उपग्रह दूरस्थ संवेदन द्वारा
नंदिनी जलाशय, झारखंड का अवसादन आंकलन

Sedimentation Assessment of Nandini Reservoir, Jharkhand, through Satellite Remote Sensing

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FOREWORD

Acknowledgement

The Project Team is thankful for the guidance provided by Chief Engineer (EMO), CWC, and Director, Remote Sensing Directorate, CWC, New Delhi in completing the work "Sedimentation Assessment Study of Thirty (30) Reservoirs in India through Remote Sensing Technique" and in particular the present study of Nandini Reservoir.

The project team is thankful to the Secretary (CAD), Water Resources Department, Government of Maharashtra for his keen interest and constant encouragement in completion of this study. Our special thanks are due to Shri. R. V. Panse, Director General, MERI and Shri. R. V. Shrigiriwar, Superintending Engineer, MERI for their valuable support and motivation for carrying out this work.

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PROJECT TEAM

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Abbreviations

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

Units Used

ha	Hectare
km	Kilometre
m	Metre
Mm^2	Million square metre
Mm^3	Million cubic metre
sq km	Square kilometre

EXECUTIVE SUMMARY

Water resources sector has got high priority in all our developmental plans and accordingly large numbers 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 storages 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. Ministry of Water Resources, River Development and Ganga Rejuvenation, 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 Thirty (30) Reservoirs in India through Remote Sensing Technique". The present study is in regard to Nandini Reservoir, Jharkhand, India.

Present study aims in updating the elevation-area-capacity curve of Nandini Reservoir, Jharkhand, and finding the capacity loss due to sedimentation in live storage. For carrying out the analysis, IRS P6 and Resourcesat 2 LISS III data with 23.5 m resolution have been used. Satellite data for five passes falling between RL (670.30 m) and FRL (674.69 m) are used for the analysis.

The Nandini Dam is located on the Nandini River. The dam site is located near Khwash Amba village in block Bhandara of Lohardaga district. The dam is constructed in 1988. The project has designed gross reservoir capacity of 19.284 Mm3, with live capacity of 16.704 Mm^3.

This study reveals that the present live capacity of reservoir is reduced by 5.50 Mm^3 witnessing a loss of 32.91 % in a period of 28 years from year 1988. This amounts to 1.18 % loss per annum in live storage since the impoundment.

SEDIMENTATION ASSESSMENT OF NANDINI RESERVOIR, JHARKHAND, THROUGH SATELLITE REMOTE SENSING

1. Introduction

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 agencies. Silting encroaches in dead as well as live capacity of the reservoir. This reduction in capacity has both long and short-range impact on the functioning of the project and on economics. Sedimentation adversely affects irrigation planning, power generation, drinking water supply and flood moderation. Correct assessment of sedimentation rate is essential for estimating useful life of the reservoir and preparing reservoir operation schedule. Since 1958, when it was established that the live storage of the reservoir is getting reduced due to siltation, a systematic effort has been made by agencies to evaluate the capacity of reservoir. The conventional technique like boat echo sounder has been replaced by hydrographic data acquisition system (HYDAC) and HITECH method using Differential Global Positioning System (DGPS). The conventional techniques were time consuming, costly and requiring considerable manpower. In this context the remote sensing technique to evaluate the present reservoir live capacity is found very useful, due to its synoptic and repetitive coverage. Further the surveys based on remote sensing data are faster and economical.

Impact of sedimentation on multipurpose reservoir is more significant. In some of the reservoirs, the rate of sedimentation has been higher than what has been considered at the planning stage. Some reservoirs in the world have been silted up so fast that they have lost large capacity. Many of the reservoirs in India are losing capacity at the rate of 0.2 to 1 percent annually. Therefore, it has become necessary to conduct sedimentation survey of the existing reservoirs. This will also make data available for deriving siltation indices of different regions and river basins on which the future design of reservoirs can be planned. These surveys also help in selection of appropriate measures for controlling sedimentation, efficient management and operation of reservoirs. Recent observations have brought to light the alarming fact that the reservoir sedimentation resulting from watershed degradation is much higher than the designed rate of erosion.

Appreciating the importance of sedimentation problems the Government of India constituted a Working Group of National Action Plan for reservoir sedimentation assessment. Accordingly, on recommendations of the Group, the Ministry of Water Resources, Government of India formulated a list of reservoirs to be taken up in X^{th} five year plan for sedimentation assessment.

The present report deals with the study of Nandini Reservoir, Lohardaga district of Jharkhand State. This work is carried out for Central Water Commission New Delhi under the project "Sedimentation Assessment Study of 30 (Thirty) Reservoirs in India through Remote Sensing ".

