उपग्रह दूरस्थ संवेदन द्वारा
नागार्जुन सागर जलाशय, आन्ध्र प्रदेश एवं तेलंगाना का अवसादन आंकलन

SEDIMENTATION ASSESSMENT OF NAGARJUNA SAGAR RESERVOIR, ANDHRA PRADESH AND TELANGANA, THROUGH SATELLITE REMOTE SENSING

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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**

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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 and 2020 in the sedimentation study of Nagarjuna Sagar 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 Nagarjuna Sagar Reservoir. As compared to Optical remote sensing, Microwave remote sensing has advantages as the satellite operates day and night allowing the acquisition of imagery at frequent time intervals regardless of weather and illumination conditions. The Sentinel-1 mission is a constellation of two polar-orbiting satellites (Sentinel-1A and Sentinel-1B), with a C-band synthetic aperture radar instrument operating at a center frequency of 5.405 GHz, that acquires Synthetic Aperture Radar (SAR) data in single or dual polarization with a revisit time of 6 days.

The Nagarjuna Sagar dam was constructed during the period 1956-1968 to store water from the Krishna river. Project has a designed live storage capacity of 5733.54 MCM. In 1999 Satellite Remote Sensing survey was done that reported the live capacity as 5544.63 MCM. The Reservoir Hydrographic survey was carried out in year 2001 and 2009 that reported live capacity as 6158.19 MCM and 6042.49 MCM respectively.

After analysis of the satellite data in the present study, it is found that live capacity of Nagarjuna Sagar reservoir in 2020 is 5360.252 MCM witnessing a live storage loss of 373.288 MCM (i.e. 6.511%) in a period of 52 years during 1968 to 2020. This accounts for live capacity loss of 0.125% per annum since 1968.

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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 NAGARJUNA SAGAR RESERVOIR, ANDHRA PRADESH & TELANGANA 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 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 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 Nagarjuna Sagar Reservoir, Andhra Pradesh and Telangana by Central Water Commission, New Delhi.

2. SOURCES AND MECHANISM OF SEDIMENTATION

1. The principal sources of sediments are as follows:
2. Deforestation
3. Excessive erosion in the catchment
4. Disposal of industrial and public wastes
5. Farming
6. Channelisation works

7. Human activities
8. 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 river bank 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.

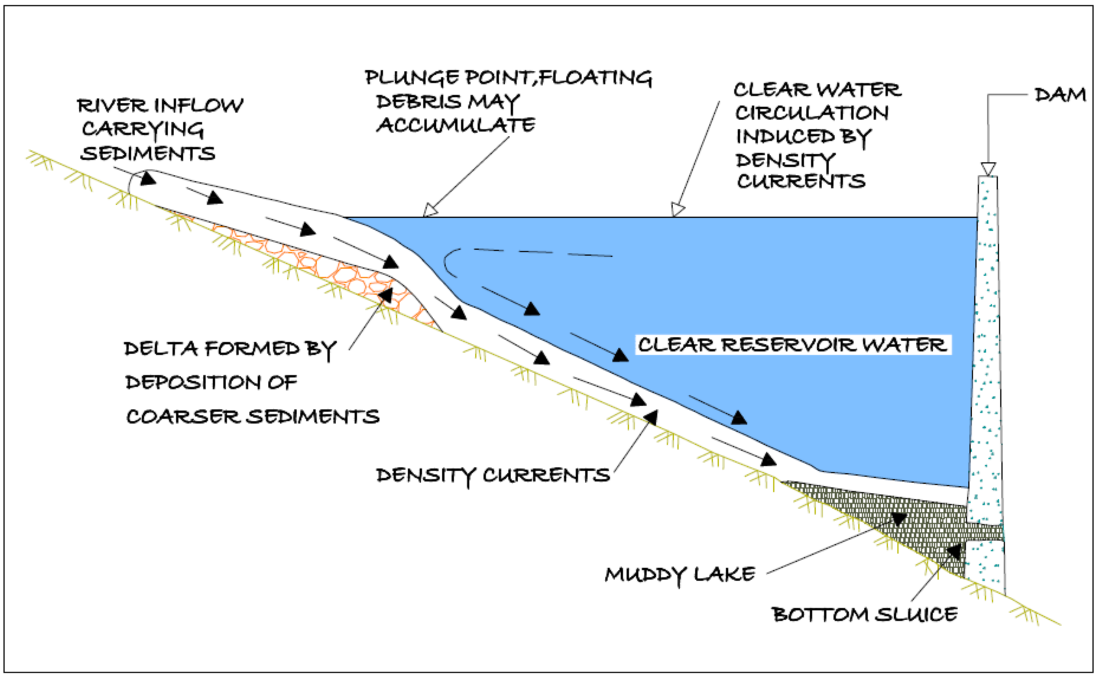


Fig. 1: Conceptual sketch of density currents in a reservoir

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.

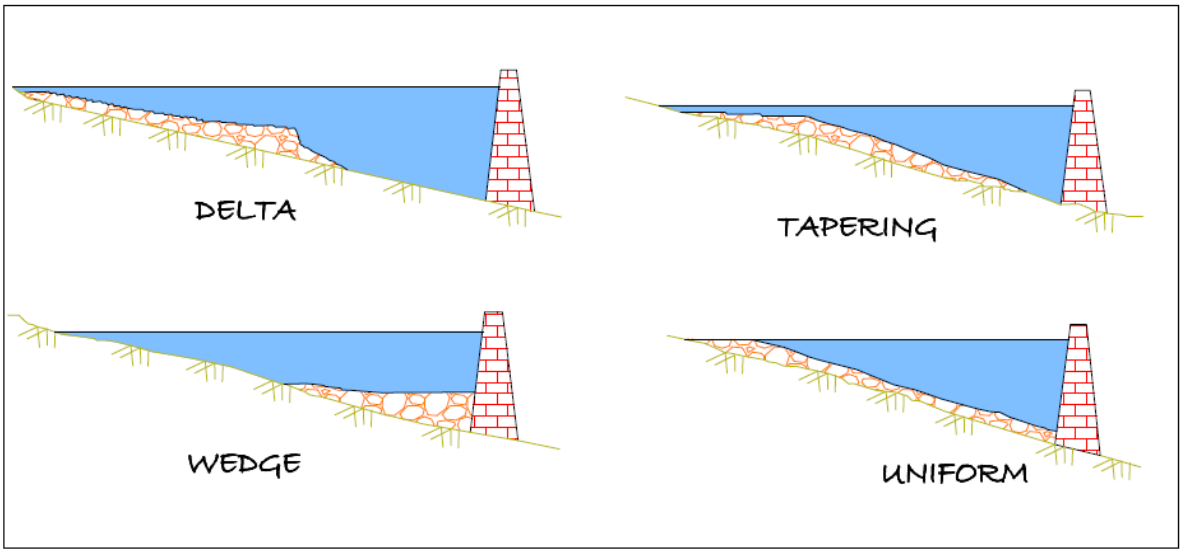


Fig. 2: Longitudinal Patterns of sediment deposition in reservoirs.

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.

