SEDIMENTATION ASSESSMENT OF KANHER RESERVOIR, MAHARASHTRA, THROUGH SATELLITE REMOTE SENSING

1.   Introduction

India – the second largest country in the world in terms of population – has about 17.3% of world's population, about 4% of world's water resources, and 2.44% of total geographical land area of the world. Therefore, in spite of having an average annual average precipitation to the tune of more than 1105 mm/year, the population density (lack of land resources) and per capita water resources availability make India a water-stressed country, as a whole. However, at a regional or basin level, many areas in the country are water-scarce or severely water-scarce owing to the spatial and temporal variability of water resources.

It is estimated that average annual precipitation over India is about 3880 BCM. Out of this precipitation, the average annual water resources availability of the country is about 1999.2 BCM, as estimated by Central Water Commission (CWC) in 2019. The water resources availability situation gets more murkier due to topographical and other constraints. Due to this, the total utilisable water resources in the country are about 1122 BCM (690 BCM of surface water and 432 BCM of groundwater). On one hand, the per-capita water resource availability is reducing due to increasing population and on the other, per-capita water usage is increasing due to industrialisation, urbanisation and change in lifestyles or dietary habits, making the available water resources still dearer.

India has typical monsoon-based climate where more than 75% rainfall occurs in three months i.e. July, August, and September. The total number of rainy days typically are in the tune of only 20-25 days per year (100-150 hours of rain per year) for most parts of the country. As a result, the bulk of annual water (75-80%) in rivers is available only in these three months. Therefore, in order to sustain life and other activities throughout the year from a resources that are available only through 20-25 rainy days, it is absolutely essential to store the water in appropriately-sized storage structures (depending upon the topography and hydrology of the area).

So far, India has developed just 257.812 BCM as live storage capacity and 46.765 BCM is under construction. Realising the importance of storage structures, a large number of reservoirs have been built, since independence, during each plan in almost

all river basins, except Ganga and Brahmaputra, to tap the available surface water and to utilize it as and when needed. The capacity of reservoirs is gradually reducing due to silting and hence sedimentation of reservoir is of great concern for all the water resources development projects.

Correct assessment of the sedimentation rate is essential for assessing useful life of the reservoir as well as optimum reservoir operation schedule. Since 1958, when it was established that the live storage of reservoir is getting reduced due to siltation, a systematic effort has been made by various departments / organizations to evaluate the capacity of reservoirs. Various techniques like boat echo sounder, etc. being replaced by hydrographic data acquisition system (HYDAC) and HITECH method using Differential Global Positioning System (DGPS). The conventional techniques are found either time consuming or costly and require considerable manpower. Remote sensing technique to calculate the present live capacity of reservoir is found to be very useful in this context due to its synoptic and repetitive coverage. The surveys based on remote sensing data are faster, economical and more reliable.

These surveys will enable selection of appropriate measures for controlling sedimentation along with efficient management and operation of reservoirs thereby deriving maximum benefits for the society.

This report covers the study of Kanher reservoir, Maharashtra by Central Water Commission, New Delhi.

2.   Sources and Mechanism of Sedimentation

The principal sources of sediments are as follows:

1. Deforestation
2. Excessive erosion in the catchment
3. Disposal of industrial and public wastes
4. Farming
5. Channelisation works
6. Human activities
7. Land development, highways, and mining

The sedimentation is a product of erosion in the catchment areas of the reservoir and hence lesser the rate of erosion, smaller is the sediment load entering the reservoir. Various factors govern the erosion, transport and deposition of sediment in the

reservoir. Type of soil, drainage density, vegetation, rainfall intensity and duration, shape of catchment and land use /land cover affect the erosion. Sediment transportation depends upon slope of the catchment, channel geometry and nature of riverbank and bed. Deposition is a function of bed slope of the reservoir, length of reservoir, flow patterns, inflow - outflow rates, grain size distribution, mode of reservoir operation, etc.

In order to obtain the knowledge of sedimentation in the reservoir, it is necessary to study the mechanism of sedimentation, which will help to mitigate reservoir sedimentation, prolong the life span of reservoirs and to take full benefits of reservoirs. The sediment deposition in a reservoir depends on the following:

- Longitudinal and lateral valley shape
- Length and shape of reservoir
- Flow patterns in reservoir
- Capacity to inflow volume ratio (trap efficiency)
- Grain size distribution of sediment
- Water and sediment discharges
- Mode of reservoir operation
- Nature of incoming floods

Reservoirs created by dams on rivers lose their storage capacity due to sedimentation. As water enters a reservoir, its velocity diminishes because of the increased cross-sectional area of the channel. If the water stored in the reservoir is clear and the inflow is muddy, the two fluids have different densies and the heavy turbid water flows along the channel bottom towards the dam under the influence of gravity (Figure 1). This condition is known as "stratified flow" and the underflow is called a "density current". A large proportion of the transported silt eventually gets deposited at different levels of a reservoir and causes reduction not only in dead storage but also in live storage capacities.
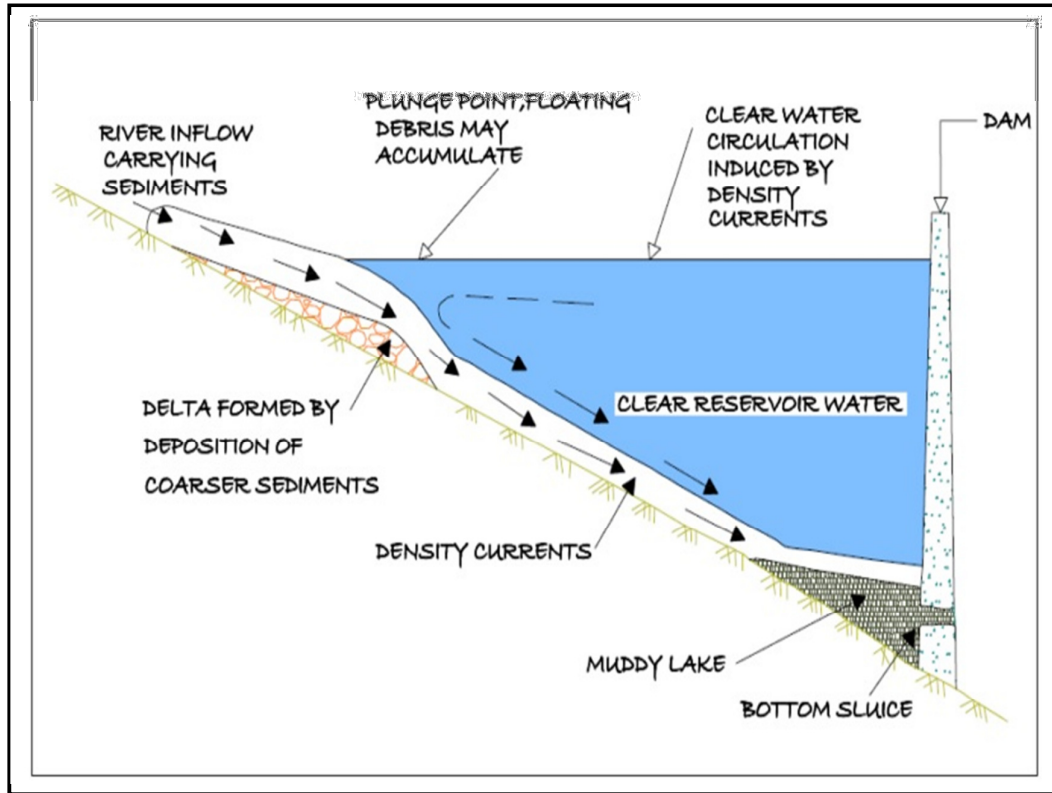
Figure 1: Conceptual sketch of density currents in a reservoir

Earlier it was believed that sediment always gets deposited in the bottom elevations of reservoir affecting the dead storage rather than depositing throughout the full range of reservoir depth. It is now fully realized that deposition takes place throughout the reservoir reducing the incremental capacity at all elevations.

