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उपग्रह दूरस्थ संवेदन द्वारा हरभंगी जलाशय, ओडीशा का अवसादन आंकलन

Sedimentation Assessment of Harabhangi Reservoir, Odisha, through Satellite Remote Sensing

भारत सरकार
दूरस्थ संवेदन निदेशालय
केन्द्रीय जल आयोग, नई दिल्ली

Government of India
Remote Sensing Directorate
Central Water Commission, New Delhi

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FOREWORD

CWC

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 of “Sedimentation Assessment Study of Thirty (30) Reservoirs in India through Remote Sensing Technique” and in particular the present study of Harabhangi 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, the Director General, MERI and Shri. R. V. Shrigiriwar, the Superintending Engineer, MERI for their valuable support and motivation for carrying out this work.

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PROJECT TEAM

CONTENTS

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 Harabhangi Reservoir, Odisha, India.

Present study aims in updating the elevation-area-capacity curve of Harabhangi Reservoir, Odisha, 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 seven passes falling between MDDL (378.00 m) and FRL (387.50 m) are used for the analysis.

The Harabhangi dam is located on the Harabhangi river. The dam site is located near Adava village in Mohana taluka, Gajapati district. The project has a designed gross reservoir capacity of 141.25 Mm^3, with live capacity of 86.25 Mm^3. This study reveals that the present live capacity of the reservoir has been increased by 0.353 Mm^3 in a period of 14 years.

SEDIMENTATION ASSESSMENT OF HARABHANGI RESERVOIR, ODISHA, 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 to be 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 the basis of 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 Harabhangi Reservoir, of Gajapati district of Odisha State. This work is carried out for Central Water Commission New Delhi under the project "Sedimentation Assessment Study of 30 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 the 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. types 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.

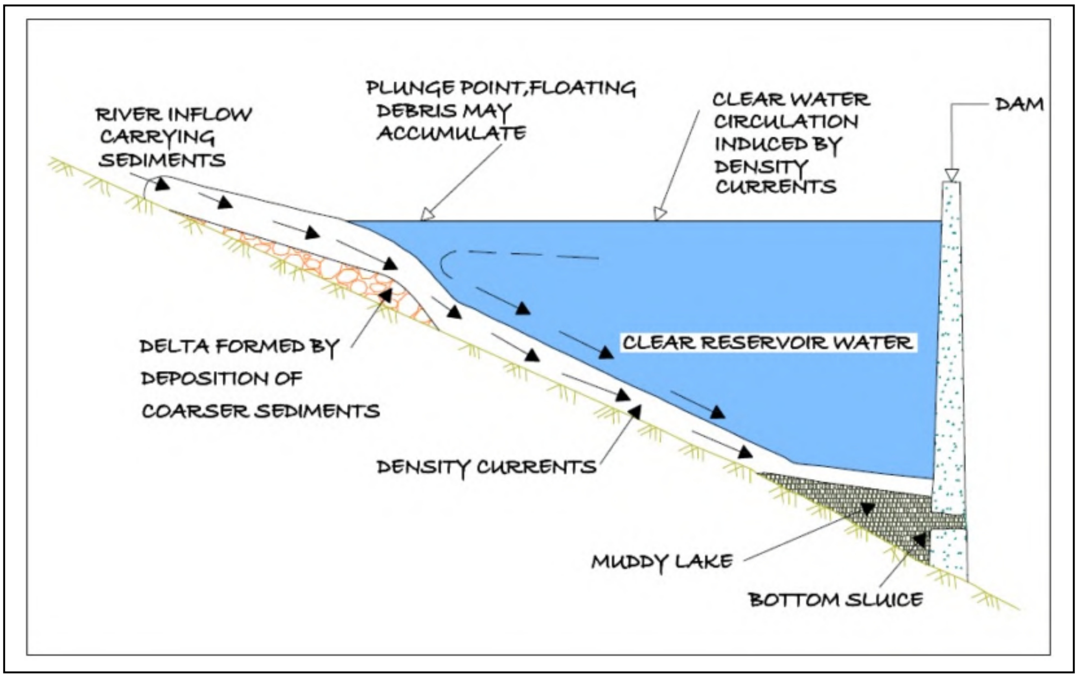

Figure 1 Conceptual sketch of density currents and sediment deposits in a reservoir (Varshney, 1997)

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.

