



उपग्रह दूरस्थ संवेदन द्वारा  
मनीमुथार जलाशय, तामिलनाडू का अवसादन आंकलन  
**Sedimentation Assessment of Manimuthar Reservoir,  
Tamil Nadu, through Satellite Remote Sensing**



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## **Sedimentation Assessment of Manimuthar Reservoir, Tamil Nadu, through Satellite Remote Sensing**

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## FOREWORD

Sedimentation is a byproduct of erosion in the catchment area of the reservoir and therefore, lesser the rate of erosion, smaller is the sediment load entering the reservoir. Type of soil, drainage density, vegetation, rainfall intensity and duration, shape of the catchment and land use/land cover affect the erosion. Deposition of silt takes place in various parts of reservoir which gradually reduces its capacity. Dead storage capacity as well as live storage capacity gets affected due to siltation. Information about reduction in the storage capacity is necessary for the planning and operational purposes. In some of the reservoirs, the rate of siltation has been higher than what was considered at the planning stage. Therefore, it has become necessary to conduct surveys in all the existing reservoirs for ascertaining siltation rate and consequently to assess their useful life. The data will also be useful for deriving siltation indices for different regions and river basins for use in the future design of the reservoirs. These surveys will enable selection of appropriate measures for controlling sedimentation along with efficient management and operation of reservoirs. The conventional techniques like boat mounted eco-sounder, HYDAC etc. are time consuming as well as costly. Remote sensing technique can be used to calculate the present live storage capacity of a reservoir due to its synoptic and repetitive coverage. These surveys based on remote sensing data are faster, economical and reliable.

Central Water Commission has been regularly involved in carrying out sedimentation assessment studies of various reservoirs through remote sensing techniques. As a part of 50 reservoirs study which were proposed to be taken up under the plan scheme “Research & Development Programme in Water Sector” during the period 2017-20 (i.e. beyond 12<sup>th</sup> Five Year Plan) / upto the end of 14<sup>th</sup> Finance Commission, the work “Sedimentation assessment study of Forty (40) reservoirs in India through Remote Sensing Technique” was awarded to MERI, Nashik. Rest will be carried out in-house. Out of these forty (40) reservoirs, the study of twenty three (23) reservoirs were found feasible and hence, completed. The balance were found non feasible due to non-availability of cloud free imageries or non-attainment of FRL/MDDL.

I would like to compliment Shri Rishi Srivastava, Director (Remote Sensing Dte), Shri Ashish Awasthi, Dy. Director (Remote Sensing Dte) and other officers and staff of Remote Sensing Directorate for their dedicated efforts in bringing out this report. I would also like to compliment Shri Makarand Kulkarni, Executive Engineer (REC, MERI) and his team for timely completion of the report.

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## **Acknowledgement**

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## Abbreviations

<b>AOI</b>	Area of Interest
<b>μm</b>	Micrometer
<b>CWC</b>	Central Water Commission
<b>DGPS</b>	Differential Global Positioning System
<b>ERS</b>	European Remote Sensing Satellite
<b>FCC</b>	False Color Composite
<b>FRL</b>	Full Reservoir Level
<b>IR</b>	Infra Red
<b>IRS</b>	Indian Remote Sensing Satellite
<b>LISS</b>	Linear Imaging Self Scanning Sensor
<b>MDDL</b>	Minimum Draw Down Level
<b>MERI</b>	Maharashtra Engineering Research Institute
<b>MOU</b>	Memorandum of Understanding
<b>MWL</b>	Maximum Water Level
<b>NDVI</b>	Normalized Difference Vegetation Index
<b>NDWI</b>	Normalized Difference Water Index
<b>NIR</b>	Near Infra Red
<b>NRSC</b>	National Remote Sensing Centre
<b>R</b>	Red band
<b>SAT</b>	Shift Along Track
<b>SQRT</b>	Square Root
<b>SRS</b>	Satellite Remote Sensing
<b>WSA</b>	Water Spread Area

## Units Used

<b>ha</b>	Hectare
<b>km</b>	Kilometer
<b>m</b>	Meter
<b>Mm<sup>2</sup></b>	Million square meter
<b>Mm<sup>3</sup></b>	Million cubic meter
<b>sq km</b>	Square kilometer
<b>sq mi</b>	Square mile

## **EXECUTIVE SUMMARY**

*Water resources sector has got high priority in all our developmental plans and accordingly large number of dams have been constructed to supply water for domestic, irrigation and industrial purposes. Natural processes like erosion in the catchment area and its deposition in various parts of the reservoir gradually, reduce the capacity of the reservoir. Dead as well as live storage get affected by it. The information about the reduction in capacity is necessary for all planning and operational purposes, which can be obtained through capacity surveys done at regular interval. The Remote Sensing technique can be used to calculate present capacity of the reservoir. It is very useful due to its simple analysis procedure and repetitive coverage by imagery. The surveys based on remote sensing data are faster, economical and more reliable. Department of Water Resources, River development and Ganga Rejuvenation, Ministry of Jalshakti, Government of India has initiated the programme to evaluate capacity of various reservoirs in the country. Accordingly the Central Water Commission has entrusted MERI, Nashik the work of “Sedimentation Assessment Study of Forty (40) Reservoirs in India through Remote Sensing Technique”. The present study is in regard to Manimuthar reservoir, Tamil Nadu, India.*

*Present study aims in updating the elevation-area-capacity curve of Manimuthar reservoir, Tamil Nadu, and finding the capacity loss due to sedimentation in live storage. For carrying out the analysis, IRS P6, Resourcesat 2 and Resourcesat 2A LISS III data with 23.5 m resolution have been used. Satellite data for eight passes falling between MDDL (73.150 m) and FRL (109.120 m) are used for the analysis.*

*The Manimuthar dam is located on the Manimuthar River. The dam site is located near Singampatti village in Ambasamudram taluka, Tirunelveli district. The project has a designed gross capacity of 156.053 Mm<sup>3</sup>, with live capacity of 155.821 Mm<sup>3</sup>.*

*This study reveals that the present live capacity of reservoir is 157.701 Mm<sup>3</sup>. It shows no loss in live capacity in a period of 60 (1958-2018) years.*



# SEDIMENTATION ASSESSMENT OF MANIMUTHAR RESERVOIR, TAMIL NADU, 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 resources that are 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 Manimuthar reservoir, Tamil Nadu 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.

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 (Figure 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.

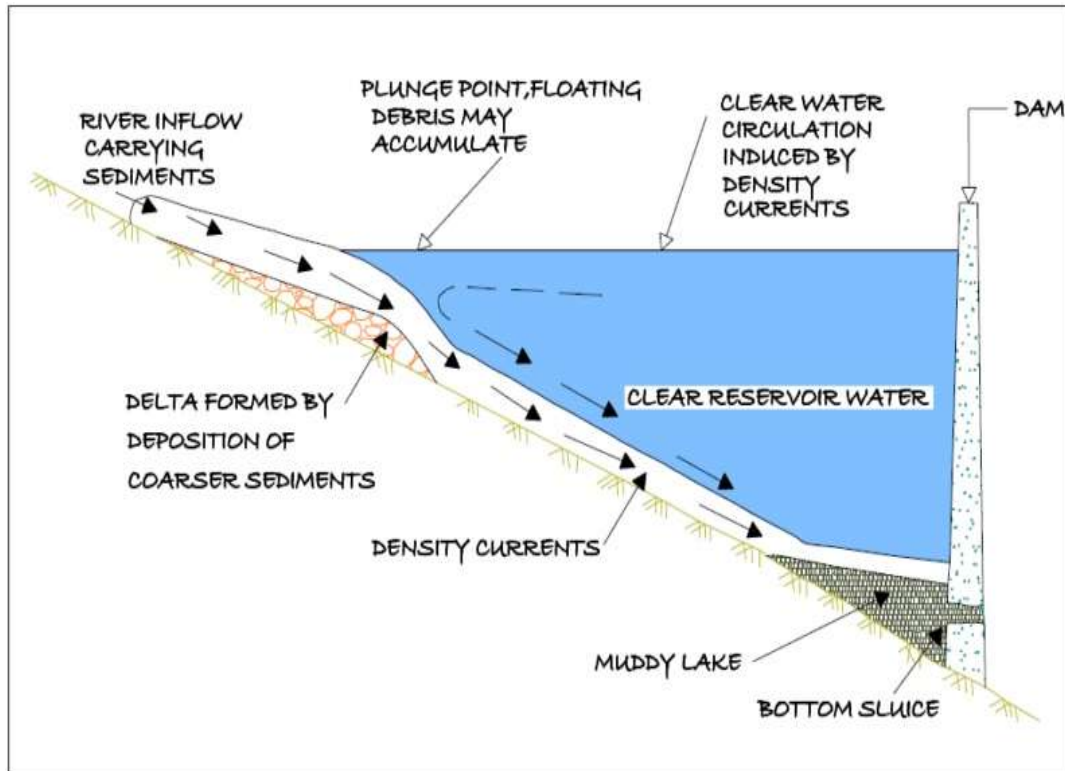


Figure 1: Conceptual sketch of density currents in a reservoir

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 figure 2.

