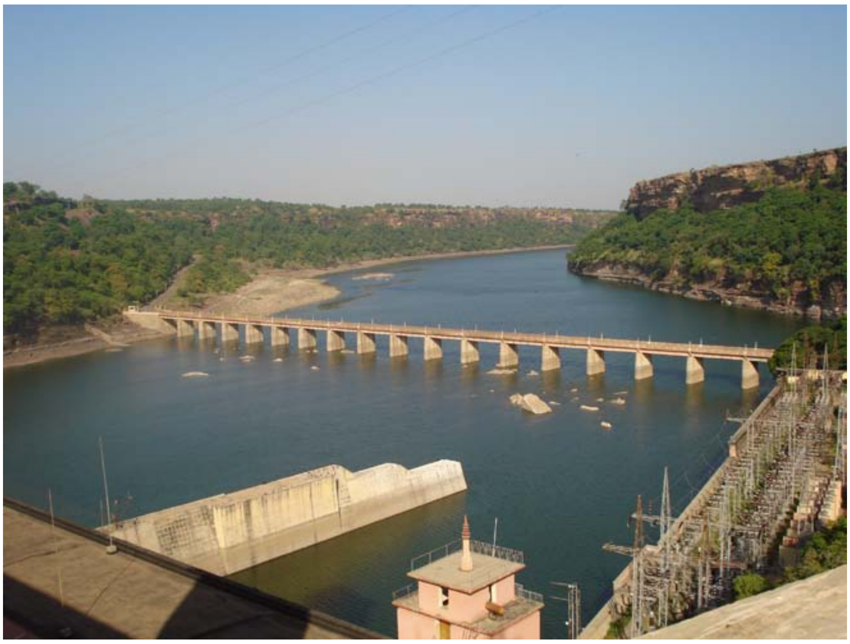
परियोजना शीर्षक

उपग्रह दूरस्थ संवेदन द्वारा गॉधी सागर जलाशय,मध्यप्रदेश का अवसादन आंकलन



सर्वेक्षण वर्ष

2015

अध्ययन टीम

पर्यवेक्षण

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PROJECT TITLE

SEDIMENTATION ASSESSMENT
OF
GANDHISAGAR RESERVOIR, MADHYA PRADESH THROUGH SATELLITE REMOTE SENSING

Year of Survey 2015
Data Used 2010- 2013

STUDY TEAM

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EXECUTIVE SUMMARY

The dynamic aspects of the reservoir, mainly water spread, suspended sediment distribution and concentration requires periodical mapping and monitoring. Sedimentation in a reservoir has a bearing on the capacity of the reservoir as it affects both live and dead storages. In other words, the life of a reservoir depends on the rate of siltation. The satellite data provides opportunity to study these aspects on various scales and at different stages. The present report comprises of use of satellite remotely sensed data for the years 2010-13 in the sedimentation study of Gandhisagar 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.

The original gross and live storage capacities were 7746 MCM & 6910 MCM respectively. As per WS&RS Dte, CWC report, Gandhisagar reservoir project work was completed in 1960 and Hydrographic Sedimentation surveys were conducted during 1975, 1989 and 2001 for this reservoir. The live storage capacity was estimated as 6669 MCM by Consulting Engineering Services (India) Pvt. Ltd. New Delhi in association with Sea Geo Surveys Pvt. Ltd. New Delhi in 2001.

After analysis of the satellite data in the present study, it is found that live capacity of the Gandhisagar reservoir in 2013 is 6513.21 MCM witnessing a loss of 396.79 MCM (i.e. 5.74%) in a period of 53 years during 1960 to 2013. This accounts for live capacity loss of 0.11% per annum since 1960.

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ABBREVIATIONS

DSL	Dead Storage Level
FCC	False Colour Composite
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
NRSA	National Remote Sensing Agency
SRS	Satellite Remote Sensing
N.A.	Not Available
NDVI	Normalised Difference Vegetation Index
WSA	Water Spread Area

UNITS USED

cumec	cubic metre per second
m	metre
million m^2	million square metre
million m^3 /MCM	million cubic metre
ha	hectare
Sq Km	Square Kilometre
mm/year	millimetre per year

SEDIMENTATION ASSESSMENT OF GANDHISAGAR RESERVOIR, MADHYA PRADESH THROUGH SATELLITE REMOTE SENSING

1 INTRODUCTION

Water is a scarce resource and is becoming even scarcer with the time. It is estimated that annual precipitation over India is 4000 BCM out of which available water is 1869 BCM. Utilizable water resources account for 1123 BCM only. Out of 1869 BCM available water resources, India has developed 253 BCM as live storage capacity and 51 BCM is under construction. For sustaining the needs of increasing population and environmental ecological needs of the country, we are fast approaching the scarcity situation even when we account for water availability and requirements in totality for the country as a whole. Out of total utilizable water resources about 690 BCM of surface water and 450 BCM of ground water per year is available for use through conventional structures. The country has 20 major river basins. A large number of reservoirs have been built during each plan on almost all river basins to tap the available surface water and to utilize it as and when needed.

The country is mainly dependent on the rainfall, which is most erratic in nature. However, 50% of the total utilizable surface water has been harnessed by way of constructing large, medium and small dams till date. Due to unfavourable distribution of fresh water both in time and space, storage reservoirs are effective tools for eliminating the discrepancies in time variations of the requirement and resources. Storage reservoirs play a vital role in serving long-term benefits in many ways. The reservoirs serve the purpose of water supply, irrigation, hydropower generation, flood control, recreation and various other purposes.

All our developmental plans have given high priority to water resources projects involving construction of dams and a large number of dams have been constructed since independence. The capacity of reservoirs is gradually reducing due to silting and hence sedimentation of reservoir is of great concern to 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 (DGFS). The conventional techniques are found either time consuming or costly and require considerable manpower. Remote sensing technique to calculate the present 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 Gandhisagar reservoir, Madhya Pradesh by Central Water Commission, New Delhi.

2. MECHANISM OF SEDIMENTATION

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

Characteristics of reservoir sedimentation include amount, distribution, configuration and composition of reservoir deposits. 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". In a general sense, a density current may be defined as a gravity flow, a fluid under, over, or through a fluid or fluids of approximately equal density. From Fig. 1 It may be seen that the depth of the turbid flow increases to the point where the density current is established after which it tends to decrease again (Varshney, 1997).

The magnitudes of these relative change and their effects upon sediments deposition depend on many factors such as reservoir shape, channel slopes, relation of outflow to inflow and density differences. As a rule, however, conditions are such that density currents move very slowly. In many respects deposits in a reservoir resemble those in a delta, made by stream where it discharges into a lake or sea. The deposits are (i) bottom set beds consisting of the fine sediments brought in by the stream, (ii) the forest beds formed of the coarser sandy sediments, (iii) top set beds consisting of coarser particles and (iv) density current deposits.

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.

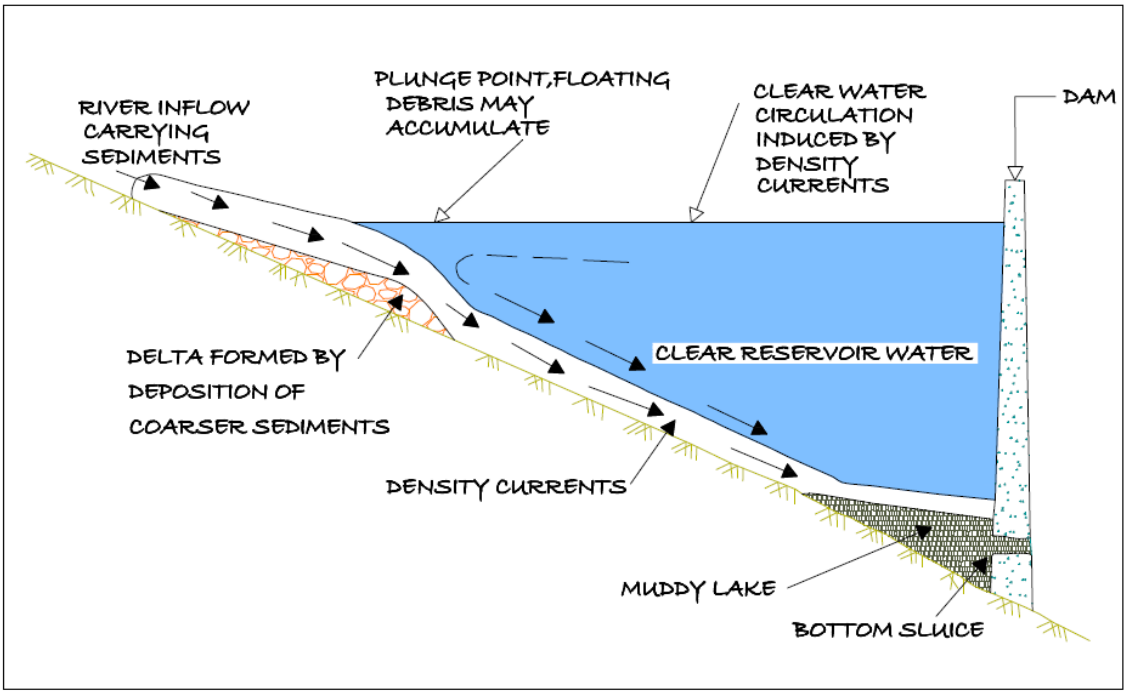


Fig. 1: Conceptual sketch of density currents in a reservoir

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.