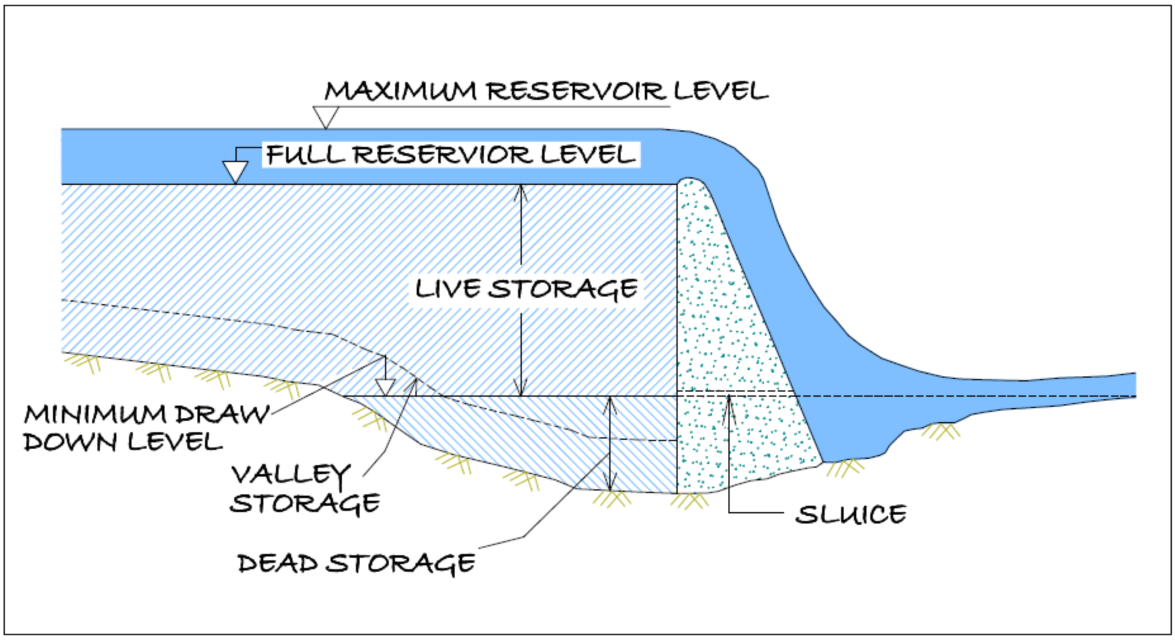


Fig. 3: Conceptual sketch of different levels in a reservoir

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 Nagarjuna Sagar 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

Nagarjuna Sagar Reservoir is located at 16°34'24"N latitude and 79°18'47"E longitude at Nandikonda(V), Pedavoora(M) and Nalgonda District at a distance of 150 Km from Hyderabad. It was constructed in the year 1968 on river Krishna. The river Krishna originates at Mahabaleshwar in Western Ghats near Pune in Maharashtra State. It traverses towards south and then takes easterly direction flowing through the States of Maharashtra, Karnataka and Andhra Pradesh and finally joins in the Bay of Bengal at Machilipatnam in Andhra Pradesh.The total catchment area of Krishna upto Nagarjuna Sagar is 2,15,185 sq. kms., lying in three States of Maharashtra, Karnataka and Andhra Pradesh. Figure 4 shows index map of Nagarjuna Sagar Reservoir.

The Nagarjuna Sagar Project is a multi-purpose River Valley Project with a dam across river Krishna in Nandikonda village in Miryalaguda taluq, Nalgonda district and is located 185 kms. from Vijayawada and 150 kms. from Hyderabad. The project is a landmark in the history of irrigation development of the state. It comprises a 124.7 metres high dam, one of the tallest masonry dam in the world, Right Canal and Left Canal with their distributary system. The project envisages creation of irrigation potential of 8.95 lakh ha. covering six districts of Guntur, Prakasam, Nalgonda, Khammam, Krishna and West Godavari and seasonal hydroelectric power generation upto 960 MW.

Salient features of the Nagarjuna Sagar 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 Nagarjuna Sagar reservoir, the height difference between FRL (179.832 m) and MDDL (155.45 m) is 24.382 m.

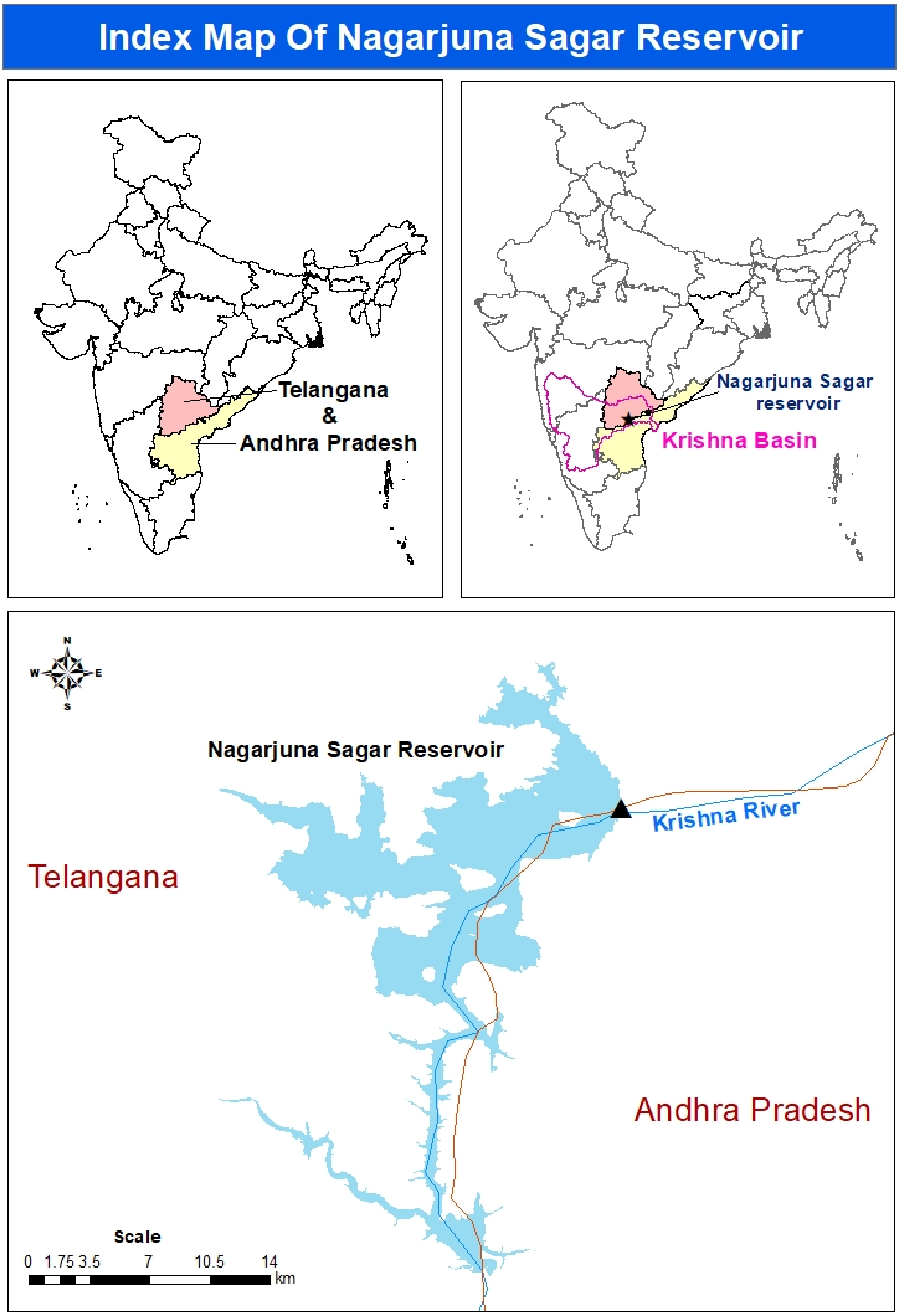


Fig. 4: Index map of the Nagarjuna Sagar Reservoir

8. DATA USED

8.1. SATELLITE DATA

Microwave data from Sentinel 1A/1B for Ten (10) dates has been used in the analysis. Table 1 depicts the date of pass of satellite along with elevation observed on that date.

