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Sedimentation assessment of Hirakud reservoir using Microwave Remote sensing Technology

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ABSTRACT:

Optic remote sensing provides information on elevation contours, in the form of water spread area of reservoirs, which is the only thematic information required to assess the sedimentation in a reservoir. However, due to the presence of cloud in the optic satellite data during monsoon and other extreme weather conditions it cannot be used. To overcome this situation microwave satellite data (Sentinel 1-SAR) is used on Hirakud reservoir wherein, most of the year it is covered by clouds. For the year 2018-19, eleven SAR pass were available between the water level 181.23 m (near MDDL) and 190.19m (near FRL). The pre-processing techniques were applied to all the eleven SAR, dual polarized data. From the VV+VH data thresholiding methodology was utilized to identify the water pixels. It was found that the water pixels contain values ranging from -40.56db to -20db, these pixels were extracted and the water spread area occupied by all the eleven SAR data were estimated. These water spread areas were used in simple volume estimation trapezoidal formula and the volume between different water levels were calculated. These volumes were added up to assess the revised capacity between the water level 181.23 m and 190.19m for the period 2018-19. The assessment revealed that the capacity between these water levels is 32.29 M.cum/year. This study shows that reservoir water spread and in turn the amount of sediment deposited in a reservoir are can be effectively estimated using Sentinel1-SAR, which is a replacement to the cloud covered optic data.

Keywords: Reservoir sedimentation, Water spread area, Synthetic Aperture Radar (SAR), Sentinel-1A.

1 Introduction

Natural processes, such as erosion in the catchment area, movement of sediment and its deposition in several parts of the reservoir, require cautious consideration in the planning of major reservoir projects. The silt that is deposited at different levels reduces the storage capacity of the reservoir [1]. Reduction in the storage capacity beyond a limit avoids the reservoir from providing the purpose for which it is intended. Periodic capacity surveys of the reservoir help to assess the rate of sedimentation and reduction in storage capacity. Conventional techniques for the estimation of the capacity of a reservoir, such as hydrographic survey and inflow-outflow approaches, are cumbersome, time consuming and expensive, and they involve significant manpower. As an alternative to conventional methods, the remote sensing technique provides cost- and time-effective estimation of the live capacity of a reservoir [2].The surveys conducted by conventional methods were sometimestaken up to three years to complete just one survey of a major reservoir like Hirakud [3]

Optic satellite remote sensing provide information on elevation contours, in the form of water spread area, at different water levels of a reservoir. However, the challenge in using the optic satellite data is that if the scene is shielded by cloud, no information on the land surface could be attained. To overcome this situation microwave satellite data (Sentinel1A & 1B-SAR) is used in this study. Compared with optical sensors microwave sensors have longer wavelength ranging from less than one centimetre to one metre. Synthetic Aperture Radar (SAR) is an active microwave remote sensing technique with the potentialityof being independent from solar illumination.Due to the wavelength nature, the microwave signal has a very narrow interaction with the droplets in the cloud and hence the observation is not impaired[4].More importantly SAR systems are capable of carrying observations in both daytime and nighttime and even under extreme weather conditions. It becomes the most suitable instruments for high resolution, reservoir water spread area estimation from space [5].Because of Sentinel-1' potentiality in providing data and value-added information for water resource management applications [6] and free availability in public domain from april-2014 the water spread area thus interpreted from the satellite data is used as an input into a simple volume estimation formula [7]and in turn the sedimentation deposited in a reservoir is assessed.

2 Study reservoir

Hirakud Reservoir isspread between latitude 21 º25' to 21º 55 and longitude 83º10'to 84º05'as shown in Fig 1.The dam is located across the river Mahanadi about 15 Km up-stream of Sambalpur.The total length of the dam is 25.8Km. The prime purpose of the reservoir is flood control and management. The Full Reservoir level (FRL) of the Hirakud Reservoir is 192.024 m and Minimum draw down level is MDDL is 179.830 m.During 1957at the time of impoundment, the original gross storage was 8136 M.cum and dead storage was 2318 M.cum The project provides 1, 55,635 ha of Kharif and 1,08,385 ha of Rabi irrigation to the districts of Sambalpur, Bargarh, Bolangir and Subarnapur. The water released through the power house irrigates further 4,36,000 ha of CultivableCommand Area (CCA) in Mahanadi Delta. The mounted capacity of the power generation is 347.5 MW through its two power houses at Burla, at the right bank and Chiplima, at 22 km downstream of the Dam. In addition, the project provides flood protection to 9500 sq. km of delta area in districts of Puri and Cuttack.[8]