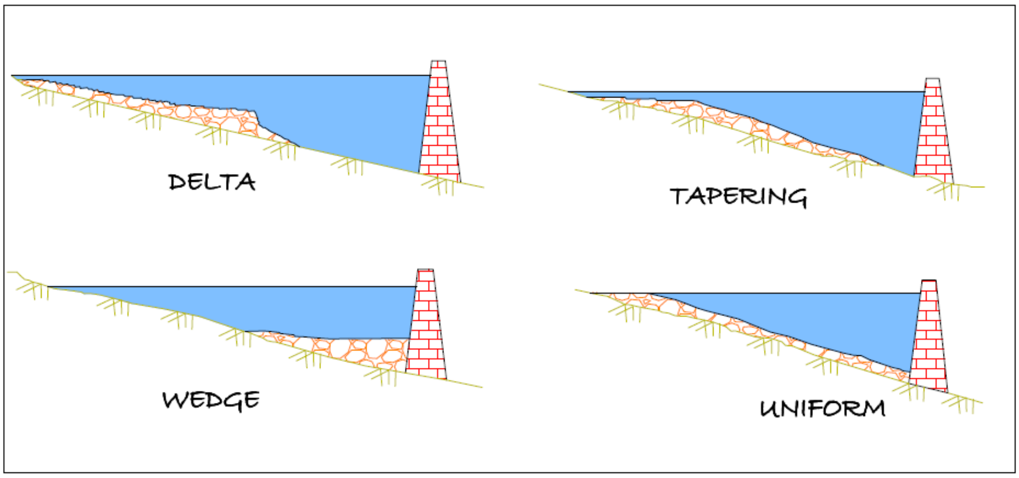


Fig. 2: Longitudinal Patterns of sediment deposition in reservoirs.

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.

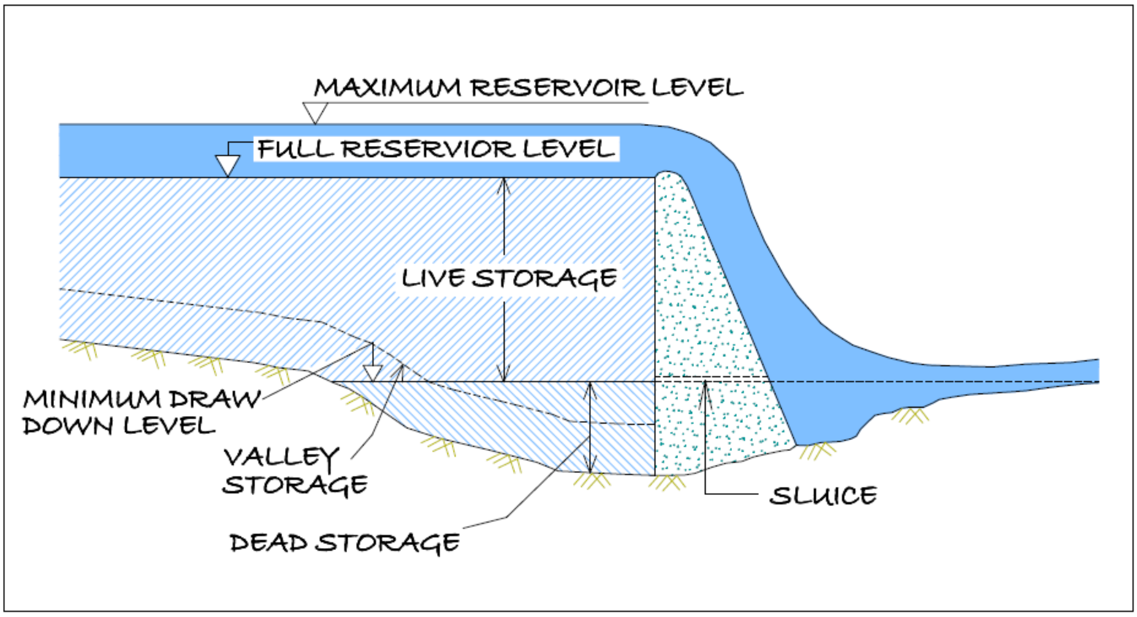


Fig. 3: Conceptual sketch of different levels in a reservoir

3. SOURCES OF SEDIMENTS

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

4. 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.

5. 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 more useful for mapping and monitoring the surface water bodies and other land resources based on which, better water management strategies could be planned. Water is one of the most easily delineable features on the satellite data due to high contrast between land and water bodies in NIR band. Water absorbs all the incident energy in NIR region depending upon nature and status of water body. Land features reflect more energy in NIR region. The Figure 4 shows the reflectance curves for clear and turbid water categories.

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.

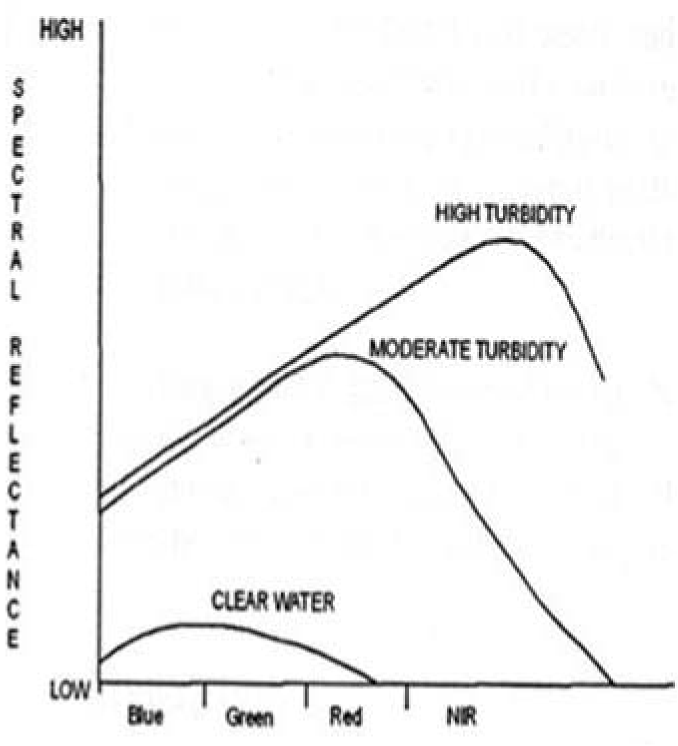


Fig. 4: Reflectance curves for Clear and Turbid water

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 also poses limitation in the analysis. This is overcome by combining data from different water years to get full operative range. This technique gives accurate estimates for fan shaped reservoir where there is a considerable change in water spread area with change in water level.

6. OBJECTIVES

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

a. Updation of Elevation - Area - Capacity curve using satellite data in live storage zone.

b. Estimation of storage loss due to Sedimentation

7. STUDY AREA

The Gandhisagar reservoir, one of the first major reservoirs of the State of Madhya Pradesh (M.P.), is the uppermost dam in a series of three dams (Gandhisagar, Rana Pratap Sagar and Jawahar Sagar) and a barrage (Kota barrage) of Chambal Valley Project. The dam was a joint venture of the States of M.P. and Rajasthan, which, was completed in the year 1960. It is the main storage dam constructed across river Chambal, intercepting a catchment area of about 23025 sq.km. The dam serves as a backup storage for power generation in Gandhisagar, Rana Pratapsagar and Jawaharsagar dams and irrigation through canal systems taking off from Kota Barrage. The dam is 64.63 m high straight gravity masonary type with installed capacity of 115 MW and irrigation potential of 7.57 lakh ha.The index map of the reservoir is shown in Figure – 5.

