JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

APPLICATION OF REMOTE SENSING TECHNIQUES TO QUANTIFY THE SEDIMENTATION IN A RESERVOIR AND TO ASSESS ITS DISTRIBUTION AND DEPOSITION PATTERN OF KALAGARH DAM, UTTARAKHAND

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Abstract : **—** Periodic mapping and monitoring of reservoirs are needed due to the reservoir's dynamic properties, particularly the distribution and concentration of suspended material and the spread of water. Reservoir Sedimentation has a severe effect on reservoir’s storage capacity and has its affects on the live storage capacity as well as the dead storage capacity. In other words, the rate of siltation determines how long a reservoir will last. The ability to analyze these elements at various scales and phases is made possible by the satellite data.

The sedimentation study of the Ramganga reservoir is conducted in this research study using remote sensing data for the years 2016, 2017, 2018, 2019, 2020, 2021, and 2022. The study discusses the different Elements related to the accumulation of sediment in reservoirs including the phenomenon and rate of accumulation of sediments within reservoir and highlighting limitations pertaining to remote sensing technology in the study. The Satellite remote sensing data acquired at multiple time points offer specific details about the reduced levels contours in form of water-covered regions. If there is a decline in the extent of water coverage in a reservoir at any particular reduced level that corresponds to the date of satellite data, it indicates the presence of sediment deposition. Thus, by assessing the change in the spread of the reservoir water area distribution at various elevations, the amount of sediment load that has settled down over time may be calculated. In the current study, this aerial distribution of Ramganga Reservoir is estimated using satellite data from Sentinel 2A/2B satellites.

Index Terms **- Reservoir Capacity, Reservoir Sedimentation Study, Rate of Sedimentation, Sediment Yield Rate, Remote Sensing Techniques, Multi-date Satellite Data, Sentinel satellites**

1. INTRODUCTION

India has a typical monsoon climate, with three months—July, August, and September—having more than 75% of annual rainfall. In the majority of regions within the country, the annual average of rainy days usually remains below 30, resulting in approximately 100-150 hours of rainfall each year. As a result, only these three months offer the majority of the river's yearly water supply (75–80%). Hence, it is vital to preserve the water within storage facilities of suitable sizes, taking into account the topography and hydrology of the region. This ensures the sustenance of life and various activities around the year, relying on a resource that is accessible solely during 20-25 days of rainfall. Acknowledging the importance of such storage structures, numerous reservoirs have been built across all river basins since independence as part of each development plan. Because silting steadily reduces reservoir capacity, sedimentation of reservoirs is a major concern for many water resources development initiatives.

The traditional method of studying sedimentation in a reservoir entails a time- and money-consuming bathymetric survey of the reservoir area using sounding techniques. This can be strengthened by using remote sensing techniques to examine temporal variations in relation to the field-observed reservoir level. Using remote sensing data, this research attempts to estimate the sediment yield rate of the Ram Ganga Dam, also known as the Kalagarh Dam, using a standard methodology.

The primary aim of the research is

I. To estimate revised live storage capacity of Ram Ganga Reservoir.
II. To estimate the rate of sedimentation.
III. To assess the distribution and deposition pattern of sediments in the reservoir.

Students and researchers will benefit from this study's understanding of the sedimentation study of reservoirs based on RS and GIS. In order to make it simple to integrate RS and GIS technology into project works related to development of water-resources, this study intends to provide administration at both the Central and State Government levels with a reference framework. It will support projects that employ geospatial technology to manage water resources. For the reservoir to operate at its best, capacity estimation using this technique at regular intervals can provide crucial characteristics such as the yearly sediment yield from the catchment and the distribution pattern of sediment in the Ramganga reservoir area. It can also provide a new elevation-area-capacity curve.

2. LITERATURE REVIEW

Irrigation Research Institute, Roorkee, conducted surveys for the Ramganga reservoir in 1974, 1997, and 2008. The most recent survey was carried out in 2008 (pre-monsoon), and the report was published in November 2008 by T.M. No. 80 RR (H4 - 01). The following were the findings of the previous studies.