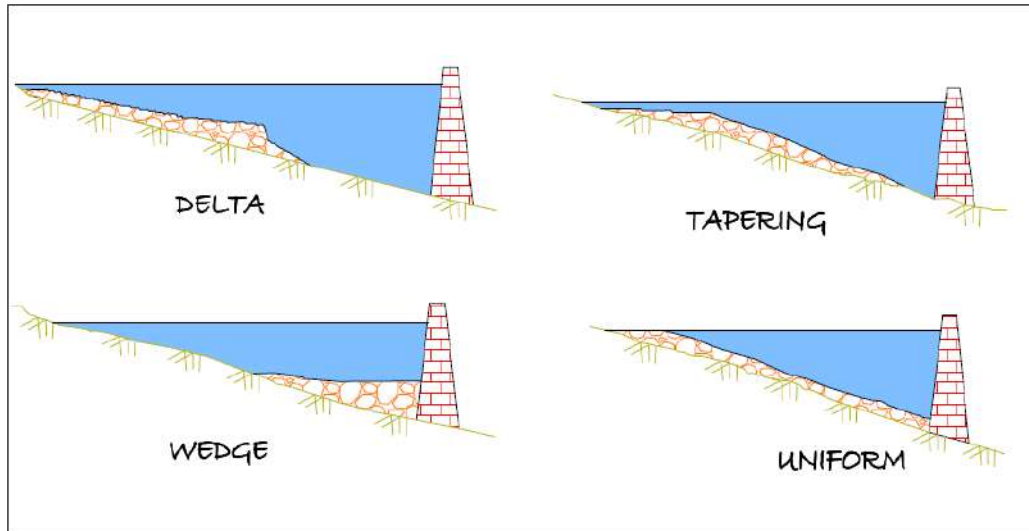


Figure 2: Longitudinal patterns of sediment deposition in reservoirs

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 fluctuation 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 Figure 3. The storage below MDDL is the dead storage. Water stored along the valley bed is known as valley storage.

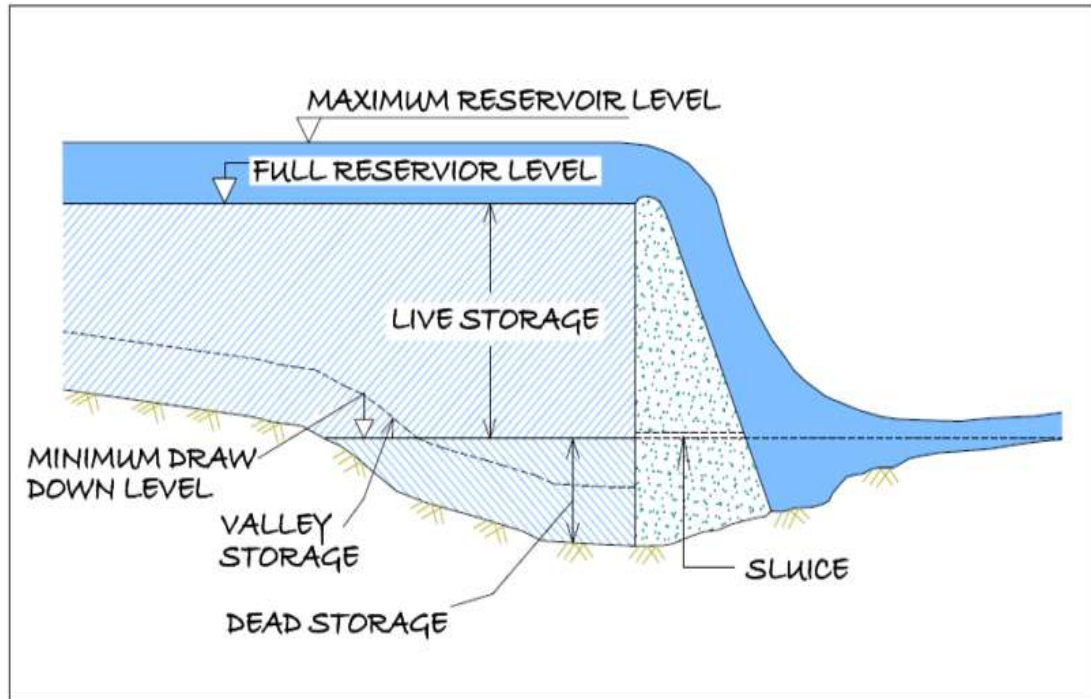


Figure 3 : Conceptual sketch of different levels in a reservoir

### 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 sensors onboard satellite and then are transmitted back to earth. Discrimination between features depends on the fact that the 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.

Data acquisition is done from various polar orbiting satellites (orbiting around 800 to 900 km altitude), namely Indian Remote Sensing (IRS) satellite, European Remote Sensing (ERS) satellite, Landsat and SPOT satellites. Data from these satellites are being received and archived by National Remote Sensing Centre (NRSC) at Hyderabad.

Present study utilizes data from Resourcesat 2 and Resourcesat 2A satellite. They have LISS III sensor, which operates in four spectral bands. Three bands are in the visible and near infra red region with spectral band widths as 0.52-0.59  $\mu\text{m}$ , 0.62-0.68  $\mu\text{m}$  and 0.77-0.86  $\mu\text{m}$  and spatial resolution as 23.5 m. Fourth band with spectral bandwidth of 1.55-1.75  $\mu\text{m}$  falls in short wave infra red region.

Reservoir sedimentation surveys are essentially based on mapping of water-spread areas at the time of satellite over pass. It uses the fact that water-spread area of the reservoir reduces with the sedimentation at different levels. The water-spread area and the elevation information are 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 change in capacity between different levels.

## 5. Objectives

The objective of the study is to estimate capacity loss of Manimuthar reservoir due to sedimentation through satellite remote sensing. Following objectives will be achieved in the study.

- (i) Updating of Elevation-Area-Capacity curve using satellite data in live storage zone of Manimuthar reservoir.
- (ii) Estimation of live storage loss due to sedimentation in Manimuthar reservoir.

## 6. Study Area

The Manimuthar dam is located near Singampatti village in Ambasamudram taluka, Tirunelveli district, on the Manimuthar river. The dam site is located at  $08^{\circ} 39' 30''$  N latitude and  $77^{\circ} 26' 00''$  E longitude. The location of the dam is shown in Figure 4 as Index Map.

The Manimuthar dam serves purpose of irrigation. The catchment area at the dam site is 161.82 sq km. The dam was completed in the year 1958. The FRL and MWL of the reservoir are at a level of 109.120 m. The dead storage and live storage capacity of Manimuthar dam are  $0.232 \text{ Mm}^3$  and  $155.821 \text{ Mm}^3$  respectively. The sill level of River sluice is at 73.150 m.

The chief source of irrigation in Tirunelveli and Thoothukudi district is the Thambraparani river and its tributaries. The Manimuthar River is one of the major tributary of Thambraparani. The Manimuthar River originates from the eastern slopes of western ghats, receives enormous supply from keela Manimuthar and other tributaries.

The Manimuthar reservoir was constructed and completed during 1951-1958 with an impounding capacity of  $156.053 \text{ Mm}^3$ . The construction of this reservoir is enable to impound the flood flows and utilized the water in later to help to supplement the crops under the anicuts, of Thambraparani river viz., Kannadian, Ariyanakipuram, Palavoor, Suthamalli, Marudhur and Srivaikundam all below the Confluence of Manimuthar and Thambraparani.

This reservoir not only fulfills the irrigation needs but also serves as tourist spot. A waterfall and Swimming pool is also located in the nearby area. In the reservoir, fishing is being carried out by the Fisheries department. The National fish farm is also



developed by the same department and there by earns revenue to the government. Over the years after the constructions, the dam has surplus 17 times up to the year. During the cyclone in November 13 of 1992, the peak flood discharge was 1.12 Lakhs cusecs for a brief period of 15 minutes between 8.15 pm to 8.30 pm. Salient features of Manimuthar project are given in Annexure (I).

## 7. Previous Surveys

Summery of previous surveys is as shown in Table 1. It is to mention that, the field authority is using the design storages for water planning purpose in current situation. Hence they have provided the data of design storages only. Therefore comparison of current study is done with design data only.

Table 1 : Summary of previous surveys

Details of survey	Live capacity (Mm <sup>3</sup> )	Cumulative loss	Cumulative % loss to design capacity
Design survey 1958	155.821	-	-
Survey 1980	155.410	0.411	0.263
Survey 1988	154.220	1.601	1.027
Survey 2006	149.448	6.373	4.089

