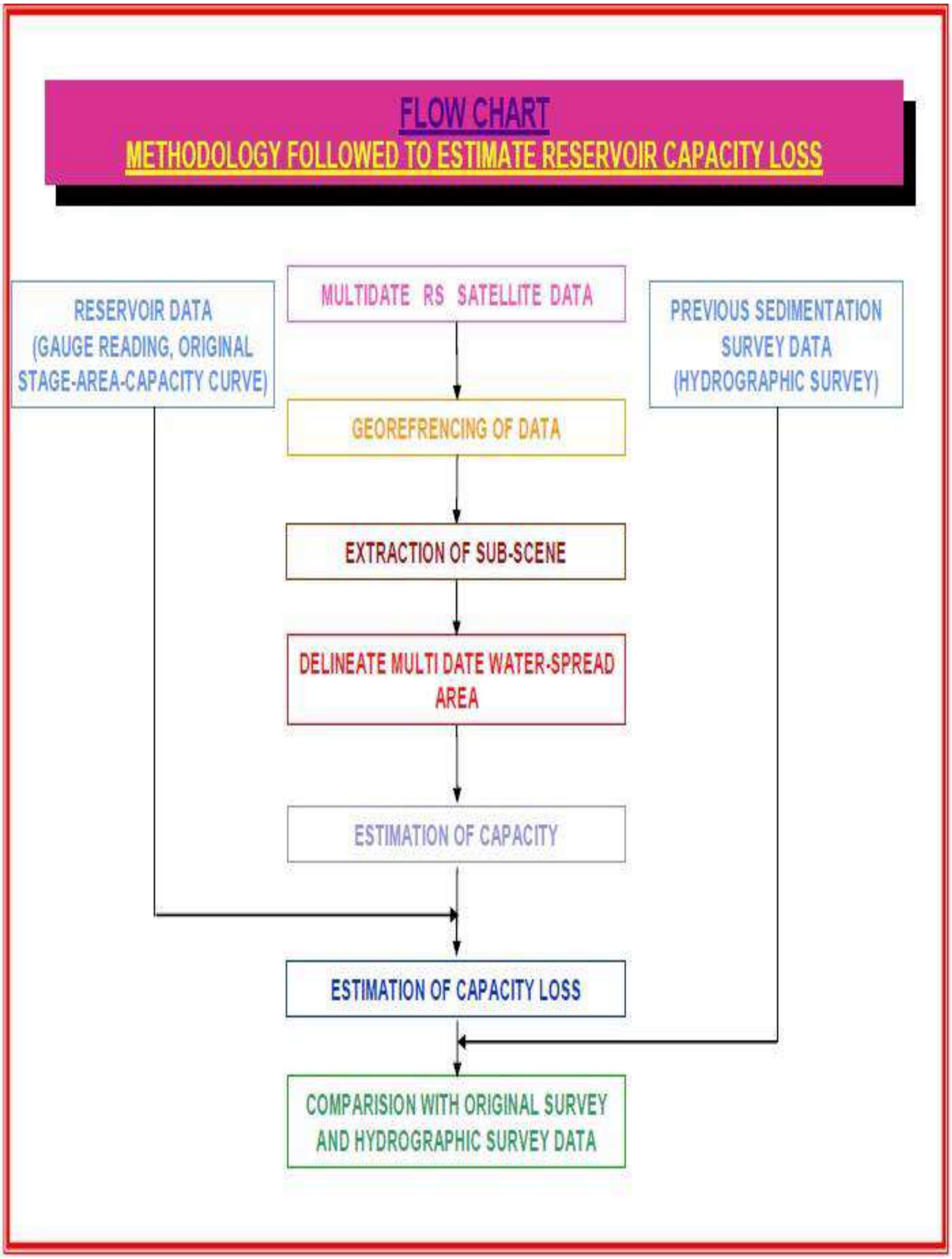



**Fig.5 : Flow chart showing methodology followed to estimate reservoir capacity loss**

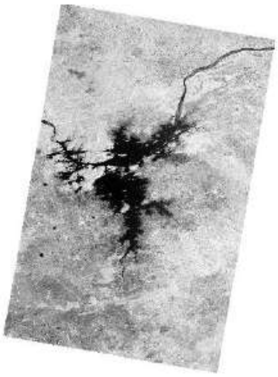
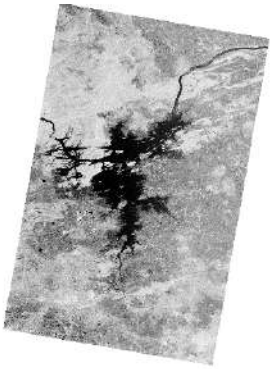
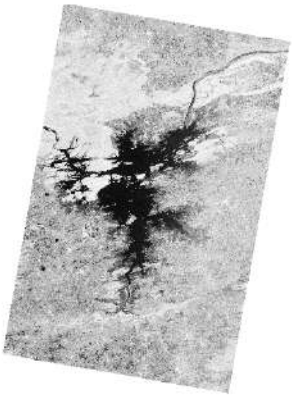
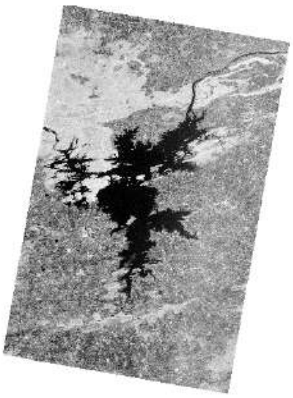
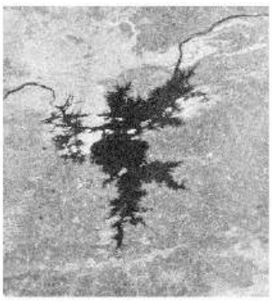
| | |
|---|---|
|  |  |
| **07-07-2021 (245.80 m)** | **23-06-2021 (246.60 m)** |
|  |  |
| **06-06-2022 (248.30 m)** | **10-08-2021 (251.01 m)** |
|  |  |
| **26-03-2022 (252.60 m)** | **10-03-2023 (254.22 m)** |

**Fig.6 : Sentinel 1/ EOS-4 SAR imageries showing water spreads at different dates**

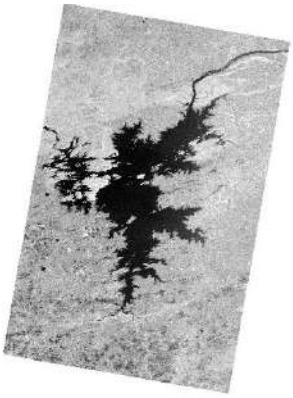
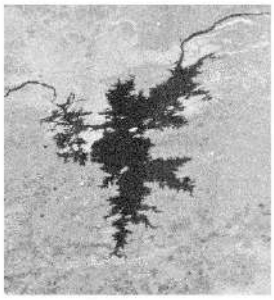
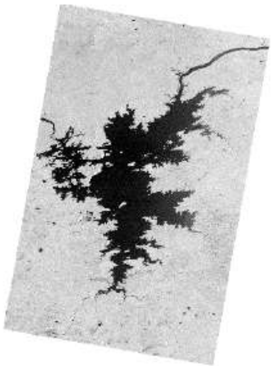
|  |  |
|---|---|
| **13-01-2022 (256.50 m)** | **04-02-2023 (258.14 m)** |
|  |  |
| **27-12-2022 (260.35 m)** | **22-09-2022 (262.13 m)** |