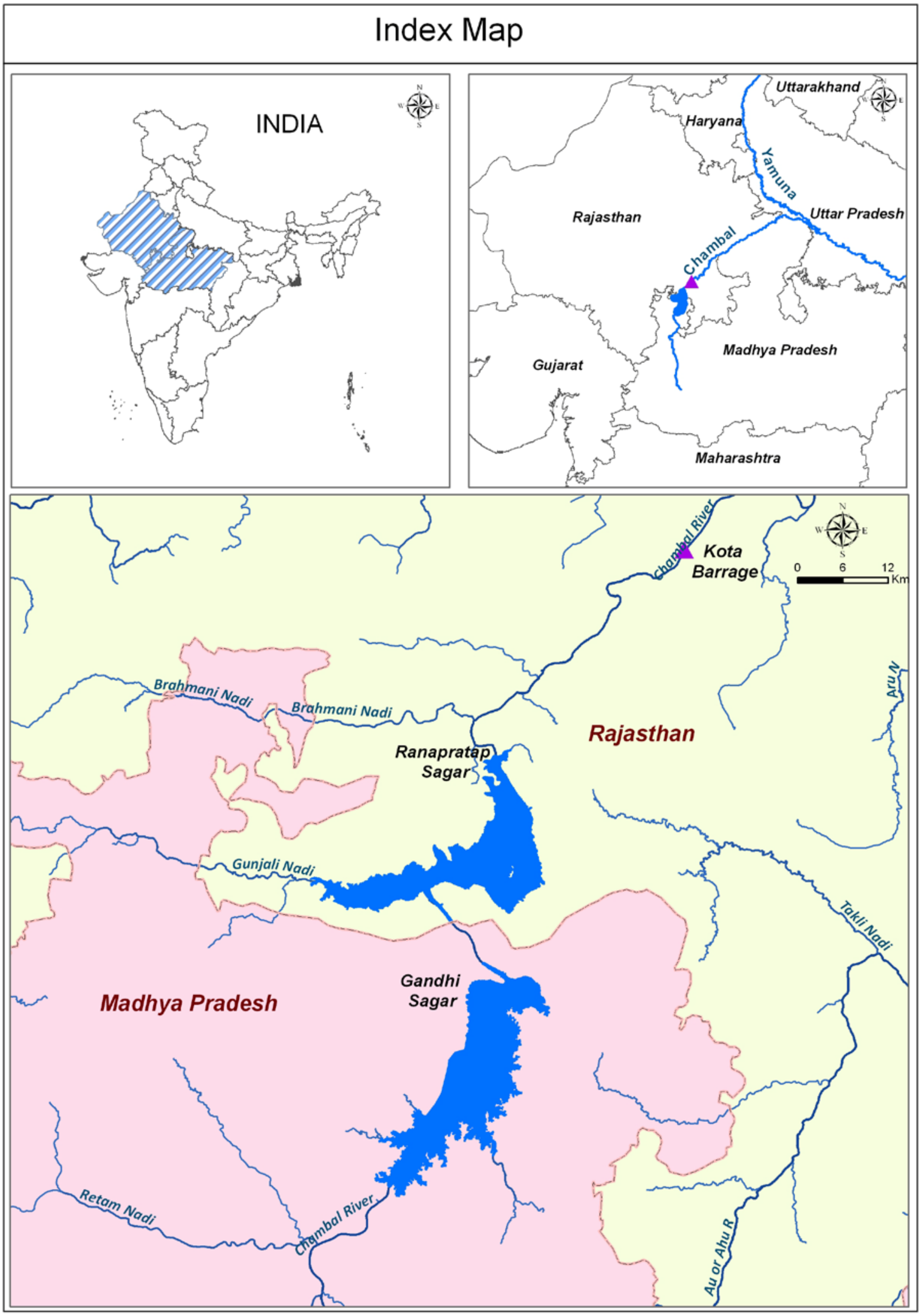


Fig. 5: Index map of the Gandhisagar Reservoir

8. PREVIOUS SURVEYS

Gross storage capacity of Gandhisagar dam was originally assessed at planning stage from toposheets as 8450 M cum, with full reservoir at 400 m (1312 ft). Subsequently, the gross storage was revised based on aerial photographs and contour surveys conducted in 1961 by Survey of India, the gross storage was refixed at 7746 M cum. In all subsequent publications, above gross storage is considered as original gross capacity.

The hydrographic capacity surveys for Gandhisagar reservoir were conducted earlier in 1975 and 1989. The latest hydrographic survey was conducted in 2001 by Consulting Engineering Services (India) Pvt. Ltd. New Delhi in association with Sea Geo Surveys Pvt. Ltd. New Delhi which estimated the total sedimentation upto 2001 A.D. at 520 M.Cum. upto FRL. According to that report, the gross capacity has reduced 6.71% in 41 years from 7746 M.Cum to 7226 M.Cum .The live storage was 6669 M.Cum.

The surveys conducted by various methods from time to time have indicated progressive reduction of storage capacity as under :

Period of Project	Planning Stage	Gross capacity (M. Cum)	Live Storage Capacity (M.Cum)	Dead Storage Capacity (M.Cum)
	Planning Stage	8450	-	-
1960-61	Base Surveys	7746	6910	836
1975	Sedimetation Surveys	7413	6827	586
1989	Sedimetation Surveys	7323	6798	525
2001	Sedimetation Surveys	7226	6669	557

Dead Storage provision of 836 MCum has been made at the planning stage with Dead Storage level at RL 381 m . Entire provision for sedimentation was made in the dead storage zone exclusively provided upto RL 381 m. Minimum drawdown level has been kept at 381 m.

9. 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 Gandhisagar reservoir, the height difference between FRL (399.89 m) and MDDL (381 m) is 18.89 m and the use of satellite remote sensing in the present study has been restricted in live storage.

10 DATA USED

10.1. SATELLITE DATA

IRS P6- LISS III data for eight (08) dates has been used in the analysis. Table 1 depicts the Path and Row index along with date of pass of satellite.

Table – 1: Date of pass for satellite data

Satellite	Path	Row	Shift	Date of pass	Elevation (m)
IRS-P6 LISS III	95	54	50%	21st Oct, 2012	398.48
IRS-P6 LISS III	95	54	50%	01st Jan, 2013	397.00
IRS-P6 LISS III	95	54	50%	25th Jan, 2013	396.04
IRS-P6 LISS III	95	54	50%	07th Apr, 2013	394.08
IRS-P6 LISS III	95	54	50%	25th May, 2013	392.92
IRS-P6 LISS III	95	54	50%	19th Mar, 2012	389.97
IRS-P6 LISS III	95	54	50%	30th May, 2012	387.21
IRS-P6 LISS III	95	54	50%	19th Dec, 2010	383.88

10.2. FIELD DATA

The following field data has been obtained from project authorities:
Elevation – Area - Capacity data (Original and 1989 survey)
Salient features of Gandhisagar reservoir, reservoir levels on specified dates

11. 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. Digital image analysis using Image Processing System on computer mainly, edge enhancement ratios (B/NIR. B/R, R/G), principle component (PC) and classification were found very good for mapping water spread, turbidity levels and surgical aquatic vegetation. For Gandhisagar reservoir studies, multi-date IRS– P6 LISS III data (06 nos. imageries) is used for the analysis. Image processing with ERDAS imagine software was used for the analysis. The analysis comprised,

- Data base geo-referencing.
- Water spread area estimation.
- Estimation of reservoir capacity.
- Comparison with previous surveys.

The methodology adopted in this analysis is shown in the flow chart (Fig6).

