Footprints of Sedimentation on Loss of Reservoir Life using Satellite Remote Sensing Technique

Tulshidas M. Jibhakate\textsuperscript{1},\textsuperscript{a}, Yashwant B. Katpatal\textsuperscript{2},\textsuperscript{b}

\textsuperscript{1}Research Scholar, Civil Engineering Department, Visvesvaraya National Institute of Technology, Nagpur-440010, Maharashtra, India
\textsuperscript{2}Professor, Civil Engineering Department, Visvesvaraya National Institute of Technology, Nagpur-440010, Maharashtra, India

Email: \textsuperscript{a}tulshimj@gmail.com, \textsuperscript{b}ybkatpatal@rediffmail.com

Abstract: Reservoir is the most important water storage systems especially in areas where groundwater potential is low which can be used for domestic, irrigation as well as industrial water supply. The sedimentation which is a natural phenomenon of settling sediment particles in a reservoir is observed to be enhanced with construction of dams due to change in flow dynamics. Sedimentation in a reservoir takes place in dead storage zone as well as in live storage zone causing reduction in useful capacity of reservoir over a period of time, thereby affecting the designed water supply planning. Sedimentation in live storage zone can be estimated using Remote Sensing Technique which will give us synoptic view of a reservoir. Present study aimed at estimating a reduction in live storage capacity with the help of satellite imageries. For this, the Totladoh Reservoir which is situated on the boundary of Maharashtra and Madhya Pradesh, India has been selected for the study. Totladoh reservoir is situated in calc gneisses type of metamorphic rocks. Green and near-infrared bands were used to calculate the Normalized Difference Water Index (NDWI). The rate of siltation for Totladoh reservoir has been estimated for the period of 1982-2020 using LANDSAT 8 satellite imageries having 30 m spatial resolution. Percentage loss of live storage for year 2020 is found to be 17.63. Rate of Siltation in the reservoir is 1173 m$^3$/km$^2$/year which is more under prevailing conditions when compared to CWC values.

Keywords: Reservoir, Sedimentation, Live storage Capacity, LANDSAT 8, Satellite imageries, Totladoh Reservoir, Elevation Capacity Curve.

1. Introduction

Sedimentation is a natural phenomenon that takes place when high velocity of water is flowing through the catchment carrying the dissolved and suspended load which is ultimately deposited along its way to the reservoir; here maximum deposition occurs at the reservoir. Sedimentation in reservoirs takes place in both the dead and the live storage zone. It is essential to conduct the sedimentation surveys to determine the percentage of sediment deposition and the rate of sedimentation/siltation after a specific time interval, using the impounding year as a reference. Sedimentation in reservoir can be estimated and collate with the original designed data. Elevation capacity curve needs to be modified from time to time for the management of available water to users.

The life of the reservoir depends upon many factors but the one which is influencing more is Sedimentation. Designed life of a reservoir will reduce, if sedimentation rate is higher than the designed one. Proper management of sedimentation can make the reservoir renewable otherwise it will be exhaustible (Jibhakate et al. 2022). Earlier Sedimentation surveys were carried out by different methods i.e. hydrographic survey, inflow-Outflow method, mathematical models and empirical methods, etc. These conventional methods are cumbersome and time-consuming. Hydrographic surveys were often used for sediment deposition surveys, which were tedious, expensive, and less accurate when compared to remote sensing techniques (Foteh et al. 2018). The technology of satellite remote sensing (SRS) is now commonly employed for assessing sediment deposition (Jain et al. 2002; Katpatal et al. 2017).

The current study looks into the sedimentation of the Totladoh Reservoir in Maharashtra, and adjoining Madhya Pradesh, India using the spatial approach i.e. LANDSAT 8 satellite imageries have...
been used in satellite remote sensing technique for estimating the past 38 years of sedimentation. Totladoh reservoir shares its boundary with Maharashtra and Madhya Pradesh which makes it important for both states.

2. Study Area

Totladoh dam is a gravity dam at the Pench River close to Ramtek in Nagpur district within the state of Maharashtra and adjacent Madhya Pradesh in India. Figure 1 shows the index map of the research area. The reservoir's latitude and longitude are 21° 39′ 32.28″ N and 79° 13′ 55.59″ E. The reservoir was first impounded in 1982. Minimum drawdown level (M.D.D.L.) = 464 m, Full reservoir level (F.R.L.) = 490 m, Gross storage capacity (MCM-Million Cubic Metre) = 1241.11, Dead storage capacity (MCM) = 149.58, Live Storage Capacity (MCM) = 1091.53, Catchment Area= 4273 Km², Area at F.R.L. = 77.71 Km² (Source: India Water Resources Information System).