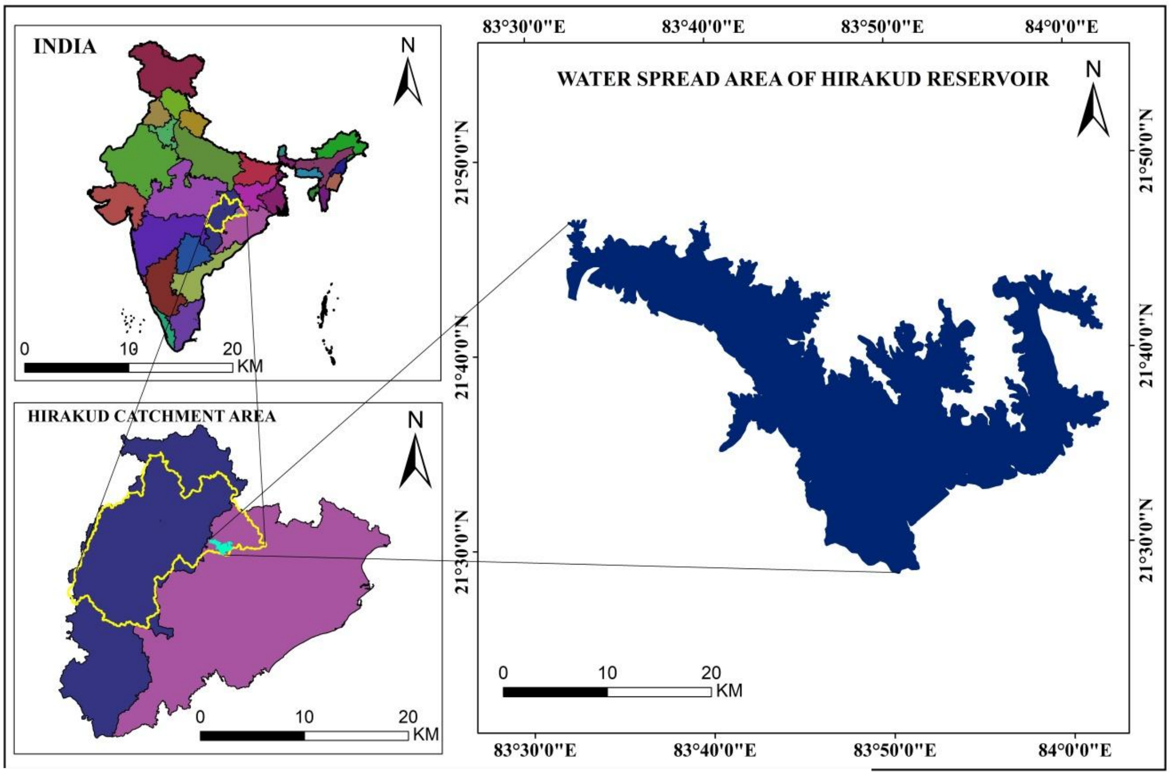


Figure 1 Location of Hirakud Reservoir

3 Materials and methodology

3.1 Sentinel-1 data

In this research Level-1 Ground Range Detected (GRD) Sentinel-1 C-band (5.405 GHz) data collected in the Interferometric Wide (IW) mode were used. This mode allows the combination of a large swath width (250 km) with the considerably high spatial solution (10 m). Sentinel-1 SAR data has dual-polarization capability (HH+HV or VV+VH) which can provide more ground surface information.Eleven SAR images have been used for the period from October 2018 to June 2019, which are available from the European space agency through Sentinels Scientific Data Hub.The IW mode is the default acquisition mode overland. The methodology adopted to delineate the water spread from Sentinel1-SAR and sedimentation estimation is shown in the Fig 2.