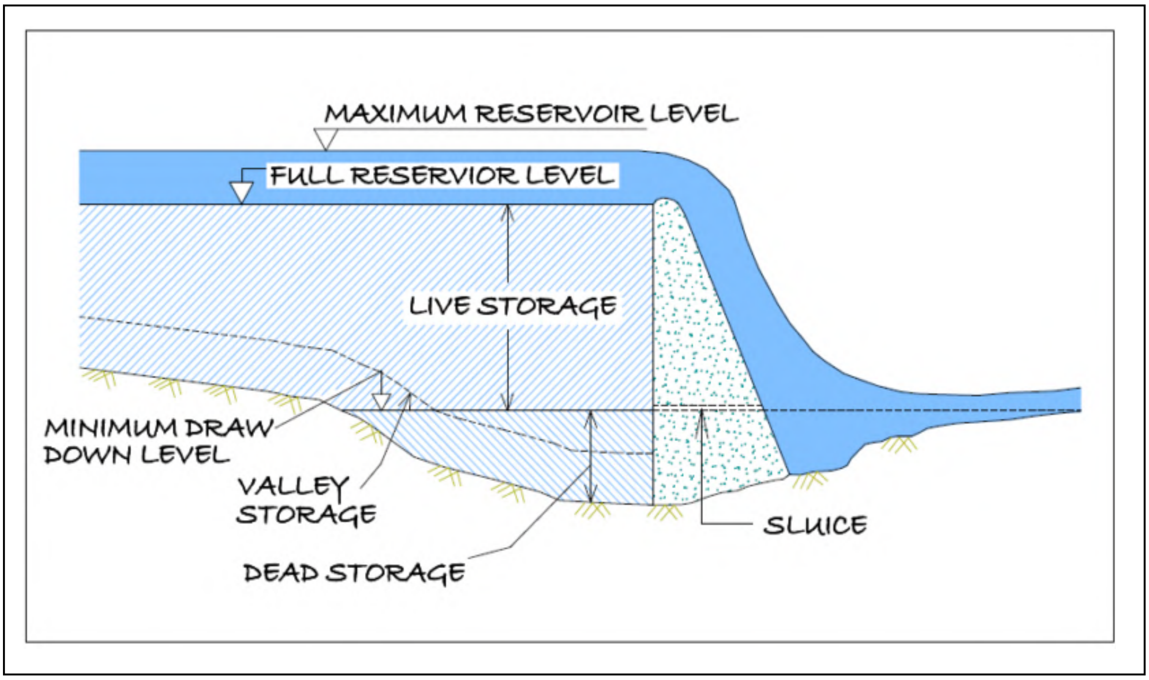

Figure 2 Conceptual sketch of different levels in a reservoir

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).

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 satellites. 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 Harabhangi 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 Harabhangi reservoir.

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

5. Study Area

The Harabhangi dam is located near Adaba village in Adava taluka, Gajapati district, on the Harabhangi river. The dam site is located at 19^0 30' 30" N latitude and 84^0 08' 00" E longitude. The location of the dam is shown in Figure 3 - Index Map.

The Harabhangi dam serves dual purpose of irrigation and flood control. The catchment area at the dam site is 503.80 sq km. The dam was completed in the year 1998. The FRL and MDDL of the reservoir are 387.50 m and 378.00 m. The dead storage and live storage capacity of Harabhangi dam are 55 $Mm^3$and 86.25 Mm^3 respectively.

The dam site is located across two small hillocks covering Harabhangi river. The river bed has isolated outcrops of granetiferrous granite gneiss rock confined along left bank which occurs in a moderately to highly weathered state. The river bed consists of medium to coarse with little gravel and boulders in it. The right bank is covered with reddish brown to dark grey coloured sandy to silty soil with isolated patches of 0.5 m to 1 m thick black cotton soil mixed with kankar. The left bank has scattered exposures of weathered granite gneiss and pegmatite from RD 150 m to 360 m The stretch from RD 00 m to 105 m consists of hard but extensively jointed garnetiferrous granite gneiss which is dissected by several sets of long and open joint. The pegmatites of 5 m and 10 m width occur between RD 220 m and 225 m which are highly fractured.