![Index Map of Totladoh Reservoir, Maharashtra and Madhya Pradesh (INDIA)](image)

3. Data Used

For assessment of sedimentation, variation of reservoir levels should cover the live storage zone which is from M.D.D.L. to F.R.L. (ideally) within a year. But due to non-availability of cloud free satellite imageries within a year, three years of satellite imageries (2018, 2019, and 2020) were considered for the present study to cover the maximum live storage zone.

Green and Near-Infrared bands are essential to quantify NDWI. To cover the maximum useful storage zone, cloud-free satellite imageries (LANDSAT 8) were acquired from earth explorer (USGS) for the years 2018, 2019, and 2020 by considering the minimum drawdown level as lowest level and full reservoir level as the highest level. Reservoir levels on the date of satellite passing were downloaded from India Water Resources Information System (IWRIS) for the same year mentioned above. All the specifications of the reservoir and dam were collected from the same source of IWRIS.
4. Methodology

The basic concept of sediment assessment is to find out the water spread area using spatial data for different water levels between M.D.D.L. to F.R.L. The difference between synoptic view of water spread area between current year and earlier years is the aerial extent of sedimentation or silting at these levels. While applying satellite remote sensing techniques to determine the storage capacity of any reservoir, a water spread area is necessary. The elevation capacity curves were drawn by obtaining the original reservoir elevation values w.r.t live storage values at the time of the first impoundment and revised one. NDWI was used for extracting the water spread area. Estimation of reservoir capacity at different elevations has been calculated using trapezoidal formula. Figure 2 illustrates a flowchart for assessing sediment deposition using satellite remote sensing.

Due to sedimentation, the water spread area shrinks at different altitudes inside the reservoir submergence region, reducing the reservoir's live and dead storage capacity. The live storage zone is the area between the minimum drawdown level (M.D.D.L.) and the full reservoir level (F.R.L.). Water spread area can be calculated using satellite imageries (cloud-free images) at various elevations by computing the pixel counts.

NDWI is widely used spectral index for water body mapping. NDWI value varies between -1 to 1. Zero is the threshold. As suggested by McFeeters (1996) if, NDWI values greater than zero represents water spread area and if NDWI is less than or equal to Zero, it covers Soil, vegetation, and other features (McFeeters 1996).

Water pixels that give water spread area are obtained using the normalized difference index (NDWI). The water spread area and elevation between two reservoir levels can be multiplied to get the live storage capacity for any height interval. NDWI formula is mentioned below.

$$NDWI = \frac{(Green\ band - NIR\ band)}{(Green\ band + NIR\ band)}$$

Water spread area (m²) = No. of water pixels*each pixel area.
Spatial resolution of LANDSAT 8 satellite is 30 m. Hence, Each Pixel area is 30 m²*30 m.
The following is the trapezoidal formula for calculating reservoir capacity between two successive water levels or reduced levels (R.L):

$$V = \frac{h}{3} \left[ A1 + A2 + \sqrt{A1 \cdot A2} \right]$$
Where, $V$ is capacity/volume of a reservoir between corresponding intervals, $A1$ is water spread area at RL 1 and $A2$ is water spread area at RL 2, $h$ is the difference between RL or height interval (Jain et al., 2002).

5. Results and Discussions

Water spread area can be determined using the raster calculator (i.e. NDWI) in ArcMap software by multiplying the number of water pixels with the spatial resolution, i.e. pixel size. By using the Trapezoidal formula, the revised live storage capacity of a reservoir was obtained between the maximum (489.85 m) and minimum (464.14 m) which are near to F.R.L. and M.D.L. respectively. All findings related to sediment assessment are shown in Table 1.