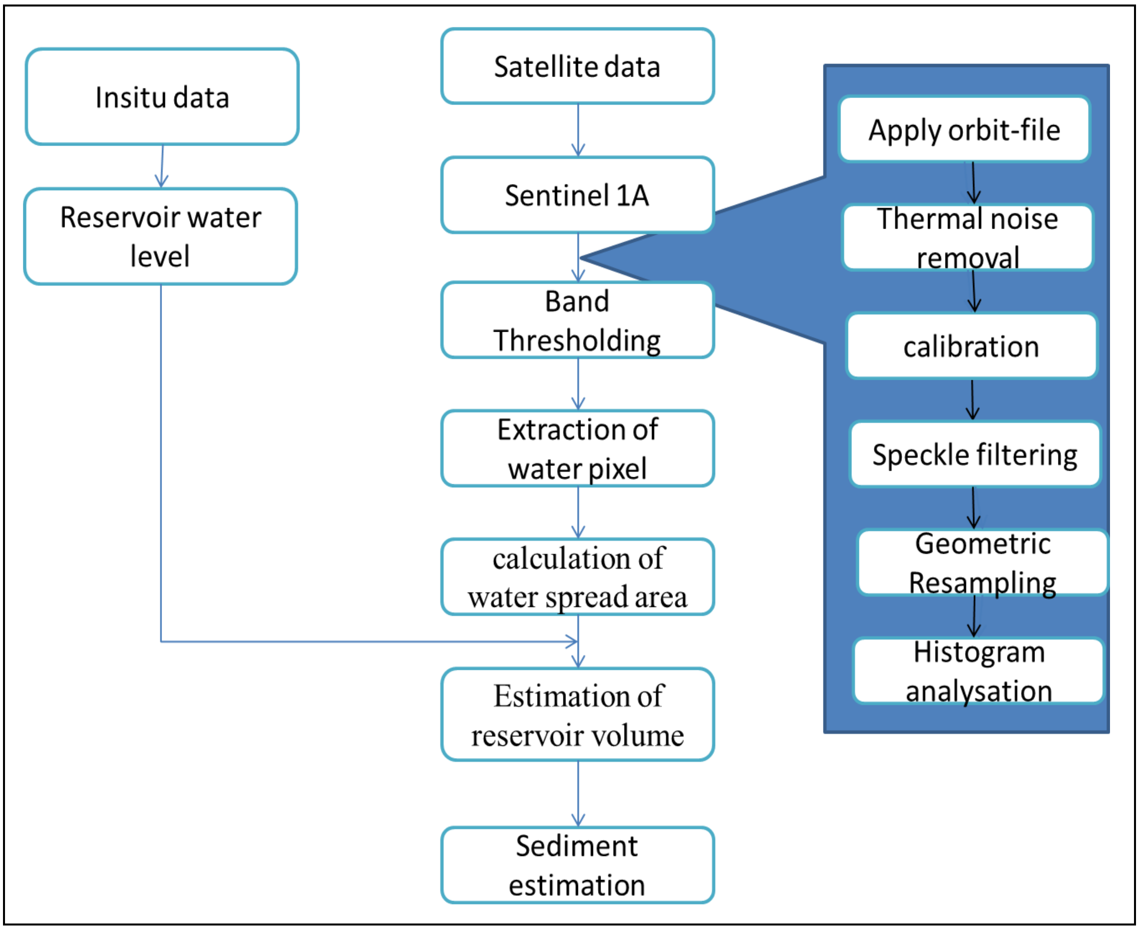


Figure 2Flowchart showing estimation of sedimentation using microwave satellite data

3.2 Pre-processing of Sentinel 1-SAR data

Generally, a Indian reservoir attains its Full Reservoir Level (FRL) during the end of the monsoon period (October or November) and drops down to its Minimum Draw Down Level (MDDL) during the summer season, one such water year (Oct.2018 to June 2019) has been selected to delineate the corresponding water spread area of different reservoir levels of Hirakud reservoir from the SAR data. It is imperative to mentioned here that most the FRL and near FRL optical data could not be obtained due to coverage of cloud over the Hirakud reservoir area during the monsoon period. In such situations the microwave data comes in hand and the water spread area could be delineated without any impediment.

The pre-processing steps which are mandatory for any microwave data has been carried out using SNAP platform. The first step in the pre-processing sequence is orbit file application wherein that the precise orbit details are included in the SAR imagery for further processing. Noise removal reduces the noise effects in the inter-sub-swath texture, in particular, normalizes the backscatter signal within the entire Sentinel-1 scene and resulting in reduced discontinuities between sub-swaths for scenes in multi-swath acquisition modes. Radiometric calibration, specklefiltering, range Doppler terrain correction and finally sigma naught ($\sigma 0$) image for coefficients ofbackscattering are the pre-processing steps[9] that has been applied for all the eleven SAR data used in this study.