I. Ramganga reservoir had a total capacity of 2590.72 MCM when it was built in 1974; this number can be used as the starting point to estimate how quickly silt will accumulate in the coming years.
II. The reservoir had a total capacity of 2480.25 MCM, according to a pre-monsoon 1997 capacity survey. The reservoir's overall capacity is 2456.47 MCM, according to the capacity survey conducted prior to the 2008 monsoon.
III. The average rate of silting wr.to 1974 is 12.60 Hectare-meter/100 Km²/year and wr. to Year 1997 is 6.89 Hectare-meter /100 km /year.
IV. The sediment deposited in the reservoir consist of poorly graded sand (SP), sandy-silt (SM), sand-silt mixture (SP-SM), silt-clay mixture (ML-CL) and gravel.
V. The total sediment deposited in the reservoir has been worked out as 134.25 MCM in pre-monsoon 2008 with respect to corrected value of capacity taken as 2590.72 MCM in the year 1974.
VI. The reservoir as whole is loosing its capacity at rate of 3.95 MCM / year which is 0.15% of its initial capacity.
VII. The total storage capacity of reservoir is reduced to 23.78 MCM in an interval of 11 years since 1997, which is only 2.16 MCM per year and 0.08 % of the original capacity.
VIII. The overall loss of capacity in the Ramganga River and Sona River portions has been calculated at 7.56 MCM and 7.42 MCM, respectively, during the course of 11 years, from the year 1997 to the year 2008. Results from the Mandalti River and Saddle Dam portions indicate a capacity reduction of 4.19 MCM and 4.61 MCM in 11 years, respectively. As a result, the overall loss of capacity in four reservoir parts has been estimated at 23.78 MCM. It is implied that the majority of the siltation in the Ramganga and Sona rivers occurs in the dead storage zone and very little in the living storage zone. The Mandalti River has no dead storage, therefore siltation only occurs in the live storage. In contrast, the Saddle Dam part has more live storage siltation than dead storage zone.
IX. The average silt index (from 1974 to 2008) has been calculated as 12.60 hectare-meter, per year per 100 square kilometers of the catchment area against the assumed value of 4.25 hectare-meter per year per 100 square kilometers as per project [Ref. T.M. No. 68 RR (H4-1), November 1997].
X. The average silt index (from 1997 to 2008) has been calculated as 6.89 hectare-meter per year per 100 square kilometers of the catchment area

3. METHODOLOGY

Because digital analysis minimizes subjectivity or human error, it is superior to visual analysis for precisely identifying water spread and turbidity levels. The investigation made use of Global Mapper and Arc GIS tools for image processing. The analysis comprised,

- Geo-referencing or Geo-coordinating the present database.
- Estimation of Reservoir water spread area using multi-date satellite imageries.
- Determination of present reservoir capacity.
- Comparative analysis with original capacity and capacity worked out in the past surveys.

The main foundation for reservoir sedimentation surveys is to ascertain the extent of water coverage during the satellite pass-over. Having satellite data from multiple dates at frequent intervals, which encompasses the operational water level of the reservoir, becomes essential. At that level, the water spread area is simply the water level contour. The capacity between them is determined using various contours. A flow chart explaining the sequencing of approach and methodology adopted have been shown in Figure 1 below.