Table – 1: Date of pass for satellite data

Satellite	Date of pass	Elevation (m)
Sentinel 1A	25-04-2019	155.94
Sentinel 1A	20-03-2019	158.89
Sentinel 1A	08-03-2019	160.23
Sentinel 1A	11-08-2019	162.82
Sentinel 1A	24-02-2020	166.48
Sentinel 1A	19-01-2020	170.23
Sentinel 1A	07-01-2020	172.82
Sentinel 1A	26-12-2019	174.83
Sentinel 1A	14.12.2019	176.78
Sentinel 1A	02.12.2019	178.13

8.2. FIELD DATA

The following field data have been obtained from project authorities:

- Elevation - Capacity data
- Salient features of Nagarjuna Sagar 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 Nagarjuna Sagar reservoir studies, multi-date Sentinel 1 (10 nos. imageries) is used for the analysis. Image processing with SNAP software and Arc GIS software was used for the analysis. The analysis comprised,

- 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 shows Sentinel 1A/1B images of different dates and Fig. 7 shows the superimposed reservoir water spreads for different dates. Water spread area has been calculated by multiplying number of pixels with area of each pixel i.e. (10m x 10m) in case of Sentinel 1 imagery. Table 2 shows satellite-derived reservoir water spread areas for different satellite overpass dates along with the water levels of the reservoir at the corresponding dates collected from the project authtorites.

Table – 2: Water Spread Areas estimated from Satellite Images

Sl No	Date of pass of Satellite	Water level in Meter	Water spread area (by SRS) in M m2
1	25-04-2019	155.94	164.317
2	20-03-2019	158.89	178.491
3	08-03-2019	160.23	185.050
4	11-08-2019	162.82	191.849
5	24-02-2020	166.48	215.235
6	19-01-2020	170.23	240.670
7	07-01-2020	172.82	249.419
8	26-12-2019	174.83	251.230
9	14.12.2019	176.78	258.910
10	02.12.2019	178.13	264.128

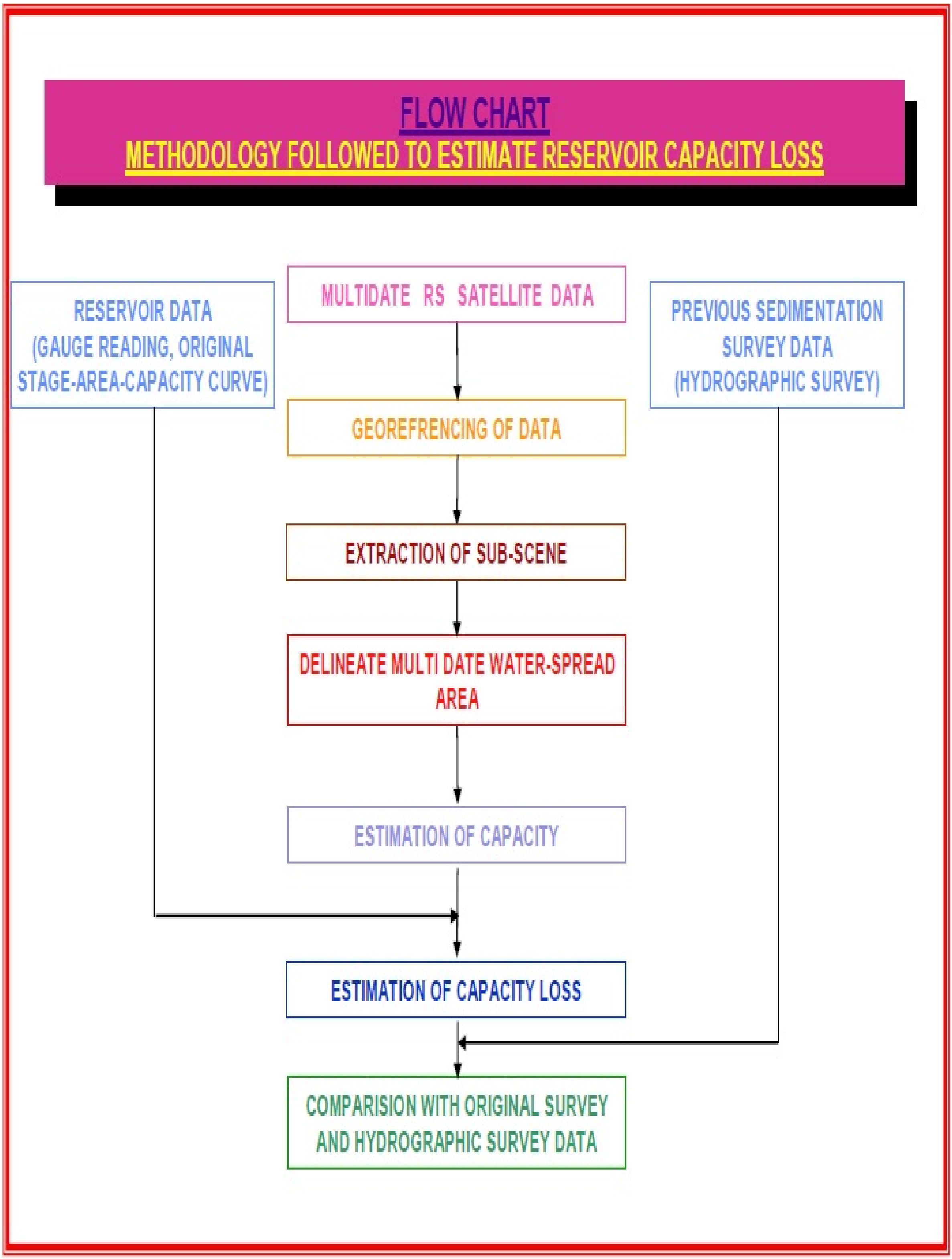
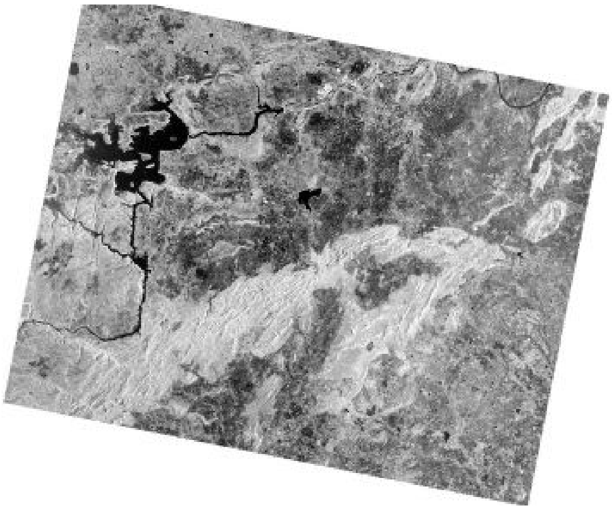
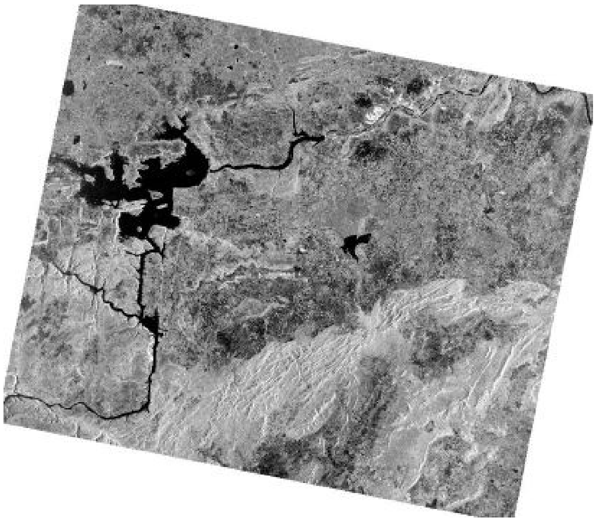
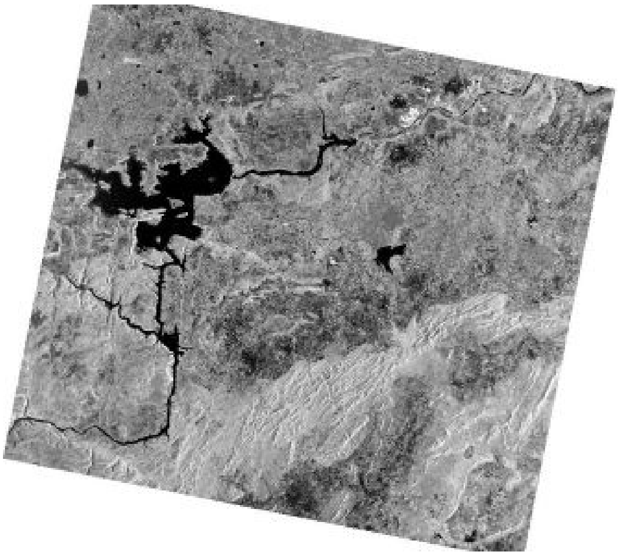
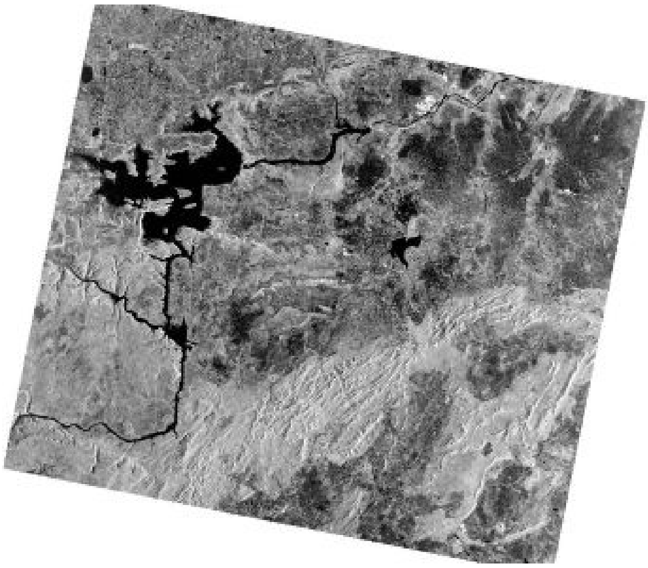
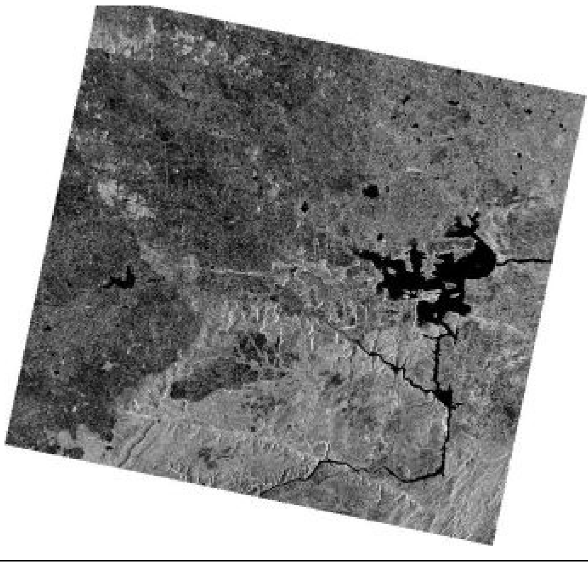
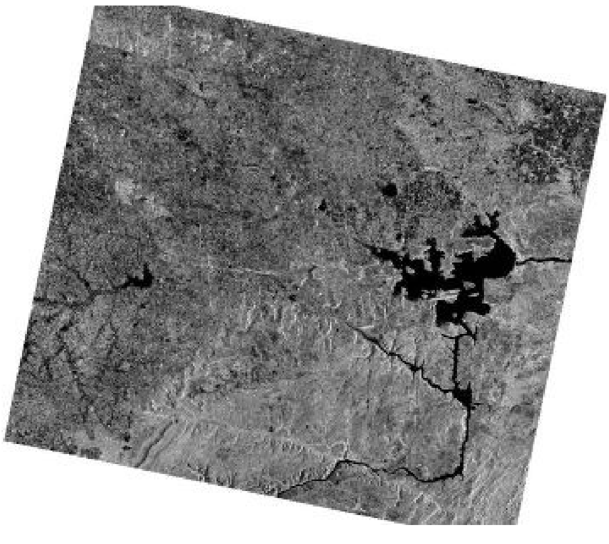