2. Mechanism of Sedimentation

In order to obtain the knowledge of sedimentation in the reservoir, it is necessary to study the mechanism of sedimentation. The objective of such study is to mitigate reservoir sedimentation thereby prolong the life span of reservoirs and take full benefits of reservoirs. Characteristics of reservoir sedimentation include quantity, distribution and composition of sediment 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 gravity. 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 and fluids of approximately equal density. From Figure 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, 1977).

The magnitude of sediment deposition and relative change therefore depend on many factors such as reservoir shape, channel slopes, relation of outflow to inflow and fluid density differences. It is observed that the density currents move very slowly. In many respects deposits in a reservoir resemble those in a delta area near to lake or sea (Varshney, 1997). The sediment deposit in different beds namely

i) Bottom set beds consisting of the fine sediments brought in by the stream,

ii) The fore-set beds formed of the coarser sandy sediments,

iii) Top set beds consisting of coarser particles and

iv) Density current deposits as shown in Figure 1 (Varshney, 1997).

As a general rule, smaller sizes of material progressively get deposited beyond the delta front, resulting in a gradual downward slope of the reservoir bed. Much of the wash-load carried by stream may not settle out as the cross sectional area of the stream increases at the entry of the reservoir. Furthermore, the suspension may not mix completely with the clear water of the reservoir because of their difference in specific gravity. The gravity underflow i. e. density currents move through the entire length of the reservoir. This portion of the flow is collected as a submerged pool, forming almost level floor in the deepest part of the reservoir, where it gradually compacts provided it is not disturbed by turbulence (Varshney, 1997).

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 detachment, transport and deposition of the sediment viz. type of soil, drainage density, vegetation, rainfall intensity and duration, shape of catchment and land use - land cover effect the detachment. 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. (Varshney, 1997).

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 depths. It is now established that deposition takes place throughout the reservoir reducing the incremental capacity at all elevations.

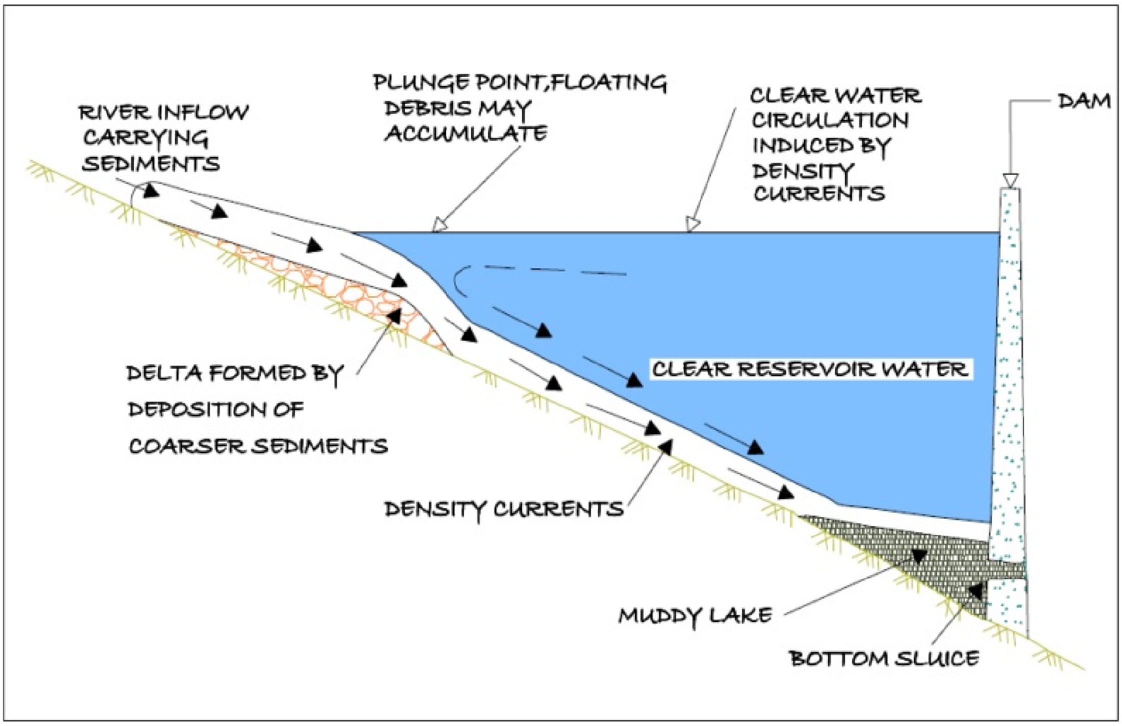


Figure 1 Conceptual sketch of density currents and sediment deposits in a reservoir

(Varshney, 1997)

Several factors like amount of sediment quantity, particle size distribution, fluctuations in stream discharge, shape of reservoir, stream valley slope, vegetation at the head of the reservoir, location and size of outlets, etc., control the location of sediment deposits in the reservoir. Figure 2 shows different control levels in the reservoir.