Longitudinal deposition patterns in the reservoir will vary from one reservoir to another as influenced by pool geometry, discharge and grain size characteristic of the inflowing load and reservoir operation. There can be four types of depositing patterns in the reservoir as shown in the Figure 2.
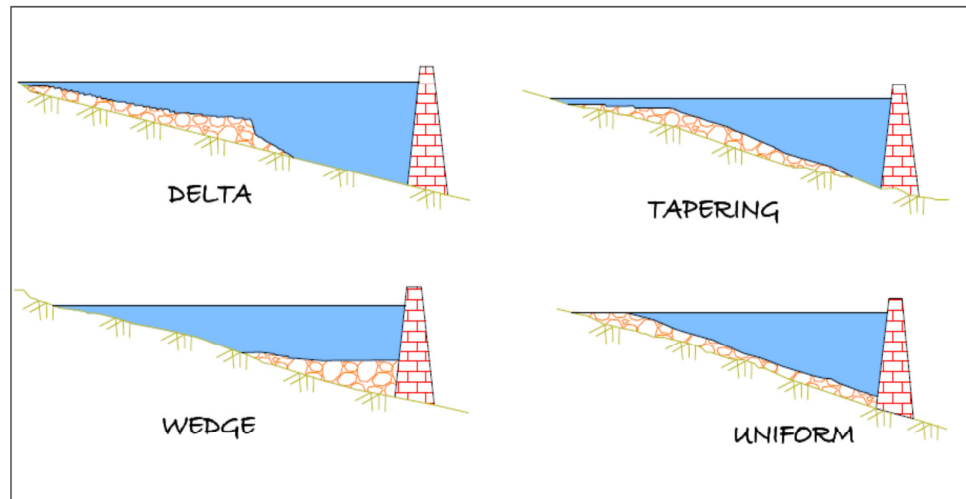
Figure 2: Longitudinal patterns of sediment deposition in reservoirs

Delta deposits contain the coarsest fraction of the sediment load, which is rapidly deposited at the zone of inflow. It may consist entirely of coarse sediment or may also contain a large fraction of finer sediment such as silt. Wedge-shaped deposits are thickest at the dam and become thinner moving upstream.This pattern is typically caused by the transport of fine sediment to the dam by turbidity currents. Wedge-shaped deposits are also found in small reservoirs with a large inflow of fine sediment, and in large reservoirs operated at low water level during flood events, which causes most sediment to be carried into the vicinity of the dam. Tapering deposits occur when deposits become progressively thinner moving toward the dam. This is a common pattern in long reservoirs normally held at high pool level, and reflects the progressive deposition of fines from the water moving toward the dam. Uniform deposits are unusual but do occur. Narrow reservoirs with frequent water level 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 Figure 3. The storage below MDDL is the dead storage. Water stored along the valley bed is known as valley storage.
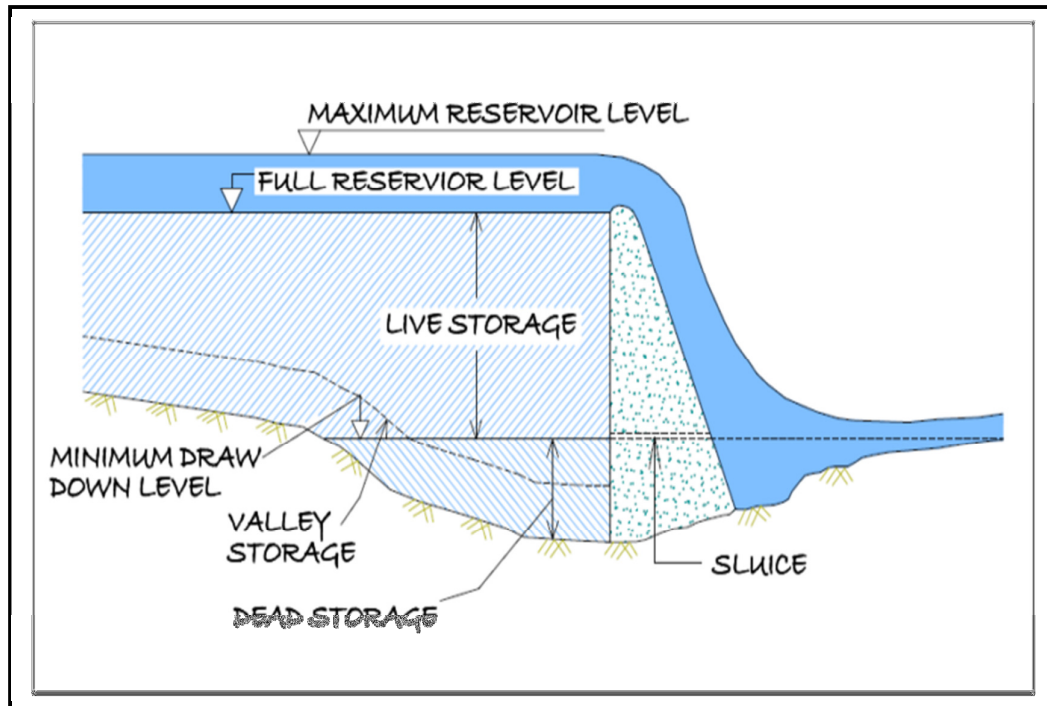
Figure 3 : Conceptual sketch of different levels in a reservoir

3. Control of Sedimentation

Due to the multiple variables involved in reservoir sedimentation, no single control measure can be considered as the most effective. The measures, which can be employed to limit sedimentation and turbidity, are as under:

1. Soil and water conservation measures within the drainage basin, contour ploughing, strip cropping, suitable farming practices, improvement of agricultural land, construction of small dams/ponds/terraces/check dams on gullies
2. Revetment and vegetation cover
3. Evacuation of sediment
4. Reservoir shoreline protection
5. Stream bank and flood plain protection
6. Ridge plantation such as pasture development and reservoir shoreline protection

Silting not only occurs in the dead storage but also encroaches into the live storage zone, which impairs the intended benefits from the reservoirs. Therefore, the problem

of sedimentation needs careful consideration. Adequate provision has to be made in the reservoir for accumulation of anticipated quantities of silt. Steps are also required to be taken to ensure that the storage capacities available are not lost or get reduced by accelerated sedimentation.

4.   Remote Sensing in Reservoir Sedimentation

Remote sensing is the art and science of collecting information about earth's feature without being in physical contact with it. Various features on earth surface reflect or emit electromagnetic energy depending upon their characteristics. The reflected radiation depends upon physical properties of the terrain and emitted radiation depends upon temperature and emissivity. The radiations are recorded by the sensors onboard satellite and then are transmitted back to earth. Discrimination between features depends on the fact that the response from different features like vegetation, soil, water is different and discernable. Data received at ground stations, is digitally or visually interpreted to generate thematic maps.

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

Present study utilizes data from Resourcesat 2 and Resourcesat 2A satellite. They have LISS III sensor, which operates in four spectral bands. Three bands are in the visible and near infra red region with spectral band widths as 0.52-0.59 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.

5. Objectives

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

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

6. Study Area

The Kanher dam is located near Kanher village in Satara taluka, Satara district, on the Venna river. The dam site is located at 17^0 45' 00" N latitude and 73^0 55' 00" E longitude. The location of the dam is shown in Figure 4 as Index Map.

The Kanher dam serves dual purpose of irrigation and drinking. The catchment area at the dam site is 204.690 sq km. The dam was first filled in year 1987. The FRL and HFL of the reservoir are at a level of 690.780 m and 690.980 m respectively. The dead storage and live storage capacity of Kanher dam are 14.320 Mm^3 and 271.680 Mm^3 respectively. Salient features of Kanher project are given in Annexure (I).

7. Previous Surveys

Kanher reservoir was impounded in 1987. The satellite remote sensing survey of reservoir was carried out in year 2006-07 by Maharashtra Engineering Research Institute, Nashik but the result of this survey has not been implemented by field authority. In this survey the capacity between FRL 690.780 m to RL 671.000 m i.e. 232.910 Mm^3 was studied. This survey shows a loss of 2.601 Mm^3 concluding the capacity in 2006-07 survey was 230.311 Mm^3.