**Fig.6 : Sentinel 1/EOS-4 SAR imageries showing water spreads at different dates**

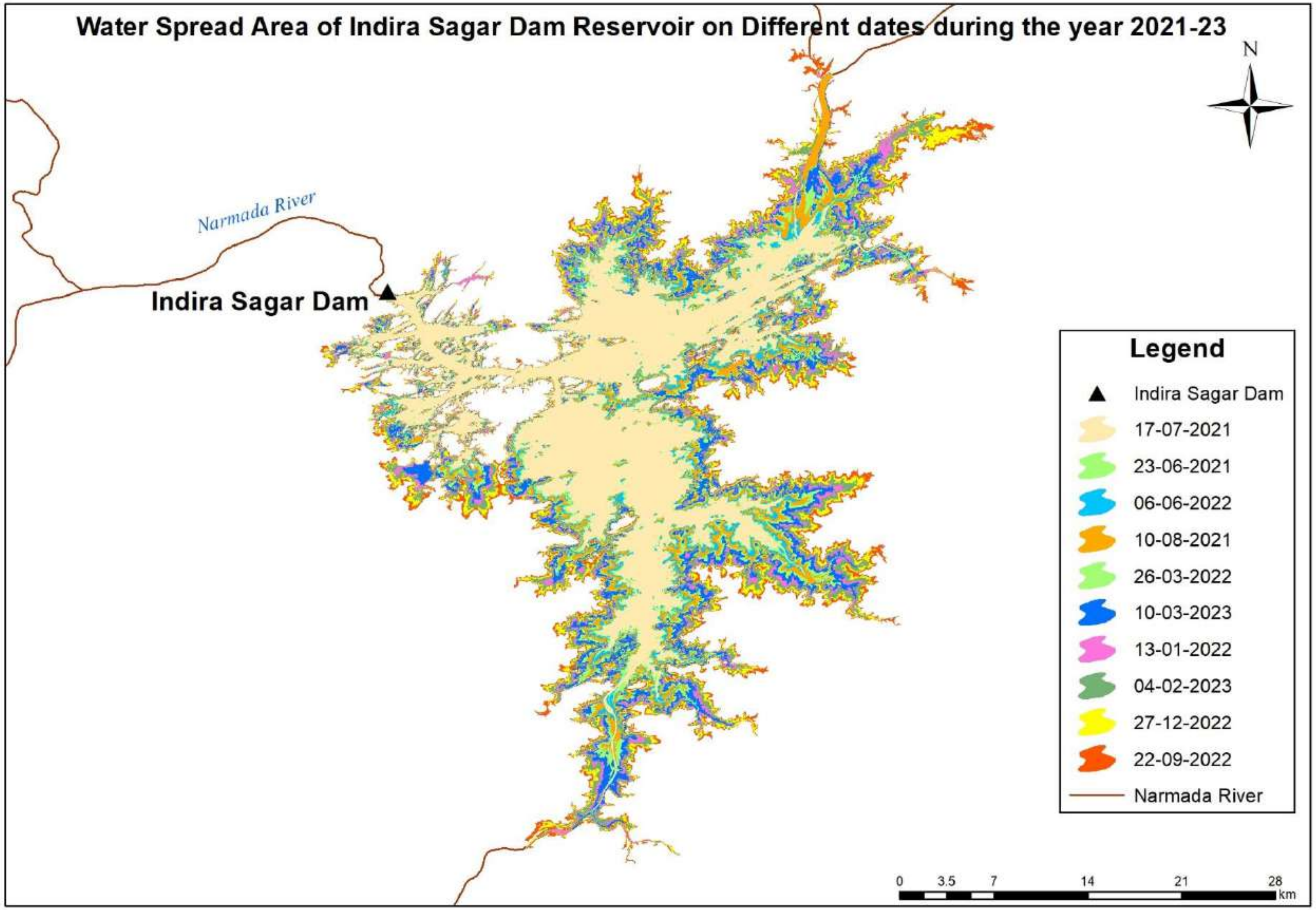



**Fig. 7: Water-spread Area of Indira Sagar Dam Reservoir on different dates**

The Satellite Images for the Indira Sagar Dam reservoir have been obtained from Copernicus Open Access Hub that provides complete, free and open access to all sentinel mission data and Bhoonidhi Portal of ISRO. The analysis has been carried out using **Sentinel Application Platform** (SNAP) and Digital Image Processing software like QGIS and ArcGIS. The digitally processed images of Indira Sagar Dam Reservoir showing its water spread area for Ten overpass dates are shown in Fig. 6.

The water elevation 262.13 m for 22-Sep-2022 is at the Full Reservoir Level (FRL). The Water elevation 245.80 m for 07-Jul-2021 is the minimum level at which data is available near the Minimum Drawdown Level (MDDL) of 243.250 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.

$$Y = 0.4989\, x^2 + 23.223 * x + 229.19$$

$$R^2 = 0.9981$$

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

$$V = \frac{h}{3}\{A1 + A2 + \sqrt{A1 * A2}\}$$

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.