Reservoir operates between minimum draw down level (MDDL) to full reservoir level (FRL). The storage between these two levels is the live storage. The storage below MDDL is the dead storage. Water stored along the valley bed is known as valley storage (Agrawal, Pandhare, Nakil et.al., 2011).

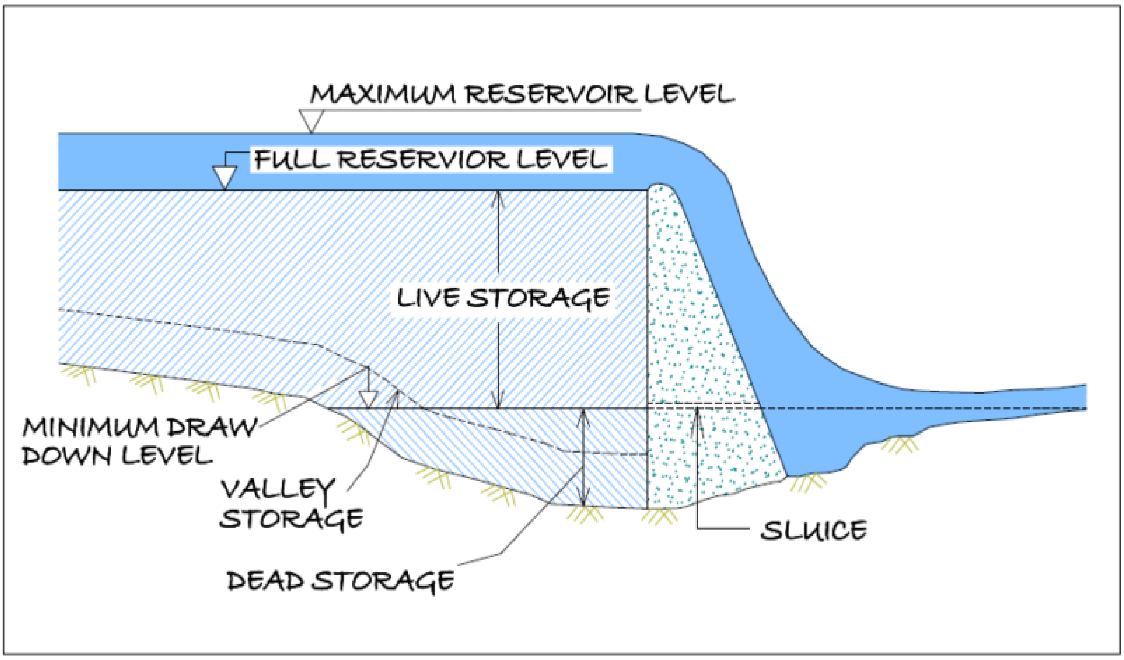


Figure 2 Conceptual sketch of different levels in a reservoir

3. 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 IRS P6 and Resourcesat 2 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 μm, 0.62-0.68 μm and 0.77-0.86 μm and spatial resolution as 23.5 m. Fourth band with spectral bandwidth of 1.55-1.75 μm 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.

4. Objectives

The objective of the study is to estimate capacity loss of Nandini 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 Nandini reservoir.

(ii) Estimation of live storage loss due to sedimentation in Nandini reservoir.

5. Study Area

Nandini Dam is located near Khwash Amba village in Bhandra taluka, Lohardaga district, on the Nandini river which is a left bank tributary of south Koel river. Nandini reservoir scheme is located at 23^0 23’ 00’’ N latitude and 84^0 50’ 00’’ E longitude. The location of the dam is shown in Figure 3 - Index Map.

The Nandini dam is an earthen dam 1646.34 m long at crest, 17.08 m high above lowest river bed level. The reservoir serves as purpose of irrigation. The catchment area at the dam site is 58.08 sq km. The dam was completed in the year 1987-88. The FRL and MDDL of the reservoir are at a level of 674.69 m and 667.68 m respectively. Gross storage capacity is 19.284 Mm^3 at FRL. The dead storage and live storage capacity of Nandini dam are 2.58 Mm^3 and 16.704 Mm^3 respectively. The crest level of the ungated ogee shaped weir of the dam is at 679.270 m. The maximum discharge capacity of spillway is 589.440 m^3/s. The length of spillway is 86.00 m. Salient features of Nandini project are given in Annexure (I).

6. Previous Surveys

Previous hydrographic survey has not been done for this project.

