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Application of Microwave Remote Sensing Technique for Capacity Assessment Study of Gangapur Reservoir

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1. INTRODUCTION

One of the essential inputs required for effective water planning of reservoir is assessment of its present storage capacity. It is therefore essential for the irrigation manager to know the quantum of water available in the live storage zone. Remote sensing technique for reservoir sedimentation surveys is 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 parameters namely 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.

The Maharashtra Engineering Research Institute the State's Water Resources Department, has done substantial work in the field of reservoir capacity assessment.

Present survey of Gangapur reservoir by satellite remote sensing technique has been conducted after 59 (1957-2016) years of its first impounding.

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 utilizable 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 industrialization, urbanization and change in lifestyles or dietary habits, making the available water resources still dearer.

So far, India has developed just 257.812 BCM as live storage capacity and 46.765 BCM is under construction. Realizing 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.

What is microwave remote sensing?

Microwave remote sensing is a method of collecting information about the Earth's surface and atmosphere by using microwave radiation, typically in the wavelength range of 1 mm to 1 m. Unlike visible or infrared remote sensing, microwaves can penetrate clouds, fog, and light rain, making microwave remote sensing especially useful for all- weather, day-and-night observation of the Earth's surface.

Key Components and Types Active Microwave Sensing:

Radar (Radio Detection and Ranging): An active sensor that transmits microwave signals and measures the return signal reflected from the Earth's surface. Common types include Synthetic Aperture Radar (SAR) and Scatterometers.

Operation: The radar sends a pulse toward the Earth, and when it bounces back, the sensor measures the strength, phase, and time delay of the returned signal. This helps determine surface properties like roughness, moisture, and structure.

Passive Microwave Sensing:

Radiometers: These sensors measure naturally emitted microwave radiation from the Earth's surface and atmosphere.

Use: Useful for measuring soil moisture, sea surface temperatures, and atmospheric properties. Passive sensors measure very low-energy signals, so they're sensitive to temperature, surface texture, and material composition.

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Problem statement

Evaluation of Capacity of Gangapur Reservoir using Microwave remote sensing technique

Key Points:
1. Data collection of Gangapur reservoir
2. Applying appropriate filters and changes to the acquired data using QGIS and SNAP TOOL.

Objective

- To estimate the present live storage capacity of reservoir.
- To update Elevation-Capacity curve for the live storage zone of reservoir.

2. SCOPE OF THE STUDY

This research extends from roughly observing the Gangapur Reservoir to downloading essential data from Copernicus Space Ecosystem Data, applying filters in softwares like SNAP Tool and QGIS and finding out the exact water spread area of reservoir.

The use of microwave remote sensing for capacity assessment studies of reservoirs like Gangapur offers several benefits due to the unique characteristics of microwave radiation, which can penetrate clouds, rain, and other atmospheric conditions, ensuring reliable data collection in various weather conditions. Here's a detailed look at the scope of applying microwave remote sensing for such studies.

3. Necessity

- To evaluate changes in the capacity of the reservoir. This can greatly affect the ecosystem and the places to which the reservoir provides water supply to.
- This could also mean changes to the water supply rate also decrease in the water supplied to the nearby city or town
- This data will be compared to previous years data to find any decrease in reservoir capacity. This decrease in capacity will mean reduced water supply to the neighbouring places
- This data can also be used to predict rainfall patterns.

3. DETAILS OF RESERVOIR:

The Gangapur reservoir lies between Latitude 19°: 58':55" N to 20°: 03': 59" N and Longitude 73°: 36': 35" E to 73°: 41': 16"E. The location of reservoir is shown in Fig.1 as Index Map. The reservoir was constructed on river Godavari near village Gangapur in taluka and district Nashik. Total catchment area of the reservoir is 357.40 sqkm . The designed gross storage capacity of the reservoir at FRL 612.35 m is
215.20 Mm' and live storage capacity between FRL and MDDL is 203.87 Mm?. The MDDL of the reservoir is 591.20m. The designed dead storage capacity is 11.33 Mm'. The reservoir was first impounded in the year 1957.