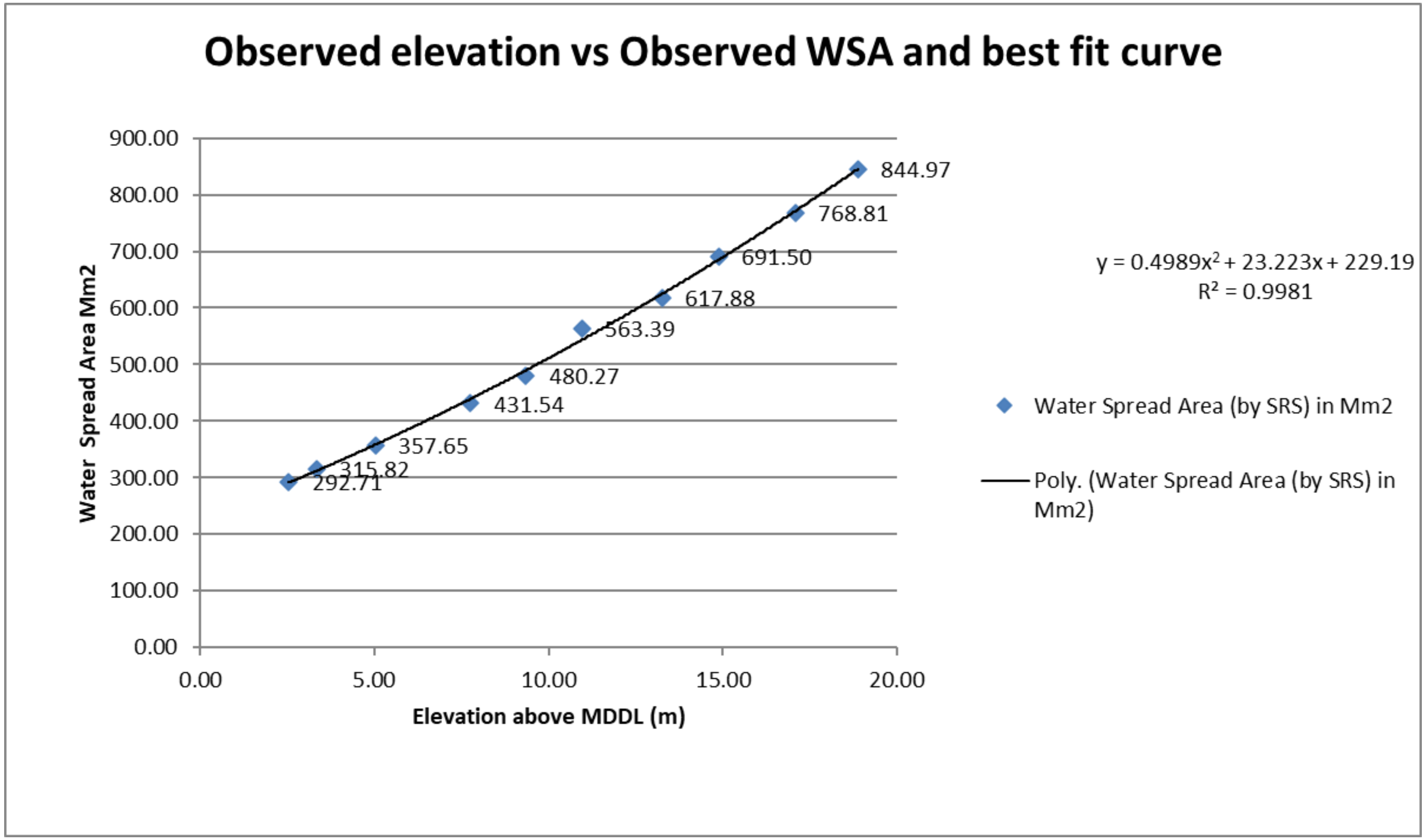



**Fig. 8: Observed elevation vs Observed WSA of Indira Sagar Dam Reservoir**

Table – 3 gives the values of Live storage capacity and submergence areas at a regular interval of 1 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 (1m) using SRS Survey 2021-23**