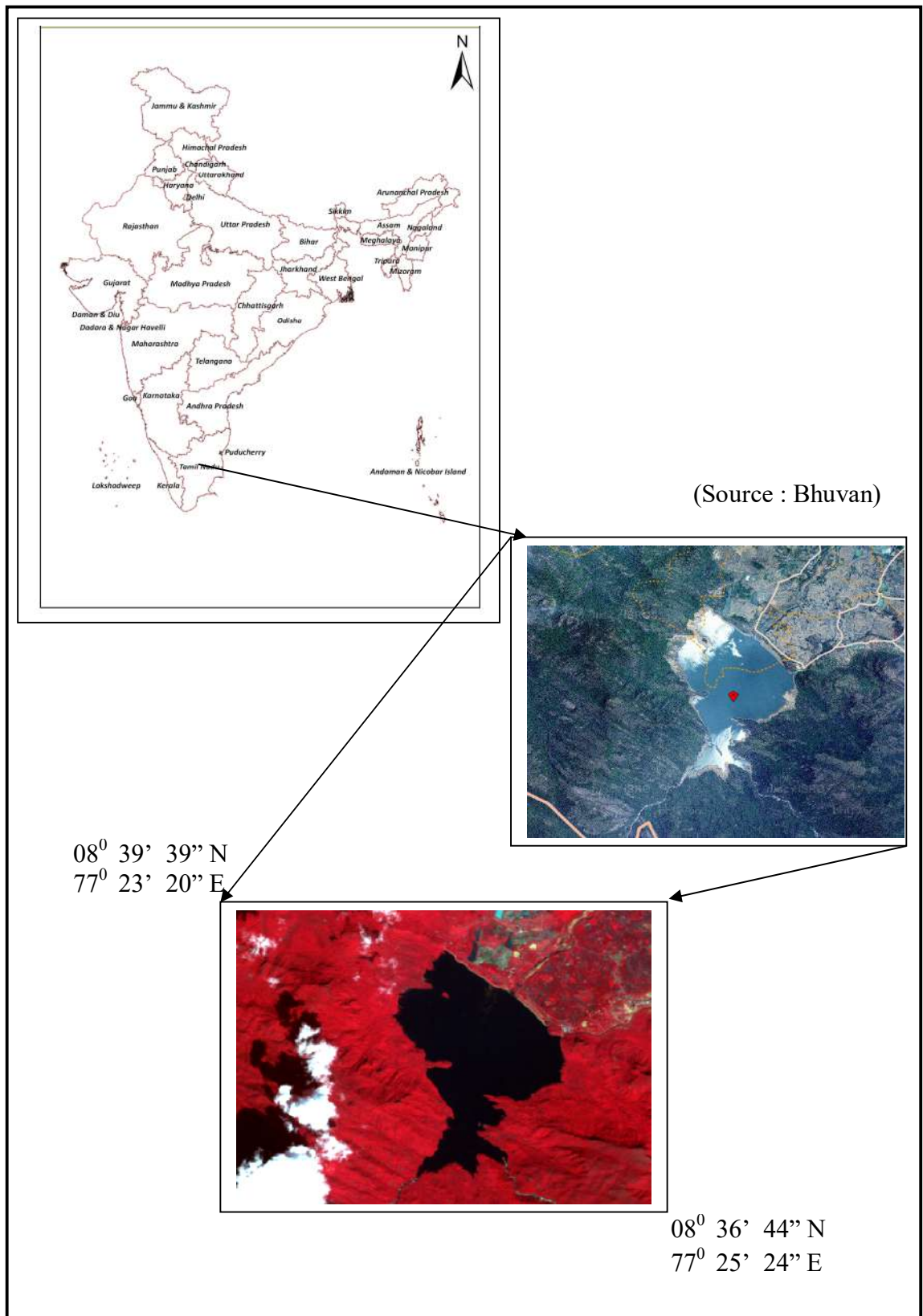


Figure 4 : Index map of Manimuthar reservoir, Tamil Nadu

## 8. Approach of Present Study

Remote sensing technique is utilized to assess the sedimentation between operating levels of reservoir. This operating range between MDDL (73.150 m) and FRL (109.120 m) varies each year and depends upon yield in the reservoir and utilization of water. During 2016 to 2019 the minimum and maximum levels in this reservoir fluctuated in various ranges. They are shown in Table 2. The cloud free levels in this range are selected for analysis.

Table 2 : Status of cloud free levels achieved during 2016 to 2019

Sr. No.	Water year	Minimum level (m) (above +73.15 m)	Maximum level (m) (above +73.15 m)	Difference of minimum and maximum levels (m)
1	2016-2017	11.04	20.00	8.96
2	2017-2018	24.12	34.69	3.0
3	2018-2019	29.59	-	-

The information reveals that in the water year 2017-2018, reservoir was filled up to 34.69 m (above +73.15 m) (FRL= 109.120 m) while it got depleted up to RL 11.04 m in 2016-2017. For present study, three images from water year 2016-2017 and four images from water year 2017-2018 and one image from water year 2018-2019 have been used. The year of survey of present study is treated as year 2017-2018.

## 9. Data

### 9.1 Field data

Following data set was obtained from office of Executive Engineer, Thambrabarani Basin Division, Tirunelveli for Manimuthar reservoir and used in the analysis.

- Index map of reservoir
- Latitude and longitude of the reservoir
- Original area capacity table at 1m interval.
- Salient features of the project
- Reservoir levels for given dates of satellite pass.

## 9.2 Satellite data

IRS P6, Resourcesat 2 and 2A LISS III images of 23.5 m resolution having Path 101, Row 68 have been used in present analysis. The FCC of the images are as given in Figure 5. The dates of satellite pass of selected images and corresponding reservoir levels are given in Table 3.

Table 3 : Details of satellite data

<b>Sr. No.</b>	<b>Date of pass</b>	<b>Elevation (m) (above +73.15 m)</b>
1	17 - Dec - 2016	11.040
2	06 - Oct - 2016	15.170
3	19 - Aug - 2016	20.000
4	23- Apr - 2018	24.120
5	22 - Feb - 2018	27.780
6	24 - Jan - 2019	29.590
7	29 - Jan - 2018	31.310
8	24 - Dec - 2017	34.690

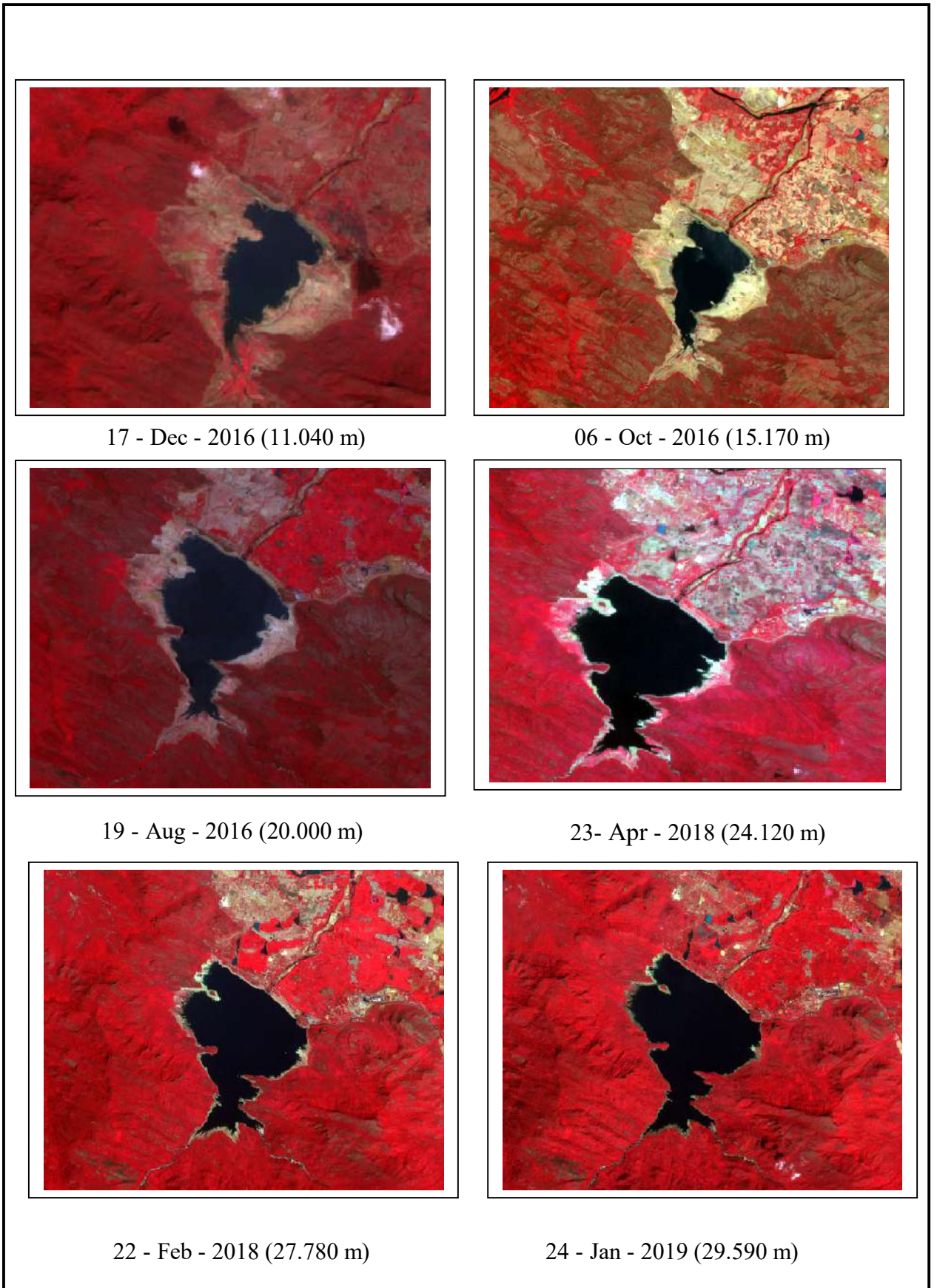


Figure 5 : FCC's Manimuthar reservoir, Tamil Nadu

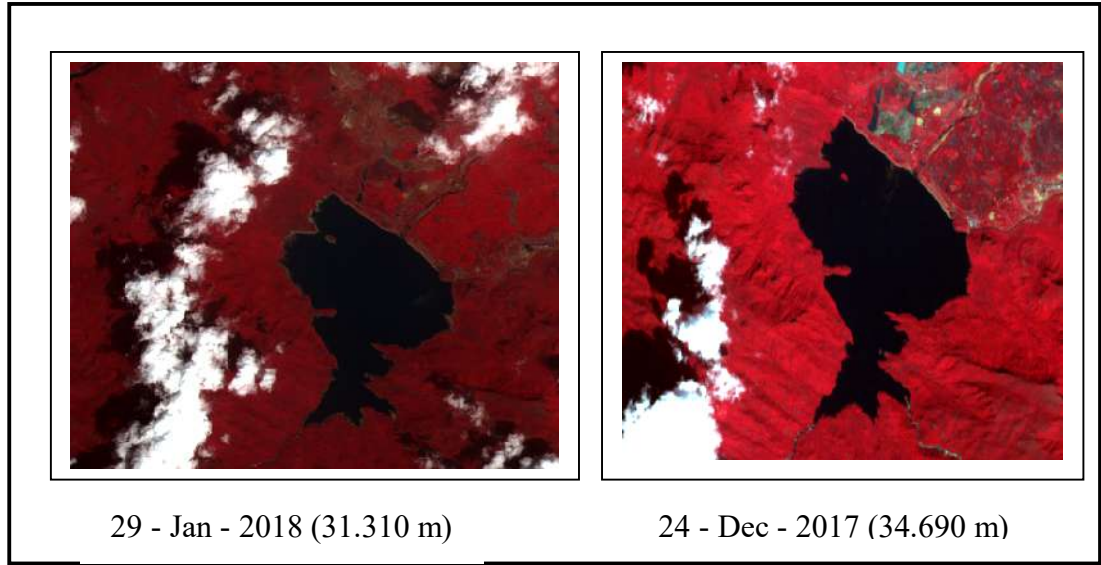


Figure 5 : FCC's Manimuthar reservoir, Tamil Nadu

### 9.3 Criteria for satellite dates selection

The selection of the satellite data for the present study is based on the following guidelines given in the MOU signed between CWC, New Delhi and MERI, Nashik.