Location map of Gangapur reservoir

4. LITERATURE REVIEW

5. METHODOLOGY

Digital analysis has an edge over visual analysis in identifying water spread and turbidity levels in detail and more accurately because of minimizing human error or subjectivity. For Gangapur reservoir studies, multi-date Sentinel 1 is used for the analysis. Image processing with SNAP software and Arc GIS/ Q-GIS software was used for the analysis. The analysis comprised,

- Water spread area estimation.
- Estimation of reservoir capacity.
- Comparison with original capacity.

5.1 Data base

The satellite data from Sentinel 1 satellite corresponding to reservoir area obtained from Copernicus open access hub was loaded on the system. The Sentinel-1 mission is a constellation of two polar-orbiting satellites (Sentinel-1A and Sentinel- 1B), that operate day and night, sensing with a C-band synthetic aperture radar instrument operating at a centre frequency of 5.405 GHz, allowing the acquisition of imagery regardless of weather and illumination conditions. Sentinel-1 satellite constellations acquire Synthetic Aperture Radar (SAR) data in single or dual polarization with a revisit time of 6 days. A series of standard corrections was applied to the data using SNAP software to apply a precise orbit of acquisition, remove thermal and image border noise, perform radiometric calibration, and apply range Doppler and terrain correction.

5.2 Water spread area estimation

Reduction in capacity of reservoir at different levels is depicted by reduction in water- spread area (WSA) at different water levels. Estimation of water-spread area is done using various digital image processing (DIP) techniques. The techniques adopted for water-spread area estimation are as follows:

- SAR data Pre-processing using Sentinel Application Platform (SNAP)
- Thresholding using Q-GIS

The basic approach of this study is to map flood area surrounding of Chiplun taluka. The methodology comprises following functional components.

i) Image Subset

ii) Thermal Noise Removal Taking subset of study area

iii) Calibration

iv) Speckle Filter

v) Terrain Correction

vi) Linear to Logarithmic

vii) Mapping in QGIS for Preflood & during flood image

viii) Preparation of report

Water spread areas extracted from satellite data

Sr. No.	Date of pass	Elevation in m.	Area in Mm^2
1	16-October-23	612.350	19.093
2	27-August-22	611.800	18.710
3	06-January-23	610.760	17.904
4	18-February-23	609.760	16.700
5	13-January-24	608.830	15.955
6	25-February-24	607.740	14.602
7	24-July-23	606.900	14.232
8	06-Jun-23	604.760	12.058
9	28-Jun-22	602.840	10.466
10	05-Jun-24	601.840	9.160

5.3 SAR data pre-processing using SNAP:

The open-source Sentinel Application Platform (SNAP) Toolkit developed by European Space Agency was used for SAR data pre-processing. Sentinel-1 intensities from high-resolution Level-1 ground range detected products (10 m; GRDH) were calibrated, speckle-filtered, and geometrically corrected using Range Doppler Terrain Correction. Specifically, the improved Lee-Sigma single product speckle filter with a window size of 7 by 7 was used to reduce speckle noise. Terrain correction were conducted using the recently released STRM 1 arc-second HGT digital elevation model (DEM) and UTM/WGS84 (Automatic) Map projection was used where in SNAP automatically selects the required UTM zones.

Sentinel-1 : The Sentinel-1 mission comprises a constellation of two polar-orbiting satellites, operating day and night. These satellites use C-band synthetic aperture radar imaging, which allows them to capture images in all weather conditions.

Two polar-orbiting satellites

The Sentinel-1 mission is the European Radar Observatory for the Copernicus joint initiative of theEuropean Commission (EC) and the European Space Agency (ESA).Copernicus is a European initiative for the implementation of information services dealing with environment and security. It is based on observation data received from Earth Observation satellites and ground-based information.

The Sentinel-1 mission includes C-band imaging operating in four exclusive imaging modes with different resolution (down to 5 m) and coverage (up to 400 km)

It provides dual polarization capability, short revisit times and rapid product delivery. Additionally, precise measurements of spacecraft position and attitude are available for every observation.