3.3 Understanding the Image Histogram

The bimodal histogram distribution of the SAR image reveals that thelower peak represents the pixels corresponding to specular reflection. The pixels from the specular reflection mostly pertain to water pixels. The average value of water pixelsranges from -35db to -20db. It is observed that in twoscenes the valueof water pixels has changedto -42.56db. The higher peak represents pixels with diffuse reflection (land features) in the study area.The value of land pixels ranges from -20db to 5db.The pixels pertaining to reservoir water spread area has been separated out from the land area for further processing. The full image and the separated water spread area pertaining to the near FRL (190.19m) which is on10thOctober 2018 is shown in the Fig 3.

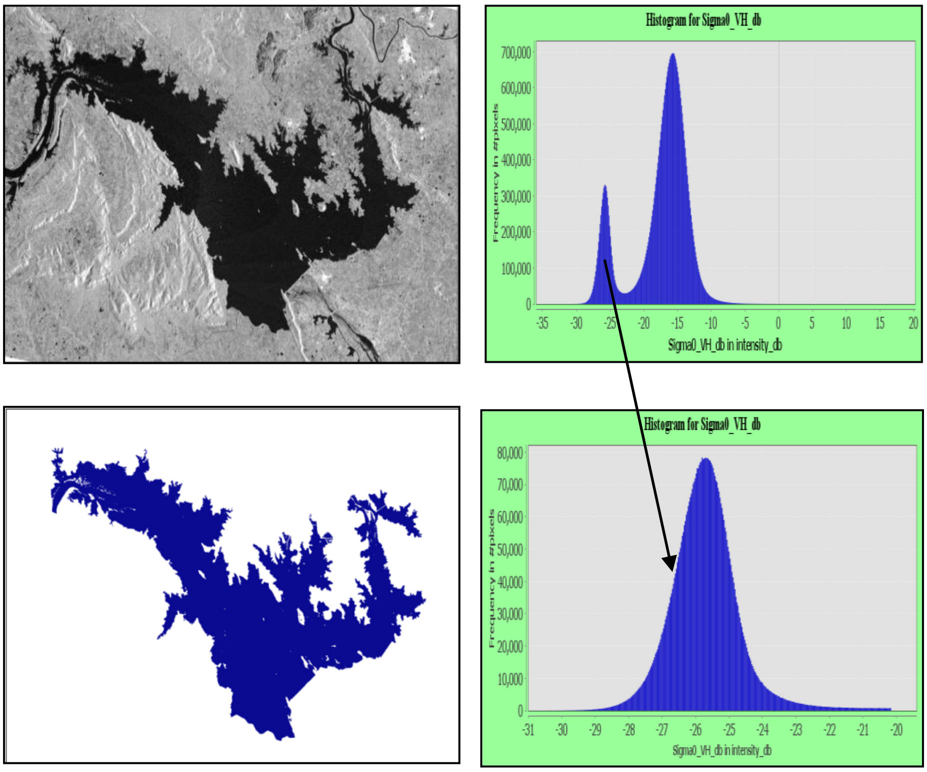


Figure 3 Histogram of SAR image & extracted water spread area pertaining to 10-oct-2018.

3.4 Computation of volume between consecutive water levels

Traditionally the reservoir volume between two consecutive reservoir water levels was computed using the prismoidal formula, the Simpson formula or the trapezoidal formula. Of these, the trapezoidal formula has been most widely used for the computation of volume [10] in Indian reservoirs. The water spread area estimated using the SAR data has been used as an input to the volume estimation formula to determine the volume at different water segments of the reservoir. In this study the volume between two consecutive reservoir water levels was computed using the following trapezoidal formula:

Trapezoidal Formula: $V = \frac{H}{3} \times (A1 + A2 + \sqrt{A1 \times A2})$ (1)

Where V is the volume between two consecutive water levels, A1 and A2 are the water spread areas at the reservoir water levels 1 and 2 respectively and H is the difference between these two water levels.

3.5 Computation of Live storage capacity of the reservoir

The volumes computed (using equation 1) between different water levels (i.e., from minimum draw down level (MDDL) to full reservoir level (FRL)) were added together to calculate the cumulative or live storage capacity of the reservoir.

3.6 Estimation of reservoir sedimentation

The difference in storage capacity between any two periods produces the amount of sedimentation deposited in the reservoir. The annual rate of sedimentation could be arrived by dividing the total amount of sediment deposited during that period.