- (i) To carry out the feasibility assessment of the given reservoir regarding availability of cloud free satellite data of dates of satellite pass corresponding to reservoir levels near MDDL as well as near FRL and at uniform interval to the extent possible in between MDDL and FRL for the latest water year or maximum up to two previous water years.
- (ii) To carry out sedimentation analysis through SRS technique to cover the entire live storage zone of the reservoir.
- (iii) In case of inability to cover the entire live storage zone of the reservoir due to non-availability of cloud free satellite data at FRL and MDDL, the study may be taken up if minimum of 80 % of live storage capacity is covered by the available cloud free dates of satellite pass on maximum and minimum reservoir levels.

NRSC website has been browsed to prepare a list of dates of satellite pass over the Manimuthar reservoir for the year 2016 to 2019. The reservoir levels on these dates along with corresponding water spread areas and capacities have been obtained from field officers.

The reservoir has been depleted up to 84.19 m as against MDDL (73.150 m). The maximum level covered in the present study is 107.84 m against to FRL (109.120 m). Variation in the study level is  $(107.840 - 84.190) = 23.65$  m. The difference between FRL and MDDL is  $(109.120 - 73.150) = 35.970$  m.

In the present study, storage of  $136.520 \text{ Mm}^3$  has been covered as against total live capacity of  $155.821 \text{ Mm}^3$ . Thus the percentage live storage covered by this study is 87.61 %. (Annexure II)

Statement giving cloud free dates of satellite pass, reservoir levels, areas and capacities for the Manimuthar reservoir has been prepared and submitted to CWC. The CWC has finalized the dates and placed order of images with NRSC, Hyderabad. The data has been received directly to MERI from NRSC, Hyderabad.

## **10. Software Used**

The analysis is done using the software ERDAS IMAGINE Ver. 2010. This software provides facility for satellite image analysis, by different methods.

## **11. Methodology**

The basic approach is to find out the water-spread areas from satellite data for different water levels between MDDL to FRL. The difference between areal spread of water between current year and earlier years is the areal extent of silting at these levels. The methodology for estimation of live capacity of reservoir using remote sensing consists of following major tasks

- (i) Digital data base creation
- (ii) Estimation of water-spread area
- (iii) Calculation of reservoir capacity
- (iv) Comparison of result with previous surveys
- (v) Estimation of live capacity loss due to sedimentation



## 11.1 Procedural flow chart

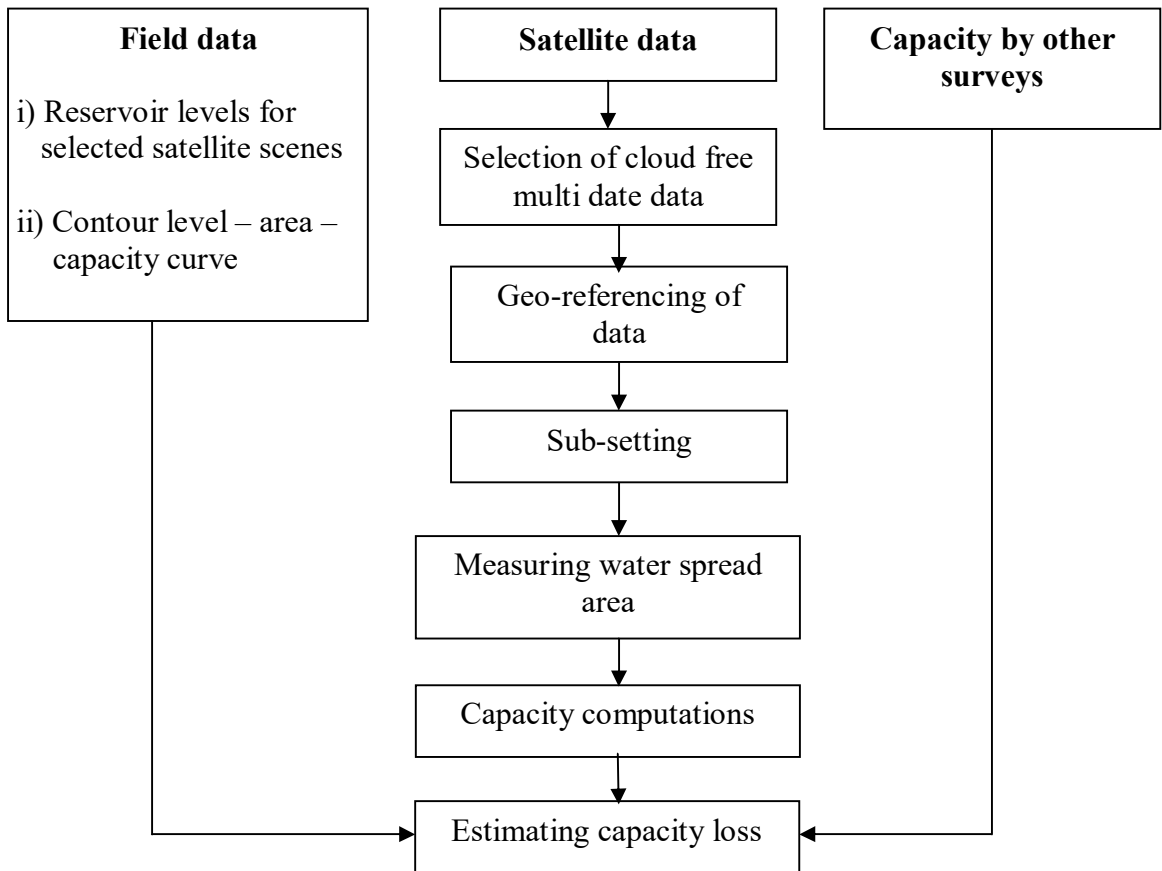


Figure 6 : Flow chart showing methodology for reservoir capacity estimation

## 11.2 Data loading

All the scenes are loaded in the system. These are listed as different files. They are renamed corresponding to falling levels. It helps in identifying the images during analysis. These files are in .img formats.

## 11.3 Image geo-referencing

Geo-referenced ready satellite images have been used in the analysis. However, when all the images are superimposed and swiped, slight displacements of images are noticed. Treating the image of the highest water level as the base image all the remaining images are again geo-referenced using image to image option of the ERDAS IMAGINE software.



## 11.4 Area extraction

A subset of the rectified scene is defined so as to facilitate and use in subsequent analysis. Rectified scene is loaded on the system. A small area around reservoir is extracted from one scene in interactive way. Once the area of interest (AOI) is finalized other scenes are extracted using the same AOI.

## 11.5 Water spread area extraction

There are various methods for the extraction of water area information from remote sensing imagery, which, according to the number of bands used, are generally divided into two categories, i.e. single-band and multi-band methods.

The multi-band method takes advantage of reflective differences of each involved band. There are two ways to extract water information using the multi-band method. One is through analyzing signature features of each ground target among different spectral bands, finding out the signature differences between water and other targets based on the analysis, and then using an if-then-else logic tree to delineate land from open water.

The other one is a band-ratio approach using two multispectral bands. One is taken from visible wavelengths and is divided by the other usually from near infrared (NIR) wavelengths. As a result, vegetation and land presences are suppressed while water features are enhanced. However, the method can suppress non-water features but do not remove them, and therefore the Normalized Difference Water Index (NDWI) was proposed by Mc Feeters (1996) to achieve this goal.

The NDWI is expressed as follows ( Mc Feeters 1996 ):

$$NDWI = \frac{Green - NIR}{Green + NIR}$$

Where Green is a green band such as TM band 1, and NIR is a near infrared band such as TM band 3.

This index is designed to

- (1) Maximize reflectance of water by using green wavelengths;
- (2) Minimize the low reflectance of NIR by water features; and
- (3) Take advantage of the high reflectance of NIR by vegetation and soil features.

As a result, vegetation and land presences are suppressed while water features are enhanced.

Table 4 : Range of NDWI values for Manimuthar reservoir

Date of pass	Minimum value	Maximum value
17 - Dec - 2016	0.4267	0.6297
06 - Oct - 2016	0.5019	0.6904
19 - Aug - 2016	0.3611	0.5373
23- Apr - 2018	0.0570	0.1209
22 - Feb - 2018	0.1446	0.5457
24 - Jan - 2019	0.1054	0.5815
29 - Jan - 2018	0.0002	0.4489
24 - Dec - 2017	0.0243	0.3166

Using the above range of values, water spread areas are extracted for all the scenes. The Water Spread Areas (WSA) derived for all the scenes and their corresponding water levels are shown in Table 5.

Table 5 : Water spread areas extracted from satellite data

Date of pass	Elevation ( m ) (above +73.15 m)	Area (Mm <sup>2</sup> )
17 - Dec - 2016	11.040	2.313
06 - Oct - 2016	15.170	3.228
19 - Aug - 2016	20.000	5.182
23- Apr - 2018	24.120	6.259
22 - Feb - 2018	27.780	7.395
24 - Jan - 2019	29.590	7.918
29 - Jan - 2018	31.310	8.547
24 - Dec - 2017	34.690	8.789

The water spread areas on selected dates of satellite pass are shown in Figure 7. The tail of the reservoir is defined by removing the river portion from extracted WSA, carefully.