It is to state that as the field authority not accepted 2006-07 survey they are presently using designed storages for water planning hence all result are compared with designed survey of the reservoir.
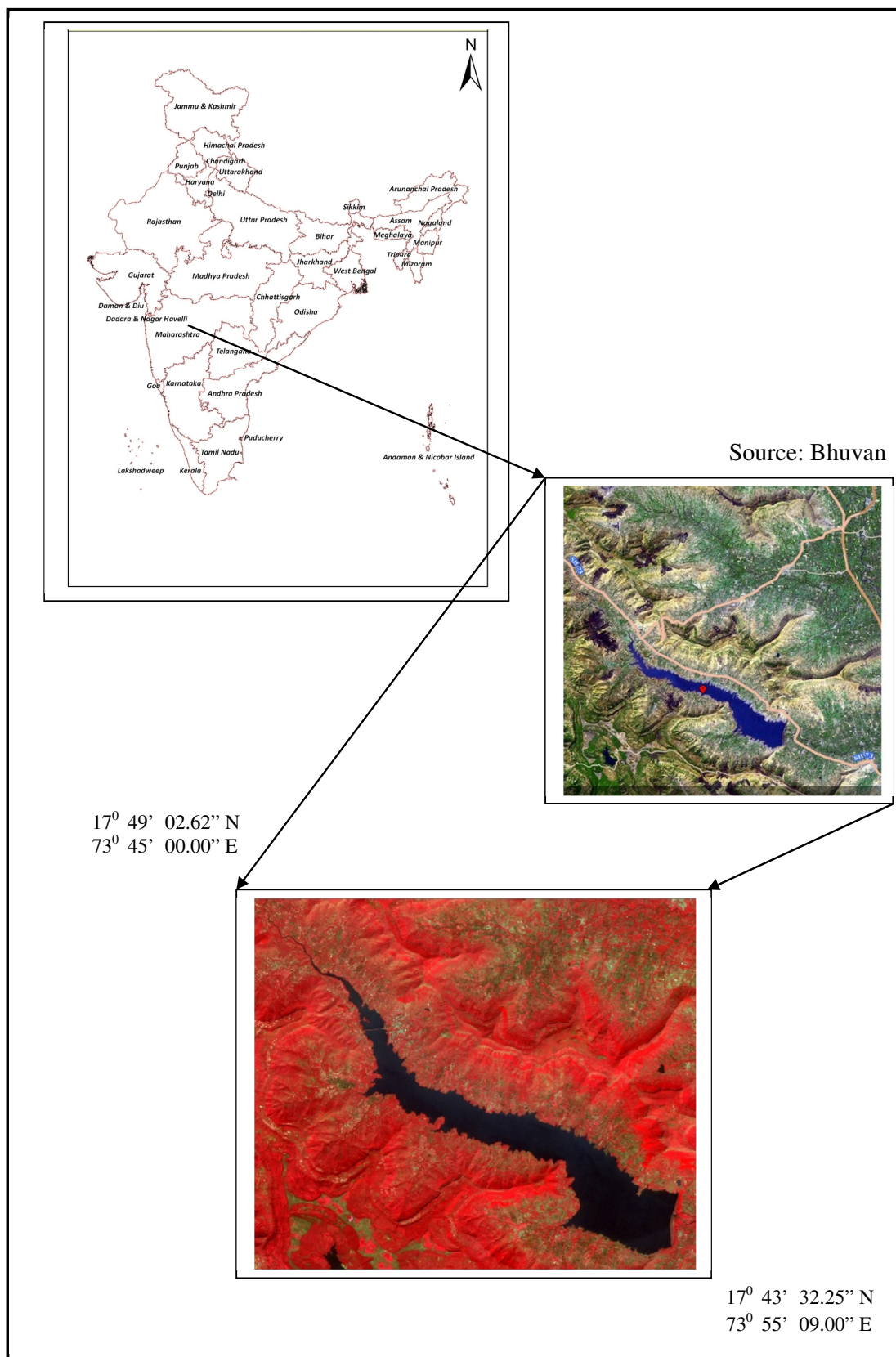
Source: Bhuvan

17^0 49' 02.62" N
73^0 45' 00.00" E

17^0 43' 32.25" N
73^0 55' 09.00" E

Figure 4 : Index map of Kanher reservoir, Maharashtra

8.   Approach of Present Study

Remote sensing technique is utilized to assess the sedimentation between operating levels of reservoir. This operating range between MDDL (662.025 m) and FRL (690.780 m) varies each year and depends upon yield in the reservoir and utilization of water. During 2015 to 2019 the minimum and maximum levels 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 2015 to 2019

Sr. No.	Water year	Minimum level (m)	Maximum level (m)	Difference of minimum and maximum levels (m)
1	2015-2016	674.750	-	-
2	2016-2017	672.300	683.930	11.630
3	2017-2018	679.070	690.780	11.710
4	2018-2019	680.620	688.810	8.190

The information reveals that in the water year 2017-2018, reservoir was filled up to FRL 690.780 m while it got depleted to Minimum RL (672.300 m) in the water year 2016-2017. For present study, one image from water year 2015-2016, three images from water year 2016-2017, five images from water year 2017-2018 and two image from water year 2018-2019 have been used. The year of survey of present study is treated as year 2017-2018.

9.   Data

9.1   Field data

Following data set was obtained from Executive Engineer, Krishna Irrigation Division, Satara for Kanher reservoir and used in the analysis.
i)   Index map of reservoir
ii) Latitude and longitude of the reservoir
iii) Original area capacity table at 0.5 m interval.

iv) Salient features of the project

v) Reservoir levels for given dates of satellite pass.

9.2 Satellite data

Resourcesat 2 and Resourcesat 2A LISS III images of 23.5 m resolution having Path 95, Row 60 have been used in present analysis. The FCC of the images are as given in Figure 5. The dates of satellite pass of selected images and corresponding reservoir levels are given in Table 2.

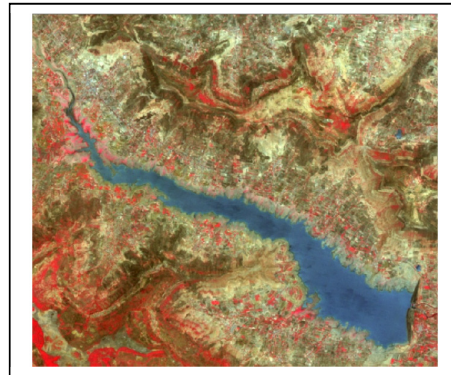Table 2 : Details of satellite data

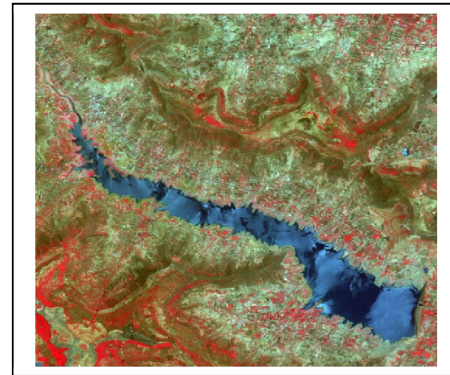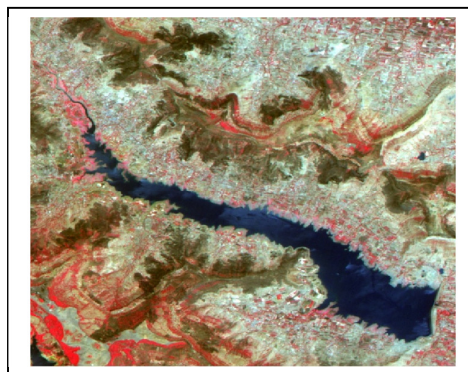| Sr. No.	Date of pass	Elevation (m)
1	16 - May - 2017	672.300
2	27 - Apr - 2016	674.750
3	22 - Apr - 2017	676.240
4	29 - Apr - 2018	679.070
5	24 - Mar - 2019	680.620
6	24 - Mar - 2018	682.300
7	09 - Feb - 2017	683.930
8	23 - Jan - 2018	686.030
9	11 - Jan - 2018	687.370
10	07 - Nov - 2018	688.810
11	31 - Oct - 2017	690.780

16 - May - 2017 (672.300 m)
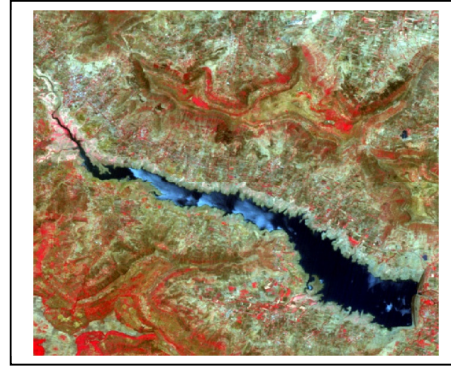
27 - Apr - 2016 (674.750 m)