Fig 5 : Flow chart showing methodology followed to estimate reservoir capacity loss

	
25-Apr-2019 (155.94 m)	**20-Mar-2019 (158.89 m)**
	
08-Mar-2019 (160.23 m)	**11-Aug-2019 (162.82 m)**
	
24-Feb-2020 (166.48 m)	**19-Jan-2020 (170.23 m)**

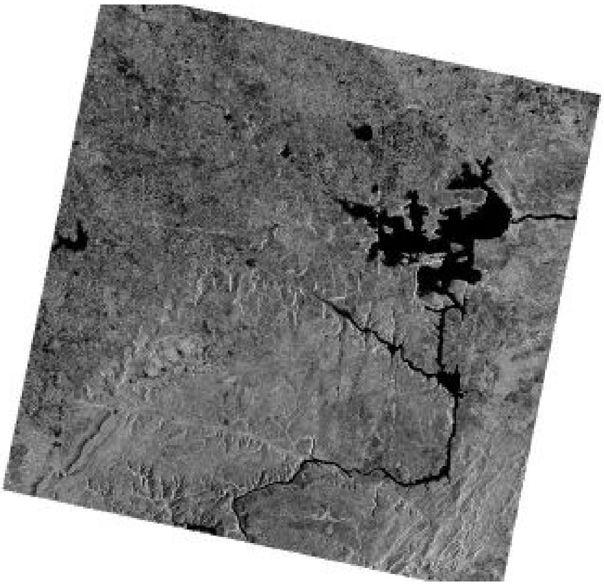
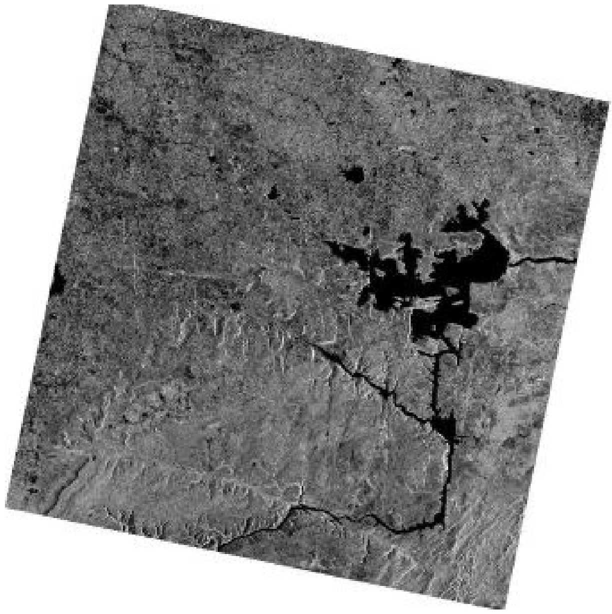
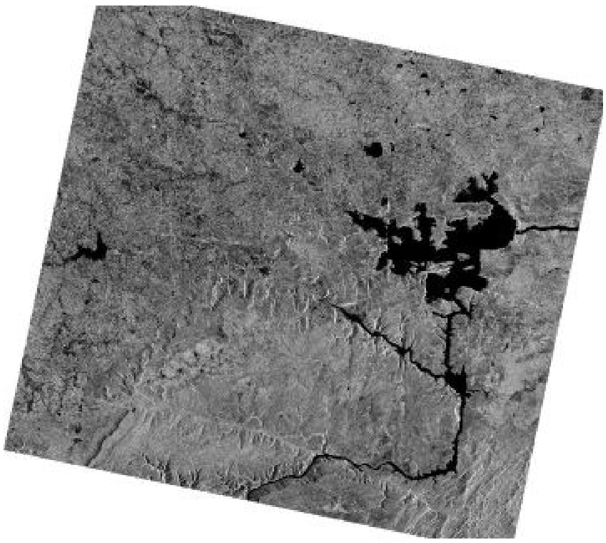
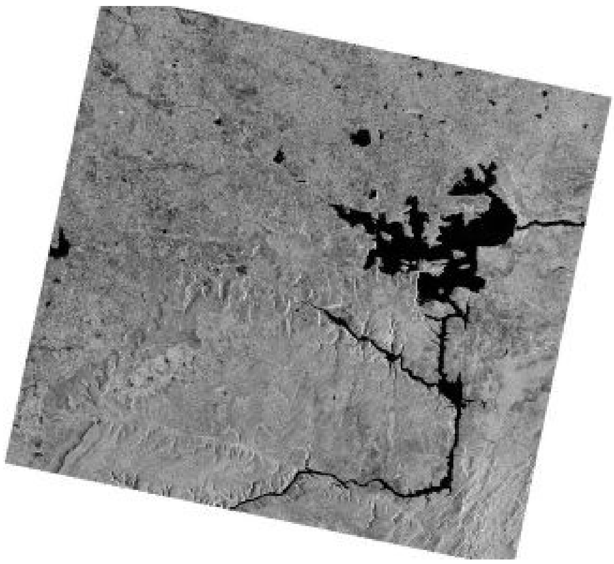
	