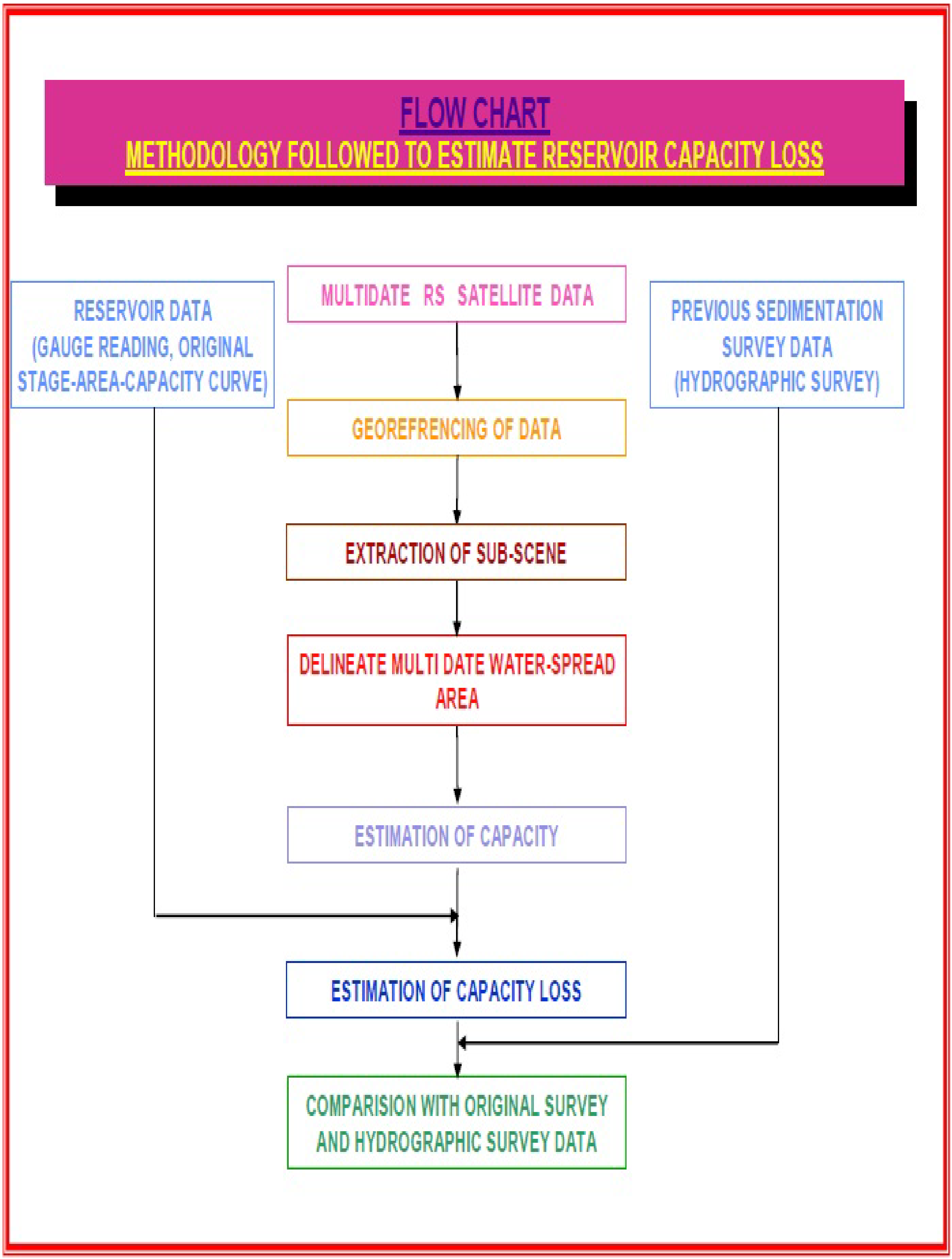


Fig 6 : Flow chart showing methodology followed to estimate reservoir capacity loss

11.1. DATA BASE GEO-REFERENCING

The satellite data corresponding to reservoir area obtained from NRSC DATA CENTRE was loaded on the system. The scene of 21st Oct, 2012 was taken as reference image for all other seven images for geo-referencing using image-to-image registration techniques. The geo-referenced images for all eight different dates pertaining to study area were used for further analysis.

11.2. 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. Various techniques adopted for water-spread area estimation are as follows:

- Generation of False Color Composite (FCC) and analysis of histogram
- Thresholding and modeling

11.2.1. GENERATION OF FCC AND ANALYSIS OF HISTOGRAM

FCC is generated from three spectral bands of satellite data, generally NIR, Red and Green bands, where water features appear in shades of black and blue depending upon depth and turbidity. Histogram, which is graph between grey values and the frequency of occurrence, is plotted for individual bands. NIR band information is more useful in identification of WSA. The spectral separability between features is more in NIR band. The water pixels are identified and range of grey values is recorded. Under normal conditions when there is no effect of cloud and shadow, water generally occupies lower range of histogram.

11.2.2. THRESHOLDING AND MODELLING

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 analyst 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. Thresholding can be performed on single and or combination of bands. Band ratioing is the technique of enhancing a particular feature or class from the satellite data. Different ratio indices are available to enhance water, vegetation, soil etc. Normalised Difference Vegetation Index (NDVI) is one such index, which enhances vegetation and water.

For estimation of water spread area of Gandhisagar reservoir, use of NDVI has been made. NDVI has been generated using 8-Bit unsigned channel with the help of formula given below:

$$NDVI = (NIR - R) / (NIR + R)$$

Where 'NIR' is digital number in near infrared band and 'R' is digital number in red band. The rationed image is then density sliced. Water pixels generally occupy lower range of histogram in ratioed image.

Table 2 shows Range of NDVI (digital number) for water body delineated and noted for different imageries of Gandhisagar Reservoir as per date of pass.

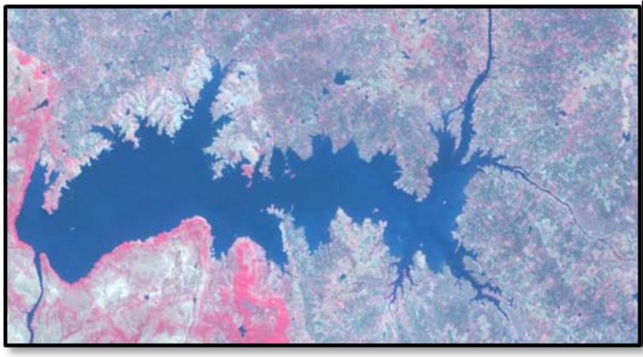
Table – 2: Range of NDVI for satellite data

Date of pass	Range of NDVI (Threshold values)	
	Minimum	**Maximum**
21st Oct, 2012	-0.466667	-0.150102
01st Jan, 2013	-0.392405	-0.168798
25th Jan, 2013	-0.476923	-0.131339
07th Apr, 2013	-0.476923	-0.0449425
25th May, 2013	-0.401869	-0.141173
19th Mar, 2012	-0.551724	-0.274311
30th May, 2012	-0.375	-0.153024
19th Dec, 2010	-0.55102	-0.106763

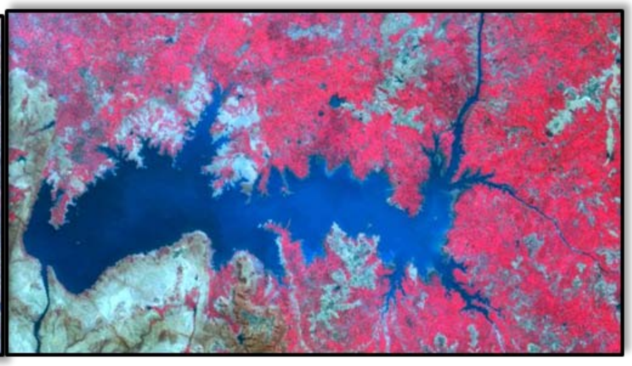
Using the above range of values, Water spread areas are extracted for all the scenes. Figure 7 shows FCC's of different dates and figure 8 shows the superimposed reservoir water spreads for different dates. Water spread area has been calculated by multiplying number of pixels with area of each pixel (23.5m x 23.5m). The water-spread area estimated from Satellite Images for different dates corresponding to the levels are shown in Table 3.