The Spillway site is located in the rocky saddle with its through at RL 390 m (about 47 m above the river bed level). Outcrops of garnetiferrous granite gneiss occur at the right abutment of the saddle at RL 390 m. The rock is hard and has high strength but is dissected by several sets of joints at close intervals. At places it exhibits spheroidal weathering. The left abutment of saddle is covered with talus and silt material with scattered outcrops of jointed granite gneiss. The downstream of spillway axis consist of hard and fresh exposures of less jointed granite gneiss along the spill channel. Salient features of Harabhangi project are given in Annexure (I).

6. Previous Surveys

Previous hydrographic survey has not been done for this project.

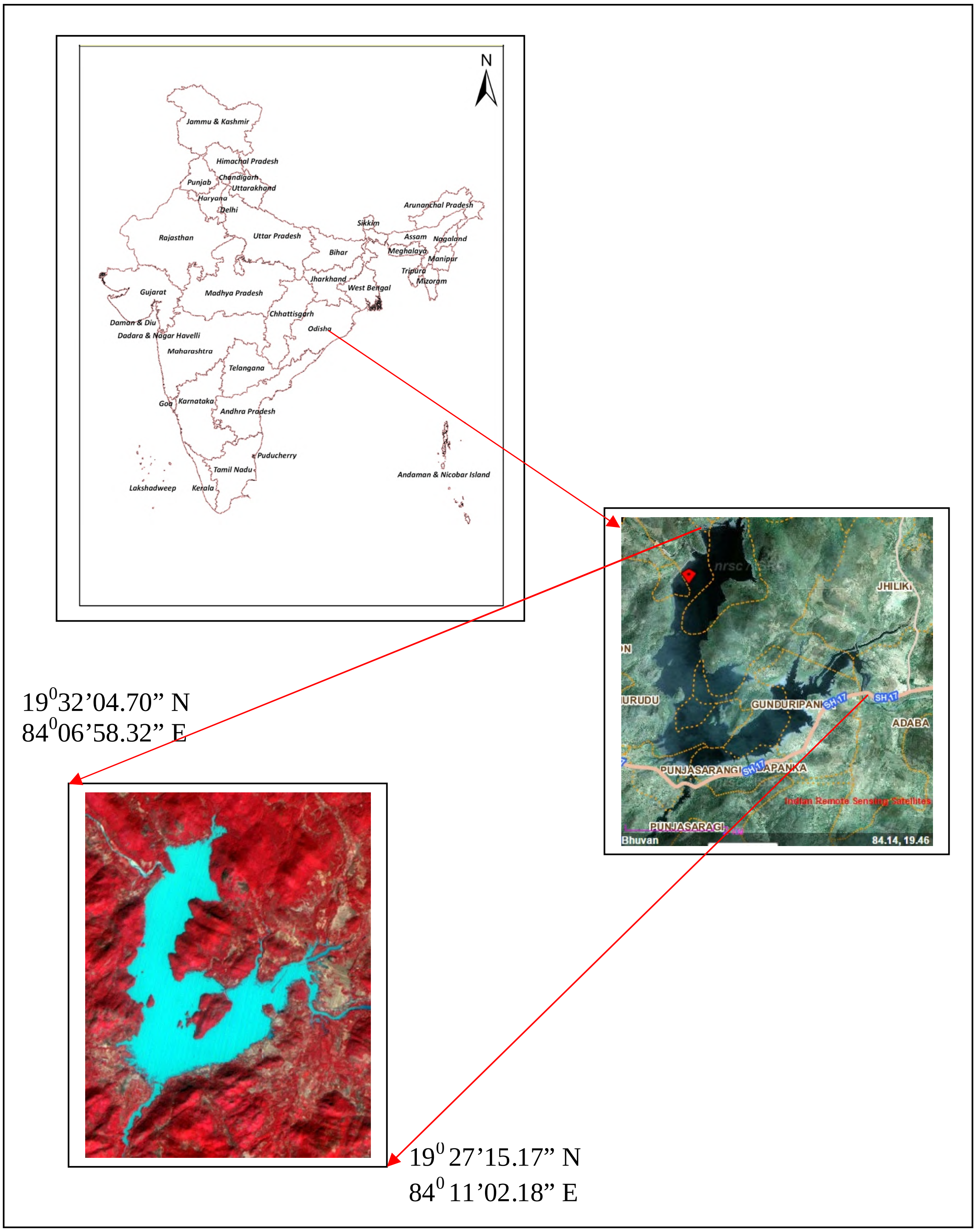

Figure 3 Index map of Harabhangi reservoir, Odisha

7. Approach of Present Study

Remote sensing technique is utilized to assess the sedimentation between operating levels of reservoir. This operating range between MDDL (378.00 m) and FRL (387.50 m) varies each year and depends upon yield in the reservoir and utilization of water. During years 2011 to 2014 the minimum and maximum level in this reservoir fluctuated in various ranges. 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 2011 to 2014