07-Jan-2020 (172.82 m)	**26-Dec-2019 (174.83 m)**
	
14-Dec-2020 (176.78 m)	**02-Dec-2019 (178.13 m)**

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

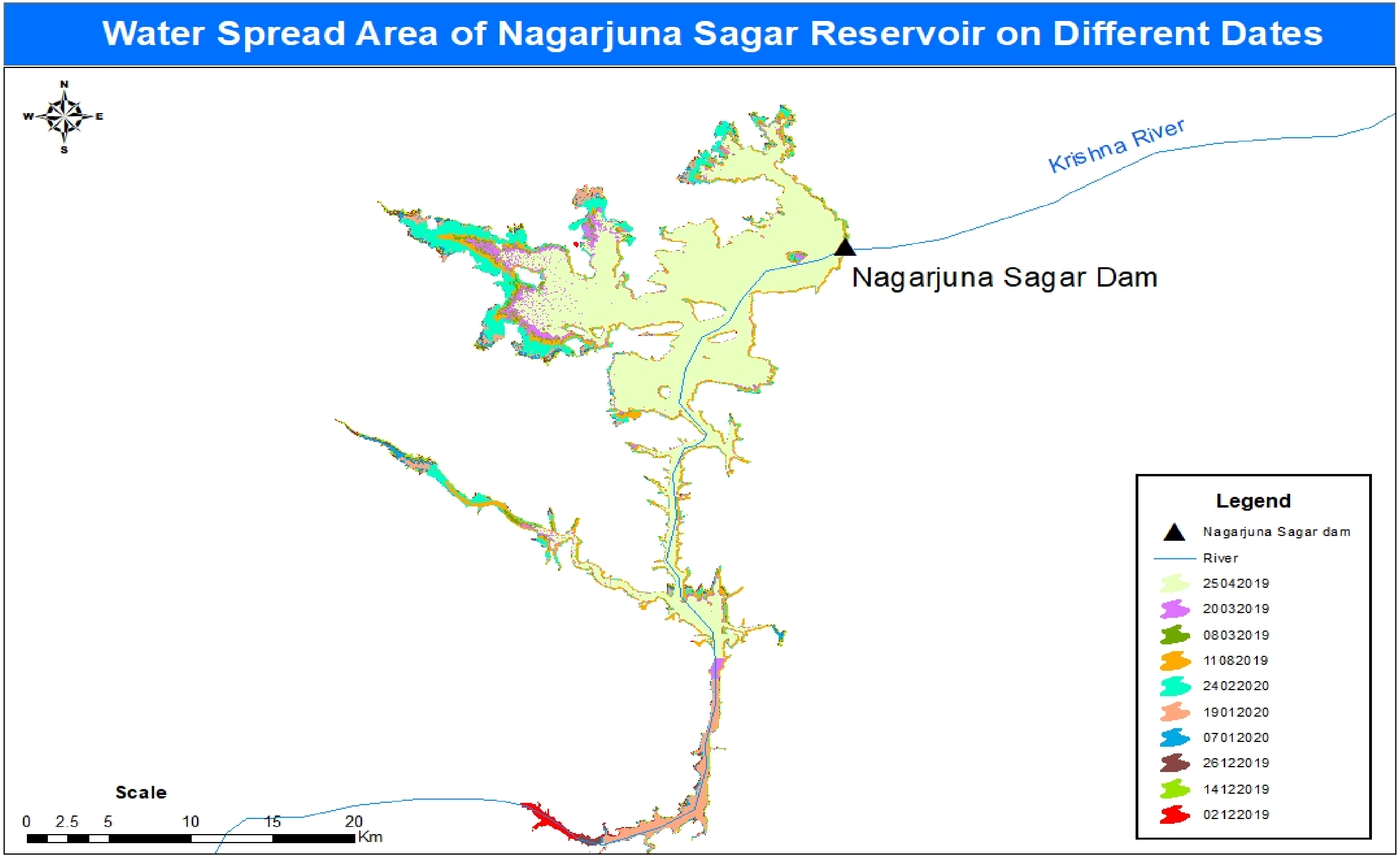


Fig. 7: Water Spread Area of Nagarjuna Sagar Reservoir on different dates

The Satellite Images for the Nagarjuna Sagar 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 Nagarjuna Sagar Reservoir showing its water spread area for ten overpass dates such as 25-Apr-2019, 20-Mar-2019, 08-Mar-2019, 11-Aug-2019, 24-Feb-2020, 19-Jan-2020, 07-Jan-2020, 26-Dec-2019, 14-Dec-2019 and 02-Dec-2019 are shown in fig. 7.

The water elevation 178.13 m for 02-Dec-2019 is near the Full Reservoir Level (FRL) of 179.832 m. The Water elevation 155.94 m for 25-April-2019 is near the Minimum Drawdown Level (MDDL) of 155.45 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 = -0.044x2 +5.718x +158.9

R^2 = 0.99

Where, X is Elevation in meters

Y is Water Spread Area in Mm^2

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.