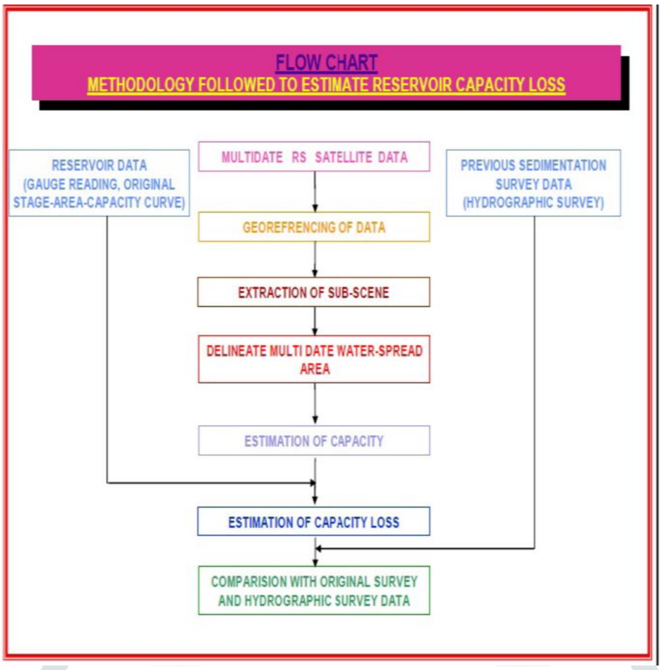

Figure 1: Methodology Flow Chart

A. DETERMINATION OF RESRVOIR SPREAD AREA

The satellite images of Ramganga reservoir were downloaded from the USGS Earth Explorer platform, which offers comprehensive, unrestricted access to satellite data. The analysis was conducted using ArcGIS. The digital images of the Ramganga Reservoir display its water spread area of satellite overpasses for the following twelve specific dates including 23-March-2016, 08-Dec-2016, 23-Nov-2017, 17-May-2018, 08-Nov-2018, 24-Oct-2019, 17-Dec-2020, 28-Oct-2021, 10-Feb-2022, 17-March-2022, 21-Apr-2022, and 26-May-2022 are shown in Figure 2 below and tabulated in Table 1 below.