## 11.6 Water spread area at regular interval

Water levels on the dates of pass for selected satellite data are not available at regular interval. However to get WSA values at regular interval of elevation, area-elevation double fitting curve is plotted for the reservoir and a second order polynomial has been fitted. The areas at an elevation interval of 1.0 m are computed from this best fit equation. These values are given in Table 6.

## 11.7 Calculation of reservoir capacity

Computation of reservoir capacities at different elevations have been derived using following formula

$$V = H / 3 * (A_1 + A_2 + \text{SQRT} (A_1 * A_2)).$$

Where V is reservoir capacity between two successive elevation of  $h_1$  and  $h_2$

H is the elevation difference,  $H = (h_1 - h_2)$

$A_1$  and  $A_2$  are areas of reservoir water spread at elevation  $h_1$  and  $h_2$  respectively.

The cumulative live capacities derived at different elevation have been shown in Table 6.

Table 6 : Areal extent and cumulative live storage capacity of reservoir at regular interval defined from graph

Water elevation m (above +73.15 m)	Water spread area Mm <sup>2</sup> (2017-18)	Cumulative capacity Mm <sup>3</sup> (2017-18)
MDDL 0.000	0.000	0.000
1.000	0.000	0.000
2.000	0.000	0.000
3.000	0.088	0.029
4.000	0.339	0.229
5.000	0.594	0.690
6.000	0.853	1.410
7.000	1.117	2.392

	8.000	1.385	3.641
	9.000	1.658	5.160
	10.000	1.935	6.955
	11.000	2.216	9.029
	12.000	2.502	11.387
	13.000	2.792	14.033
	14.000	3.087	16.971
	15.000	3.386	20.206
	16.000	3.689	23.743
	17.000	3.997	27.585
	18.000	4.309	31.737
	19.000	4.626	36.204
	20.000	4.947	40.989
	21.000	5.272	46.098
	22.000	5.602	51.534
	23.000	5.936	57.303
	24.000	6.275	63.408
	25.000	6.541	69.815
	26.000	6.902	76.536
	27.000	7.234	83.604
	28.000	7.537	90.989
	29.000	7.810	98.662
	30.000	8.054	106.594
	31.000	8.268	114.755
	32.000	8.453	123.116
	33.000	8.609	131.647
	34.000	8.735	140.319
	35.000	8.832	149.102
FRL	35.970	8.898	157.701

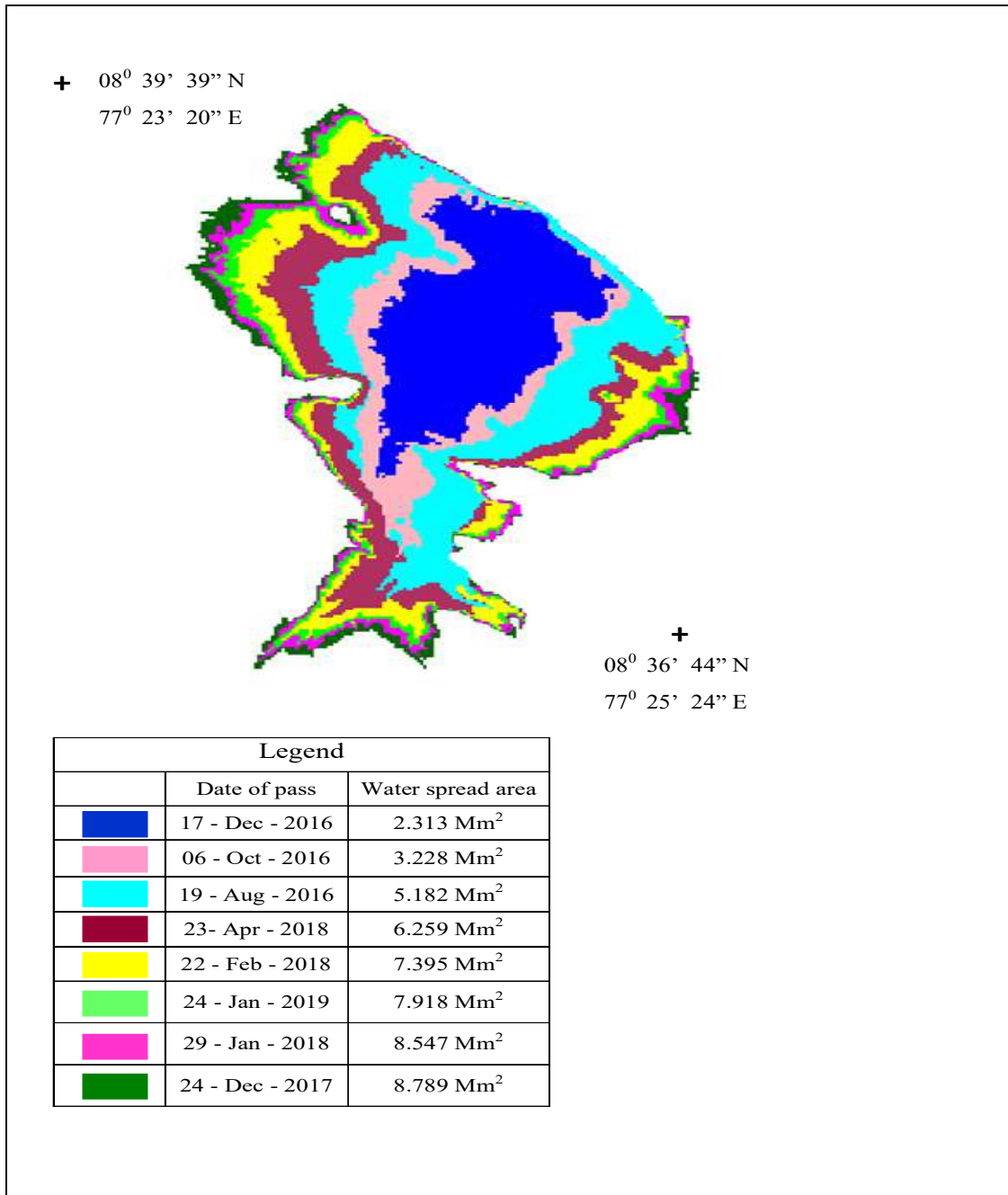


Figure 7 : Water spread areas on different dates of satellite pass

SRS elevation area curve is shown in Figure 8 and Figure 9 and tabulated in Table 5. Elevation capacity curves is shown in Figure 10 and tabulated in Table 6. The elevation-area curve drawn through original and present surveys carried out for Manimuthar reservoir are shown in Figure 11 which is based on Table 7. The elevation-capacity curve drawn through original and present surveys carried for the Manimuthar reservoir are shown in Figure 12 and tabulated in Table 8. In Figure 13 updated SRS elevation-area-capacity curve is drawn and tabulated in Table 6.

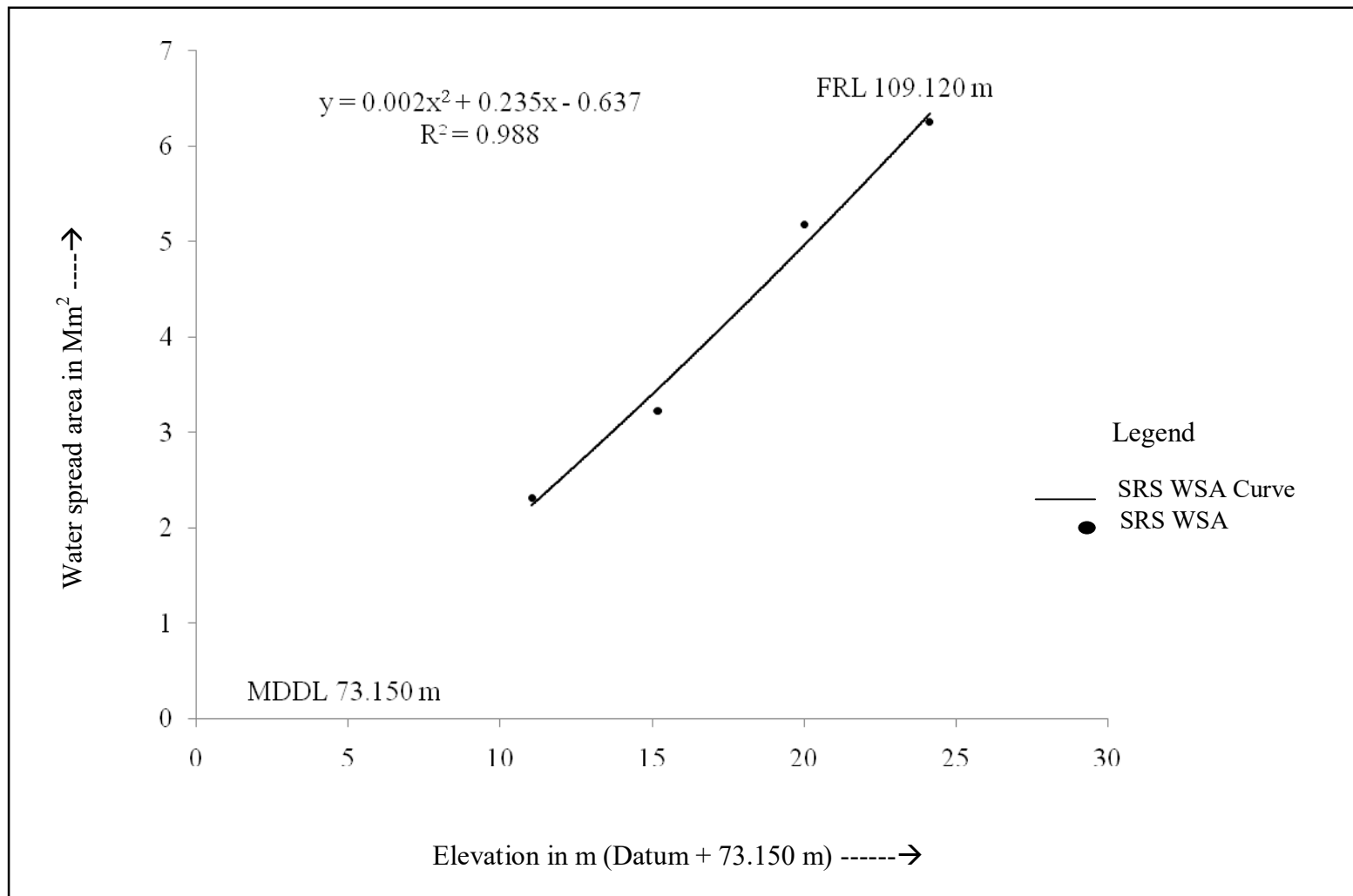


Figure 8 : SRS Elevation-Area curve for Manimuthar reservoir, Tamil Nadu (From RL 11.040 m to RL 24.120 m)