**Table 1. Observed data and Findings of sediment assessment**

| Date of satellite pass | Elevation of reservoir (m) | Pixel count (Water pixels) | Spatial Resolution (m) | Revised area (Km$^2$ or Mm$^2$) | Revised live capacity (Mm$^3$) | Cumulative revised live capacity (Mm$^3$) |
|------------------------|----------------------------|-----------------------------|------------------------|----------------------------------|---------------------------------|--------------------------------------|
| 16/05/2019             | 464.14                     | 11072                       |                        | 9.96                            | 0                               | 0                                    |
| 14/04/2019             | 466.1                      | 13947                       |                        | 12.55                           | 22.01                           | 22.01                                |
| 24/01/2019             | 470                        | 18642                       |                        | 16.78                           | 56.99                           | 79                                   |
| 20/10/2018             | 473.05                     | 25809                       |                        | 23.23                           | 60.75                           | 139.75                               |
| 04/10/2018             | 476.7                      | 34186                       | 30                     | 30.77                           | 98.23                           | 237.98                               |
| 18/05/2020             | 487.02                     | 68346                       |                        | 61.51                           | 467.1                           | 705.08                               |
| 25/10/2020             | 489.85                     | 76852                       |                        | 69.17                           | 184.8                           | 889.88                               |

The spreading of water area for different elevations is shown in Figure 3 from near Minimum drawdown level (16/05/2019) to near full reservoir level (25/10/2020). Figure 3 indicates a chronological increase in water spread area concerning reservoir elevations.
**Figure 3.** The water spread area at different reservoir elevations (i.e. From near M.D.D.L. to near F.R.L.)

**Figure 4.** The Elevation-Capacity curve of Live Storage Capacity for Totladoh Reservoir
The graph indicates that the curve has shifted leftward at the same reservoir elevation as the original pattern of reservoir, which was first impounded in 1982, and the revised pattern of elevation capacity curve for the year 2020 (Figure 4).

Cumulative revised live storage capacity = 889.88 Mm$^3$
Designed original live storage capacity = 1080.32 Mm$^3$
Loss of live storage capacity = (1080.32 - 899.88) / 1080.32 * 100 = 17.63%  
Rate of siltation = \[
\frac{\text{Cumulative loss in live storage capacity}}{\text{Catchment area} \times \text{year of last survey}}
\]
\[
= \frac{190.44}{4273 \times 38} = 1.173 \text{ Th.m}^3/\text{km}^2/\text{year}
\]

The revised live storage capacity of Totladoh Reservoir for the year 2020 is anticipated to be 889.88 Mm$^3$ between near F.R.L. at R.L. 489.85 m and near MDDL at R.L. 464.14 m, compared to a designed capacity of 1080.32 Mm$^3$ and a loss of 190.44 Mm$^3$ in 38 years. In the live storage zone, the rate of siltation is estimated to be 1.173 Th.m$^3$/km$^2$/year.

In the below table, the current study covers a live storage zone between 464.14 m (near M.D.D.L.) and 489.85 m (near F.R.L.). The current study has been compared with the CWC survey which indicates that the rate of siltation per year increases from 0.632 to 1.173 Th.m$^3$/km$^2$/year.

### Table 2. Comparison of results of previous survey with present study

| Reservoir Name   | Totladoh     | Totladoh     |
|------------------|--------------|--------------|
| Year of Survey   | 2009         | 2020         |
| Agency Name      | CWC          | Present Study|
| Gross Storage (MCM) | 1241.11     | 1241.11      |
| Live Storage-Original (MCM) | 1091.53     | 1080.32      |
| Dead Storage Capacity (MCM) | 149.58      | 149.58       |
| Present Live Capacity (MCM) | 1018.58     | 889.88       |
| Total Loss of Live storage up to last survey | 72.95       | 190.44       |
| % Loss of Live storage up to last survey | 6.68        | 17.63        |
| Average Observed rate of siltation (Th.m$^3$/km$^2$/year) | 0.632       | 1.173        |

### 6. Conclusion

Till the completion of life of reservoir, the dead storage zone is supposed to be fully filled with sediment particles. Live storage capacity of a reservoir is reduced with time, due to improper management in handling the issue of sedimentation. As the live storage capacity of the reservoir is reduced, reservoir life is drastically reduced which ultimately raises the question of unbalanced water management for the command area. The percentage decline in live storage capacity of Totladoh reservoir in the current study region is significant when compared to the previous study. In a 38-year period, the percentage loss of live storage for the year 2020 is 17.63. The rate of siltation was found to be 1173 m$^3$/km$^2$/year, which is higher than CWC values under prevailing circumstances (CWC Report, 2020). The Totladoh reservoir shares its boundary with Maharashtra and Madhya Pradesh so it is necessary to estimate present live storage capacity to resolve the water dispute. Study proves that sedimentation studies using satellite data are effective.
7. References

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