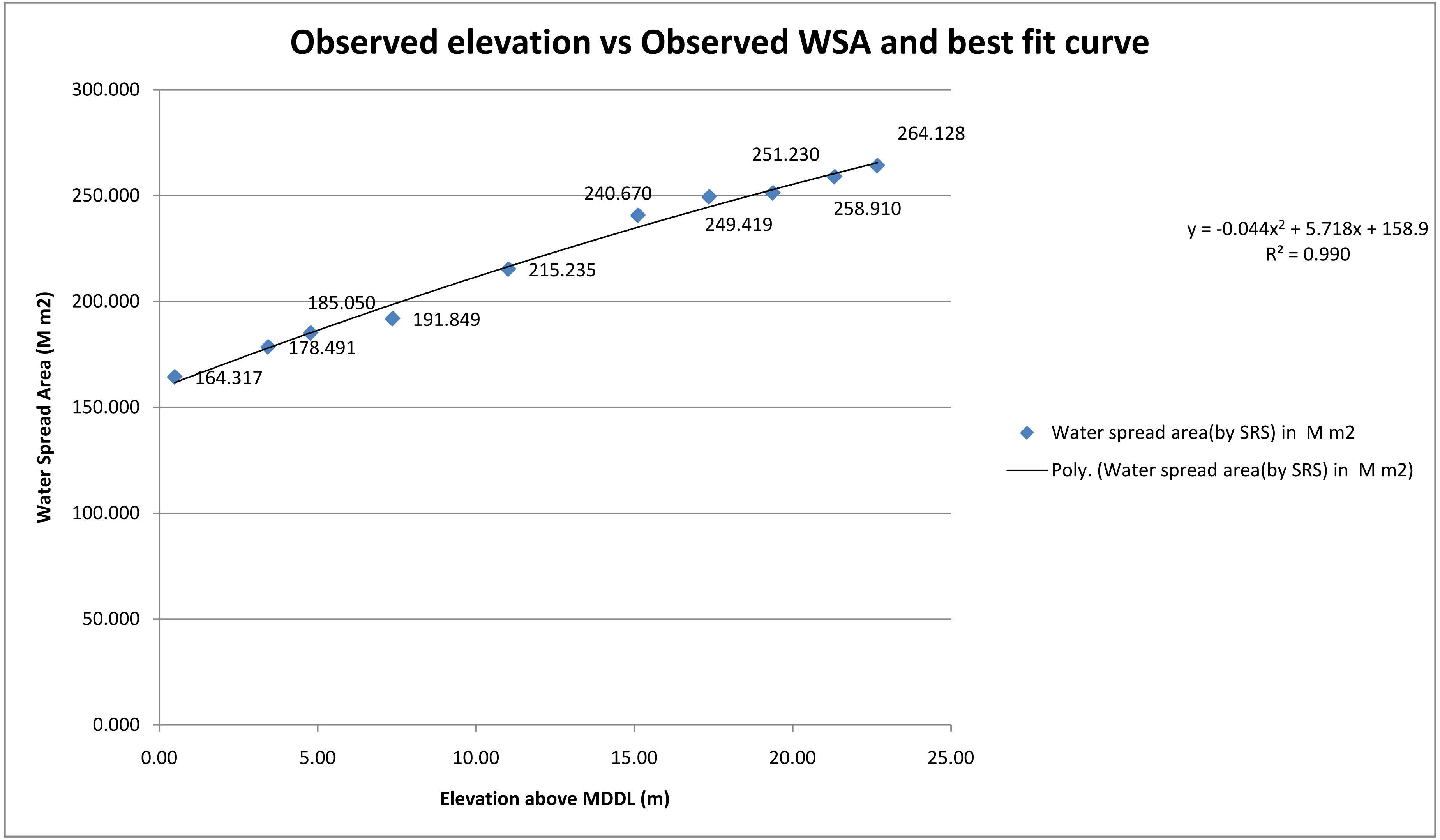


Fig.8: Observed elevation vs Observed WSA of Nagarjuna Sagar Reservoir

Table 3 gives the values of Live storage capacity and submergence areas at a regular interval of 2.0 m have been worked out using the best-fit polynomial equation at different elevations.

The Modified live capacity - elevation curve and modified elevation – area –capacity curves are plotted and shown in Fig-9 and Fig-10 respectively.

Table-3: Aerial extent of Nagarjuna Sagar reservoir at regular interval (2.0m) using SRS Survey 2020

	Reservoir water level in Metre	Water spread area by trend line (M m^2)	Segmental Live Capacity (M m3) by SRS technique	Cumulative Live Capacity (M m3) by SRS technique 2020
MDDL	155.45	158.900	0.000	0.000
	157.00	167.657	253.051	253.051
	159.00	178.644	346.243	599.295
	161.00	189.280	367.873	967.168
	163.00	199.563	388.797	1355.965
	165.00	209.494	409.017	1764.981
	167.00	219.073	428.531	2193.513
	169.00	228.300	447.342	2640.855
	171.00	237.176	465.448	3106.302
	173.00	245.699	482.849	3589.152
	175.00	253.870	499.547	4088.698
	177.00	261.689	515.539	4604.238
	179.00	269.156	530.828	5135.066
FRL	179.83	272.159	225.186	5360.252

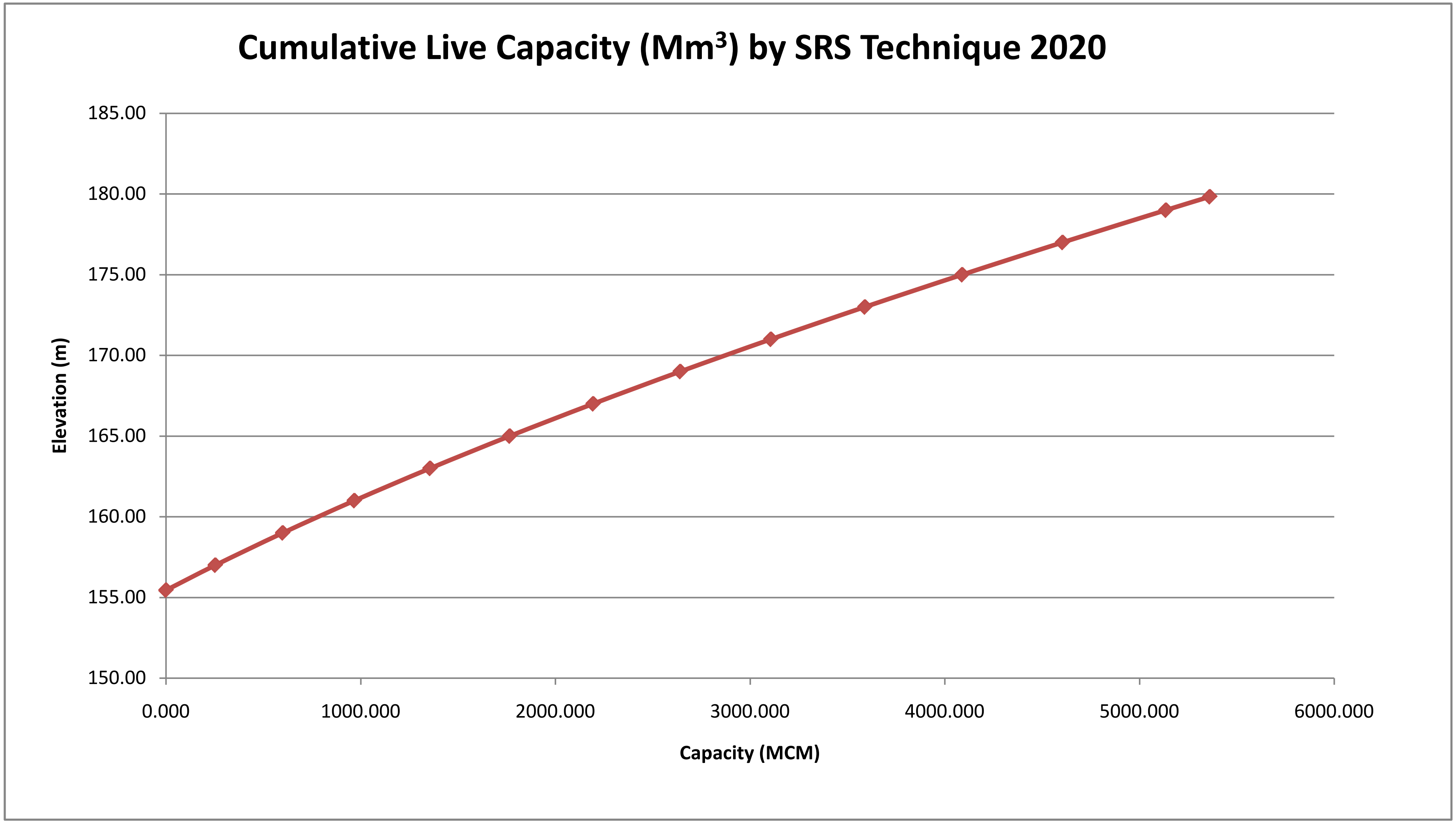


Fig. 9: Modified live capacity - elevation curve (SRS technique)-Nagarjuna Sagar reservoir