22 - Apr - 2017 (676.240 m)
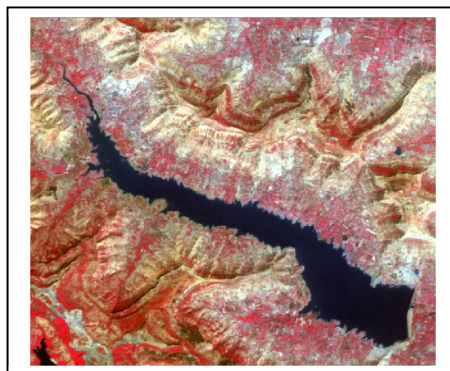
29 - Apr - 2018 (679.070 m)
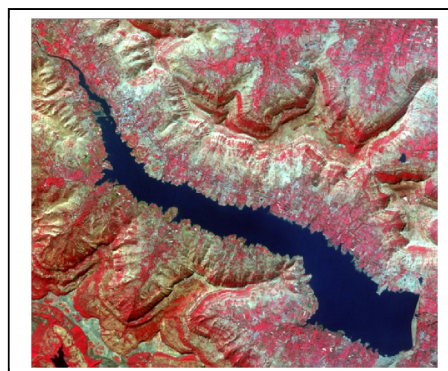
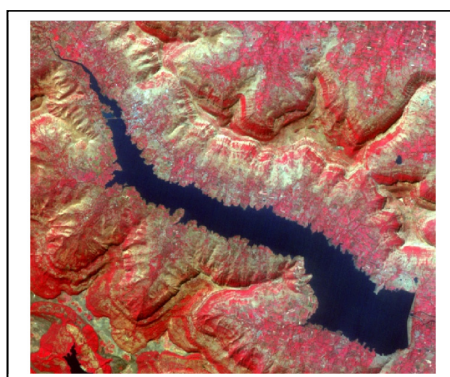24 - Mar - 2019 (680.620 m)

24 - Mar - 2018 (682.300 m)
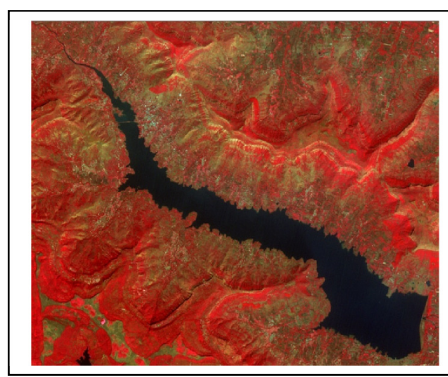
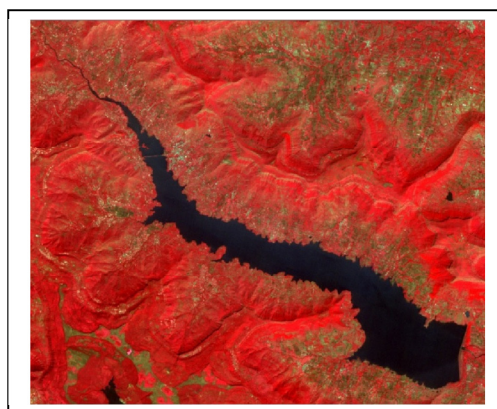Figure 5 : FCC's of Kanher reservoir, Maharashtra

09- Feb - 2017 (683.930 m)

23 - Jan - 2018 (686.030 m)

11- Jan - 2018 (687.370 m)

7 - Nov- 2018 (688.810 m)

31 - Oct - 2017 (690.780 m)

Figure 5 : FCC's of Kanher reservoir, Maharashtra

9.3   Criteria for satellite dates selection

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

(i) To carry out the feasibility assessment of the given reservoir regarding availability of cloud free satellite data of dates of satellite pass corresponding to reservoir levels near MDDL as well as near FRL and at uniform interval to the extent possible in between MDDL and FRL for the latest water year or maximum up to two previous water years.

(ii) To carry out sedimentation analysis through SRS technique to cover the entire live storage zone of the reservoir.

(iii) In case of inability to cover the entire live storage zone of the reservoir due to non-availability of cloud free satellite data at FRL and MDDL, the study may be taken up if minimum of 80 % of live storage capacity is covered by the available cloud free dates of satellite pass on maximum and minimum reservoir levels.

NRSC website has been browsed to prepare a list of dates of satellite pass over the Kanher reservoir for the year 2015 to 2019. The reservoir levels on these dates along with corresponding water spread areas and capacities have been obtained from field officers.

The reservoir has been depleted to Minimum RL (672.300 m). The maximum level covered in the present study is 690.780 m, which is FRL. Variation in the study level is (690.780 m – 672.300 m) = 18.480 m. The difference between FRL and MDDL is (690. 780 m – 662.025 m) = 28.755 m.

In the present study, storage of 225.100 Mm^3 has been covered as against total live capacity of 271.680 Mm^3. Thus the percentage live storage covered by this study is 82.855 %. (Annexure II).

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

10. Software Used

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

11. Methodology

The basic approach is to find out the water-spread areas from satellite data for different water levels between MDDL to FRL. The difference between areal spread of water between current year and earlier years is the areal extent of silting at these levels.

The methodology for estimation of live capacity of reservoir using remote sensing consists of following major tasks

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

11.1   Procedural flow chart

Field data	Satellite data	Capacity by other surveys

Field data:
i) Reservoir levels for selected satellite scenes
ii) Contour level – area – capacity curve

Satellite data flow:
Selection of cloud free multi date data → Geo-referencing of data → Sub-setting → Measuring water spread area → Capacity computations → Estimating capacity loss
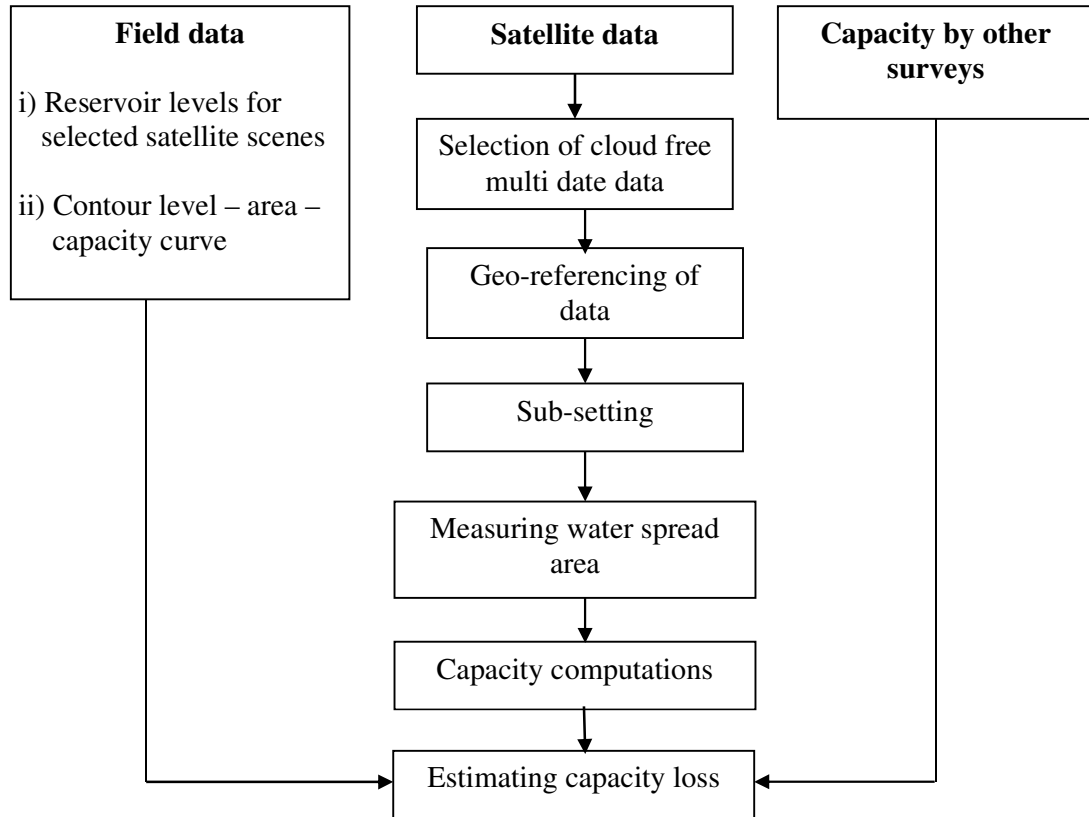
Figure 6 : Flow chart showing methodology for reservoir capacity estimation

11.2   Data loading

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

11.3   Image geo-referencing

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

11.4 Area extraction

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

11.5 Water spread area extraction

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

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

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

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

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

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

This index is designed to

 (1) maximize reflectance of water by using green wavelengths;

 (2) minimize the low reflectance of NIR by water features; and

 (3) take advantage of the high reflectance of NIR by vegetation and soil features.