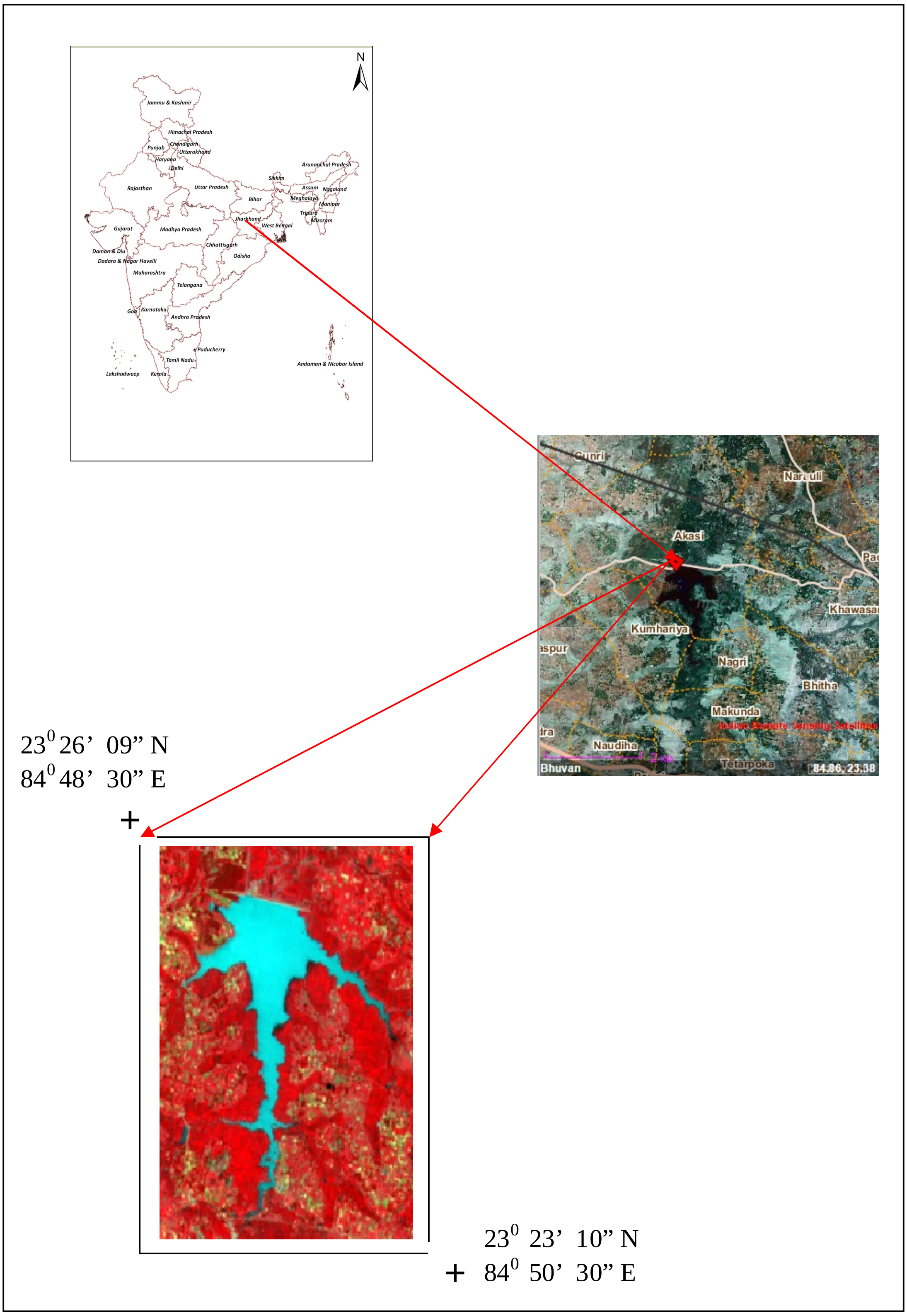


Figure 3 Index map of Nandini reservoir, Jharkhand

7. Approach of Present Study

Remote sensing technique is utilized to assess the sedimentation between operating levels of reservoir. This operating range between MDDL (667.680 m) and FRL (674.690 m) varies each year and depends upon yield in the reservoir and utilization of water. During 2011 to 2015 the minimum and maximum level in this reservoir fluctuated in various range. They are shown in Table 1. The cloud free levels in this range are selected for analysis.

Table 1: Status of cloud free levels achieved during 2013 to 2015

Water year	Minimum level (m)	Maximum level (m)	Difference of minimum and maximum levels (m)
2013-14	671.850	673.100	1.25
2014-15	670.300	674.69	4.39

The information reveals that in the water year 2014-15, reservoir was filled up to FRL (674.69 m) while it got depleted close to MDDL in 2104-2015. For present study, three images from water year 2014-2015 and two images from water year 2013-2014 have been used. The year of survey of present study is treated as year 2014-2015.

8. Data

8.1 Field data

Following data set was obtained from Nandini reservoir authority and used in the analysis.