| | Reservoir water level in Metre | Water spread area by trend line (M $m^2$) | Segmental Live Capacity (MCM) by SRS technique | Cumulative Live Capacity (MCM) by SRS technique 2023 |
|---|---|---|---|---|
| **MDDL** | 243.25 | 229.188 | 0 | 0 |
| | 244.25 | 252.910 | 240.952 | 240.952 |
| | 245.25 | 277.630 | 265.174 | 506.126 |
| | 246.25 | 303.348 | 290.394 | 796.520 |
| | 247.25 | 330.063 | 316.612 | 1113.132 |
| | 248.25 | 357.777 | 343.827 | 1456.959 |
| | 249.25 | 386.488 | 372.040 | 1828.999 |
| | 250.25 | 416.196 | 401.250 | 2230.249 |
| | 251.25 | 446.903 | 431.459 | 2661.708 |
| | 252.25 | 478.607 | 462.665 | 3124.373 |
| | 253.25 | 511.309 | 494.868 | 3619.241 |
| | 254.25 | 545.009 | 528.070 | 4147.311 |
| | 255.25 | 579.707 | 562.269 | 4709.580 |
| | 256.25 | 615.402 | 597.466 | 5307.046 |
| | 257.25 | 652.096 | 633.661 | 5940.706 |
| | 258.25 | 689.787 | 670.853 | 6611.559 |
| | 259.25 | 728.475 | 709.043 | 7320.602 |
| | 260.25 | 768.162 | 748.231 | 8068.833 |

| | Reservoir water level in Metre | Water spread area by trend line (M $m^2$) | Segmental Live Capacity (MCM) by SRS technique | Cumulative Live Capacity (MCM) by SRS technique 2023 |
|---|---|---|---|---|
| | 261.25 | 808.846 | 788.417 | 8857.250 |
| **FRL** | 262.13 | 845.474 | 727.841 | 9585.091 |