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

Table 3 : Range of NDWI values for Kanher reservoir

Date of pass	Minimum value	Maximum value
16 - May - 2017	-0.0495	0.0576
27 - Apr - 2016	0.0134	0.2764
22 - Apr - 2017	-0.0405	0.1279
29 - Apr - 2018	0.1035	0.3405
24 - Mar - 2019	0.0145	0.2614
24 - Mar - 2018	0.0460	0.2927
09 - Feb - 2017	0.0157	0.255
23 - Jan - 2018	0.2078	0.4368
11 - Jan - 2018	0.0632	0.2549
07 - Nov - 2018	0.0594	0.4184
31 - Oct - 2017	-0.1155	0.2201

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 extracted from satellite data

Date of pass	Elevation (m)	Area (Mm^2)
16 - May - 2017	672.300	6.762
27 - Apr - 2016	674.750	7.954
22 - Apr - 2017	676.240	8.991
29 - Apr - 2018	679.070	11.126
24 - Mar - 2019	680.620	11.745
24 - Mar - 2018	682.300	13.326
09 - Feb - 2017	683.930	13.673
23 - Jan - 2018	686.030	15.625
11 - Jan - 2018	687.370	16.289
07 - Nov - 2018	688.810	17.143
31 - Oct - 2017	690.780	18.035

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

11.6   Water spread area at regular interval

Water levels on the dates of pass for selected satellite data are not available at regular interval. However to get WSA values at regular interval of elevation, area-elevation 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.

11.7   Calculation of reservoir capacity

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

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

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

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

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

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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 (2017-18)	Cumulative capacity Mm^3 (2017-18)
MDDL	662.025	0.000	0.000
	663.000	0.203	0.000
	664.000	0.901	0.510
	665.000	1.597	1.742
	666.000	2.291	3.675
	667.000	2.983	6.304
	668.000	3.673	9.626
	669.000	4.361	13.638
	670.000	5.047	18.338
	671.000	5.731	23.723
	672.000	6.413	29.792
	673.000	7.093	36.542
	674.000	7.771	43.971
	675.000	8.447	52.078
	676.000	9.121	60.860
	677.000	9.793	70.315
	678.000	10.463	80.442
	679.000	11.131	91.237
	680.000	11.797	102.700
	681.000	12.461	114.828
	682.000	13.123	127.619
	683.000	13.784	141.071
	684.000	14.442	155.182
	685.000	15.098	169.951
	686.000	15.752	185.374
	687.000	16.404	201.451
	688.000	17.054	218.179
	689.000	17.702	235.555
	690.000	18.348	253.579
FRL	690.780	18.850	268.086
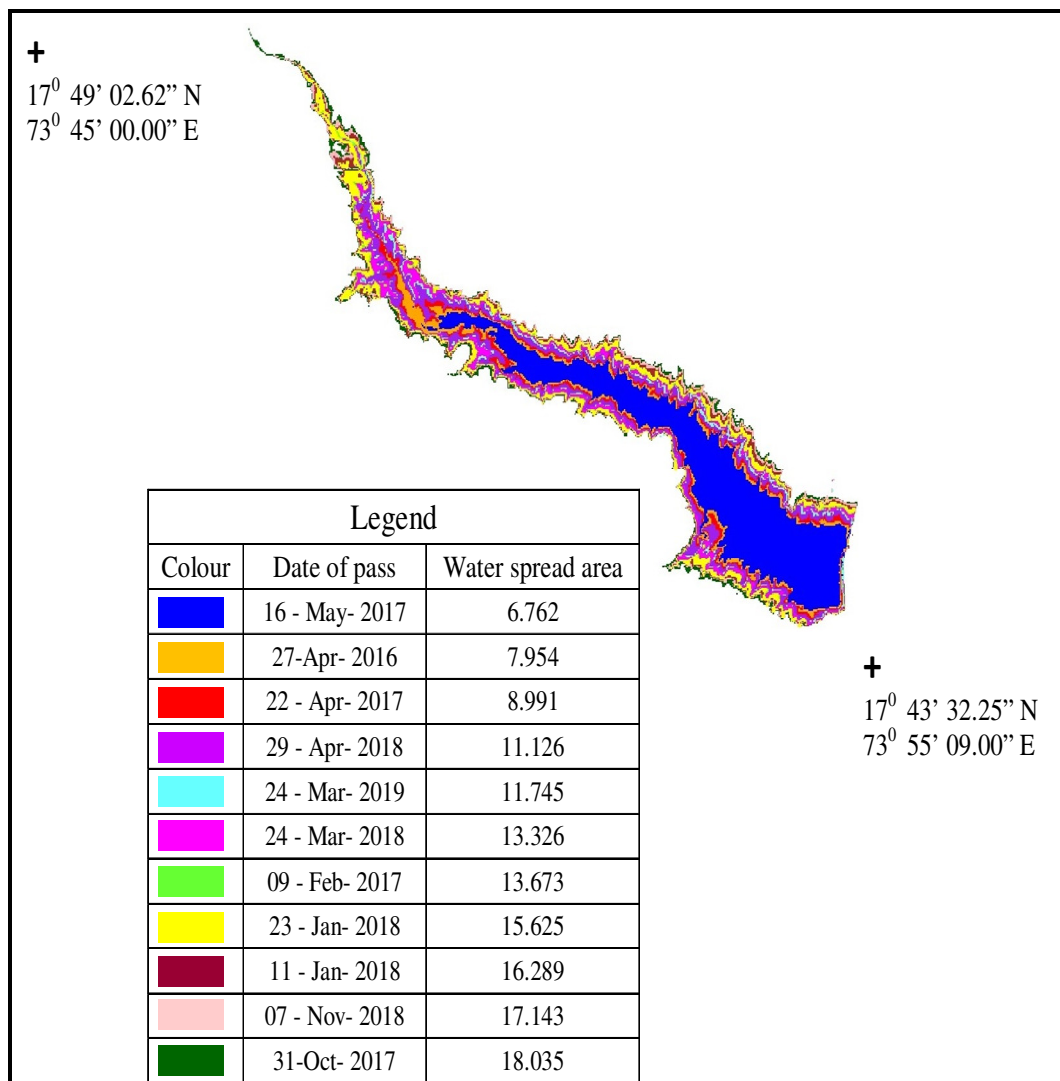
Figure 7 : Water spread areas on different dates of satellite pass

SRS elevation area curve is shown in Figure 8 and tabulated in Table 4. Elevation capacity curves is shown in Figure 9 and tabulated in Table 5. The MDDL of Kanher reservoir is 662.025 m. Due to the restriction to use only previous three water years satellite images (data), lowest water level satellite image is available at 672.300 m. The satellite image in the portion of water column R.L 672.300 m to MDDL 662.025 m was not available hence the Figure 10 is following the trend of equation derived which is based on Table 6. The elevation-capacity curve drawn through original and present surveys carried for the Kanher reservoir are shown in Figure 11 and tabulated in Table 7. In Figure 12 updated SRS elevation-area-capacity curve is drawn and tabulated in Table 5.

$$y = -0.001x^2 + 0.701x - 0.480$$
$$R^2 = 0.996$$

FRL 690.780 m

MDDL 662.025 m

Legend

— SRS WSA Curve

• SRS WSA

Water Spread Area in Mm^2 ----▲
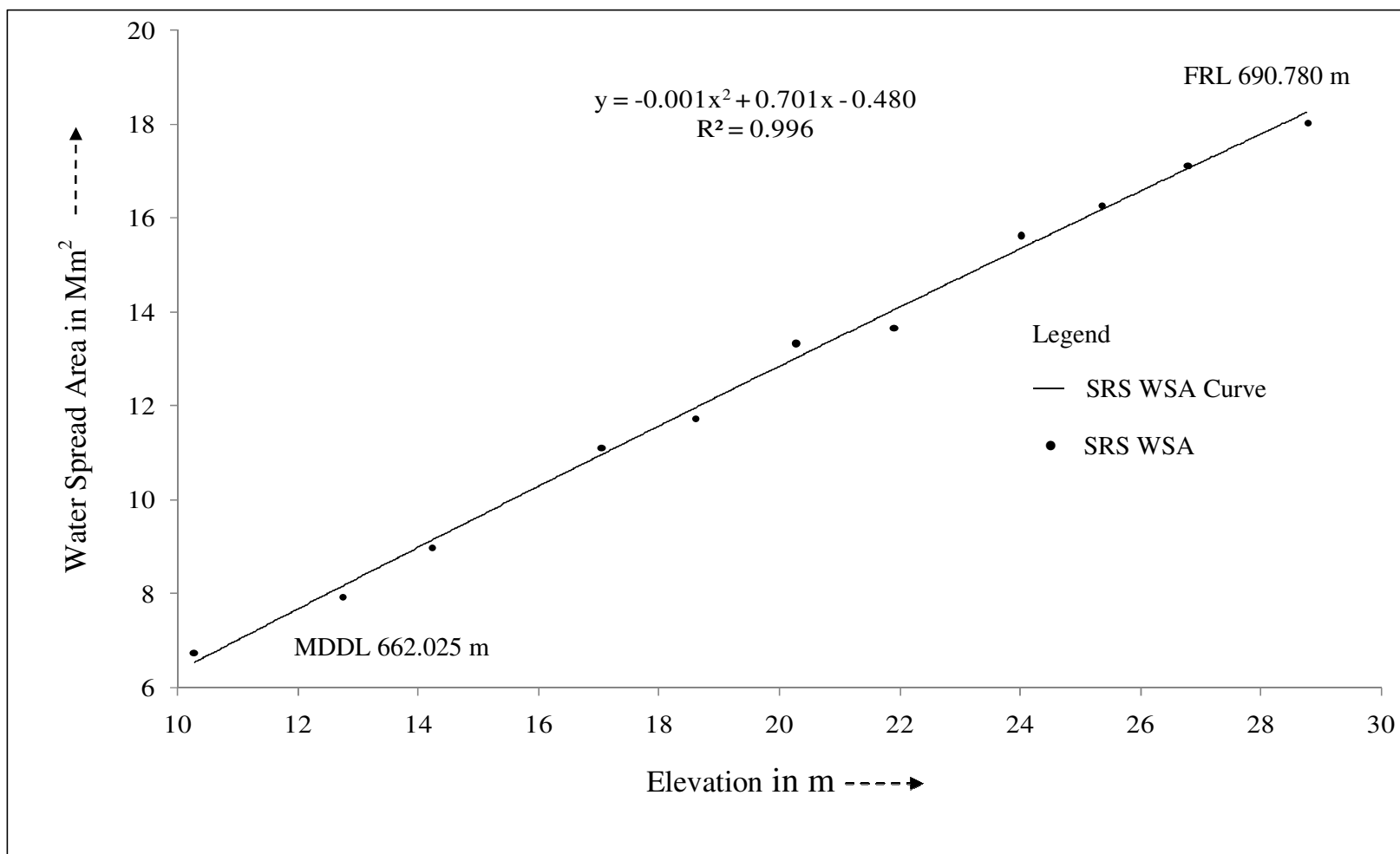
Elevation in m ----▶