Sr. No.	Water year	Minimum level (m)	Maximum level (m)	Difference of minimum and maximum levels (m)
1	2011-2012	379.70	384.27	4.57
2	2012-2013	383.59	387.42	3.83
3	2013-2014	385.35	386.37	1.02

The information reveals that in the water year 2012-2013, reservoir was filled up to 387.42 m (FRL= 387.50 m) while it got depleted close to MDDL in 2011-2012. For present study, three images from water year 2011-2012, two image from water year 2012-2013 and two images from water year 2013-2014 have been used. The year of survey of present study is treated as year 2011-2012.

8. Data

8.1 Field data

Following data set was obtained from Executive Engineer, Harabhangi Irrigation Division for Harabhangi reservoir and used in the analysis.

i) Index map of reservoir

ii) Latitude and longitude of the reservoir

iii) Original area capacity table at 1 m interval.

iv) Salient features of the project

v) Reservoir levels for given dates of satellite pass.

8.2 Satellite data

IRS P6 and Resourcesat-2 LISS III images of 23.5 m resolution having Path 105, Row 59 have been used in present analysis. The FCC of the images are 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	29-Dec-2013	387.42
2	23-Mar-2014	386.37
3	16-Apr-2014	385.35
4	17-Oct-2011	384.27
5	09-Apr-2013	383.59
6	02-Feb-2012	380.30
7	02-Apr-2012	379.70