Table – 3.: Water Spread Areas estimated from Satellite Images

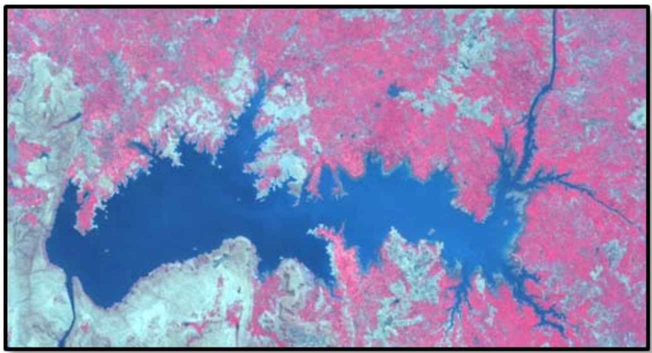
Date of pass	**Elevation (m)**	**Area (Million m^2)**
21st Oct, 2012	398.48	588.127
01st Jan, 2013	397.00	526.946
25th Jan, 2013	396.04	509.820
07th Apr, 2013	394.08	446.378
25th May, 2013	392.92	398.292
19th Mar, 2012	389.97	310.531
30th May, 2012	387.21	266.496
19th Dec, 2010	383.88	182.016



21-Oct-2012 (398.483m)

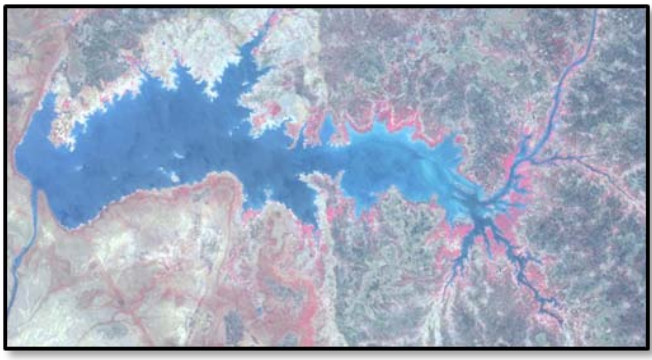


01-Jan-2013 (397.002m)

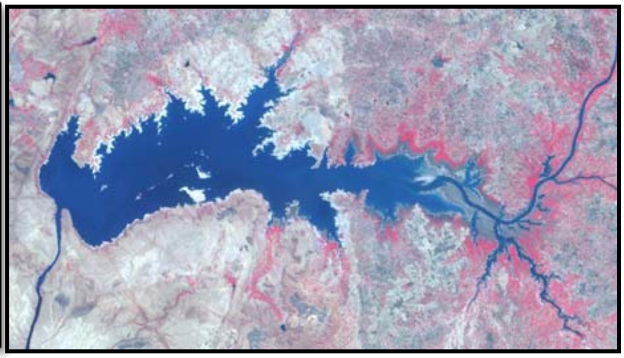


25-Jan-2013 (396.045m)

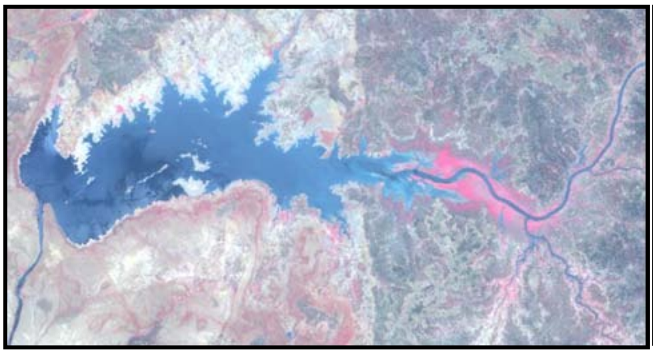
07-Apr-2013 (394.082m)



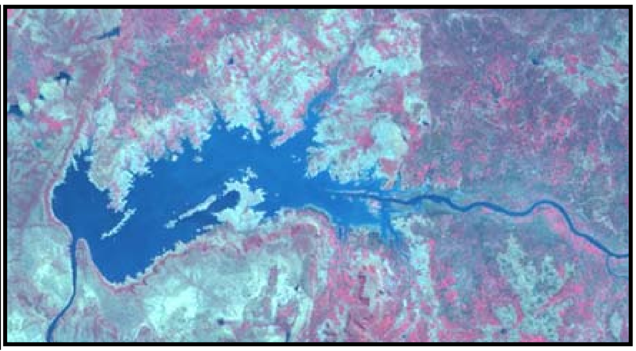
25-May-2013 (392.918m)



19-May-2012 (389.970m)



30-May02012 (387.212m)



19-Dec-2010 (383.880m)

Fig 7 : False Colour Composites(FCCs) showing water spreads at different dates

The water elevation 398.48 for 21st Oct, 2012 is near the Full Reservoir Level (FRL) of 399.89 and water elevation 383.88 m for 19th Dec, 2010 is well above the Minimum Draw Down Level (MDDL) of 381.00 m.

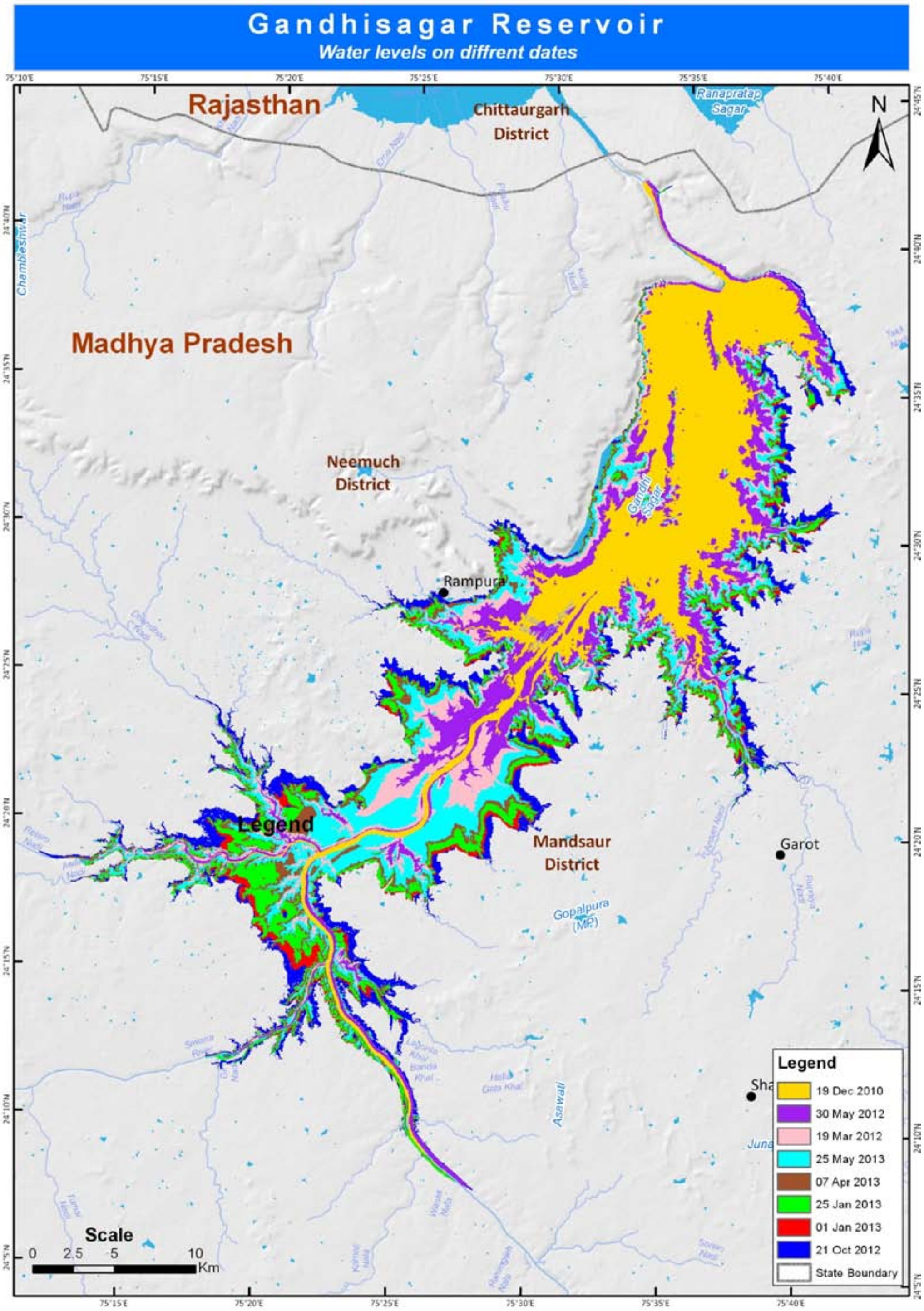


Fig. 8: Gandhisagar Reservoir area FCC'S on different date

11.3. ESTIMATION OF RESERVOIR CAPACITY

Area elevation curve has been plotted using these above eight (08) water-spread areas for different water level in the reservoir and a best-fit polynomial equation of second order as given below has been derived.