5.4 Thresholding

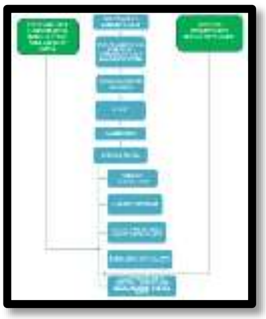
The areas where clear water/land demarcation is there, density slicing is successfully used for delineation of water spread areas. Density slicing is a technique where the entire grey values of pixels occurring in the image are divided into a series of specified intervals. All the grey values falling within a range are grouped in one grey value, which is displayed in output. This process divides the image into water and land pixels. From the study of histogram peaks, minimum and maximum value for water pixels is identified and image is then density sliced.

5.5 Monitoring day and night, under all weather conditions:

Synthetic Aperture Radar (SAR) has the advantage of operating at wavelengths that are not affected by cloud cover or lack of illumination, allowing it to acquire data over a site during both day and night time, and under all weather conditions. The C-SAR instrument of Sentinel-1 provides reliable and repeated wide area monitoring.

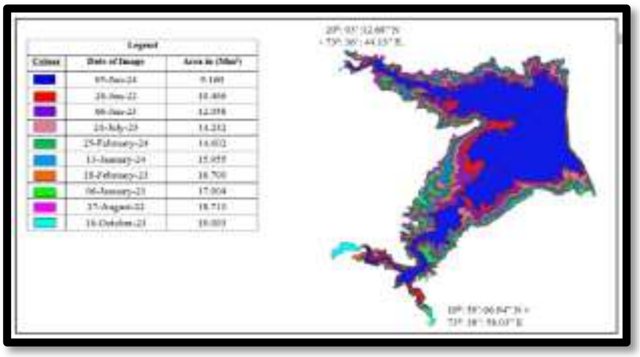
The mission consists of a constellation of two satellites, Sentinel-1A and Sentinel-1B, sharing the same orbital plane. Unfortunately, Sentinel-1B experienced a power failure on December 23, 2021, and is no longer operational. It will be replaced in 2023 by Sentinel-1C, whose data will be accessible through this ecosystem.

Sentinel-1 is designed to work in a pre-programmed, conflict-free operation mode. It captures high- resolution images of all landmasses, coastal zones, and shipping routes worldwide, and provides vignettes of the global ocean. This ensures the reliability of service required by operational services and ensures a consistent long-term data archive for applications based on long time series.



Methodology followed to estimate reservoir capacity loss

The curtailment of tail water has been carried out as per FRL layer and the same is used for other images as reference. The water spread area on selected dates of satellite pass. The classified images of different levels. The comparison of design water spread area of reservoir (year 1957) with water spread area of present SRS survey (year 2024) is shown in Table 6. The graph and the equation derived from Table 3 is shown in Figure 7. Figure 8 shows SRS Elevation- Capacity curve of present SRS survey (year 2024) for Gangapur reservoir. The Table 4 shows the comparison of water spread area of design and present survey shown in Figure 9. The Table 5 shows the comparison of live storage capacity in Mm3 for design and present storages shown in Figure 10. The modified SRS elevation-area- capacity curve is shown in Figure 11 which is tabulated in Table



7WATER SPREAD AREA AT REGULAR INTERVAL

Water levels on the dates of pass for selected satellite data are not available at regular interval. To get WSA values at regular elevation interval, a curve has been plotted between Elevation and the Revised Area. The best fit polynomial equation of second order was derived for the graph.

y = -0.0013x2 + 0.9536x +9.3059

R^2 = 0.9979 (R = Coefficient of co-relation)

Where x = Elevation difference in meters (measured above RL 601.840 m)

y = Water spread area in Mm2

The comparison of water spread area obtained through remote sensing analysis with original surveyed data for studied portion is given in Table 4

Comparison of SRS water spread areas of reservoir with design data

6.