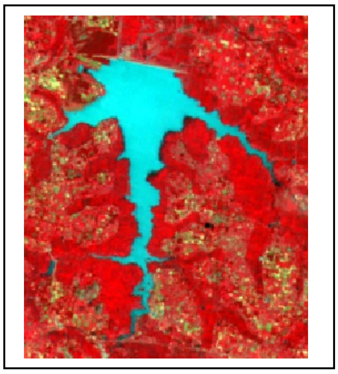
i) Index map of reservoir
ii) Latitude and longitude of the reservoir
iii) Original area capacity table at 1m interval.
iv) Salient features of the project
v) Reservoir levels for given dates of satellite pass.

8.2 Satellite data

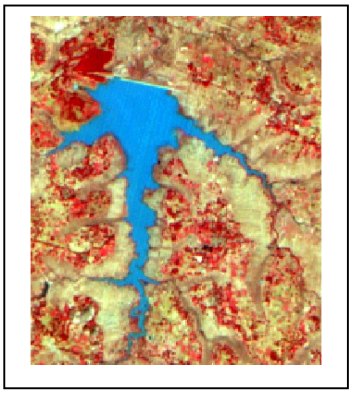
Resourcesat 2 and IRS P6 satellite LISS III images of 23.5 m resolution having Path 104, Row 55 have been used in present analysis. One image of IRS P6 and four images of Resourcesat 2 are used for classification. The FCC of the images are as given in Figure 4. The dates of satellite pass of selected images and corresponding reservoir levels are given in Table 2.

Table 2 : Details of satellite data

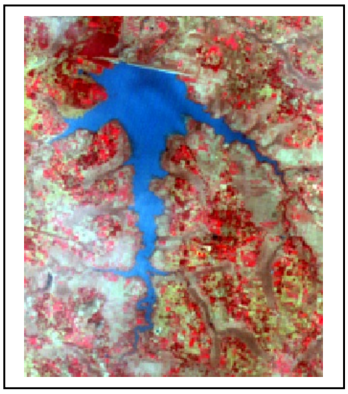
Sr. No.	Date of pass	Elevation (m)
1	26-Sept-2014	674.690
2	19-Dec-2014	673.650
3	29-Jan-2014	673.100
4	03-Jun-2013	671.850
5	30-Apr-2015	670.300



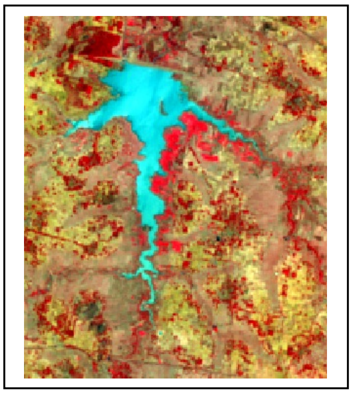
26 Sept 2014 (674.69 m)



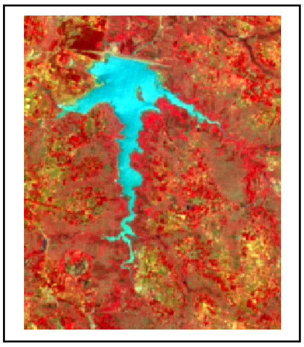
19 Dec 2014 (673.65 m)



29 Jan 2014 (673.10 m)



03 June 2013 (671.85 m)



30 Apr 2015 (670.30 m)

Figure 4 FCC’s of Nandini reservoir, Jharkhand

8.3 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 Nandini reservoir for year 2011 to 2015. The reservoir levels as on these dates along with corresponding water spread areas and capacities are obtained from field officers.

The reservoir has been depleted up to 670.30 m as against MDDL (667.68 m). The maximum level covered in the present study is 674.69 m, that is FRL. Variation in the study level is (674.69-670.30) = 4.39 m. The difference between FRL and MDDL is (674.69-667.68) = 7.01 m.

In the present study, 13.756 Mm^3 storage has been covered as against total live capacity of 16.704 Mm^3. Thus the percentage live storage covered by this study is 82.37 %.

Statement giving cloud free dates of Satellite pass, reservoir levels, areas, and capacities for the Nandini 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 directly received by this institute from NRSC, Hyderabad.

9. Software Used

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

10. Methodology

The basic approach is to find out the water-spread area 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