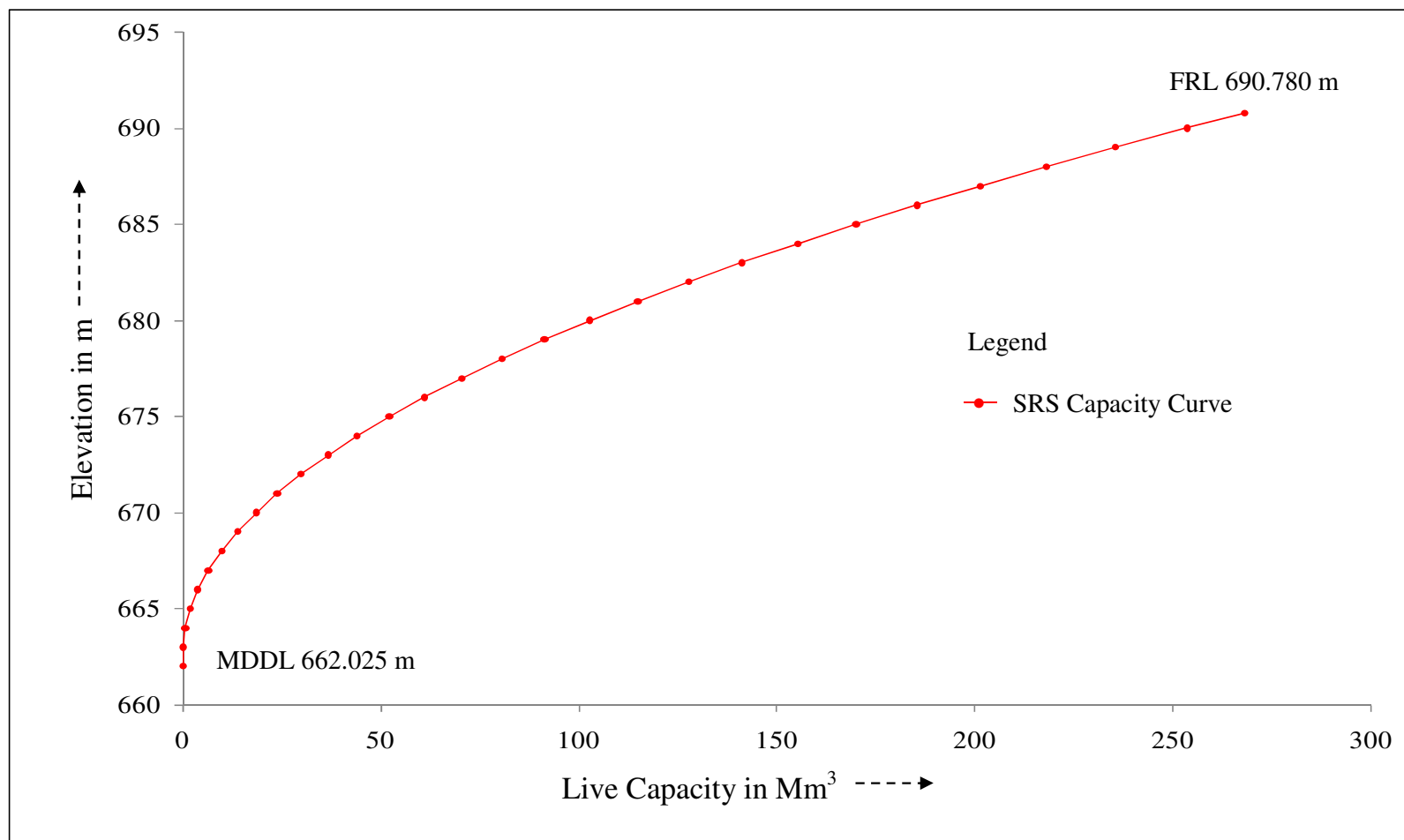Figure 8 :   SRS Elevation-Area curve for Kanher reservoir, Maharashtra