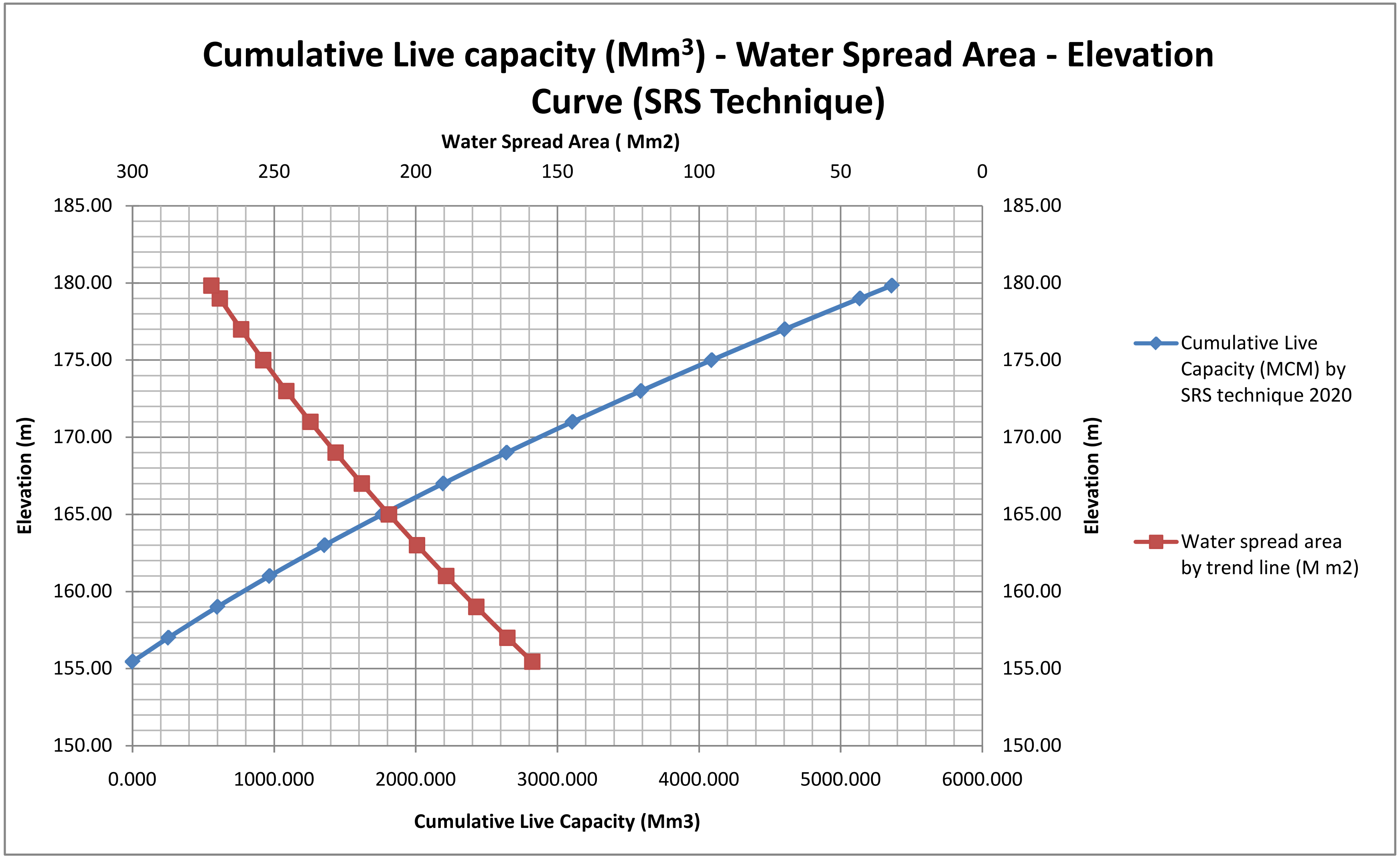


Fig. 10: Elevation – Area- Capacity Curve- Nagarjuna Sagar reservoir

9.4. Comparison with Original and Previous Surveys

Comparison of live storage capacity of SRS survey with original survey 1968, SRS survey 1996 and SRS Survey 2020 at various elevations is given below in table 4. Curve showing comparison of live capacity is drawn in figure 11.

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

Elevation (m)	Original Live Capacity (Mm^3) 1968	Cumulative live capacity by SRS survey (Mm^3) 1996	Cumulative live capacity by SRS survey (Mm^3) 2020
155.45	0.000	0.000	0.000
157.00	296.600	283.950	253.051
159.00	683.200	659.940	599.295
161.00	1084.100	1050.110	967.168
163.00	1504.400	1456.090	1355.965
165.00	1929.500	1878.060	1764.981
167.00	2382.000	2317.230	2193.513
169.00	2855.200	2774.990	2640.855
171.00	3335.100	3250.990	3106.302
173.00	3846.900	3742.940	3589.152
175.00	4371.100	4250.920	4088.698
177.00	4918.700	4774.910	4604.238
179.00	5496.800	5315.080	5135.066
179.83	5733.540	5544.63	5360.252

The original live storage capacity of Nagarjuna sagar reservoir in 1968 was reported as 5733.540 Mm^3. Results of present survey and previously conducted surveys are given in Table-4.

In the present study, it is found that live capacity of the Nagarjuna Sagar reservoir in 2020 is 5360.252 Mm^3 witnessing a live storage loss of 373.288 Mm^3 (i.e. 6.511%) in a period of 52 years during 1968 to 2020. This accounts for live capacity loss of 0.125% per annum since 1968.