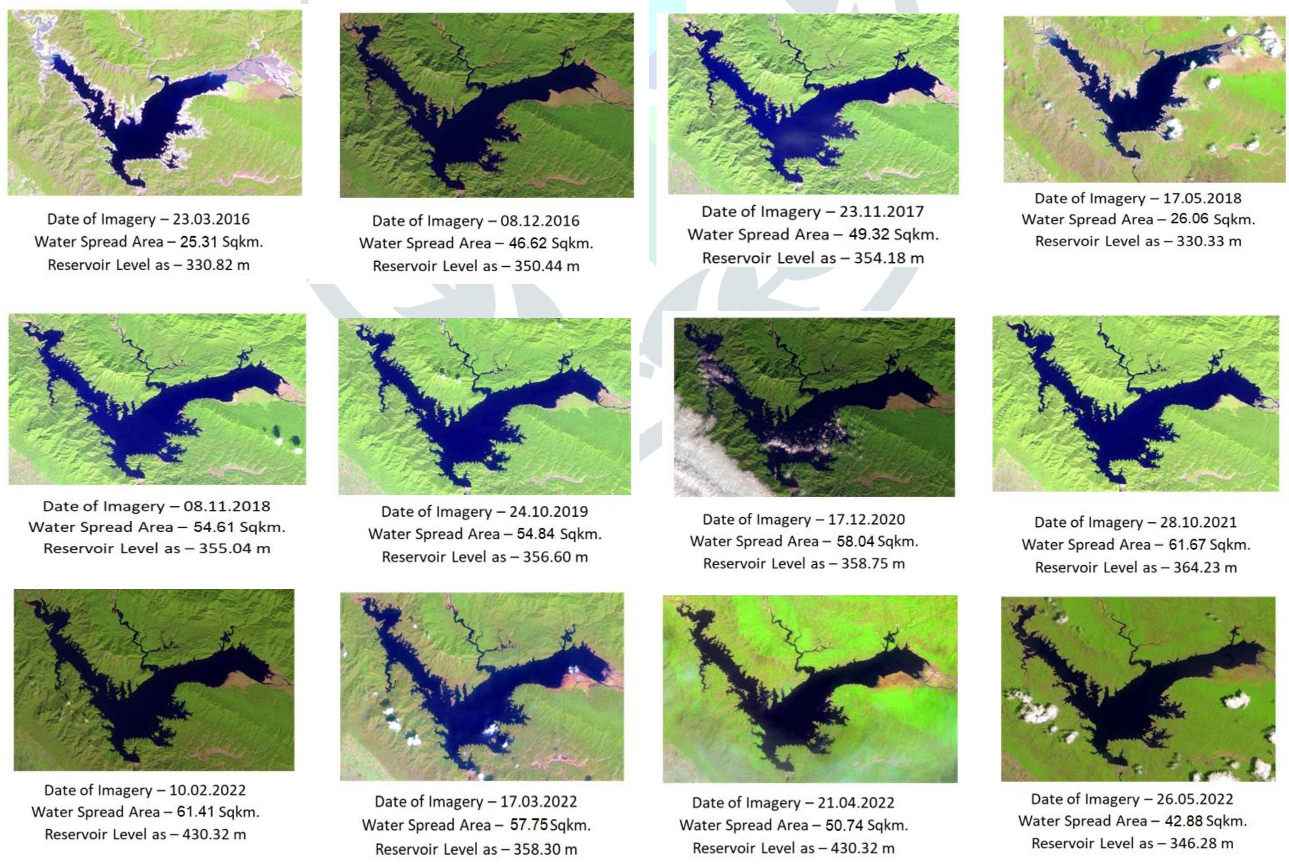

Figure 2: Satellite images displaying the water coverage area of the Ramganga Reservoir

Table 1: Water Spread Area

S. No.	Date	Reservoir Level (m)	Reservoir Area (SQKM)
1	26.05.2022	346.280	42.88
2	21.04.2022	353.620	50.74
3	17.03.2022	358.300	57.75
4	10.02.2022	362.160	61.41
5	28.10.2021	364.230	61.67
6	17.12.2020	358.750	58.04
7	24.10.2019	356.600	54.84
8	17.05.2018	330.330	26.06
9	08.11.2018	355.040	54.61
10	23.11.2017	354.180	49.32
11	08.12.2016	350.440	46.62
12	23.03.2016	330.820	25.31

B. DETERMINATION OF PRESENT RESERVOIR CAPACITY

Using the aforementioned twelve water coverage areas at varying water levels in the reservoir, an area elevation curve has been generated and illustrated in Figure 3. Furthermore, a second-order polynomial equation has been derived as the best-fit model, as presented below:

Y = 0.0013*X ^ 2 + 0.2351 * X – 191.25

R2 = 0.9898

Here, 'X' represents the elevation of the reservoir in meters, while 'Y' denote the areas of reservoir water spread at the particular elevations in Sqkm. The graph shown in Figure 3 below showcases the elevation-area curve plotted using this equation. The reservoir areas obtained from satellite data for different dates are also indicated on the curve.

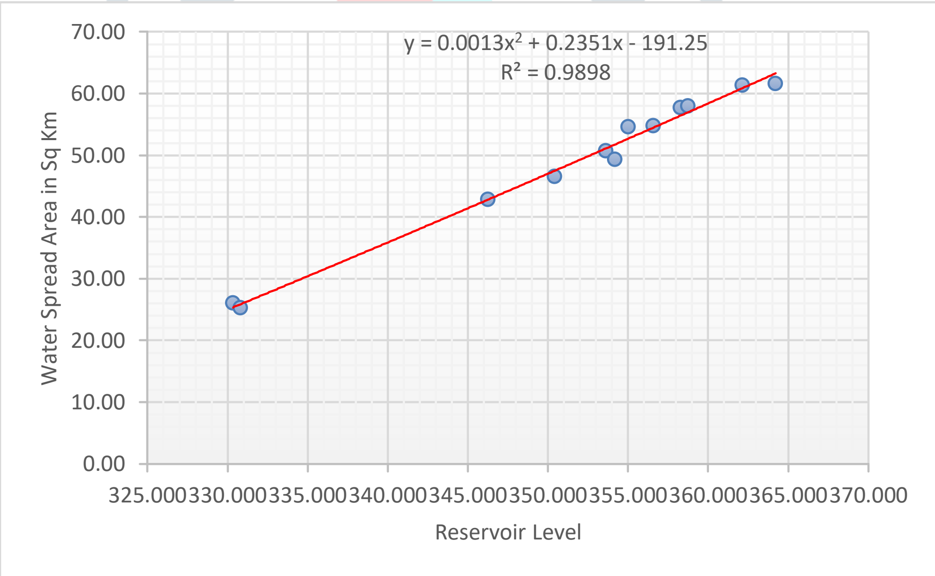

Figure 3: Observed elevation plotted against observed water spread area (WSA) along with the best-fit curve