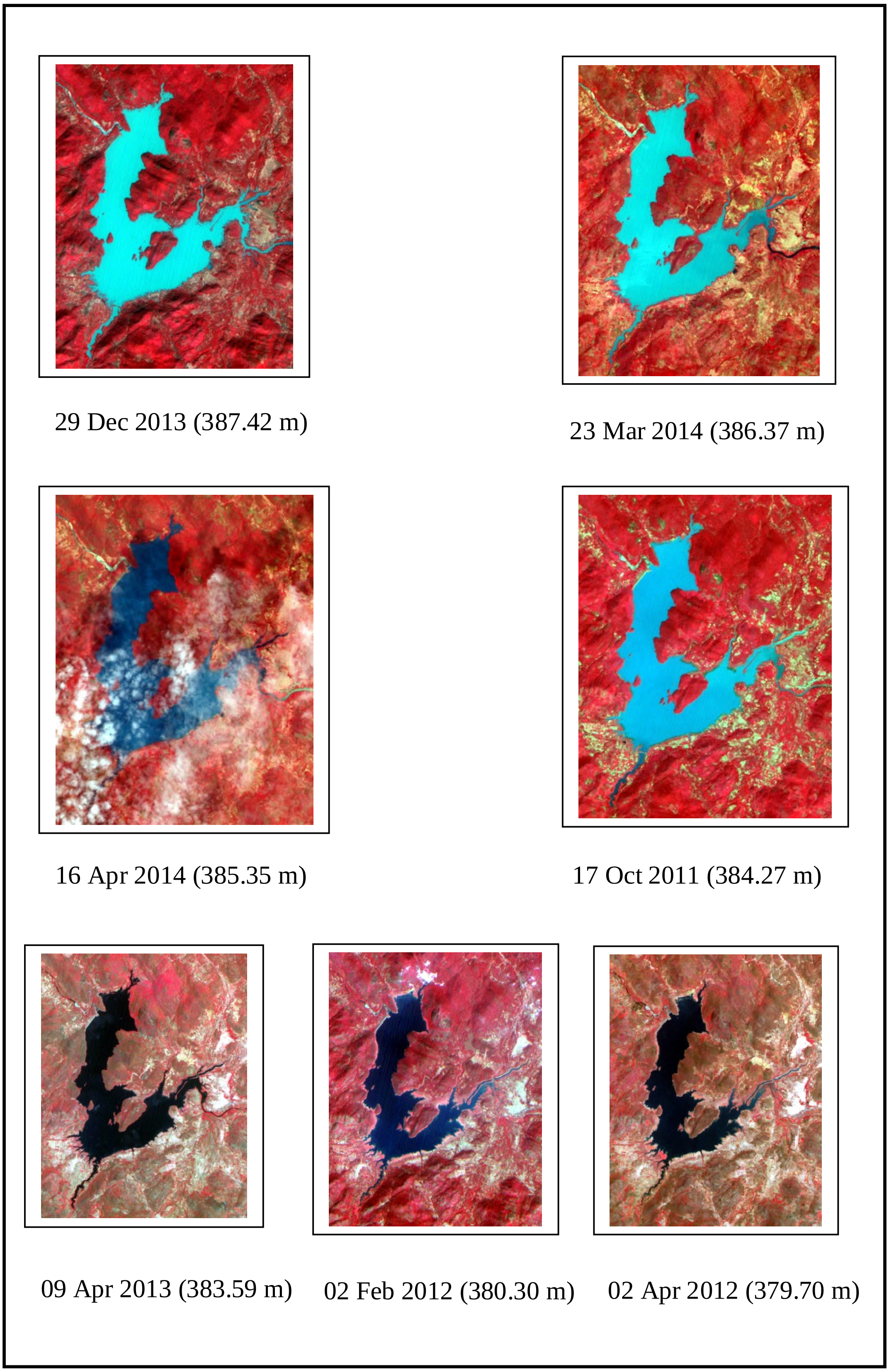

Figure 4 FCC's of Harabhangi reservoir, Odisha

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 Harabhangi reservoir for year 2011 to 2014. The reservoir levels as on these dates along with corresponding water spread areas and capacities have been obtained from field officers.

The reservoir has been depleted up to 379.70 m as against MDDL (378.00 m). The maximum level covered in the present study is 387.42 m which is near to FRL (387.50 m). Variation in the study level is (387.42 - 379.70) = 7.72 m. The difference between FRL and MDDL is (387.50 - 378.00) = 9.50 m.

In the present study, the storage of 69.5 Mm^3 has been covered as against total live capacity of 86.25 Mm^3. Thus the percentage live storage covered by this study is 80.58 %. (Annexure – II)

Statement giving cloud free dates of Satellite pass, Reservoir Levels, Areas, and Capacities for the Harabhangi reservoir has been prepared and submitted to CWC. The CWC has finalized the dates and placed the order of images with NRSC, Hyderabad. The data has been received directly to MERI 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