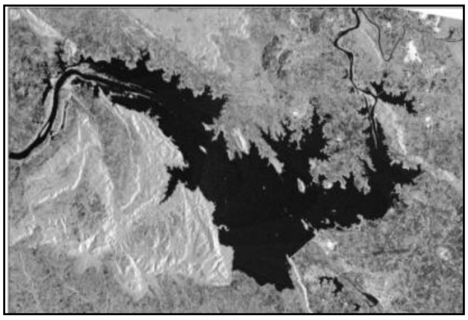
4 Results and discussion

4.1 Extraction of water pixels from the SAR data

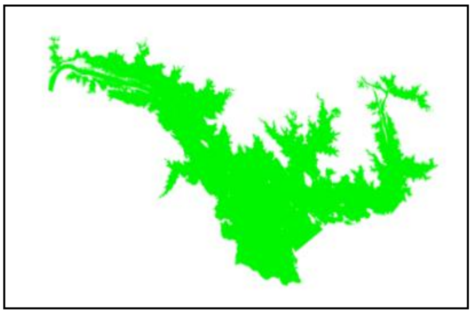
The features of stable water in SAR imagery are the result of different factors including acquisition characteristics (wavelength, incident angle, and polarization), soil moisture, and soil surface conditions[11]. In SAR image the stagnant water pixels will have low backscatter as compared to other landscapes due to specular reflection. Therefore, the water pixels appear darker in color with respect to other features of the image, which makes the water pixels to be recognized easily. The previous studies conclude that dual-polarization data provides the most informative result [12] and the thresholding is viewed an efficient class extraction method form the stable water [13] Therefore, in this study the water pixels were extracted using VV or VH polarized data through thresholding class extraction methodology. The threshold values were identified by analyzing the image histogram and interacting with the imagery. The identified threshold values and the extracted water spread area from the respective VV or VH bands are given in the Table 1 and Fig 4

Table 1 Satellite data acquisition dates, threshold used for extraction of water spread area on each day

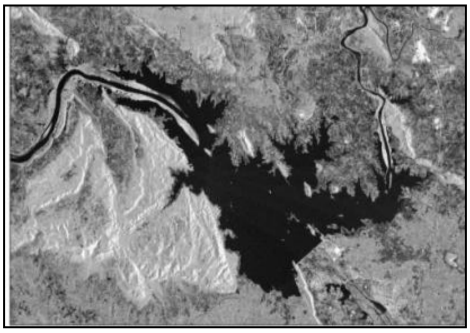
Sl.no	Date of Image acquisition	Threshold limits (dB)	Polarization
1	19-Jun-2019	-31.29 to -13.77	VV
2	26-May-2019	-35.51 to -20.82	VH
3	14-May-2019	-41.91to -20.54	VH
4	2-May-2019	-42.56 to -20.90	VH
5	20-Apr-2019	-36.62 to -20.68	VH
6	8-Apr-2019	-37.30 to -20.54	VH
7	27-Mar-2019	-37.81 to -20.92	VH
8	3-Mar-2019	-39.81 to -20.55	VH
9	26-Jan-2019	-35.78 to -20.12	VH
10	27-Nov-2018	-36.54 to -20.15	VH
11	10-Oct-2018	-35.94 to -20.16	VH



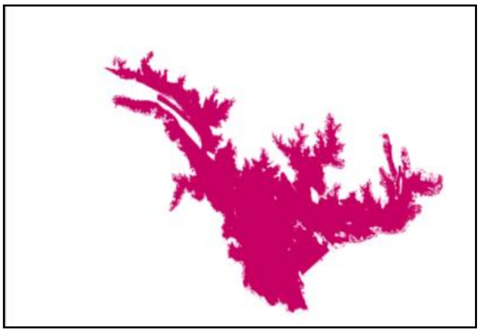
27-Nov-2018, Sigma_VH



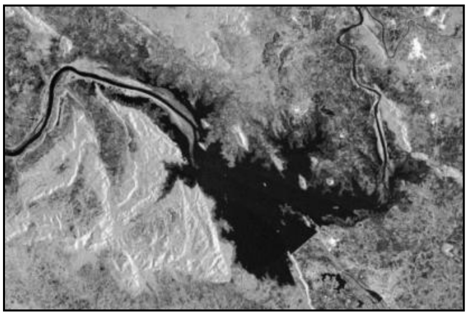
W.S.A 498.25Sq.km



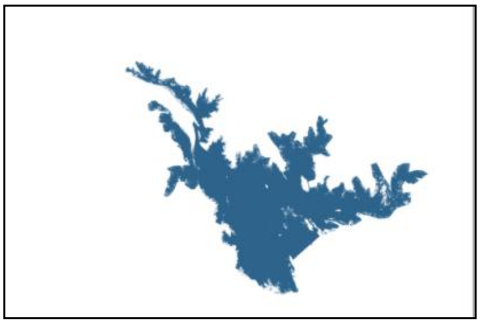
02-May-2019, Sigma_VH



W.S.A 378.41Sq.km



19-Jun-2019, Sigma_VV



W.S.A 255.24 Sq.km

Figure 4 Water pixels extracted from Sentinel-1A data of Hirakud Reservoir for three different satellite pass.