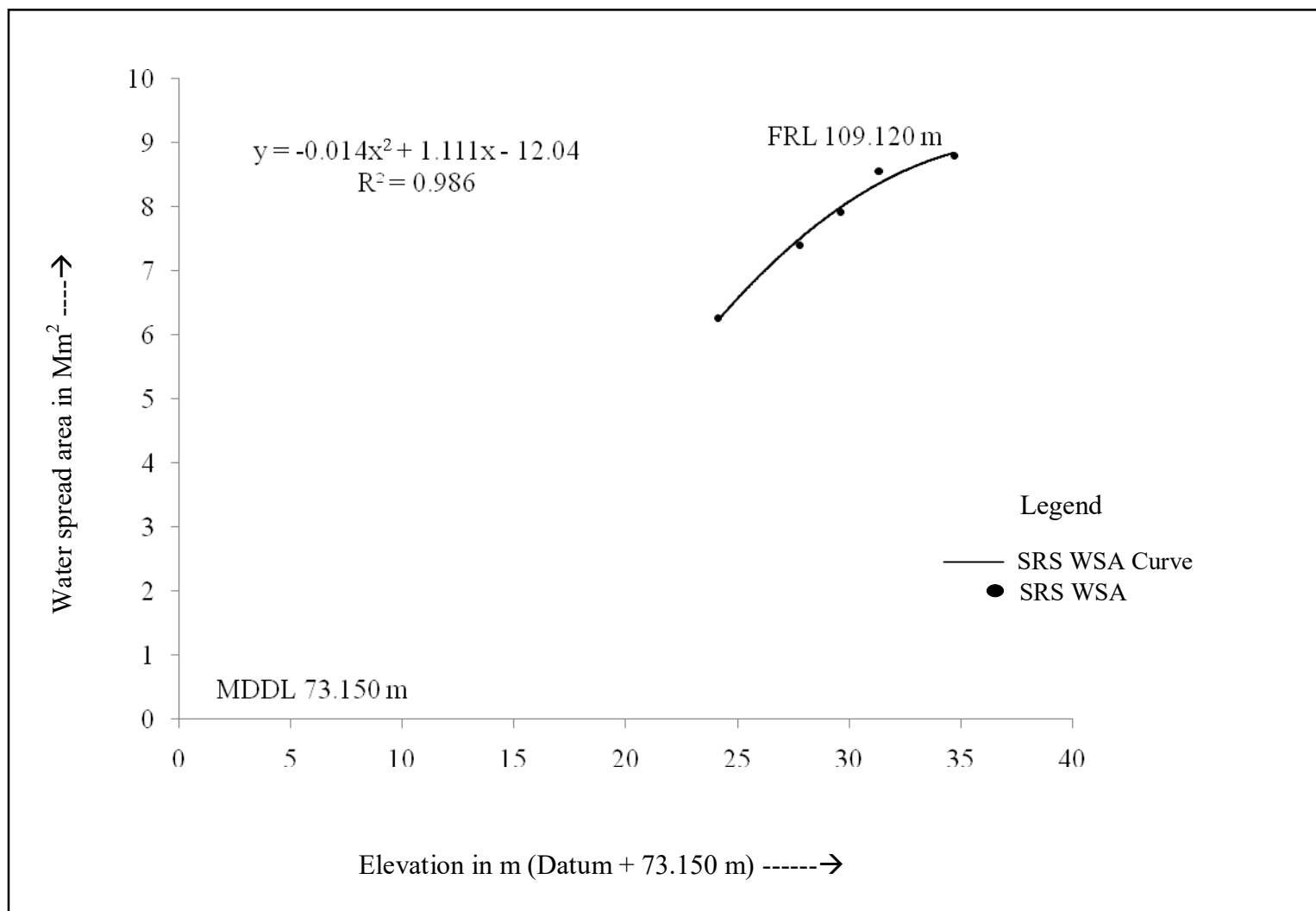


Figure 9 : SRS Elevation-Area curve for Manimuthar reservoir, Tamil Nadu (From RL 24.120 m to RL 34.690 m)