$Y = 0.6032*X^2 – 444.44 * X + 81900$

$R^2 = 0.9965$

Where X is Elevation in meters

Y is Water Spread Area in Million m^2

Elevation - area curve using this equation has been plotted and shown in Fig-9. 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.

Table 4 gives the values of Live storage capacity and submergence areas at a regular interval of 1.0 m have been worked out using this best-fit polynomial equation at different elevations.

The modified elevation – area –capacity curves are plotted and shown in Fig-11.

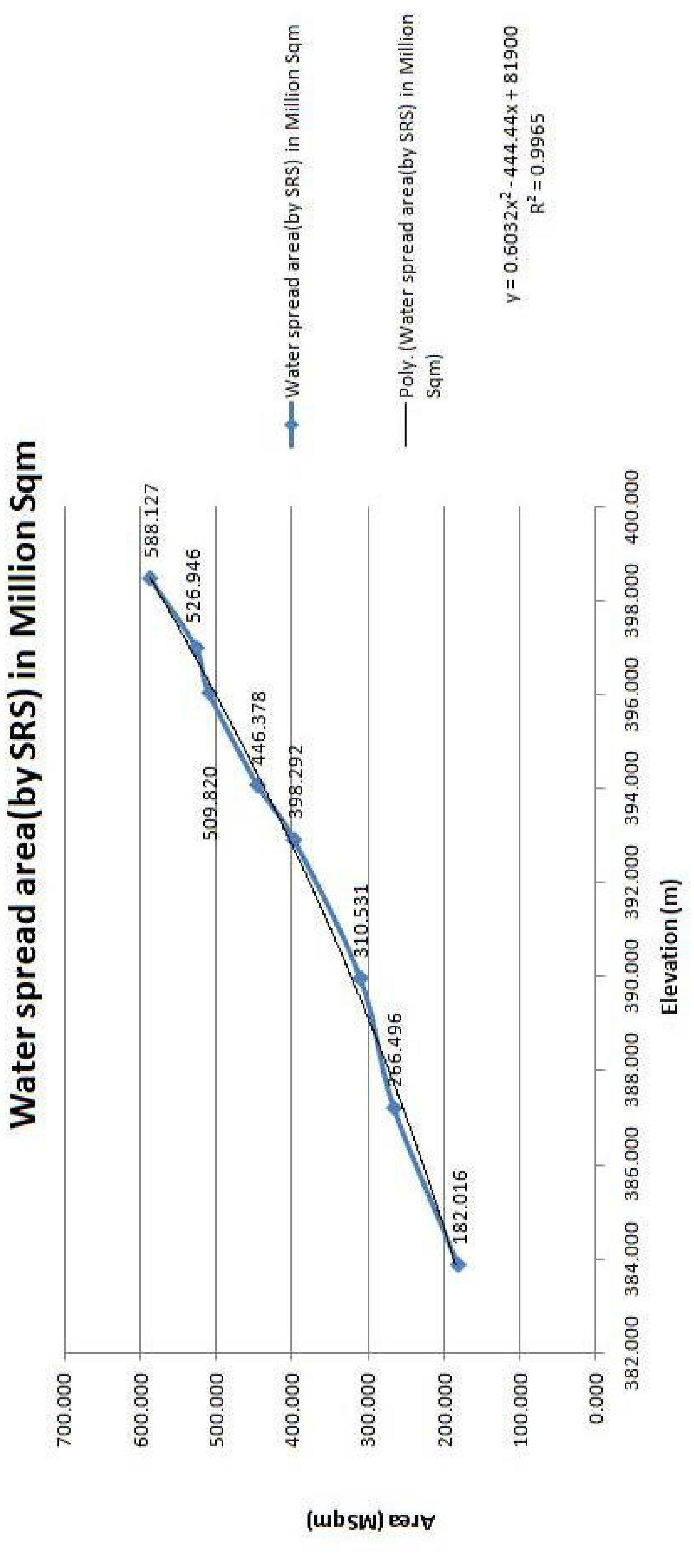


Fig. 9: Water spreads of Gandhisagar Reservoir

Table-4: Aerial extent of reservoir at regular interval (1.5m) using SRS Survey 2010

Reservoir water level in Metre		Water spread area by trend line	Segmental Live Capacity (Mcm) by SRS technique	Cumulative Live capacity (Mcm) by SRS technique
MDDL	381	129.475	0	0
	382	145.277	137.300	137.300
	383.5	171.241	237.122	374.422
	385	199.920	278.093	652.516
	386.5	231.313	323.139	975.654
	388	265.421	372.257	1347.912
	389.5	302.243	425.449	1773.361
	391	341.779	482.713	2256.073
	392.5	384.030	544.049	2800.123
	394	428.995	609.458	3409.580
	395.5	476.675	678.939	4088.519
	397	527.069	752.491	4841.010
	398.5	580.177	830.116	5671.126
FRL	399.89	631.814	842.079	6513.205

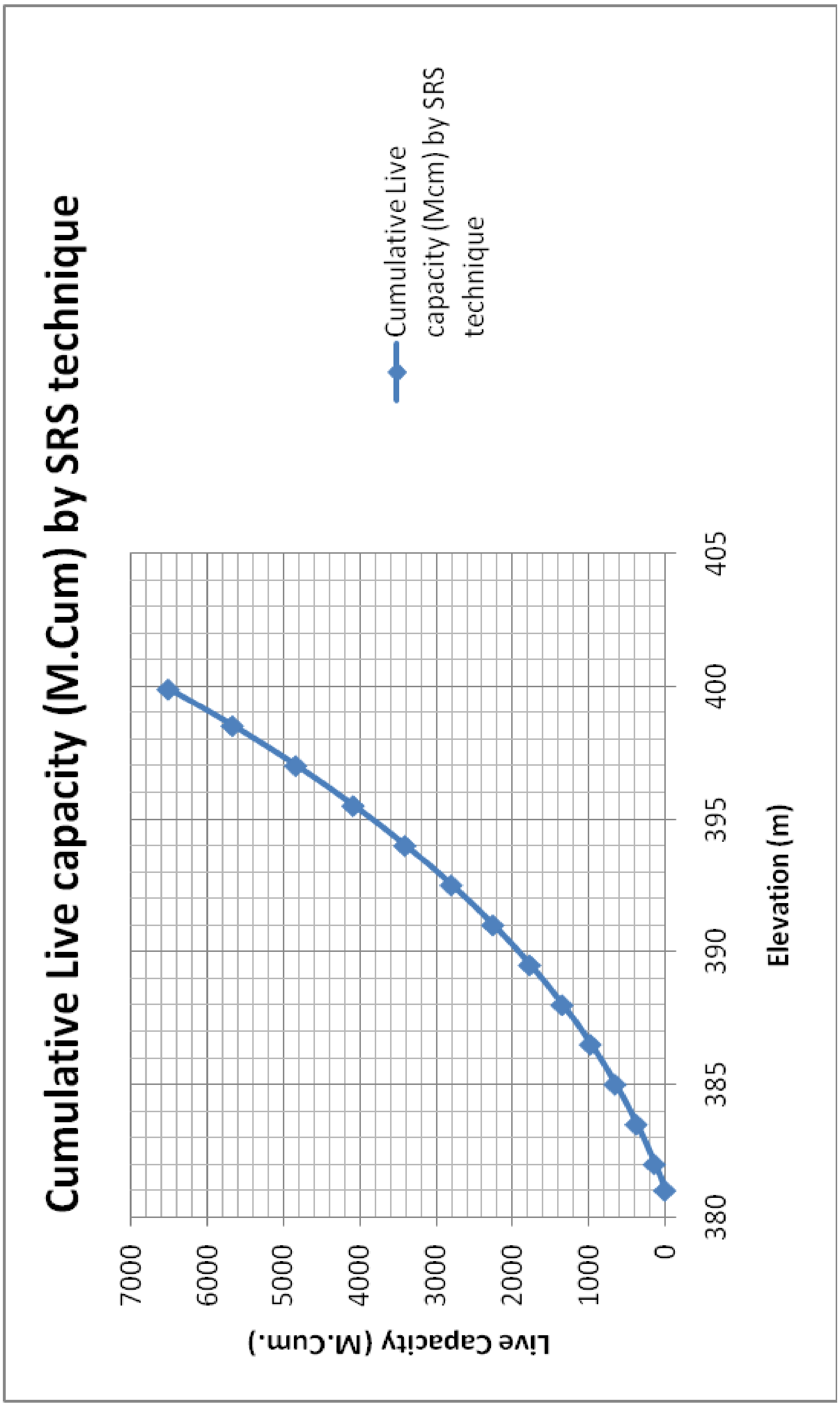


Fig. 10 : Modified live capacity - elevation curve (SRS technique)