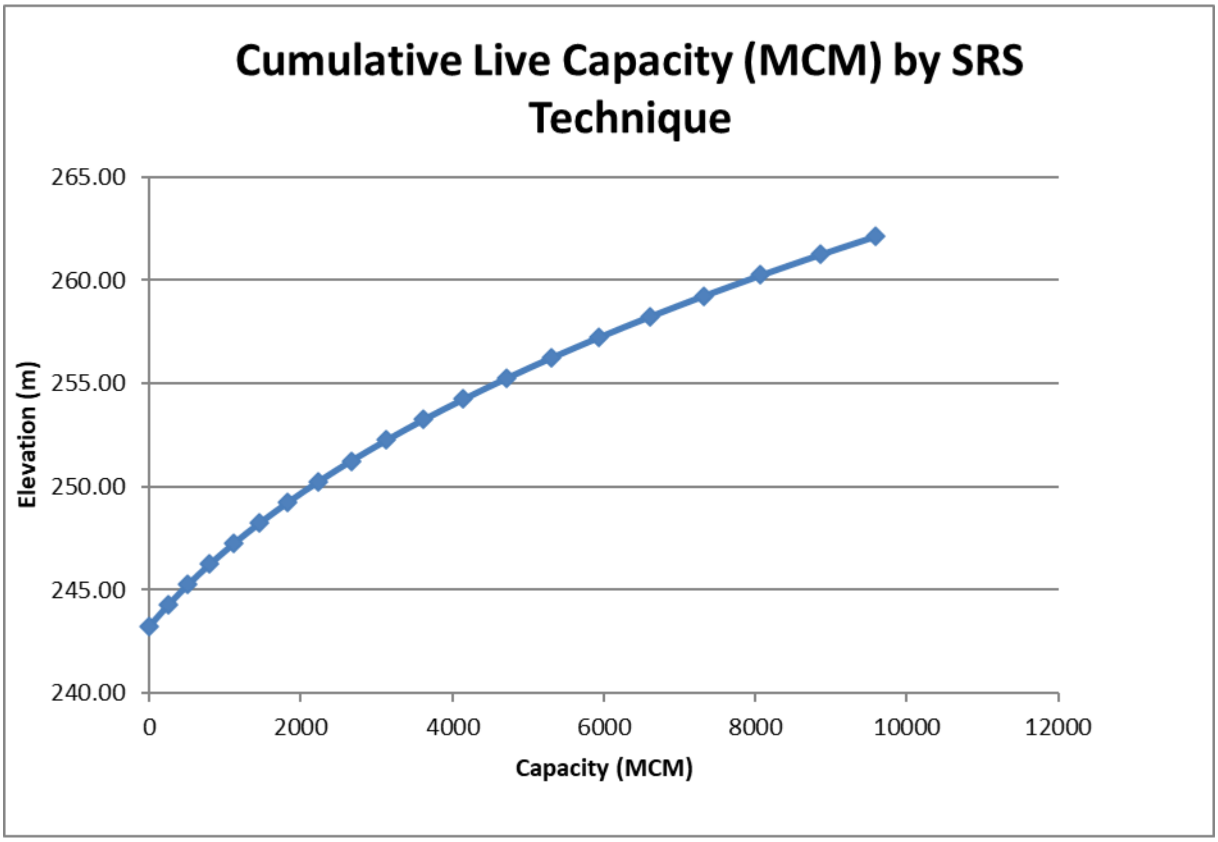



**Fig. 9: Modified live capacity - elevation curve (SRS technique)**

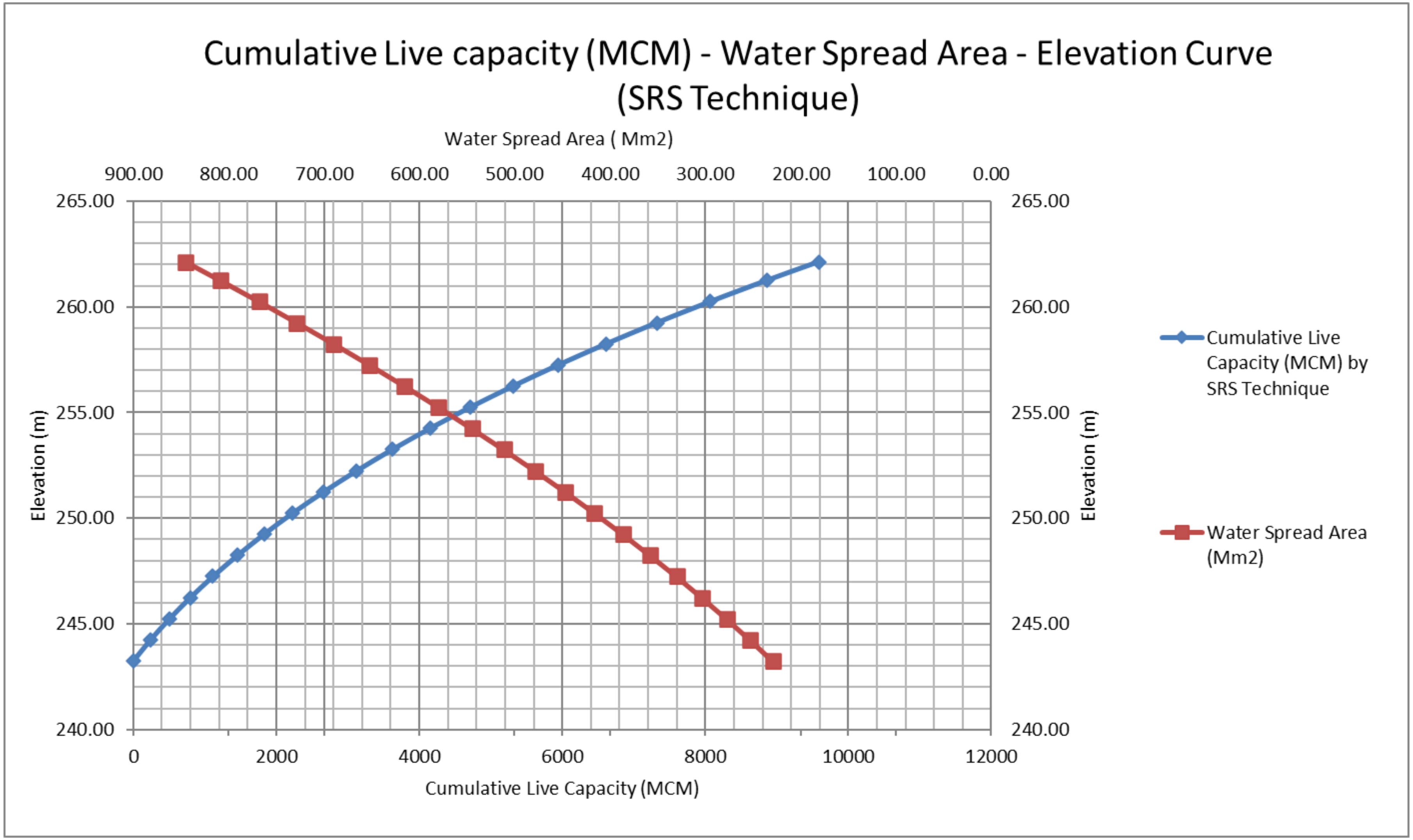



**Fig. 10: Elevation – Area –Capacity Curve**

## 10. RESULTS AND DISCUSSIONS

The loss in live storage capacity of the reservoir due to sedimentation since original survey (2005), is given in Table –4.