10.1 Procedural flow chart

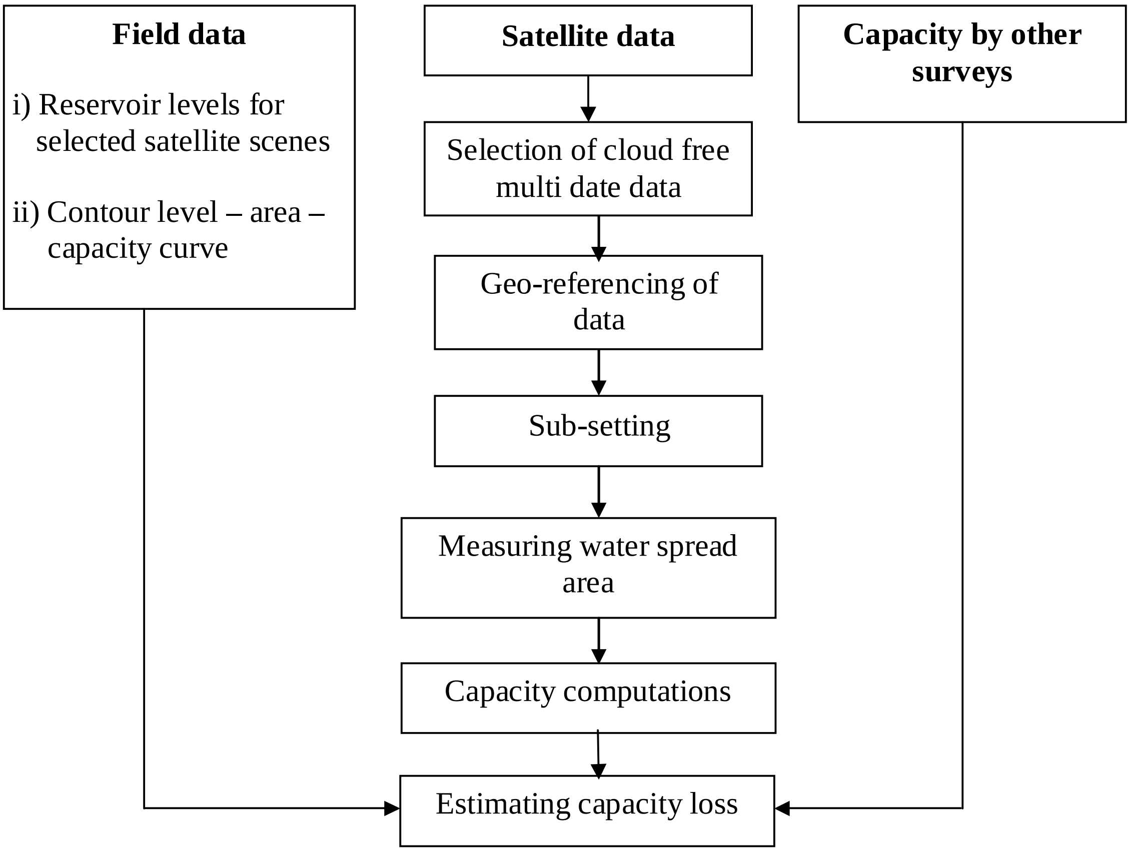


Figure 5 Flow chart showing methodology for reservoir capacity estimation

10.2 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.

10.3 Image geo-referencing

Geo-referenced ready satellite images have been used in the analysis.

10.4 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.

10.5 Water spread area extraction

Area extraction is done by either Normalized Difference Vegetation Index (NDVI) or by classification. NDVI is one index which distinguishes vegetation and water. Positive values indicate vegetation whereas negative values correspond to water. NDVI is generated using the 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 ratioed image is then density sliced. Water pixels generally occupy lower range of histogram in ratioed image. For Nandini reservoir NDVI outputs are generated for each scene and range of NDVI for water body delineation is noted for each scene. The range of NDVI values are given in Table 3**.**

Table 3 : Range of NDVI values for Nandini reservoir

Date of pass	**Minimum value**	**Maximum value**
26-Sept-2014	- 0.2222	- 0.0052
19-Dec-2014	- 0.5555	- 0.2560
29-Jan-2014	- 0.3027	- 0.0059
03-Jun-2013	- 0.1637	- 0.0031
30-Apr-2015	-0.1666	- 0.0143

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 4.

Table 4 : Water spread areas estimated from satellite data

Date of pass	Elevation (m)	Area (Mm^2)
26-Sept-2014	674.690	2.43
19-Dec-2014	673.650	2.23
29-Jan-2014	673.100	2.21
03-Jun-2013	671.850	1.57
30-Apr-2015	670.300	1.44

The water spread areas on selected dates of satellite pass are shown in Figure 6. The tail of the reservoir is defined by removing the river portion from extracted WSA, carefully.

10.6 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 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 5.

10.7 Calculation of reservoir capacity

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

$$V = h/3*(A_1 + A_2 + SQRT\ (A_1 * A_2)).$$

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

h is the elevation difference = $(h_1 – h_2)$

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 5.

Table 5 : Areal extent and cumulative live storage capacity of reservoir at regular interval defined from graph

Water elevation (m)	**Water spread area (2014-15) Mm^2**	**Cumulative capacity (2014-15) Mm^3**
667.68 MDDL	0.86	0
668.00	0.92	0.284
669.00	1.11	1.296
670.00	1.32	2.507
671.00	1.53	3.931
672.00	1.76	5.579
673.00	2.01	7.463
674.00	2.26	9.594
674.69 FRL	2.44	11.216

SRS elevation area curve is shown in Figure 7 and tabulated in Table 4. Elevation capacity curve is shown in Figure 8 and tabulated in Table 5. The elevation- area curve drawn through present survey carried out for Nandini reservoir is shown in Table 6. The elevation- live capacity curve drawn through original and present surveys carried for the Nandini reservoir are shown in Figure 9 and tabulated in Table 7. In Figure 10 updated SRS elevation-area-capacity curve is drawn and tabulated in Table 5.