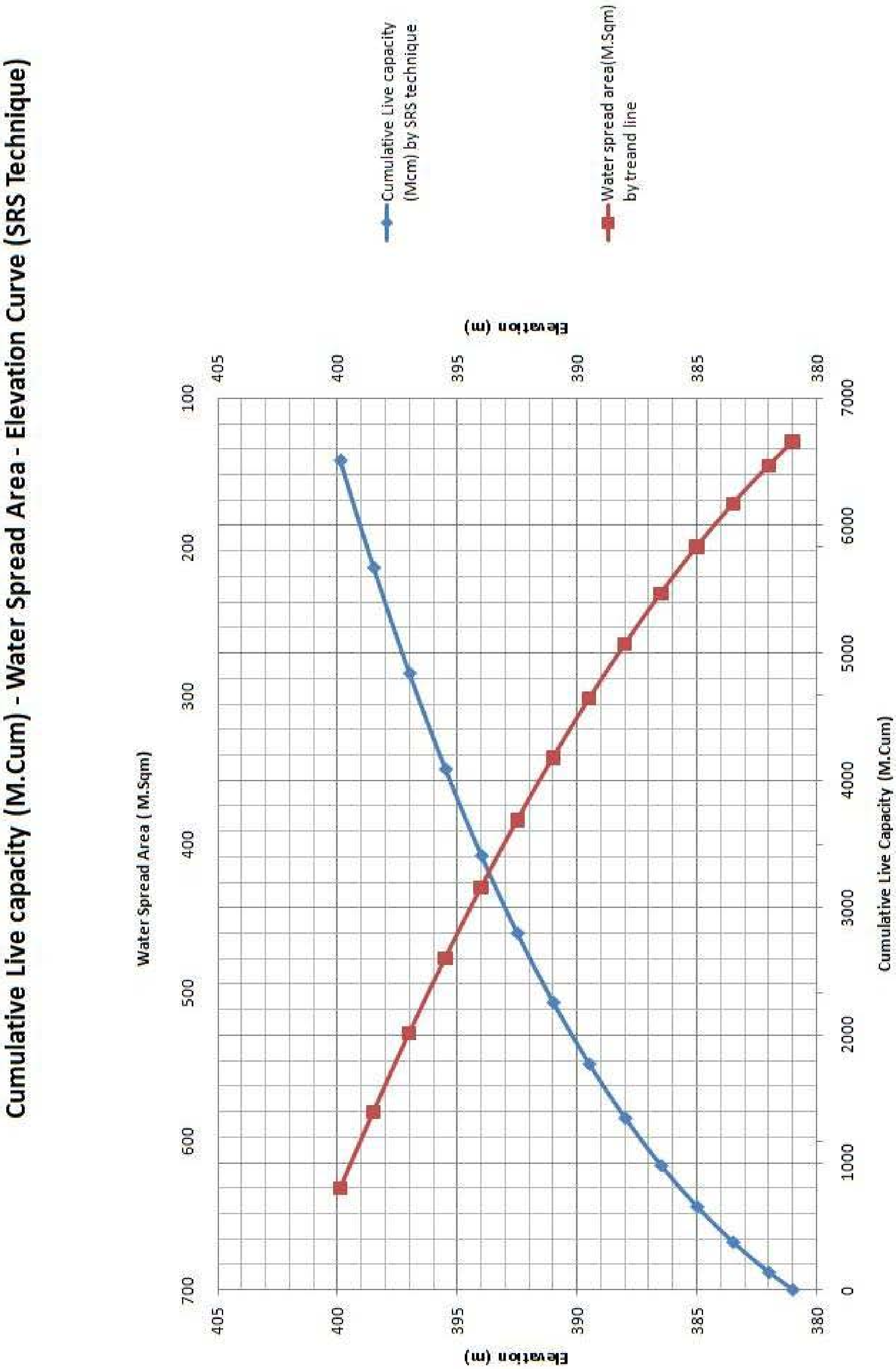


Fig. 11 : Elevation – Area- Capacity Curve

11.4. COMPARISON WITH ORIGINAL SURVEY

Table-5 & 6 as given below show the comparison of water spread areas and live storage capacity of SRS survey with original at various elevations respectively. Curve showing comparison of water spread areas and live capacity of SRS survey with previous survey is drawn in Figure- 9 & 10.

Table -5: Comparison of Water Spread Areas (Million m^2)

	Elevation (m)	**Area (Original) (Sq Km)**	**Area (SRS)**
MDDL	381	138	129
	382	155	145
	383.5	189	171
	385	218	200
	386.5	248	231
	388	281	265
	389.5	317	302
	391	356	342
	392.5	398	384
	394	446	429
	395.5	496	477
	397	549	527
	398.5	605	580
FRL	399.89	680	632

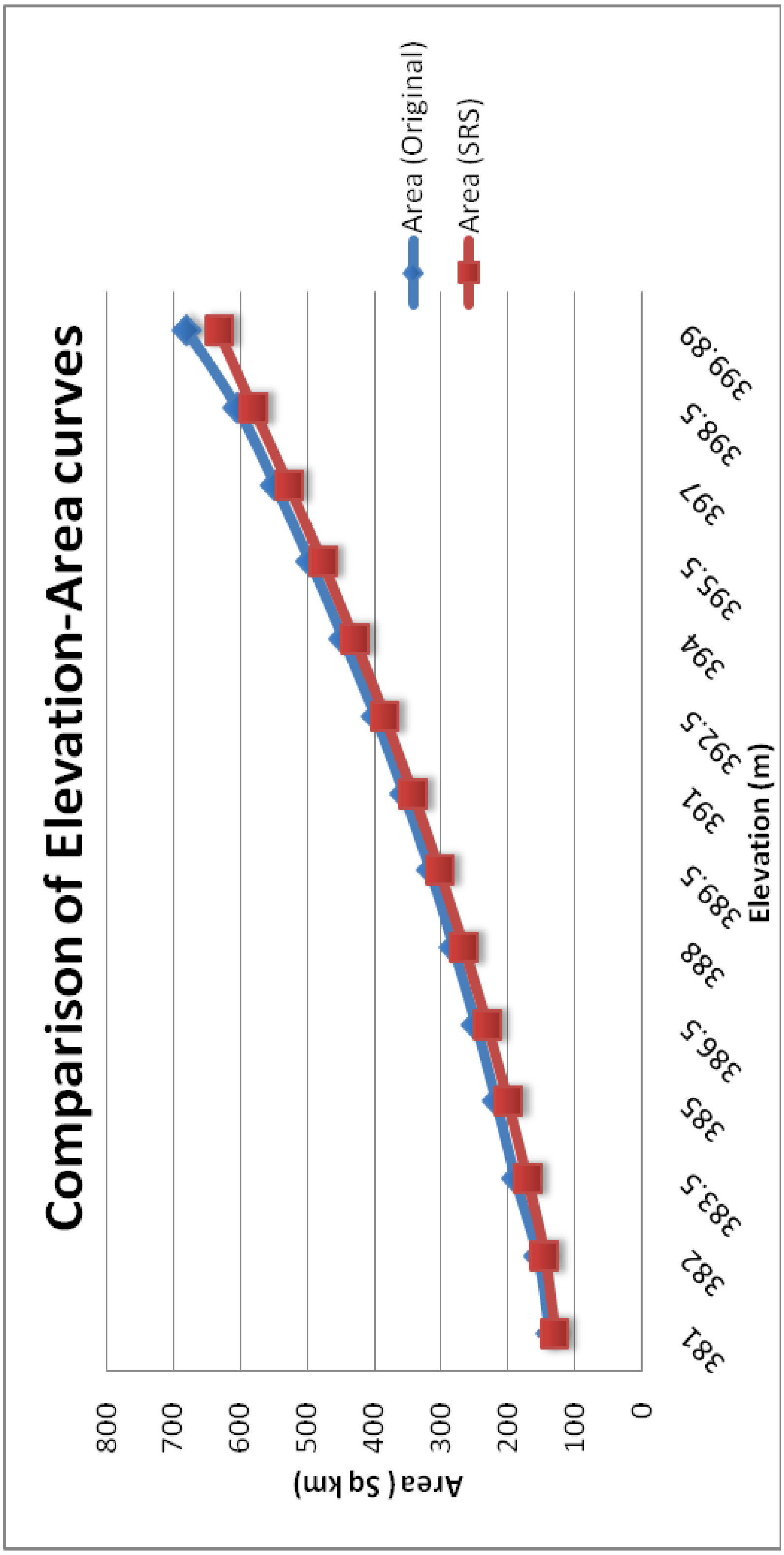


Fig. 12 : Comparison of Elevation – Area Curves

Table -6: Comparison of Live Storage Capacity (Million m^3)