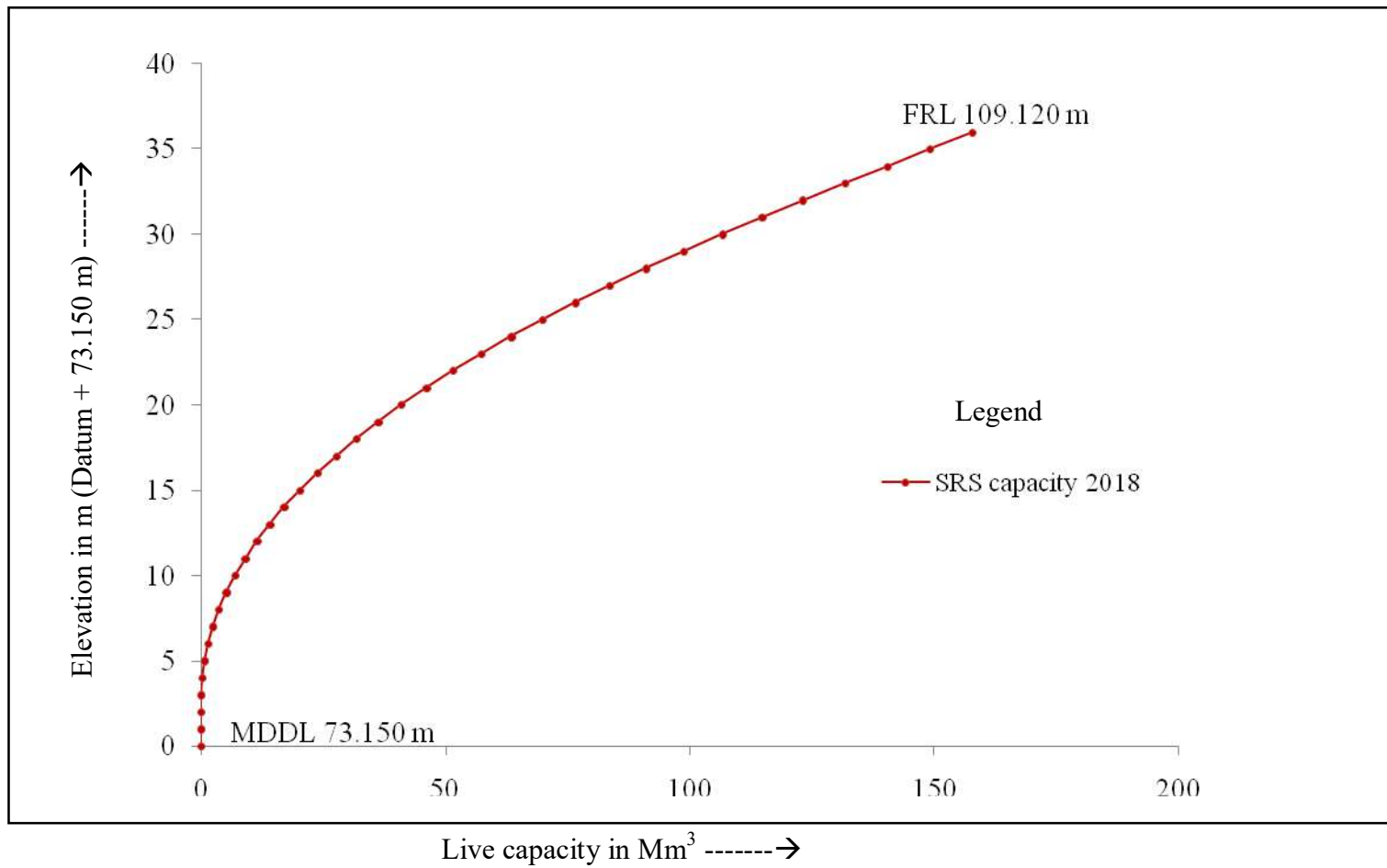


Figure 10 : SRS Elevation-Capacity curve for Manimuthar reservoir, Tamil Nadu



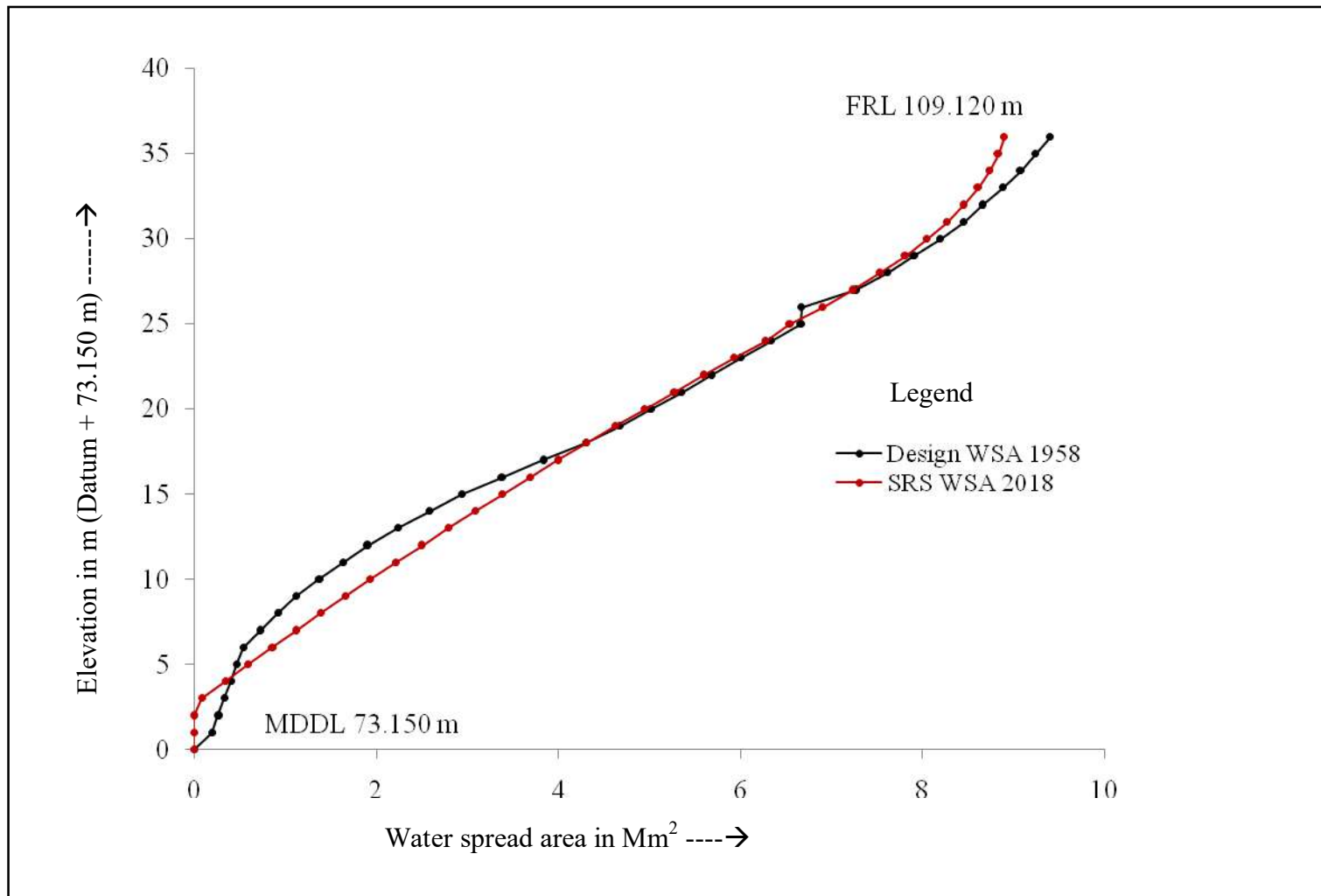


Figure 11 : Elevation - Area curve for different years for Manimuthar reservoir, Tamil Nadu

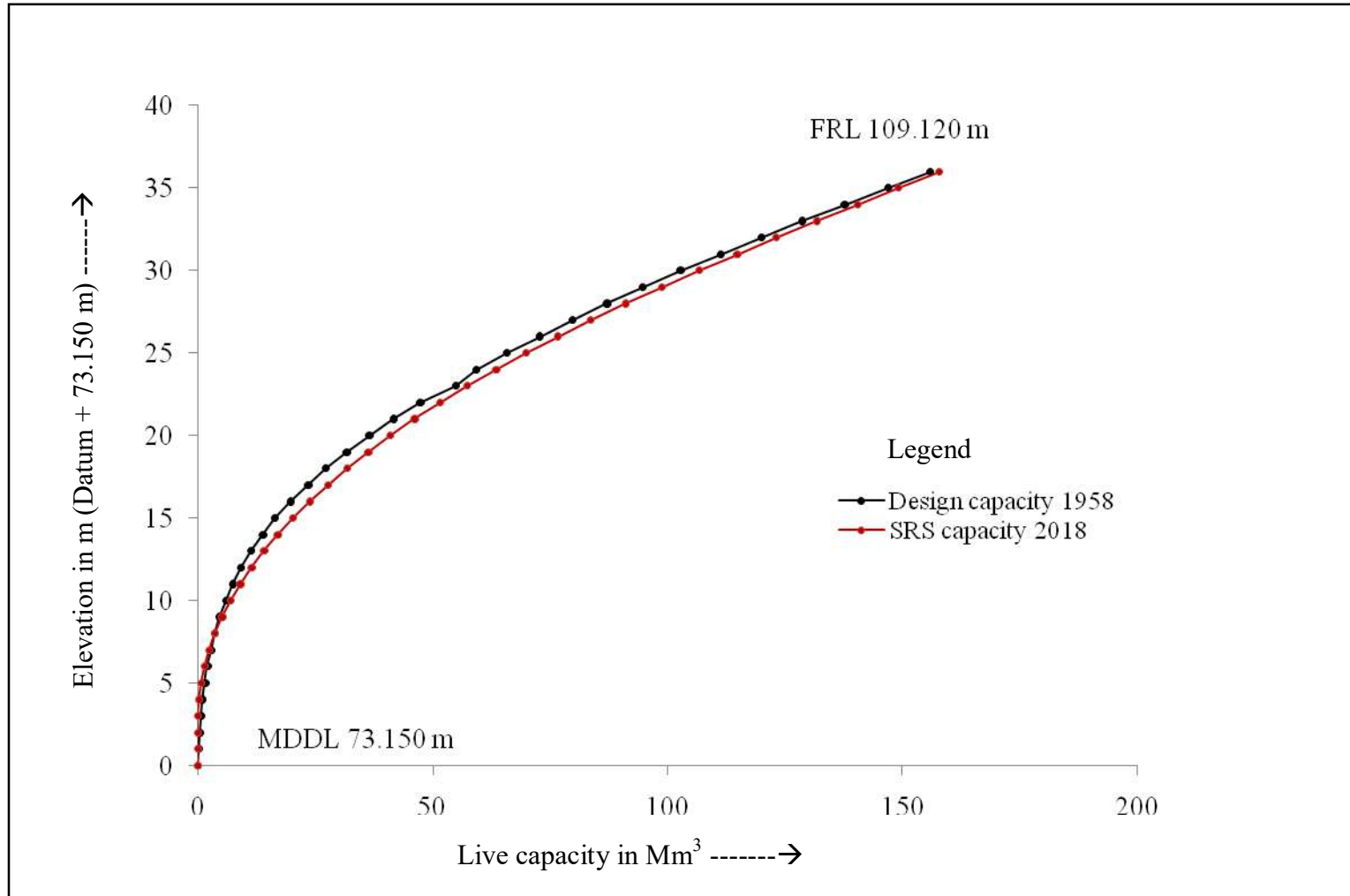


Figure 12 : Elevation - Capacity curve for different years for Manimuthar reservoir, Tamil Nadu

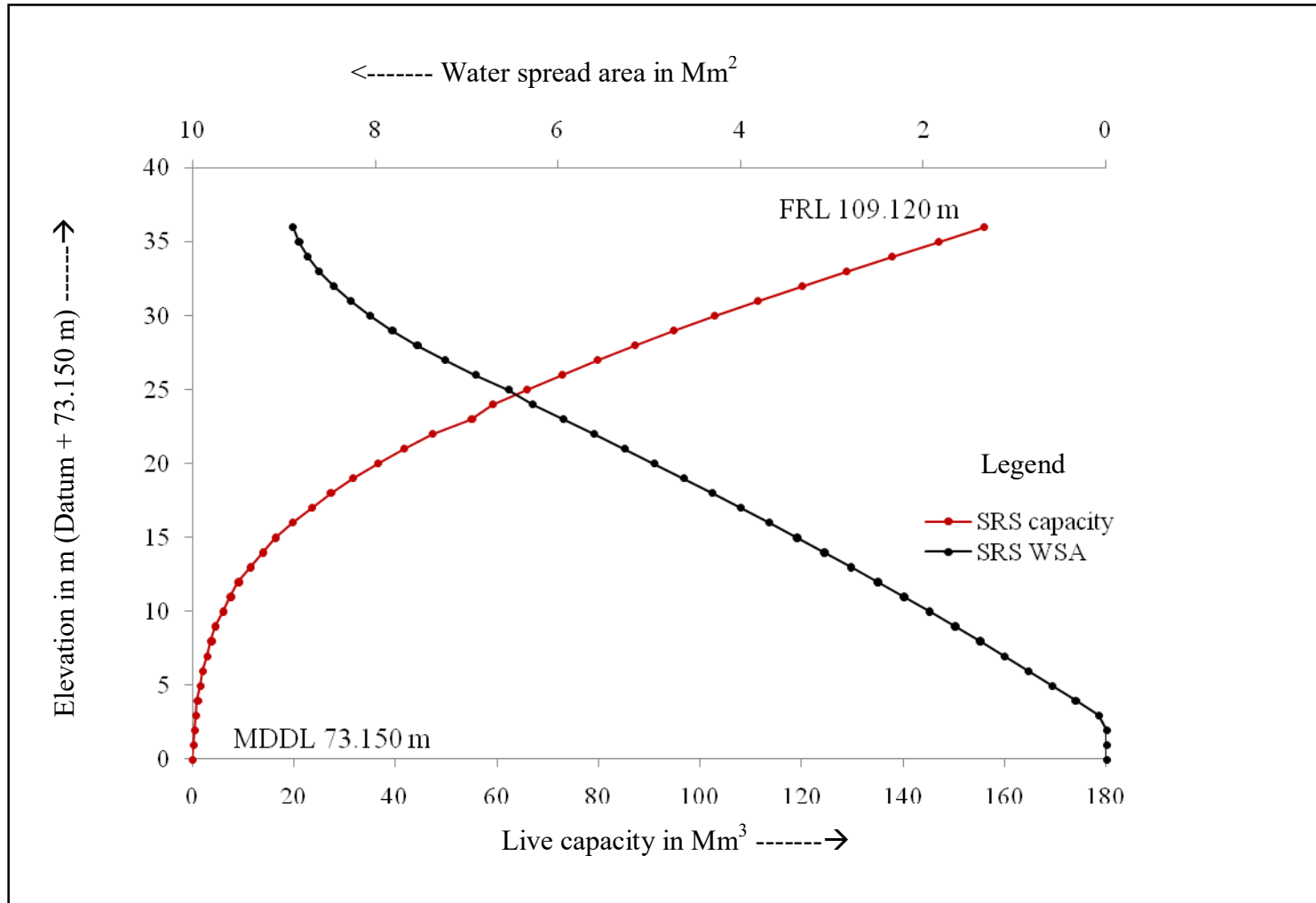


Figure 13 : Modified SRS Elevation-Area - Capacity curve for Manimuthar reservoir, Tamil Nadu

## 11.8 Comparison with earlier surveys

The comparison of water spread area obtained through remote sensing analysis with designed surveyed data is given in Table 7.