With the help of identified threshold values, water pixels were recognized and their water spread areas were estimated, then water masks were exported as GeoTIFF format from SNAP to ArcGIS platform for map composition as shown in fig 5

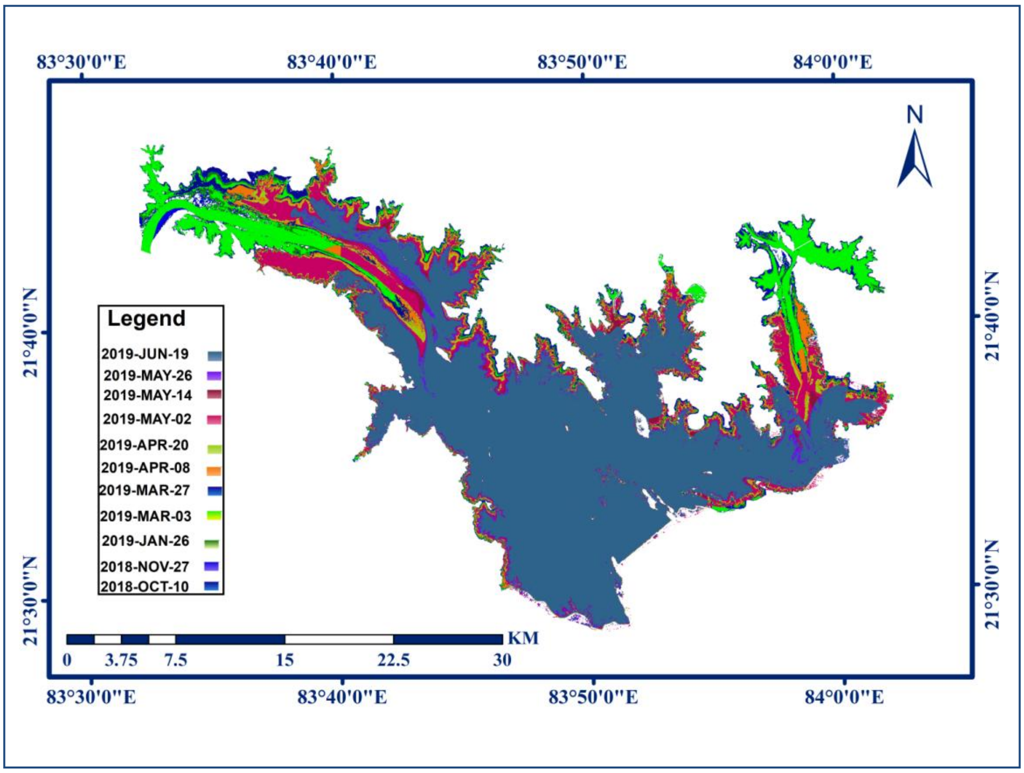


Figure 5The change in water spread area of the reservoir during water year 2018-19 extracted from Sentinel-1 data

4.2 Reservoir Capacity Estimation

The water spread area extracted from Sentinel-1A SAR data for all the eleven available dates were used to estimate revised live storage capacity of the reservoir. In Hirakud reservoir the live storage capacity ranges from 179.83m (MDDL) to 192.02 (FRL). However, for the year 2018-19 the MDDL and FRL reached was 181.79m and 190.19m respectively. Most of the Indian reservoirs utilize the trapezoidal formula to estimate the volume between two water levels during impoundment survey. Therefore, in this study the trapezoidal formula was used to calculate the different volumes arises between MDDL (181.83m) and FRL (190.19m). The volumes thus calculated have been added up to estimate the cumulative live storage capacity of the reservoir. The estimated values of the entire analysis are presented in Table 2. The estimated cumulative live storage capacity of Hirakud reservoir at the water level 190.19 m for the period 2018-19 was 3432.77 M.cum. However, the Hirakud reservoir's original live storage capacity at 190.19 m during 1957 was 5452.5M.cum. The difference between the water holding capacity 5452.5M.cum during 1957 and the present capacity 3418 M.Cum reveals the amount of sedimentation occurred during 63 years of operation of the reservoir. From, these calculations it is assessed that 2034 M.Cum of sediment has been deposited in Hirakud reservoir during the period 1957 to 2019. Therefore, the rate of sedimentation in Hirakud reservoir is assessed as 32.29 M.Cum/year.