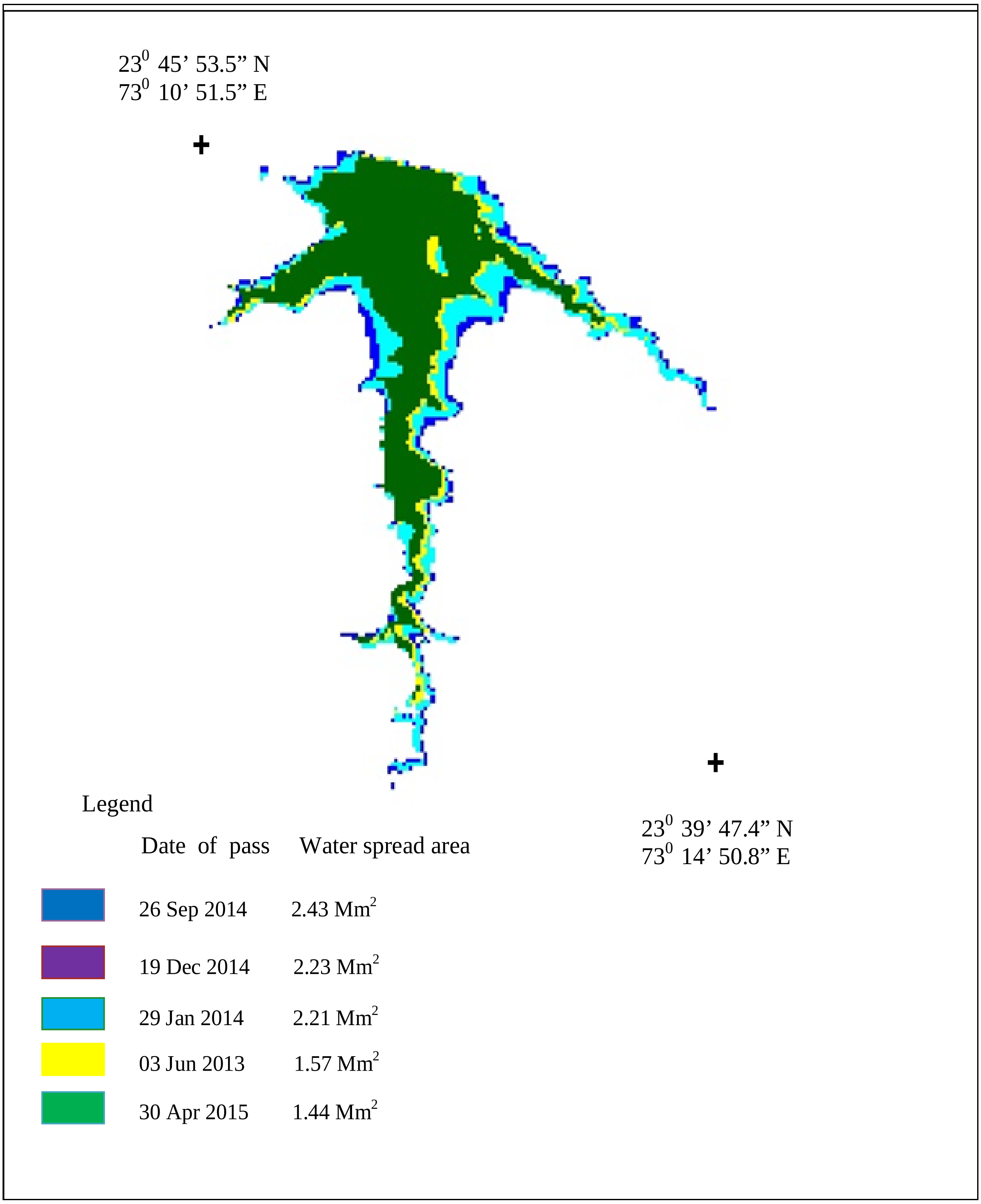


Figure 6 Water spread areas on different dates of satellite pass

10.8 Comparison with original surveys

The comparison of water spread area obtained through remote sensing analysis with original surveyed data is given in Table 6.

Table 6 : Comparison of water spread areas of reservoir

Water elevation (m)	**Original survey 1988 (Mm^2)**	**SRS survey 2014-15 (Mm^2)**
MDDL 667.68	NA	0.86
668.00	NA	0.92
669.00	NA	1.11
670.00	NA	1.38
671.00	1.50	1.53
672.00	1.65	1.76
673.00	2.16	2.01
674.00	2.30	2.26
FRL 674.69	2.43	2.44

The comparison of present live storage capacity with original capacity is given in Table 7.