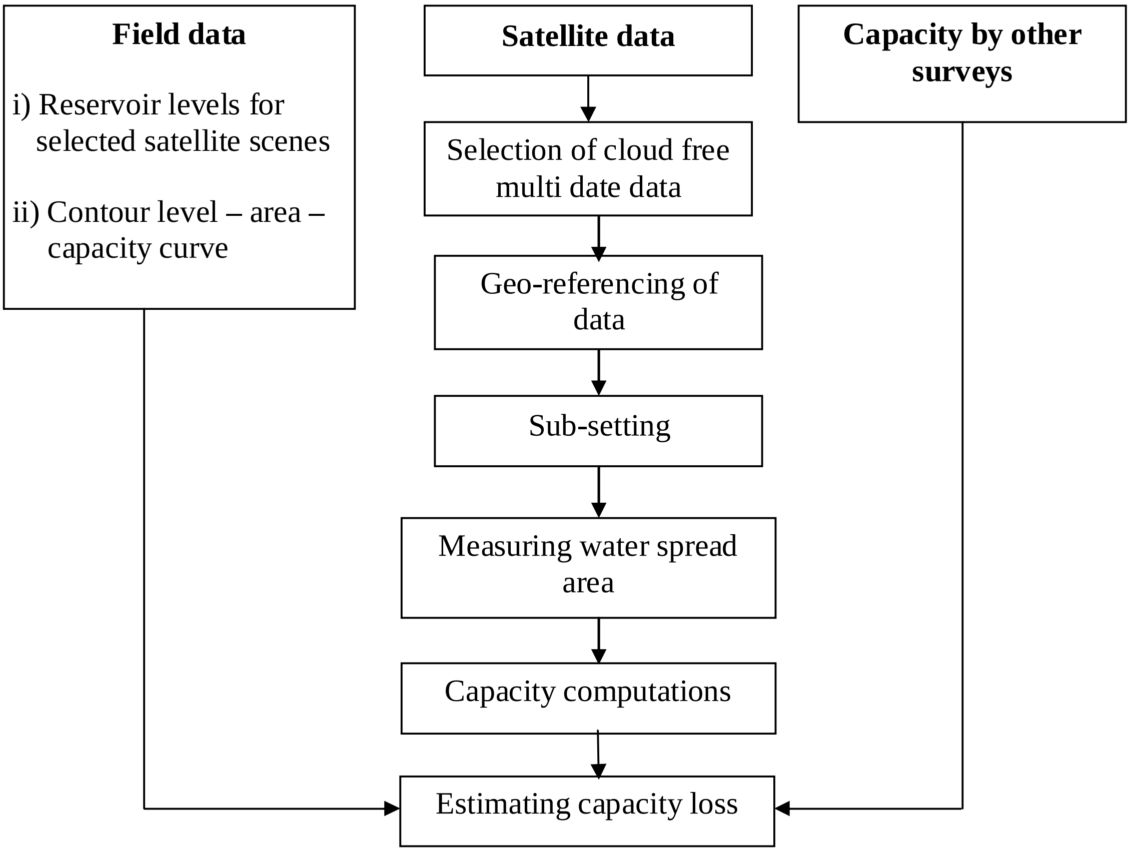

Figure 5 Flow chart showing methodology for reservoir capacity estimation

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

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 Harabhangi 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 Harabhangi reservoir

Date of pass	**Minimum value**	**Maximum value**
29-Dec-2013	- 0.490	0.005
23-Mar-2014	- 0.275	0.186
16-Apr-2014	- 0.173	0.200
17-Oct-2011	- 0.310	0.276
09-Apr-2013	- 0.333	- 0.014
02-Feb-2012	- 0.322	- 0.041
02-Apr-2012	- 0.100	0.112

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)
29-Dec-2013	387.42	11.85
23-Mar-2014	386.37	11.00
16-Apr-2014	385.35	10.67
17-Oct-2011	384.27	10.00
09-Apr-2013	383.59	9.61
02-Feb-2012	380.30	7.72
02-Apr-2012	379.70	7.41

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 (Mm^2) (2011-2012)**	**Cumulative capacity (Mm^3) (2011-2012)**
MDDL 378.00	6.448	0
379.00	7.010	6.727
380.00	7.572	14.016
381.00	8.134	21.868
382.00	8.696	30.281
383.00	9.258	39.257
384.00	9.820	48.797
385.00	10.382	58.894
386.00	10.944	69.556
387.00	11.506	80.779
FRL 387.50	11.787	86.603

SRS elevation area curve is shown in Figure 7 and tabulated in Table 4. Elevation capacity curves is shown in Figure 8 and tabulated in Table 5. The elevation-area curves drawn through original and present surveys carried out for Harabhangi reservoir are shown in Figure 9 which is based on Table 6. The elevation-capacity curve drawn through original and present surveys carried for the Harabhangi reservoir are shown in Figure 10 and tabulated in Table 7. In Figure 11 updated SRS elevation-area-capacity curve is drawn and tabulated in Table 5