The estimated rate of sedimentation (32.29 M.Cum/year) assessed using Sentinel-1 SAR data rate is slightly higher than the average rate of sedimentation (22.60 M.Cum/year) obtained from other surveys conducted during the year (1991, 2000). But the value 22.60 M.Cum/year was between the designed MDDL (179.83m) and FRL(192.02m). The revised capacity at each elevation was used to draw the revised elevation-capacity curve against hydrographic survey conducted for the year 1957. The revised capacity is important information for reservoir management authorities to operate the reservoir in sustainable manner. The elevation-capacity curve derived from remote sensing approach using the SAR data was plotted and shown in Figure 6. Apart from the capacity information, comparison of SAR data obtained water spread area with the original one will through the light on change in water spread area of the reservoir at different elevations.

Table2 The reservoir capacity estimated using available Reservoir SAR data Processing.

Sl.no	Date of image acquisition	Reservoir water level (m)	Estimated W.S.A Using Microwave data (Sq.km)	Storage Capacity (M.cum)	Cumulative capacity (M.cum)
1	19-Jun-2019	181.79	255.24	0	0
2	26-May-2019	182.86	310.54	302.209	302.20
3	14-May-2019	183.81	352.14	314.566	616.77
4	2-May-2019	184.80	378.41	361.544	978.32
5	20-Apr-2019	185.55	408.94	295.182	1273.50
6	8-Apr-2019	186.17	425.81	258.755	1532.25
7	27-Mar-2019	186.66	432.56	210.298	1742.55
8	3-Mar-2019	187.41	452.82	331.989	2074.54
9	26-Jan-2019	188.42	476.18	469.096	2543.63
10	27-Nov-2018	189.23	498.25	394.610	2938.25
11	10-Oct-2018	190.19	532.19	494.522	3432.77

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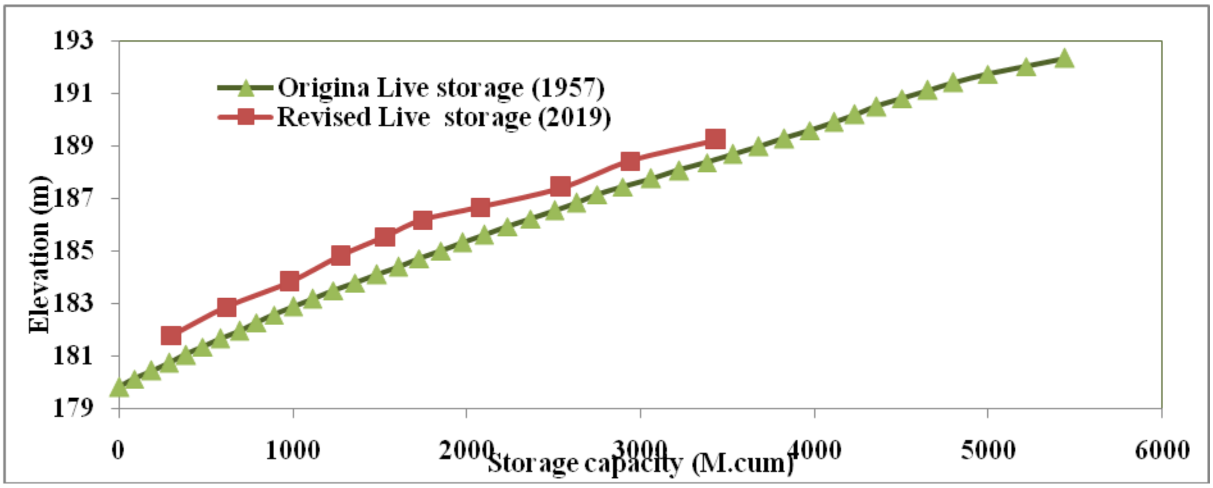

Figure 6Comparison of OriginalElevation-capacity Curve 1957 with present results.