**Table – 4: Storage Capacity loss due to sedimentation as per previous surveys**

| | Original Survey-2005 | SRS – 2023 |
|---|---|---|
| **Live Capacity (MCM)** | 9745 | 9585.091 |
| **Loss in Capacity (MCM)** | - | 159.909 |
| **% Live capacity loss** | - | 1.64% |
| **Annual % live capacity loss** | - | 0.09% |

The live storage capacity of Indira Sagar Dam reservoir as per present study is found to be 9585.091 MCM for the year 2023. As per original survey conducted in 2005 the live storage capacity was 9745 MCM. Modified elevation-area-capacity table worked out by the present study is given at Table 3.

## 11. CONCLUSION

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

1. The live storage capacity of Indira Sagar Dam reservoir has been found to be 9585.091 MCM in 2023.
2. Live storage loss of 159.909 MCM (i.e. 1.64%) was observed since original survey (2005) i.e. in a period of 18 years. This accounts for live capacity loss of 0.09% per annum since 2005.
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

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.

Remote sensing techniques give accurate estimate for fan shaped reservoir where there is considerable change in water-spread area with change in water level.

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**

| | | | | |
|---|---|---|---|---|
| 1. | **Name of Reservoir** | | : | Indira Sagar Dam |
| 2. | **General Location** | | : | Khandwa, Madhya Pradesh |
| | | Latitude | : | 22° 17’ 00” – N |
| | | Longitude | : | 76° 28’ 00” – E |
| 3. | **Nearest City/town** | | : | Indore, Madhya Pradesh |
| 4. | **Village** | | : | Punasa |
| 5. | **River** | | : | Narmada River |
| 6. | **Year of Impoundment** | | : | 2005 |
| 7. | **Reservoir Levels** | | | |
| | i. | FRL | : | 262.13 m |
| | ii. | MDDL | : | 243.25 m |
| 8. | **Reservoir Capacity Data (Original)** | | | |
| | i. | Gross Storage at FRL | : | 12212 MCM |
| | ii. | Dead Storage | : | 2462 MCM |
| | iii. | Live Storage | : | 9750 MCM |
| 9. | **Details of Dam** | | | |
| | i. | Height of Dam above Bed level | : | 92 m |
| | ii. | Length of Dam | : | 653 m |
| | iii. | Type of Dam | : | Concrete Gravity Dam |
| | iv. | Type of Spillway | : | Ogee |
| 10. | **Project Benefits** | | : | Multipurpose (Irrigation, Hydroelectric and Flood Control) |

**Annexure-II**

**PHOTOGRAPHS OF RESERVOIR**

**Photo 1: Indira Sagar Dam reservoir**

**Photo 2: Indira Sagar Dam Spillway**

**Annexure – III**

## Average and Median values for Rate of Sedimentation of Reservoirs (Region wise)

As per CWC (2020), the whole country has been classified into 7 regions based on several factors which affect the rate of sedimentation such as hydrometeorology, physiography, climate etc. The region-wise Average and Median values for Rate of Sedimentation of Reservoirs aregiven in table below:

| Average and Median values for Rate of Sedimentation of Reservoirs (Region wise) | | | |
|---|---|---|---|
| S N | Region | Average Rate of Siltation | Median Rate of Siltation |
| | | Th.cu.m./ sq.km/year | Th.cu.m./ sq.km/year |
| 1 | Deccan Plateau eastflowing rivers includingGodavari and south Indianrivers | 2.27 | 0.44 |
| 2 | East flowing rivers uptoGodavari (Excluding Ganga) | 0.76 | 0.68 |
| 3 | Himalayan Region (Indus,Ganga and Brahmaputra basins) | 1.22 | 0.42 |
| 4 | Indo Gangetic Plains | 0.95 | 0.72 |
| 5 | Narmada &Tapi Basins | 2.84 | 0.65 |
| 6 | West flowing rivers beyondTapi and south Indian rivers | 3.07 | 2.07 |
| 7 | West flowing rivers uptoNarmada | 1.12 | 0.86 |