To calculate the reservoir capacity at different elevations, the following formula was employed:

C = D/3{A1+A2 + sqrt. (A1*A2)}

Here, 'C' represents the reservoir capacity between two successive elevations X1 and X2. 'D' stands for the elevation difference (X1-X2), while 'A1' and 'A2' denote the areas of reservoir water spread at elevations X1 and X2, respectively.

Table 2, shown below, presents the calculated values of live storage capacity and submergence areas. The values are computed at regular intervals of 3.0 meters using the best-fit polynomial equation at various elevations. The modified live capacity - elevation curve and modified elevation - area - capacity curves are plotted and depicted in Figure 4 and Figure 5, respectively.

Table 2: Estimation of Differential and Cumulative Live Storage Capacity

S. No.	Reduced Level (m)	Height above DSL (m)	Area (Ha.)	Differential Live Storage Capacity (MCM)	Cumulative Live Storage Capacity (MCM)	Cumulative Live Storage Capacity (BCM)
1	317	0	1391.24	0	0	0.00
2	320	3	1710.200	46.439	46.439	0.05
3	323	6	2031.500	56.056	102.496	0.10
4	325	8	2047.000	40.785	143.281	0.14
5	326	9	2355.140	21.993	165.273	0.17
6	329	12	2681.120	75.491	240.764	0.24
7	330	13	2790.300	27.355	268.120	0.27
8	332	15	3009.440	57.984	326.103	0.33
9	335	18	3340.100	95.200	421.303	0.42
10	338	21	3673.100	105.158	526.462	0.53
11	340	23	3896.400	75.684	602.146	0.60
12	341	24	4008.440	39.523	641.669	0.64
13	344	27	4346.120	125.284	766.953	0.77
14	345	28	4459.200	44.025	810.978	0.81
15	347	30	4686.140	91.444	902.422	0.90
16	350	33	5028.500	145.689	1048.112	1.05
17	353	36	5373.200	155.997	1204.109	1.20
18	355	38	5604.300	109.767	1313.876	1.31
19	356	39	5720.240	56.622	1370.497	1.37
20	359	42	6069.620	176.822	1547.319	1.55
21	360	43	6186.600	61.280	1608.600	1.61
22	362	45	6421.340	126.072	1734.672	1.73
23	365	48	6775.400	197.927	1932.599	1.93
24	365.3	48.3	6810.935	20.379	1952.978	1.95

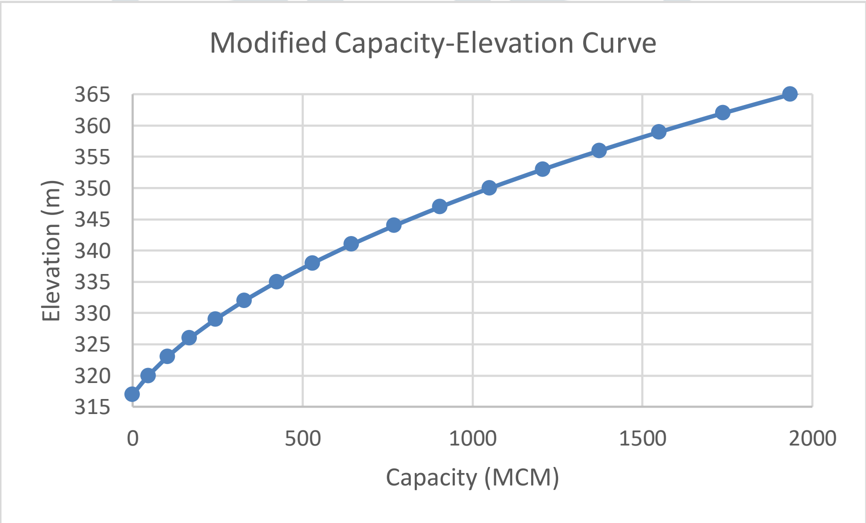

Figure 4: Modified curve depicting the relationship between live capacity and elevation