Table 7 : Comparison of live storage capacity of reservoir

Water elevation (m)	**Original survey 1988 (Mm^3)**	**SRS survey 2014-15 (Mm^3)**
MDDL 667.68	0	0
668.00	0.328	0.284
669.00	1.462	1.296
670.00	2.826	2.507
671.00	4.566	3.931
672.00	6.99	5.579
673.00	9.899	7.463
674.00	13.738	9.594
FRL 674.69	16.704	11.216

10.9 Live capacity loss due to sedimentation

Table 8 shows the live capacity loss due to sedimentation between different years.

Table 8 : Live capacity loss due to sedimentation

Details	Original survey 1988	SRS survey 2014-15
Live capacity in Mm^3 (FRL to MDDL)	16.704	11.216
Sediment deposited between two consecutive surveys Mm^3	-	5.50
Period in years since 1st impoundment year 1988	-	27
Rate of sediment deposited between two consecutive surveys Mm^3/year	-	0.20
% loss of live capacity to original live capacity	-	32.91

10.10 Field visit and ground truth

Field visit of the reservoir area has been carried out on 9th March 2016 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 field visit.

Officers from Resources Engineering Center, MERI, Nashik

i) Shri. M. M. Kulkarni, Assistant Engineer Gr.I

ii) Shri. S.G.Wagh, Assistant Engineer Gr.II

iii) Shri. D. R. Nikam, Sectional Engineer

Team from Nandini project

i) Er. Arun Kumar, Deputy Engineer

ii) Er. Ajay Shankar Ram, 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 671.52 m. The photographs of ground truth scenario are shown in Annexure III.

11. Results and Discussions

The summary of the result of sedimentation study of Nandini reservoir is shown in Table 9.

Table 9 - Summary of results

Details	**Original survey 1988**	**SRS survey 2014-15**
Live capacity in Mm^3	16.704	11.22
Catchment area - sq km	58.08	
Cumulative loss in live capacity in Mm^3	-	5.50
Cumulative % loss	-	32.91
No. of years since completion		27
Annual % loss	-	1.18

The following observations are recorded from present study.

- Present live capacity (Water year 2014-2015) of Nandini reservoir is found to be 11.22 Mm^3. Modified SRS elevation-area-capacity values are given in Table 5 and represented in Figure 10

12. 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.
- 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.

13. Conclusions

Following conclusions can be drawn from the study:

- The live storage capacity of Nandini reservoir is 11.22 Mm^3 in year 2014-2015.
- Capacity loss of 32.91 % in live storage is observed in a period of 27 years since first impounding in 1988
- Annual live capacity loss works out to 1.18 %.

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Annexure I

Salient Features

A	**Location**		
	Village	:	Khwash Amba
	Taluka	:	Bhandara
	District	:	Lohardaga
	State	:	Jharkhand
	Longitude	:	84^0 50’ 00”
	Latitude	:	23^0 23’ 00’
	River	:	Nandini
B	**Hydrology**		
	Catchment area	:	58.08 sq km
C	**Masonry and Earthen Dam**		
	Length of the dam	:	1646.34 m
	Height of the dam	:	17.08 m
D	**Capacity of Dam**		
	Gross storage capacity at FRL	:	19.284 Mm^3
	Dead storage capacity	:	2.580 Mm^3
	Live capacity	:	16.704 Mm^3
	Design spillway discharge capacity	:	589.440 m^3/s
	Type of spillway	:	Ogee cum chute spillway
E	**Reservoir Data**		
	Maximum water level	:	676.83 m
	Full reservoir level	:	674.69 m
	Spillway crest level	:	679.27 m
	Minimum draw down level	:	667.68 m
	Year of completion	:	1988

Annexure II

Reservoir Levels Pertaining to Cloud Free Satellite Data

Path/Row - 104/55

FRL – 674.690 m

MDDL - 667.680 m

Gross storage capacity at FRL – 19.284 Mm^3

Design Live Storage – 16.704 Mm^3

Dead Storage – 2.58 Mm^3

Date of pass	Reservoir level (m)	Capacity covered (Mm^3)
1	2	3
26- Sept -2014	674.690	19.284
19- Dec -2014	673.650	14.034
29- Jan -2014	673.100	12.147
03- Jun -2013	671.850	8.487
30- Apr -2015	670.300	5.528
Variation in capacity		(19.284-5.528) =13.756
% variation of live storage		(13.756/16.704)*100 = 82.37 %

Annexure - III

Ground Truth Scenario

Earthen dam

Spillway of Nandini reservoir

Upstream pitching

Canal

Water column

Forest near submergence

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