Figure 9 :   SRS Elevation-Capacity curve for Kanher reservoir, Maharashtra
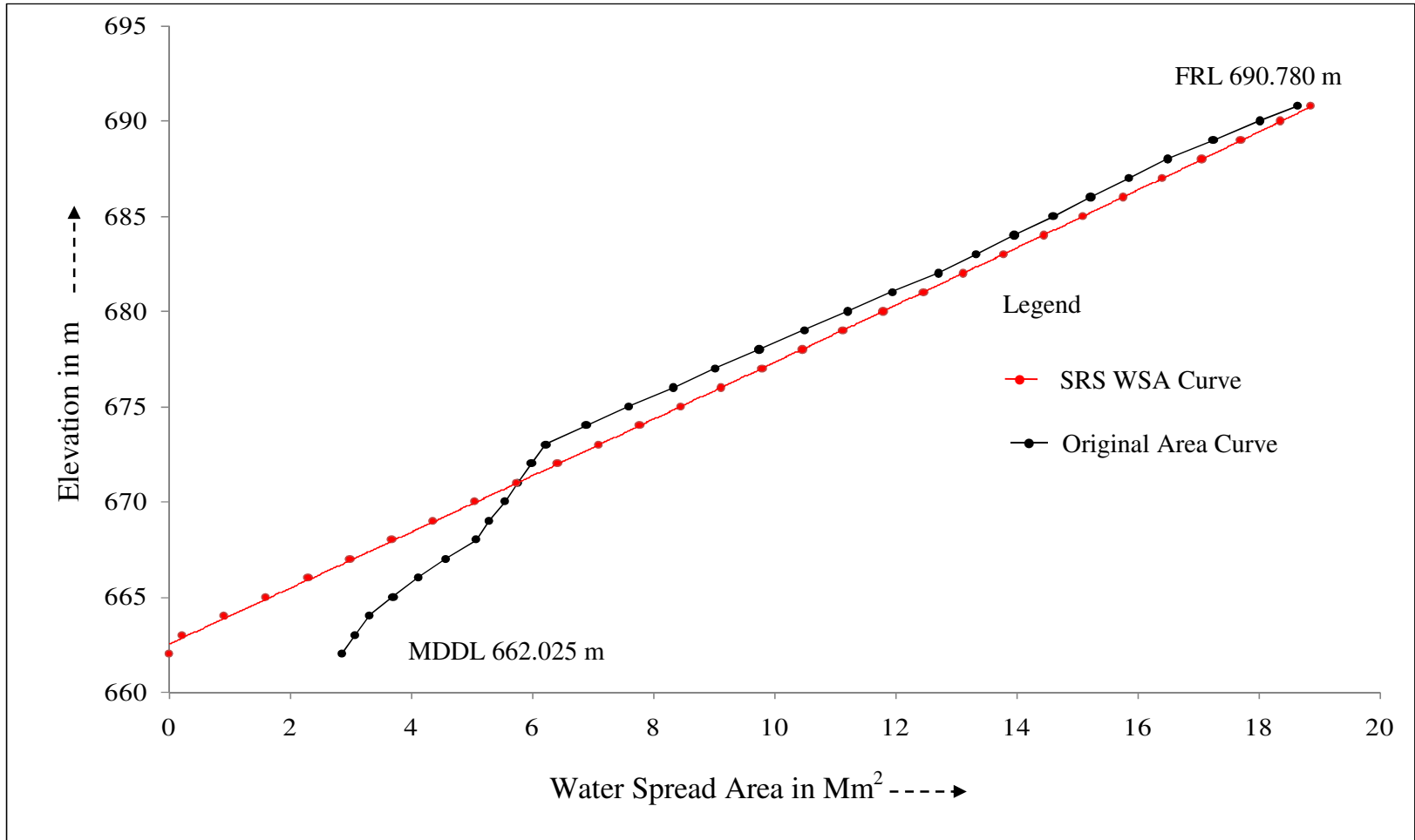
Figure 10 :   Elevation - Area curve for different years for Kanher reservoir, Maharashtra
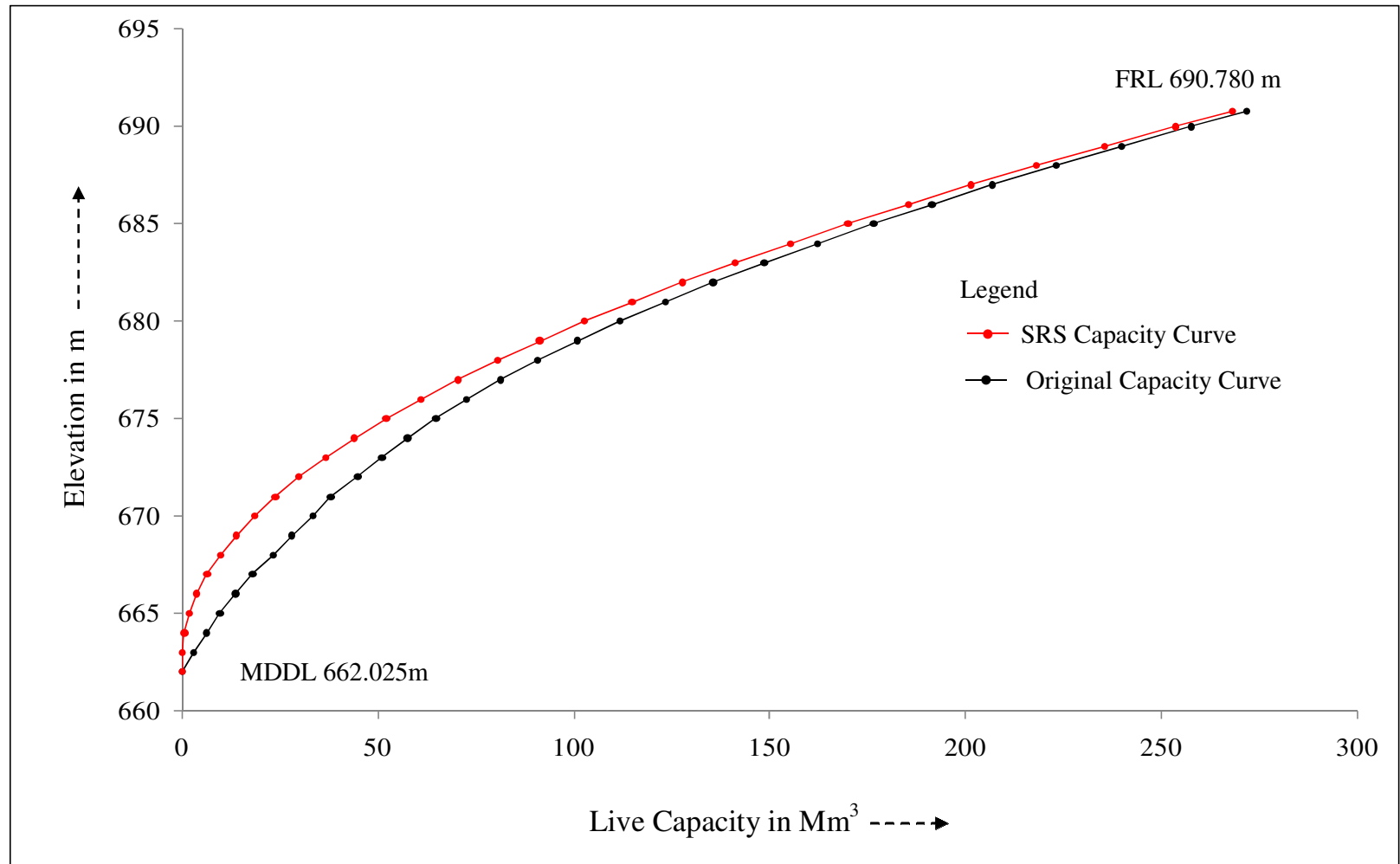
Figure 11 : Elevation - Capacity curve for different years for Kanher reservoir, Maharashtra
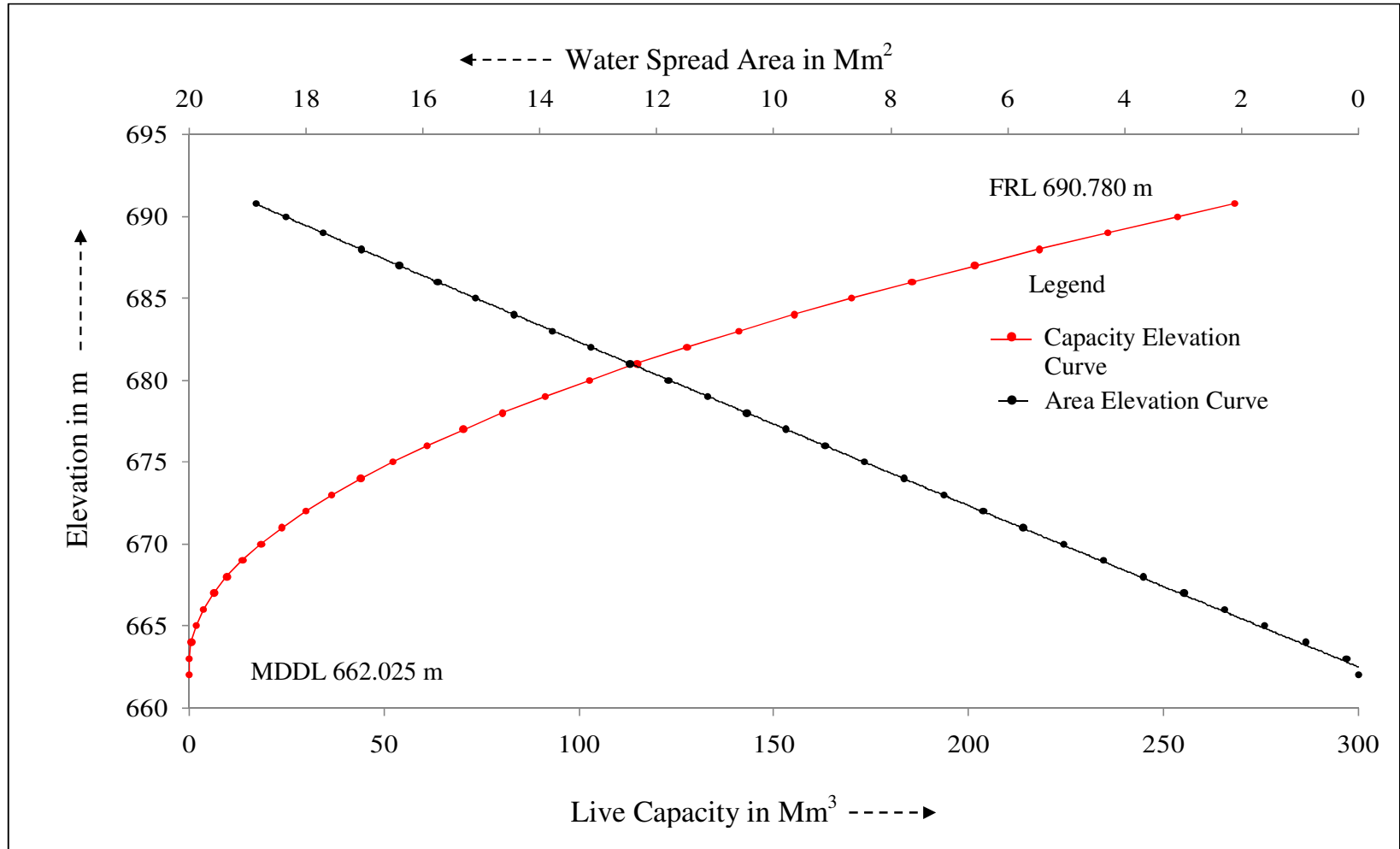
Figure 12 : Modified SRS Elevation - Area - Capacity curve for Kanher reservoir, Maharashtra