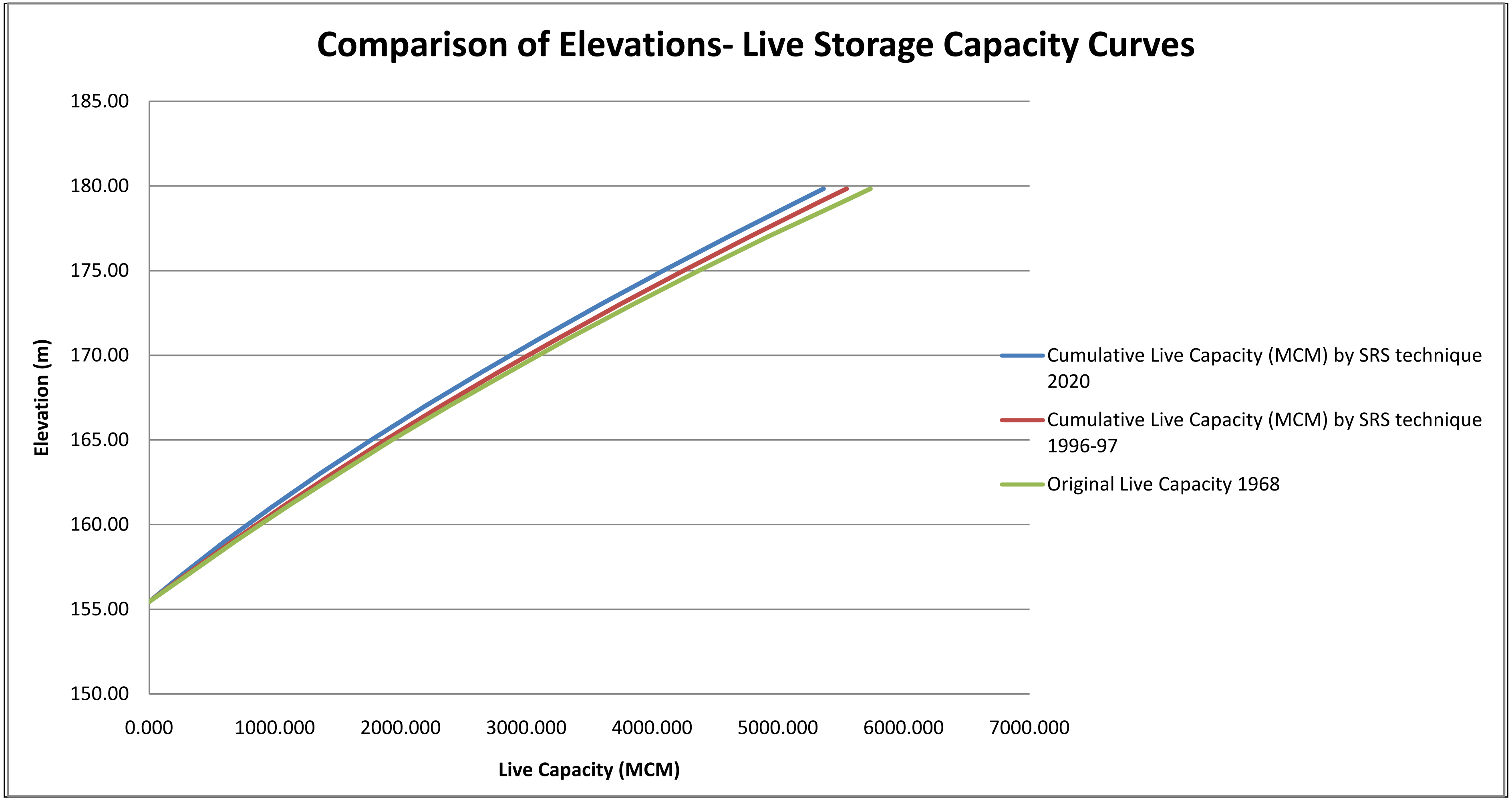


Fig. 11: Comparison of Elevation-Live Storage Capacity Curves (Mm^3)- Nagarjuna Sagar reservoir

10. RESULTS AND DISCUSSIONS

Table 10 shows the summary of the analysis done for Nagarjuna Sagar reservoir.

The loss in live storage capacity of the reservoir due to sedimentation since SRS Survey (1996) and remote sensing survey 2020 is given in Table –5.

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

	Original Survey (1968)	SRS (1996)	SRS 2020
Live Capacity (Mm^3)	5733.540	5544.630	5360.252
Loss in Capacity (Mm^3)) (since 1968)	-	188.91	373.288
% Live capacity loss (since 1968)	-	3.295%	6.511%
% Live Capacity loss between two consecutive surveys (of the original capacity)	-	3.295%	3.216%
Annual % live capacity loss	-	0.118%	0.125%
Annual % live capacity loss between two consecutive surveys	-	0.118%	0.134%

As per original survey conducted in 1968 the live storage capacity was 5733.54 Mm^3. In 1996 Remote Sensing survey the capacity was worked out as 5544.630 Mm^3. **The live storage capacity of Nagarjuna Sagar reservoir as per present study is found to be 5360.252 Mm^3 for the year 2020.**

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 Nagarjuna Sagar reservoir has been found to be 5360.252 Mm^3 in 2020.
2. Live storage loss of 373.288 Mm^3 (i.e. 6.511%) was observed since Original Survey (1968) i.e. in a period of 52 years. This accounts for live capacity loss of 0.125% per annum since 1968.
3. Satellite Remote Sensing (SRS) 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 live storage zone of reservoir 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 generally 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 -1

SALIENT FEATURES OF NAGARJUNA SAGAR DAM RESERVOIR

1. PROJECT LOCATION	Nandikonda(V), Pedavoora(M) Nalgonda District at a distance of 150 Km from Hyderabad
Latitude	16°34'24"N
Longitude	79°18'47"E
Stream	Krishna
2. RESERVOIR DATA	
Full Reservoir Level	179.832m (590.00 ft)
Maximum Water Level	181.051 m (594.00 ft)
Dead Storage Level	121.920m (400.00 ft)
MDDL(As per Nandikonda Project Report)	155.450m (510.00 ft)
Water Spread Area	285 Sq. Km.
3. PROJECT BASIN DESCRIPTION AND HYDROLOGY	
Catchment area at dam site	215185 Mm^2(83,083 sq. miles)
Maximum annual rainfall in the catchment	889mm
Maximum observed flood	30,050 cumec
Minimum dry weather flow	2.80 cumec
Design flood	58340 cumec
Routed flood	45310 cumec
4. MASONARY DAM	
Length of spillway dam	470.916m (1545 ft.)
Length of non-over flow dam	978.712 (3211 ft.)
Total length of Masonary dam	1449.628m (4756 ft.)
Maximum height of dam above deepest foundation	124.663m (409 ft.)
Top width of dam	8.534m (28 ft.)
Maximum base width of dam	97.536m (320 ft.)

Overall width of roadway at top	9.373m (30 ft. 9")
Deepest foundation level	59.71m (196.00 ft.)
Average river bed level	74.676m (245.00 ft.)
Spillway crest level	166.421m (546.00 ft)
Top of dam	184.404m (605.00 ft.)
Crest gates Chute sluices (operable upto +560 ft	26 Nos.of size 45'x44'(13.716m xl3.140m) 2 vents of size 10'x25' with sill at 137.16m
Diversion Tunnel (operable upto +560 ft)	(450') discharging 17,000 C/s at full gate Opening 2 vents of size 10'x25' with sill at 137.16m
Right Canal Head Sluice Left Canal Head Sluice	(450') discharging 20,000 C/s at full gate Opening 3 vents of size 10'x25' with sill at149.047m (489')

5. EARTH DAM

Length of Left Earth Dam	2560.32m (8400 ft.)
Length of Right Earth Dam	853.44m (2800 ft.)
Total length Maximum	3413.76m (11,200 ft.)

6. POWER GENERATION (River Bed Powerhouse)

Penstocks (8 numbers)	(30 ft. 6") 185.928m
	1 number conventional and 7 Nos. reversible with each 110MW Generation capacity

7. RIGHT CANAL POWER HOUSE

Units	3 Nos. conventional
Capacity	30 MW each
Discharging capacity	5000 Cusecs each

8. LEFT CANAL POWER HOUSE

Units	2 Nos.
Capacity	30 MW each

9. JAWAHAR (RIGHT CANAL AND LALBAHADUR (LEFT) CANAL

	Right Canal	Left Canal
Length of Main canal	203 km (126miles)	179 km (111miles)
Maximum bed width	73.5m (241 ft.)	29m (95 ft.)
Depth of flow (head reach	3.78m (12.4 ft.)	6.71m (22 ft.)
Maximum discharge	311.5 Cumec	311.5 Cumec
Head regular		
a) Sill level	149.05m (489 ft.)	149.05m (489 ft.)
b) Vent way	9 vents of 10ft x 15ft	3 vents of 10ft x 25ft
Length of branches and distributories	5342 km (3320miles)	7722 km(4800miles)
Length of field channels	14400 km(9000miles)	9654 km(6000miles)
Net Irrigable Area	0.47 million ha. (1.174 million acres)	0.42 million ha. (1.038 million acres)

PHOTOGRAPH OF RESERVOIR

Photo 1:Nagarjuna Sagar Dam

Photo 2: Nagarjuna Sagar Dam

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