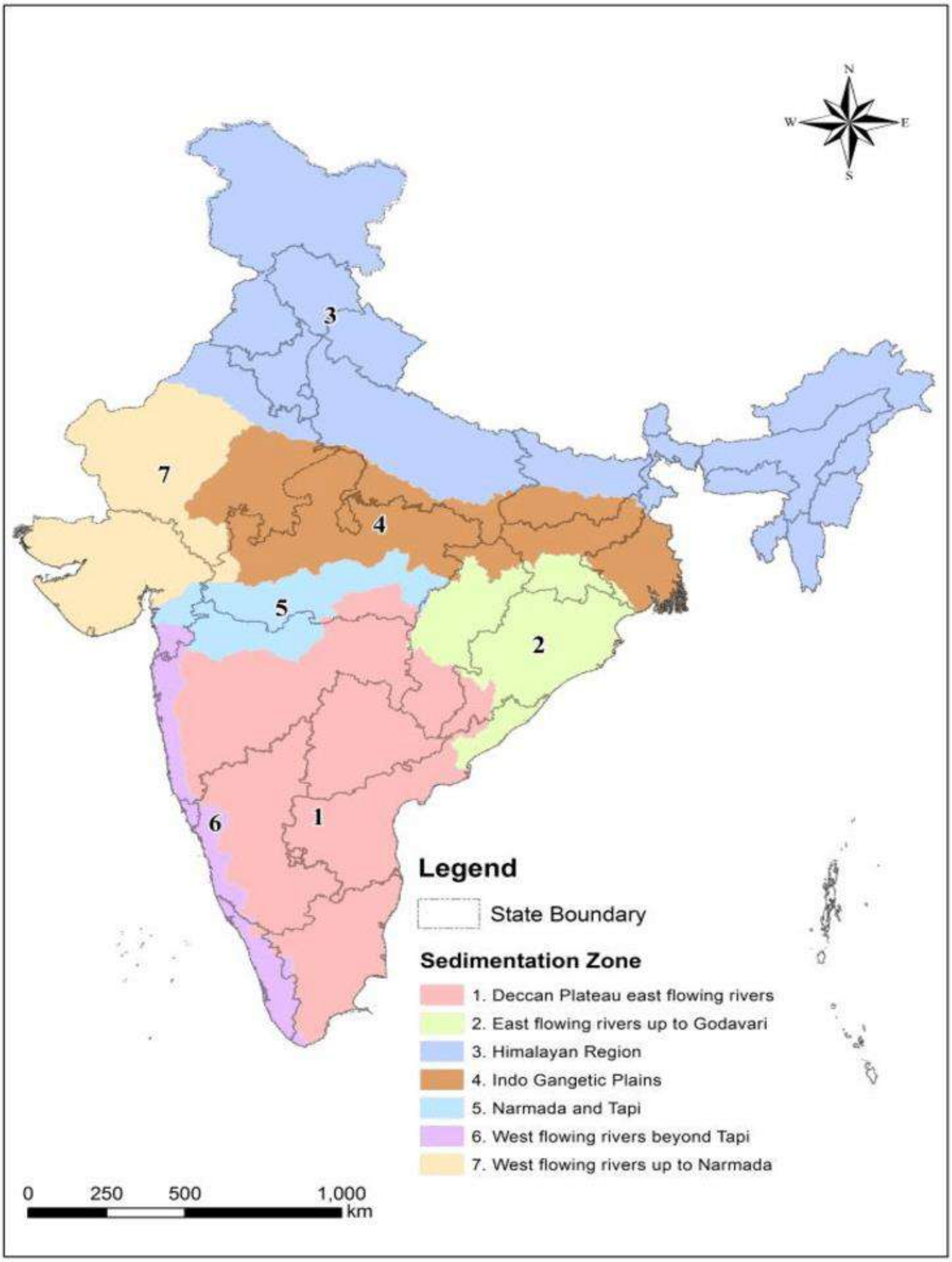



Figure:Sedimentation Zones of India as presented in the Compendium on Silting of Reservoirs in India (CWC, 2020)

# References


1. Muley M V. Application of Remote Sensing in the study of Reservoir Sedimentation, SAC, Ahmedabad, 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* (2020), WS&RS Dte, Environment Management Organization, WP&P Wing, CWC.
5. *National Register of Large Dams (2019)*, Dam Safety Monitoring Dte, DSO, CWC.
6. Sentinel-1 SAR Technical Guide, <https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-1-sar.>
7. EOS-4 (RISAT-1A) Handbook: https://bhoonidhi.nrsc.gov.in/bhoonidhi_resources/help/docs/EOS-04_Handbook.pdf