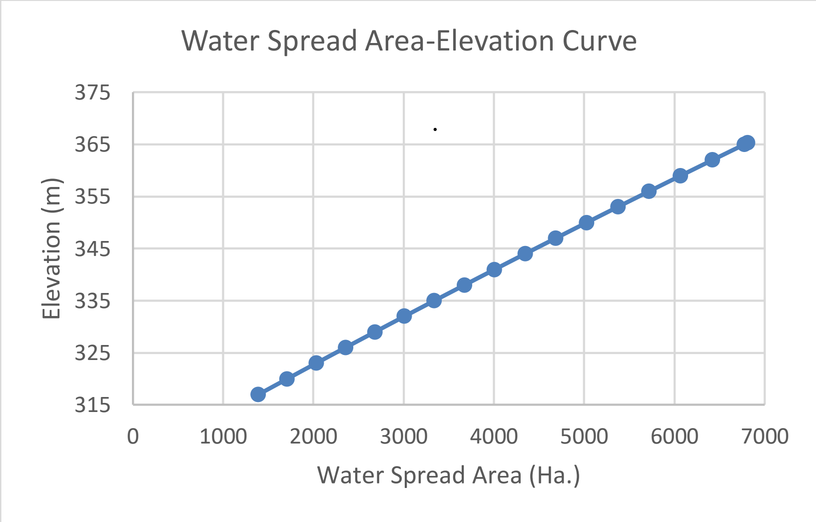

Figure 5: Modified curve illustrating the relationship between water spread area and elevation

C. COMPARISON ANALYSIS WITH ORIGINAL AND PREVIOUS SURVEYS

Table 3 below provides a comparison of live capacity between the present study and the previous surveys conducted in 1974, 1997, and 2008 at different elevations. The curve depicting evaluation of the live capacity is illustrated in Figure 6 below.

Table 3: Live Storage Capacity Comparison (MCM)

Elevation (m)	Original Live Capacity in 1974 (MCM)	Cumulative Live Capacity of 1997 (MCM)	Cumulative Live Capacity of 2008 (MCM)	Cumulative Live Capacity by SRS survey of 2023 (MCM)
365.3	2370.00	2270.144	2260.04	1952.98
360.00	1966.85	1884.00	1875.61	1608.60
355.00	1632.25	1549.48	1540.59	1313.88
350.00	1309.22	1243.43	1233.91	1048.11
345.00	1027.83	974.64	960.13	810.98
340.00	781.34	735.23	718.02	602.15
335.00	555.97	520.16	502.91	421.30
330.00	354.76	331.09	314.68	268.12
325.00	206.44	188.16	167.41	143.28
320.00	81.08	70.96	54.72	46.44