5 Conclusion

The rate of sedimentation in reservoirs is aggravated year by year due to frequent floods, soil erosion, deforestation and change in land cover pattern. Conventional appraisal such as hydrographic survey, Inflow-outflow methods are laborious, expensive and time consuming. In place of conventional methods, the optic remote sensing technique provides near real time assessment, cost- and time-effective estimation of the live capacity of reservoirs. However, the optic satellite data during monsoon period and other extreme weather conditions cannot be used due to the presence of clouds. During such situations the microwave data from the platforms such as Sentinel-1, RADARSAT, RISAT, etc., provides cloud free data. Hirakud reservoir is located in a geographical area where, most of the year it is covered by clouds. Therefore, it was decided to use the microwave data (Sentinel1-SAR) to delineate the water spread area of the reservoir. Eleven satellite pass were available between the water level 181.23 m (near MDDL) and 190.19m (near FRL). The pre-processing techniques were applied to all the eleven SAR dual polarized data. From the VV+VH data thresholiding methodology was utilized to identify the water pixels. It is found that the water pixels contain values ranging from -40.56db to -20db, these pixels were extracted and the water spread area occupied by all the eleven SAR data were estimated. These water spread areas were used in simple volume estimation; trapezoidal formula and the volume between different water levels were calculated. These volumes were added up to assess the revised capacity between the water level 181.23 m and 190.19m for the period 2018-19. The assessment revealed that the capacity between these water levels is 32.29 M.Cum/year. Whereas, the average rate of siltation for the earlier conducted surveys during 1991 and 2000 between the designed MDDL (179.83m) and FRL(192.02m) was 22.60 M.Cum/year. The increase in rate of sedimentation is due to the reason that the comparison was not made to same level of water level. However, this study shows that reservoir water spread and in turn the amount of sediment deposited in a reservoir are can be effectively estimated using Sentinel1-SAR, which is a replacement to the cloud covered optic data.

6 Acknowledgements

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References

[1] Smith, L.C., and Pavelsky, T.M. (2009).“Remote sensing of volumetric storage changes in lakes.” *Earth Surface Process and Landforms, 34, 1353 – 1358.*

[2] Sabastin, M., Rao, P.P.N., Jayaraman. V., and Chandrasekhar, M.G.(1995). “Reservoir storage loss assessment and sedimentation modeling through remote sensing techniques*.” Proceedings of 6th Inter. Symp. River sedimentation on Management of Sediment – Philosophy, Aims and Techniques, New Delhi, India.*

[3] Central Water Commission. "Compendium on silting of reservoirs in India." Published by the Central Water Commission. Government of India, New Delhi (2015).P.6,98

[4] Schumann, Guy, Giuliano Di Baldassarre, and Paul D. Bates. "The utility of space borne radar to render flood inundation maps based on multi-algorithm ensembles." *IEEE Transactions on Geoscience and Remote Sensing 47.8 (2009): 2801-2807*.

[5] Prasad, N. R., VaibhavGarg, and Praveen K. Thakur. "Role of SAR data in water body mapping and reservoir sedimentation assessment." *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 4 *(2018): 151-158*

[6] Amitrano, Donato, et al. "Sentinel-1 for monitoring reservoirs: A performance analysis." *Remote Sensing 6.11 (2014): 10676-10693*

[7] Jeyakanthan, V.S., et al., 2002. Reservoir capacity estimation using satellite data. In: IAPRS & SIS: resources and environmental monitoring, Vol. 34. Hyderabad, India: National Remote Sensing Agency, 863–866.

[8] Report of the High Level Technical Committee To Study Various Aspects of Water Usage for Hirakud Reservoir, Government of Orissa, Water Resources Department, *August 2007*

[9] Filipponi, Federico. "Sentinel-1 GRD Preprocessing Workflow." Multidisciplinary Digital Publishing Institute Proceedings. Vol. 18. No. 1. 2019

[10] Goel, M. K., and Sanjav K. Jain. "Evaluation of reservoir sedimentation using multi-temporal IRS-1A LISS II data." *Asian-Pacific Remote Sensing and GIS Journal* 8.2 *(1996): 39-43.*

[11] Hostache, Renaud, Patrick Matgen, and Wolfgang Wagner. "Change detection approaches for flood extent mapping: How to select the most adequate reference image from online archives?." International Journal of Applied Earth Observation and Geoinformation 19 (2012): 205-213.

[12] Matgen, P., et al. "Towards an automated SAR-based flood monitoring system: Lessons learned from two case studies." Physics and Chemistry of the Earth, Parts A/B/C 36.7-8 (2011): 241-252.

[13] Bazi, Yakoub, Lorenzo Bruzzone, and Farid Melgani. "Image thresholding based on the EM algorithm and the generalized Gaussian distribution." Pattern Recognition 40.2 (2007): 619-634.