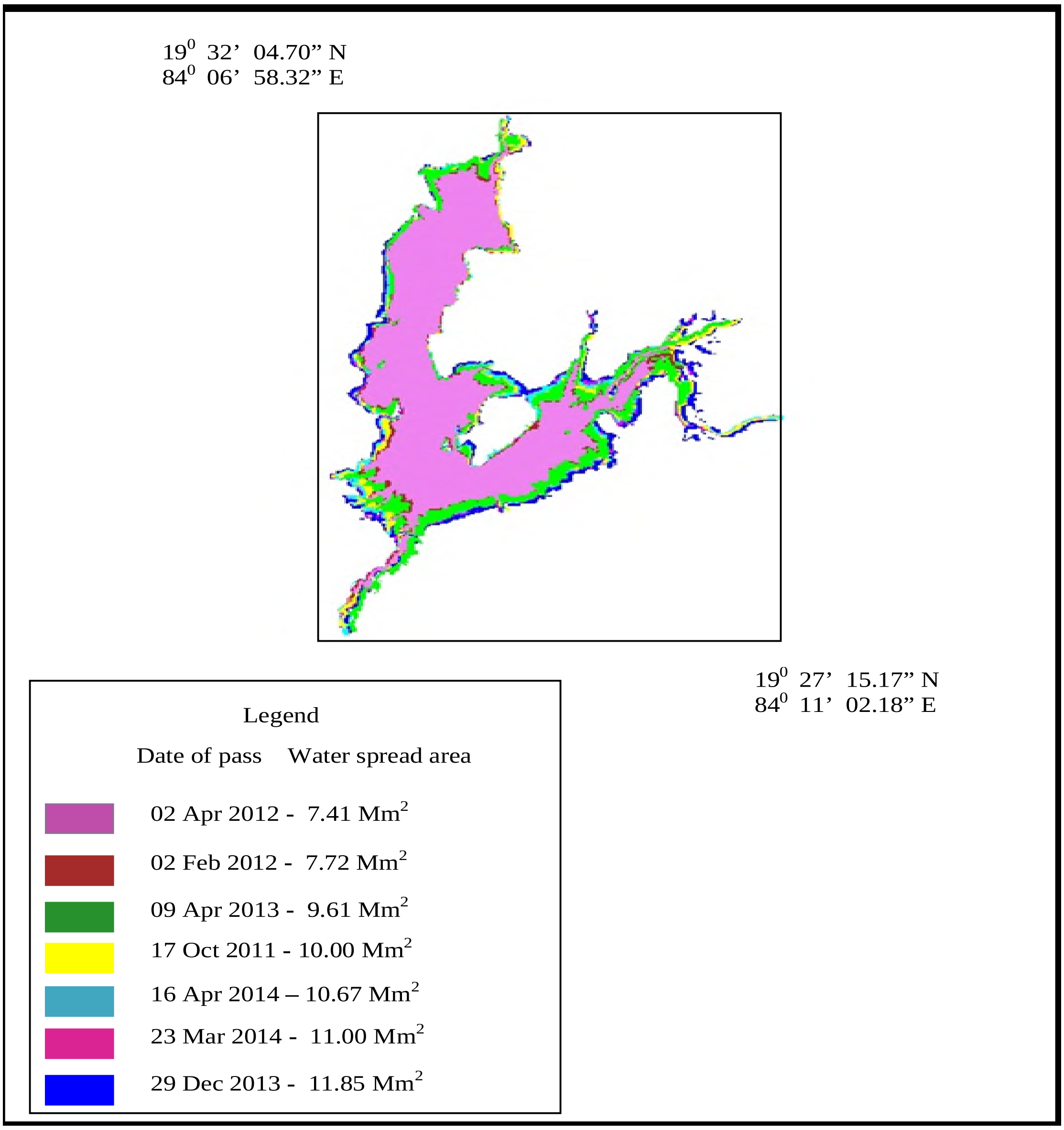

Figure 6 Water spread areas on different dates of satellite pass

Fig7

Fig8

Fig9

Fig10

Fig11

10.8 Comparison with earlier 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 1998 (Mm^2)**	**SRS survey 2011-2012 (Mm^2)**
MDDL 378.00	6.25	6.448
379.00	7.10	7.010
380.00	7.58	7.572
381.00	8.10	8.134
382.00	8.70	8.696
383.00	9.27	9.258
384.00	9.85	9.820
385.00	10.40	10.382
386.00	11.00	10.944
387.00	11.57	11.506
FRL 387.50	12.15	11.787

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 1998 (Mm^3)**	**SRS survey 2011-2012 (Mm^3)**
MDDL 378.00	0.00	0.000
379.00	10.50	6.727
380.00	18.00	14.016
381.00	26.00	21.868
382.00	34.25	30.281
383.00	42.00	39.257
384.00	50.25	48.794
385.00	59.00	58.894
386.00	68.50	69.556
387.00	80.00	80.779
FRL 387.50	86.25	86.603

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 1998	SRS survey 2011-2012
Live capacity in Mm^3 (FRL to MDDL)	86.25	86.603
Sediment deposited between two consecutive surveys Mm^3	-	-0.353
Period in years since 1st impoundment year 1998	-	14
Rate of sediment deposited between two consecutive surveys Mm^3/year	-	-
% loss of live capacity to original live capacity	-	-

It is noticed that in comparison to the original capacity of year 1998, present live capacity has been increased by 0.353 Mm^3.