11.8   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 (Mm^2)

Water elevation m		Original survey 1987	SRS survey 2017-18
MDDL	662.025	2.8620	0.000
	663.000	3.0780	0.203
	664.000	3.3080	0.901
	665.000	3.7050	1.597
	666.000	4.1250	2.291
	667.000	4.5746	2.983
	668.000	5.0717	3.673
	669.000	5.2913	4.361
	670.000	5.5410	5.047
	671.000	5.7630	5.731
	672.000	5.9896	6.413
	673.000	6.2210	7.093
	674.000	6.8888	7.771
	675.000	7.5913	8.447
	676.000	8.3280	9.121
	677.000	9.0208	9.793
	678.000	9.7414	10.463
	679.000	10.4900	11.131
	680.000	11.2050	11.797
	681.000	11.9439	12.461
	682.000	12.7070	13.123
	683.000	13.3220	13.784
	684.000	13.9522	14.442
	685.000	14.5970	15.098
	686.000	15.2120	15.752
	687.000	15.8398	16.404
	688.000	16.4810	17.054
	689.000	17.2364	17.702
	690.000	18.0096	18.348
FRL	690.780	18.6250	18.850

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

Table 7 : Comparison of live storage capacity of reservoir (Mm^3)

Water elevation m		Original survey 1987	SRS survey 2017-18
MDDL	662.025	0.000	0.000
	663.000	2.922	0.000
	664.000	6.088	0.510
	665.000	9.591	1.742
	666.000	13.504	3.675
	667.000	17.852	6.304
	668.000	23.167	9.626
	669.000	27.830	13.638
	670.000	33.246	18.338
	671.000	37.897	23.723
	672.000	44.774	29.792
	673.000	50.879	36.542
	674.000	57.431	43.971
	675.000	64.668	52.078
	676.000	72.525	60.860
	677.000	81.297	70.315
	678.000	90.676	80.442
	679.000	100.790	91.237
	680.000	111.636	102.700
	681.000	123.209	114.828
	682.000	135.532	127.619
	683.000	148.540	141.071
	684.000	162.182	155.182
	685.000	176.455	169.951
	686.000	191.359	185.374
	687.000	206.884	201.451
	688.000	223.043	218.179
	689.000	239.901	235.555
	690.000	257.523	253.579
FRL	690.780	271.680	268.086

11.9 Field visit and ground truth

Field visit of the reservoir area has been carried out on 28th November 2019 for ground truth verification. Some predetermined ground truth points marked on the satellite image printouts along with their latitude and longitude values have been verified, with the help of GPS (Trimble Juno) receiver. Following officers were present during this visit.

Officers from Resources Engineering Center, MERI, Nashik

      i)   Shri. G. R. Gangapurkar, Deputy Engineer

      ii)   Shri. R. V. Gaikawad, Assistant Engineer Grade - II

      iii)   Shri. A. B. Dhokchaule, Junior Engineer

Team from Kanher reservoir project

      i)   Shri. L. S. Bhujbal , C.E.A.

      ii)   Shri. A. K. Sawant, C.E.A.

      iii)   Shri. N. B. Jangam, Canal Inspector

      iv)   Shri. R. H. Phadtare, Wireless Operator

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 690.780 m. The Photographs of ground truth scenario are shown in Annexure III.

12. Results and Discussions

The loss in live storage capacity of the reservoir in remote sensing survey (2017-18) due to sedimentation since original survey (1987) is given in Table 8

Table 8 : Live storage capacity loss due to sedimentation from original survey

Details	Original survey (1987)	SRS (2017-18)
Live capacity in (MCM) at FRL 690.780 m	271.680	268.086
Loss in capacity (MCM)	-	3.594
% Live capacity loss (since 1987)	-	1.322
Annual % live capacity loss	-	0.042
% Live capacity loss between two consecutive surveys (of the original capacity)	-	1.322
% Loss in live storage between the survey since impoundment	-	1.322

The following observations are recorded from the present study.

- Present live capacity (year 2017-2018) of Kanher reservoir is found as 268.086 Mm^3. Modified SRS elevation-area-capacity values are given in Table 5 and Figure 12.

13. Limitations

The sedimentation survey using Remote Sensing Technique has following limitations

- The remote sensing based capacity estimation works between the operating levels i.e. MDDL to FRL only. Thus changes can be estimated only in live capacity of reservoir.
- 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.

- MDDL of Kanher reservoir is 662.025 m. As per the restriction to take previous three water year satellite images, minimum water level satellite image is available at 672.300 m. The satellite image in the portion of water column 672.300 m to MDDL 662.025 m was not available. Hence in Figure 10 the satellite remote sensing curve is following the trend of equation derived. Due to which satellite remote sensing curve is significantly different at lower elevation.

14.   Conclusions

Following conclusions can be drawn from the study:
- The live storage capacity of Kanher reservoir is 268.086 Mm^3 in year 2017-18.
- Capacity loss of 1.322 % in live storage is observed in a period of 31 years since first impounding in 1987.
- Annual live capacity loss works out to 0.042 %.
- It is to be mentioned that hydrographic survey is recommended.

References

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Central Water Commission, Technical reports on reservoir capacity estimation using satellite remote sensing for different reservoirs. RS Directorate, New Delhi.

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Salient Features

A	Location		
	Village	:	Kanher
	Taluka	:	Satara
	District	:	Satara
	State	:	Maharashtra
	Longitude	:	73^0 55' 00"
	Latitude	:	17^0 45' 00"
	River	:	Venna
B	Hydrology		
	Catchment area	:	204.690 sq km
C	Masonry and Earthen Dam		
	Length of dam	:	1955.000 m
	Height of the dam	:	50.340 m
D	Capacity of Dam		
	Gross storage capacity at FRL	:	286.000 Mm^3
	Dead storage capacity	:	14.320 Mm^3
	Live capacity	:	271.680 Mm^3
	Design spillway discharge capacity	:	1778.000 m^3/s
	Type of spillway	:	Ogee
	No. and Size of spillway	:	4 Nos., 12.000 m x 8.500 m
E	Reservoir Data		
	Top of dam	:	693.500 m
	Highest flood level	:	690.980 m
	Full reservoir level	:	690.780 m
	Spillway crest level	:	682.780 m
	Minimum draw down level	:	662.025 m
	Year of completion	:	1988-89
	Year of impounding	:	1987

Reservoir Levels Pertaining to Cloud Free Satellite Data

Path/Row - 95 / 60   Gross storage capacity at FRL – 286.000 Mm^3

FRL – 690.780 m   Design live storage – 271.680 Mm^3

MDDL – 662.025 m   Dead storage capacity – 14.320 Mm^3

| Date of pass	Reservoir level (m)	Capacity covered (Mm^3)
1	2	3
16 - May - 2017	672.300	60.900
27 - Apr - 2016	674.750	77.110
22 - Apr - 2017	676.240	88.960
29 - Apr -2018	679.070	115.840
24 - Mar - 2019	680.620	133.040
24 - Mar - 2018	682.300	153.690
09 - Feb - 2017	683.930	161.930
23 - Jan - 2018	686.030	206.140
11 - Jan - 2018	687.370	227.110
07 - Nov - 2018	688.810	250.960
31 - Oct - 2017	690.780	286.000
Variation in capacity		(286.000 – 60.900) = 225.100
% variation of live storage		(225.100/271.680)*100 = 82.855 %

Ground Truth Scenario

Dam view

Main canal
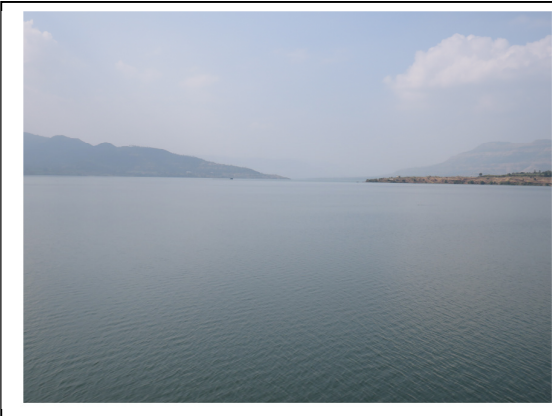
Water spread area

Upstream pitching

Downstream pitching

Power generation plant

Water gauge level

Top bund level

Peripheral vegetation

Peripheral vegetation

Peripheral siltation

Ground truthing team

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