Water elevation (m)	As per Design Survey Year 1957 (Mm^2)	SRS Survey 2023-24 (Mm^2)
RL 601.840	--	9.306
602.000	--	9.458
602.840	10.307	10.258
603.000	10.310	10.410
604.000	10.840	11.360
604.760	11.729	12.079
605.000	12.010	12.306
606.000	13.180	13.250
606.900	14.233	14.098
607.000	14.350	14.192
607.740	15.216	14.887
608.000	15.520	15.131
608.830	16.491	15.908
609.000	16.690	16.067
609.760	17.708	16.777
610.000	18.030	17.001
610.760	19.421	17.709
611.000	19.860	17.932
611.800	21.271	18.675
612.000	--	18.860
FRL 612.350	--	19.185

CALCULATION OF RESERVOIR CAPACITY

Computation of reservoir capacity at different elevations has been done using following prismoidal formula.

$V=H/3\ (A_1+A_2+\sqrt{A_1 \times A_2})$

Where, V = Reservoir capacity between two successive elevations h1 and h2

H = Elevation difference (h2 – h1)

A1 and A2 are areas of reservoir water spread at elevation h1 and h2.

The comparison of SRS live storage capacity with design live storage capacity of reservoir of year 1957 with available satellite image data is given in Table

4. Present capacity of reservoir from RL 601.840 m to FRL 612.350 m is 149.950 Mm3 as against design content of 146.642 Mm3 between these same levels.

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Water elevation (m)	Design Live Storage As Per Survey Year 1957 (Mm³)	Live Storage SRS Survey 2023-24 (Mm³)
RL 601.840	0.000	0.000
602.000	1.547	1.501
602.840	9.795	9.780
603.000	11.366	11.433
604.000	21.567	22.315
604.760	29.599	31.220
605.000	32.134	34.146
606.000	43.202	46.922
606.900	53.528	59.227
607.000	54.717	60.641
607.740	64.405	71.399
608.000	67.873	75.301
608.830	79.887	88.181
609.000	82.590	90.899
609.760	95.239	103.379
610.000	99.170	107.432
610.760	113.393	120.621
611.000	117.965	124.898
611.800	134.813	139.539
612.000	138.883	143.293
FRL 612.350	146.642	149.950

Comparison of live storage capacity of reservoir (Mm³)

1 FIELD VISIT AND GROUND TRUTH COLLECTION

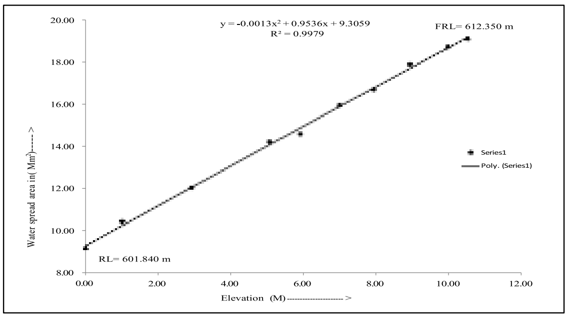
The field visit was conducted by the team of this Institute for ground truth data collection on Date 21st January 2025. For verification of ground truth, doubtful/ mixed signature locations along the periphery of the reservoir were marked on satellite images as well as on classified image printouts. Field visit helps in identification of correct class between vegetation and water at such locations. GPS readings were taken with the help of Trimble Juno Handheld GPS device and simultaneously latitude /longitude values of reservoir components have been recorded during the visit. Water level of the reservoir on the day of visit was 610.960 m.