Table 7 : Comparison of water spread areas of reservoir (Mm<sup>2</sup>)

Water elevation m (above +73.15 m)	Design survey 1958	SRS survey 2017-18
MDDL 0.000	-	0.000
1.000	0.191	0.000
2.000	0.263	0.000
3.000	0.335	0.088
4.000	0.403	0.339
5.000	0.471	0.594
6.000	0.540	0.853
7.000	0.724	1.117
8.000	0.919	1.385
9.000	1.116	1.658
10.000	1.370	1.935
11.000	1.636	2.216
12.000	1.901	2.502
13.000	2.236	2.792
14.000	2.588	3.087
15.000	2.940	3.386
16.000	3.377	3.689
17.000	3.840	3.997
18.000	4.304	4.309
19.000	4.679	4.626
20.000	5.016	4.947

	21.000	5.356	5.272
	22.000	5.685	5.602
	23.000	6.008	5.936
	24.000	6.341	6.275
	25.000	6.664	6.541
	26.000	6.671	6.902
	27.000	7.278	7.234
	28.000	7.615	7.537
	29.000	7.907	7.810
	30.000	8.202	8.054
	31.000	8.458	8.268
	32.000	8.669	8.453
	33.000	8.885	8.609
	34.000	9.076	8.735
	35.000	9.242	8.832
FRL	35.970	9.402	8.898

The comparison of present live storage capacity with designed capacity is given in Table 8.

Table 8 : Comparison of live storage capacity of reservoir (Mm<sup>3</sup>)

<b>Water elevation m (above +73.15 m)</b>	<b>Design survey 1958</b>	<b>SRS survey 2017-18</b>
MDDL 0.000	0.000	0.000
1.000	0.230	0.000
2.000	0.457	0.000
3.000	0.685	0.029
4.000	0.966	0.229
5.000	1.561	0.690
6.000	2.004	1.410
7.000	2.813	2.392
8.000	3.657	3.641
9.000	4.500	5.160
10.000	5.948	6.955
11.000	7.485	9.029
12.000	9.036	11.387
13.000	11.337	14.033
14.000	13.844	16.971
15.000	16.324	20.206
16.000	19.748	23.743
17.000	23.470	27.585
18.000	27.207	31.737
19.000	31.634	36.204
20.000	36.491	40.989
21.000	41.606	46.098
22.000	47.298	51.534
23.000	54.956	57.303

	24.000	59.157	63.408
	25.000	65.760	69.815
	26.000	72.726	76.536
	27.000	79.720	83.604
	28.000	87.054	90.989
	29.000	94.642	98.662
	30.000	102.717	106.594
	31.000	111.310	114.755
	32.000	119.974	123.116
	33.000	128.704	131.647
	34.000	137.657	140.319
	35.000	146.882	149.102
FRL	35.970	155.821	157.701

## 11.9 Field visit and ground truth

Field visit of the reservoir area has been carried out on 3<sup>rd</sup> January 2020 for ground truth verification. Some predetermined ground truth points marked on the satellite image printouts along with their latitude and longitude values have been verified, with the help of GPS (Trimble Juno) receiver. Following officers were present during this visit.

### **Officers from Resources Engineering Center, MERI, Nashik**

- i) Shri. M. M. Kulkarni, Executive Engineer

### **Team from Manimuthar reservoir project**

- i) Er. S. Palanivel, Assistant Executive Engineer
- ii) Er. S. Maheswaran, Assistant Engineer

Latitude and longitude values of the reservoir components have been recorded during the field visit. Reservoir levels used in the present analysis have been confirmed in field visit. The reservoir level on the day of visit was observed 34.762 m. The Photographs of ground truth scenario are shown in Annexure III.

## 12. Results and Discussions

The loss in live storage capacity of the reservoir in remote sensing survey (2017-18) due to sedimentation since original survey (1958), survey (1980), survey (1988) and survey (2006) is given in table 9.

Table 9 : Live storage capacity loss due to sedimentation from original survey

Details	Original survey (1958)	Survey (1980)	Survey (1988)	Survey (2006)	SRS survey (2017-18)
Live capacity (MCM) at FRL 463.906 m	155.821	155.410	154.220	149.448	157.701
Loss in capacity (MCM)	-	0.411	1.601	6.373	(+)1.880
% Live capacity loss (since 1958)	-	0.263	1.027	4.089	-
Annual % live capacity loss	-	0.011	0.034	0.085	-
% Live capacity loss between two consecutive surveys ( of the original capacity)	-	-	-	-	-
% Loss in live storage between the survey since impoundment	-	Error	Error	Error	-

The following observations are recorded from the present study.

- Present live capacity (year 2017-2018) of Manimuthar reservoir is found as 157.701 Mm<sup>3</sup>. Modified SRS elevation-area-capacity values are given in Table 6 and Figure 13.

## 13. Limitations

The sedimentation survey using Remote Sensing Technique has following limitations

- The remote sensing based capacity estimation works between the operating levels i.e. MDDL to FRL only. Thus changes can be estimated only in live capacity of reservoir.
- From year 2016 to 2019 images below water level 11.040 m (Datum 73.150 m) are not available. Hence extrapolation from water level 11.040 m to MDDL is carried out to cover entire live storage.



- The cloud free satellite data throughout reservoir operation in single year is not possible. As such data from different years are selected.
- General error can creep in the identification of tail end of reservoir, particularly in the rainy season. Reservoir authorities have been consulted to remove this ambiguity.

## 14. Conclusions

Following conclusions can be drawn from the study:

- The live storage capacity of Manimuthar reservoir is 157.071 Mm<sup>3</sup> in year 2017-18.
- No Capacity loss in live storage is observed in a period of 60 years since first impounding in 1958.
- It is to be mentioned that hydrographic survey is recommended.

## References

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Varshney, R.S., (1997), Impact of siltation on the useful life of large reservoirs, State of art report of INCOH, No. INCOH/SAR-11/97, NIH, Roorkee.

## Annexure I

### Salient Features

<b>A</b>	<b>Location</b>		
	Village	:	Singampatti
	Taluka	:	Ambasamudram
	District	:	Tirunelveli
	State	:	Tamil Nadu
	Longitude	:	08 <sup>0</sup> 39' 30"
	Latitude	:	77 <sup>0</sup> 26' 00"
	River	:	Manimuthar
<b>B</b>	<b>Hydrology</b>		
	Catchment area	:	161.820 sq km
<b>C</b>	<b>Masonry and Earthen Dam</b>		
	Length of dam	:	2.928 km
	Height of the dam	:	31.390 m
<b>D</b>	<b>Capacity of Dam</b>		
	Gross storage capacity at FRL	:	156.053 Mm <sup>3</sup>
	Dead storage capacity	:	0.232 Mm <sup>3</sup>
	Live capacity	:	155.821Mm <sup>3</sup>
	Max. spillway discharge capacity	:	1699.200 cumecs
	Type of spillway	:	Ogee
	No., and Size of spillway	:	7 Nos., 12.19 m x 4.57 m
<b>E</b>	<b>Reservoir Data</b>		As per field      In m
	Top level of dam	:	+39.015 m      +112.165 m
	Maximum water level	:	+35.970 m      +109.120 m
	Full reservoir level	:	+35.970 m      +109.120 m
	crest level of dam	:	+31.400 m      +104.550 m
	Sill level of highest sluice	:	+24.385 m      +97.535 m
	Sill level of lowest sluice	:	0.000 m      +73.150 m
	Sill level of River sluice	:	0.000 m      +73.150 m
	Year of completion	:	1958

## Annexure II

### Reservoir Levels Pertaining to Cloud Free Satellite Data

Path/Row – 101 / 68

Gross storage capacity at FRL – 156.053 Mm<sup>3</sup>

FRL – 109.120 m

Design live storage – 155.821Mm<sup>3</sup>

MDDL - 73.150 m

Dead storage capacity – 0.232 Mm<sup>3</sup>

Date of pass	Reservoir level (m) (above +73.15 m)	Gross Capacity covered (Mm <sup>3</sup> )
1	2	3
17 - Dec - 2016	11.040	7.780
06 - Oct - 2016	15.170	16.980
19 - Aug - 2016	20.000	36.720
23- Apr - 2018	24.120	60.120
22 - Feb - 2018	27.780	87.500
24 - Jan - 2019	29.590	99.460
29 - Jan - 2018	31.310	114.240
24 - Dec - 2017	34.690	144.300
Variation in capacity		(144.300-7.780) = 136.520
% variation of live storage		(136.520/155.821)*100 = 87.61 %

## Annexure III

### Ground Truth Scenario



Dam view



Downstream side of dam



Upstream side of dam



River sluices



Drainage gallery



Top bund level



Submerged area



Digital water gauge recorder



Energy dissipation arrangement of dam



Main canal



Head regulator



Ground truth team



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