10.10 Field visit and ground truth

Field visit of the reservoir area has been carried out on 6th 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 receiver. Following officers were present during this 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 Harabhnagi reservoir project

i) Santosh Kumar Subhudi , Assistant Executive Engineer
ii) Sanat Kumar Mallick , Sectional 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 382.740 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 Harabhangi reservoir is shown in Table 9.

Table 9 - Summary of results

Details	Original survey 1998	SRS survey 2011-2012
Live capacity in Mm^3	86.25	86.603
Catchment area – sq km	503.80	
Cumulative loss in live capacity in Mm^3	-	-0.353
Cumulative % loss	-	-
No. of years		14
Annual % loss	-	-

The following observations are recorded from present study.

- Present live capacity (year 2011-2012) of Harabhangi reservoir is found to be 86.603 Mm^3. Modified SRS elevation-area-capacity values are given in Table 5 and Figure 11.

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 Harabhangi reservoir is 86.603 Mm^3 in year 2011-2012. It is noticed that in comparison to the original capacity of year 1998, present live capacity has been increased by 0.353 Mm^3.
- The hydrographic survey is recommended in present case to verify the gross storage capacity of the reservoir.

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Annexure I

Salient Features

A	**Name of project**		Harabhangi Project (Odisha)
	Village	:	Adava
	Taluka	:	Mohana
	District	:	Gajapati
	State	:	Odisha
	Latitude	:	19^0 : 30': 30" N
	Longitude	:	84^0 : 08': 00" E
	River	:	Harabhangi
B	**Hydrology**		
	Catchment area	:	503.80 sq km
	Annual Maximum Rainfall	:	1736 mm
	Annual Minimum Rainfall	:	602.50 mm
	Annual Average Rainfall	:	1223.30 mm
C	**Masonry and Earthen Dam**		
	Length of the dam	:	690 m
	Height of the dam	:	49 m
D	**Capacity of Dam**		
	Gross storage capacity at FRL	:	141.25 Mm^3
	Dead storage capacity	:	55.00 Mm^3
	Live capacity	:	86.25 Mm^3
	Design spillway discharge capacity	:	4608 m^3/s
	Type of spillway	:	Ogee
	No., Size of spillway gates	:	8 Nos., (12.00 m x 9.00 m)
E	**Reservoir Data**		
	Top of dam	:	390.25 m
	Maximum water level	:	387.50 m
	Full reservoir level	:	387.50 m
	Spillway crest level	:	378.50 m
	Minimum draw down level	:	378.00 m
	Year of completion	:	1998

Annexure II

Reservoir Levels Pertaining to Cloud Free Satellite Data

Path/Row - 105/59 | Gross storage capacity at FRL - 141.25 Mm^3

FRL – 387.50 m, | Design live storage – 86.25 Mm^3

MDDL - 378.00 m | Dead storage capacity- 55.00 Mm^3

Date of pass	**Reservoir level (m)**	**Capacity covered (Mm^3)**
1	2	4
29-Dec-2013	387.42	85.25
23-Mar-2014	386.37	72.75
16-Apr-2014	385.35	62.32
17-Oct-2011	384.27	52.61
09-Apr-2013	383.59	46.86
02-Feb-2012	380.30	20.40
02-Apr-2012	379.70	15.45
Variation in capacity		(85.25-15.45) = 69.83
% variation of live storage		(69.83/86.25)*100 = 80.96 %

Annexure III

Ground Truth Scenario

Dam view

Pitching on U/S side

Gated spillway

Gated spillway

Water spread of dam

Water spread of dam

D/S side of spillway

Gauge level of dam

Forest

Village at the D/S side of dam

Rock toe

D/S side of spillway

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