Figure 10: Collected GPS data overlaid on FCC image

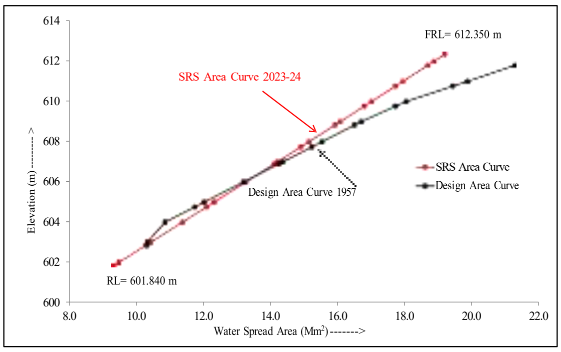
Sr. No.	Feature type	Particulars	Latitude	Longitude
1	Line	Dam Line	20⁰ 02’ 20.79’’ N	73⁰ 40’ 46.32’’ E
2	Point 1	Submergence	20⁰ 03’ 20.82’’ N	73⁰ 40’ 21.78’’ E
3	Point 2	Spillway	20⁰ 02’ 57.56’’ N	73⁰ 40’ 47.30’’ E
4	Point 3	Gauge Meter	20⁰ 02’ 24.18’’ N	73⁰ 40’ 44.05’’ E
5	Point 4	LBC	20⁰ 02’ 24.19’’ N	73⁰ 40’ 46.21’’ E
6	Point 5	RBC	20⁰ 01’ 38.80’’ N	73⁰ 40’ 59.82’’ E
7	Point 6	Submergence	20⁰ 01’17.37’’ N	73⁰ 41’ 07.45’’ E
8	Point 7	Submergence	20⁰ 01’16.52’’ N	73⁰ 40’ 24.33’’ E

Details of features collected during ground truthing of Gangapur reservoir

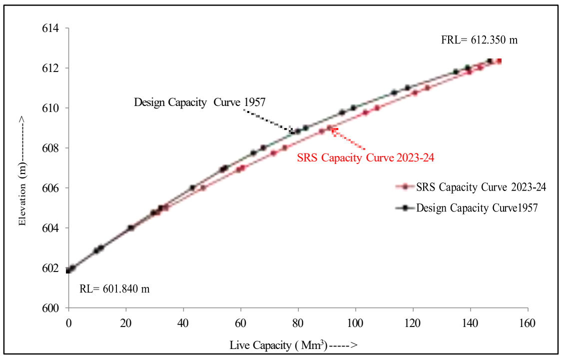
RESULT



SRS Elevation-Area curve for Gangapur reservoir



Comparison of Elevation - Area curve for Gangapur, reservoir



`reservoir

7. RESULT AND DISCUSSIONS

Studied Area:

Present live storage capacity of Gangapur reservoir between FRL 612.350 m and RL 601.840 m is estimated 149.950 Mm3 for the Water year 2023-24 as against design live storage capacity of 146.642 Mm3 between these levels.

Disclaimer

i) The satellite remote sensing survey primarily based on the water levels provided by the field authority. Accuracy of the result depends on the data provided by field authorities.

ii) Live storage capacity calculation done by comparing design survey and present survey. However, design survey is not done by Maharashtra Engineering Research Institute, design survey data (salient features) are provided by the field office. Hence, this study is totally done with the reference of data provided by filed authorities.

iii) Hence, it is to be mention that designs data like elevation-area-capacity table, controlling levels, storages, impounding year, water levels etc. are provide by field authorities. Maharashtra Engineering Research Institute has not validated the design data provided by the filed authorities.

Limitations

For this study of Gangapur reservoir, following limitations are observed.

i) The MDDL of the reservoir is 589.940 m but images were not available below 601.840 m, hence analysis for level 589.940 m to 601.840 m is not part of this study. Thus, study was restricted to level RL 601.840 m to FRL 612.350 m.

ii) General error can creep in the identification of tail end of reservoir in marginal periphery.

8. CONCLUSION

Following conclusions can be drawn from the study:

The live storage capacity of studied portion (RL 601.840 m to FRL 612.350 m) of Gangapur reservoir is 149.950 Mm3 in year 2024.

"The design capacity of Gangapur dam might have been underestimated:

9. During the site visit to Gangapur dam on...............21/01/2020, it was told by field authorities that large amount of silt is excavated and removed from submergence area of Gangapur Reservoir Removal of silt from submergence area might have resulted in increase in storage capacity.

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