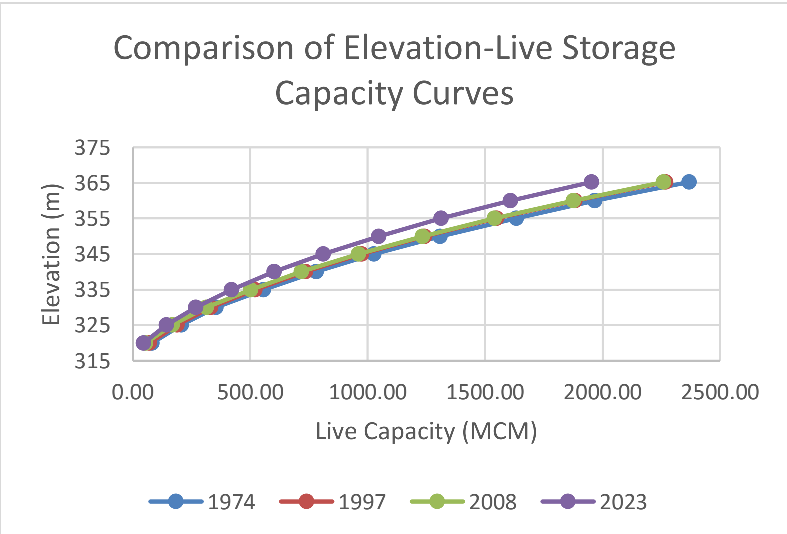

Figure 6: Comparison of curves showing the relationship between elevation and live storage (MCM)

The initial total and live storage capacity of the Ramganga reservoir in 1974 were recorded as 2590.72 MCM and 2370.00 MCM, respectively. Subsequent reservoir sedimentation surveys conducted by IRI in 1997 and 2008 indicated a live storage capacity of 2270.144 MCM and 2260.04 MCM, respectively.
In the current study, it has been discovered that the live capacity of the Ramganga reservoir in 2023 amounts to 1952.98 MCM, reflecting a decrease in live storage of 417.02 MCM (equivalent to 17.60%) over a span of 49 years from 1974 to 2023. This translates to an annual live capacity loss of 0.36% since 1984.
Table 4 below presents the decline in live storage of the reservoir resulting from deposition of sediments since the initial survey conducted in 1974, as well as subsequent surveys carried out in 1997, 2008, and the present study in 2023.

Table 4: Loss in Storage Capacity Due to Sedimentation Based on Study

S. No.	Particular	Original Survey (1974)	Survey of 1997	Survey of 2008	Present Study (2023)
1	Live Capacity (MCM)	2370.00	2270.14	2260.04	1952.98
2	Loss in Capacity (MCM) since 1974	-	99.86	109.96	417.02
3	% Live Capacity Loss since 1974	-	4.21%	4.64%	17.60%
4	Annual % live capacity loss	-	0.18%	0.14%	0.36%
5	% Live Capacity Loss between two consecutive surveys	-	4.21%	0.45%	13.59%

4. CONCLUSION

From the above results and observations for both test , the following conclusion can be drawn :
Estimating the rate of sedimentation in the watershed of Ram Ganga Reservoir is the primay goal of this effort. This study is expected to show whether the watershed is susceptible to soil erosion or not, allowing planners and decision-makers to take the proper action to improve the catchment's ability to conserve both land and water. These investigations can benefit greatly from the use of remote sensing data, which can be utilized to infer surface features.
The findings of this study hold potential value for researchers and professionals involved in various fields, including urban planners, policymakers, government organizations, and others. These results can be applied to a wide range of studies and provide useful insights for different areas of interest. The following are the conclusions from the present study:

I. In 2023, the available live storage capacity of the Ramganga reservoir was determined to be 1952.98 MCM.
II. A live storage loss of 417.02 MCM (equivalent to 17.60%) has been recorded since the original survey conducted in 1974, covering a duration of 49 years. This corresponds to a loss of annual live capacity of 0.36% since 1974.
III. Remote sensing surveys are the sole source of information regarding capacities within the water level fluctuation zone, typically situated between the Minimum Drawdown Level (MDDL) and Full Reservoir Level (FRL) of reservoir. The utilization of satellite remote sensing methods allows for a rapid and cost-effective assessment of loss in the live storage capacity of the reservoir caused by sedimentation.
IV. For the reservoir to operate at its best, capacity estimation using this technique at regular intervals can provide crucial characteristics like the annual sedimentation rate and the pattern of sediment distribution in the reservoir region. It can also provide a new elevation-area-capacity curve.
V. As they are unaffected by weather or lighting conditions, cloud-free imageries are frequently accessible for capacity assessment utilizing microwave remote sensing technology throughout the year.