	Elevation (m)	Live Capacity (Original) 1960	Live Capacity (Hydro graphic survey) 2001	Live Capacity (SRS) 2013
MDDL	381 (MDDL)	0.000	0.000	0
	382	144.019	138.239	137.300
	383.5	432.018	402.589	374.422
	385	720.773	682.819	652.516
	386.5	1078.363	1022.809	975.654
	388	1480.061	1405.339	1347.912
	389.5	1922.678	1832.849	1773.361
	391	2417.403	2308.889	2256.073
	392.5	2975.046	2847.909	2800.123
	394	3632.585	3461.549	3409.580
	395.5	4350.990	4149.019	4088.519
	397	5140.211	4908.179	4841.010
	398.5	6011.410	5772.589	5671.126
FRL	399.89 (FRL)	6910.000	6668.739	6513.205

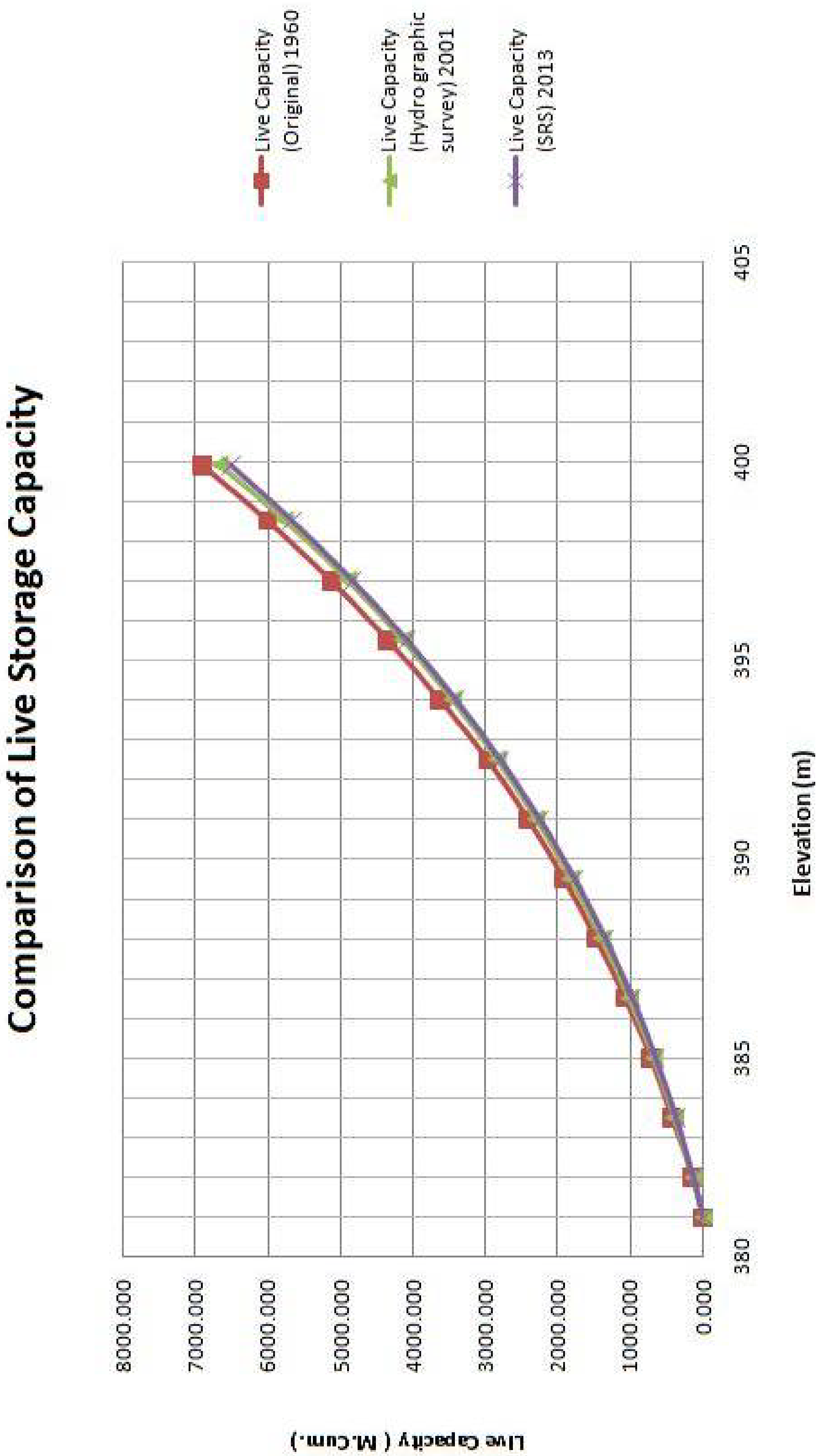


Fig 13: Comparison of Elevation - Live Storage Capacity curves (Million m^3)

12 RESULT AND DISCUSSIONS

The loss in live storage capacity of the reservoir due to sedimentation since original survey has been shown in Table 7.

Table-7: Live storage capacity loss due to sedimentation

Details	Original (1960)	SRS (2013) CWC
Live Capacity in Million m^3	6910	6513.21
Loss in live capacity in Million m^3	-	396.79
% Live capacity loss (since 1960)	-	5.742
Annual % live capacity loss	-	0.108

13 CONCLUSION

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

- The live storage capacity of Gandhisagar reservoir has been found to be 6513.21 Million m^3 in 2013 against the original live storage capacity of 6910 Million m^3 in 1960.

There is a live capacity loss of 396.79 M cum in 53 years which is 5.742 % of original live capacity. Annual live capacity loss is 0.11%.

14 LIMITATIONS

As the reservoir operates in between DSL and FRL, the satellite data is available for this region only. The satellite remote sensing based reservoir capacity estimation works between DSL 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.

Data from two to three water years was combined to get the required data set.

General error can creep in the identification of tail end of reservoir, particularly in the rainy season.

SALIENT FEATURES **Annexure-I**

1.	**Name of Reservoir**	Gandhisagar
2.	**Location**:	
	a. District	Mandsur near Chaurasigarh
	b. State	Madhya Pradesh
	c. Longitude	75^0 33' E
	d. Latitude	24^0 44' N
	e. Year of commencement	1954
	f. Year of completion	1960
	g. Year of Impoundment	1960
3.	**Average Annual Rainfall**	860 mm
4.	**Type**	Straight Gravity Masonry
5.	**River** (on which located)	Chambal
6.	**Year of First Impounding**	1960
7.	**Total catchment area** up to dam site	23025 Sq Km
8.	**Salient Levels**:	
	i. Maximum Water Level	399.89m
	ii. FRL	399.89 m
	iii. MDDL	381.00 m
9.	**Designed storage capacity**	
	i. Gross Storage	7746.0 MCM
	ii. Live Storage	6910.0 MCM
	iii. Dead Storage	836.0 MCM
10	**Total Water spread area at FRL**	680 sq Km
11	**(a) Dam Details**	
	(i) Length of dam at top	514 m
	(ii) Max. Height	63.70 m
	(iii) Top width	11.73 m
	(b) Spillway	
	(a) Length of Spillway	182.88m
	(b) **S**ize of gates (10Nos.)	18.3m x 8.54m
	(c) Mode of energy dissipation	Ski-jump bucket with 42.67m (140 ft radius)

Annexure II

Ground Truth Photographs

Photo 1: Spillway of Gandhisagar Dam and Power House as seen from downstream

Photo 2 : Statue of Chambal Mata – Symbol of cooperation between MP and Rajasthan, erected on the left bank of Gandhisagar Dam.

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