TRAINING COURSE
ON

APPLICATIONS OF REMOTE SENSING AND GIS IN WATER RESOURCES MANAGEMENT

<u>ORGANISED UNDER</u>
HYDROLOGY PROJECT PHASE II

AT
NATIONAL INSTITUTE OF HYDROLOGY, ROORKEE

OCTOBER 20-24, 2008

LECTURE NOTE
ON

REMOTE SENSING APPLICATIONS IN RESERVOIR SEDIMENTATION STUDIES

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Remote sensing applications in reservoir sedimentation studies

The detachment and transportation of the soil is termed as soil erosion. Every stream carries some sediments in suspension and moves larger particles along its bed. The deposition of sediment in channels or reservoirs creates a variety of problems, such as raising of stream beds, meandering and overflow along the banks, and, of course, depletion of storage capacity in reservoirs.

The sediment content in river waters varies with flow conditions. While it is small in lean flow months, it attains the maximum value during floods. The total quantity of sediment transported annually to the sea by rivers of the world is about $2*10^{10}$ tons or about 13.5 km^3 in terms of volume (Alam, 2001). According to Mahmood (1987), world wide, reservoirs are annually losing about 1% of the storage capacity or about 65 km^3/year. Based on weighted average data of 144 reservoirs in India, the annual loss of gross storage was estimated at 0.44%.

The soil erosion is considerably high in arid climates. In India, about 5333 million tonnes (16.35 t/ha) of soil is detached annually due to agriculture and associated activities. Of this, about 29% is carried away to oceans by the rivers. Nearly 10% of it is deposited in reservoirs resulting in loss of 1 to 2 % of the storage capacity (Dhruva Narayana, 1995).

Each sediment particle being transported by flow is affected by two dynamic forces: a horizontal component acting in the direction of flow and a vertical component due to gravity; there is also a force of water turbulence. Since the specific gravity of soil materials is about 2.65, the particles of suspended sediment tend to settle to the channel bottom, but upward currents in the turbulent flow counteract the gravitational settling. The sediment inflow and outflow in the natural river reaches is mostly in balance. A reservoir changes the flow characteristics and its sediment transport capacity. As the reservoir width is much bigger than the river width, the velocity of flow entering into it decreases tremendously and there is a dampening of turbulence. Consequently, the flow is unable to transport all the sediments and the particles begin to deposit. First, the larger suspended particles and most of the bed load is deposited at the mouth of the reservoir. The smaller particles remain in suspension for a long time and some may leave the reservoir with water.

1.0 RESERVOIR SEDIMENTATION

The ultimate destiny of all reservoirs is to be filled with sediments. Accumulation of sediments is one of the principal factors that threaten the longevity of reservoirs. Sometimes a project is not constructed just because the silting rate is so high that the reservoir will fill up before the investment is fully recovered.

There are instances of reservoirs being filled-up within a few years of their operation. The Sanmexia dam was the first major dam on the middle reaches of Yellow River. In the first 18 months after dam closure, 1.8 billion metric tons of sediment accumulated in the reservoir, representing a trap efficiency of 93% (Morris and Fan, 1998). The Xinghe reservoir in the Shaanxi province took two years to construct but only one year to fill with sediment.

The right approach to solve reservoir sedimentation problem consists of three tasks: (a) collect and analyse field data, (b) set up appropriate models, and (c) develop operational policy for the reservoir. Deposition and scour may differ considerably when different operation policies are adopted.

The sediment deposits in a reservoir can be divided in three groups: topset beds, foreset beds, and bottomset beds (see Fig. 1). The topset beds are composed of large size sediment deposits but may also have fine particles. These extend up to the point where the backwater curve ends. The downstream limit of the topset bed corresponds to the downstream limit of bed material transport in the reservoir. These deposits cause minor reduction in the reservoir storage capacity. Foreset deposit is the face of the delta deposit advancing towards the dam. It is a transition zone having steeper slopes and decreasing grain size. The bottomset beds consist of fine sediments which are deposited beyond the delta by turbidity currents or non-stratified flow. This scene of deposits may change due to reservoir drawdown, slope failures and extreme floods.

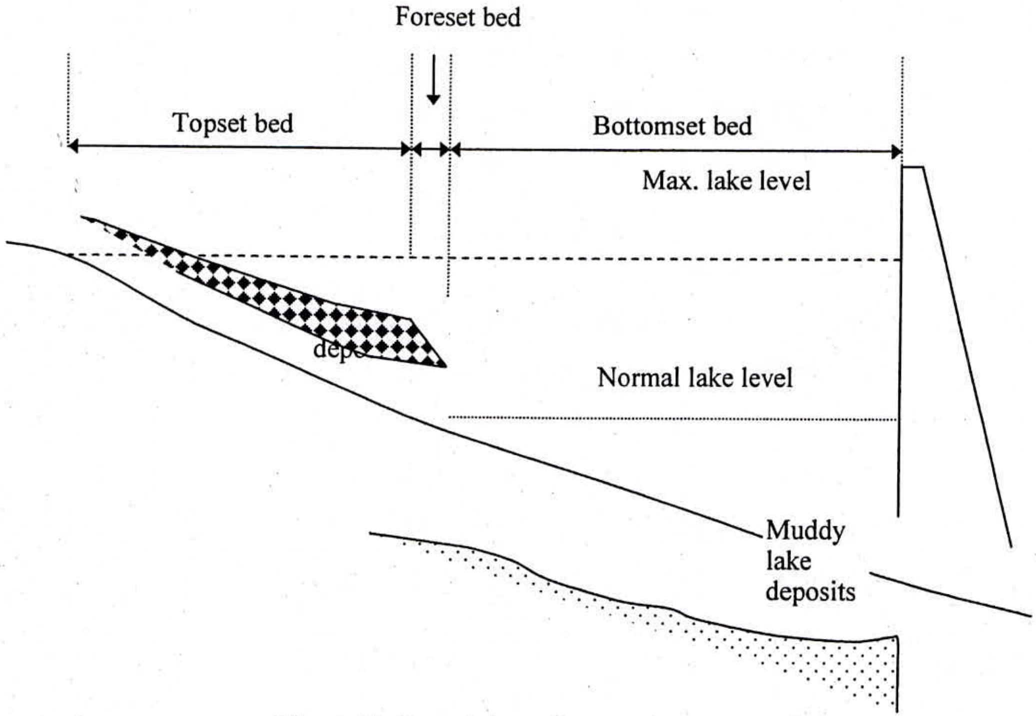

Fig. 1 Sediment deposit zones in a reservoir.

For proper reservoir management, knowledge about the sediment deposition pattern in various zones is essential. Timely remedial measures can be undertaken with the correct knowledge of the sedimentation processes in a reservoir.

1.1 Factors Influencing Reservoir Sedimentation

Two dominant factors that influence the rate of silting in a reservoir are: (a) capacity to inflow ratio (CIR) and (b) sediment content in the water flowing in. The other factors are the texture and size of the sediment, trap efficiency of the reservoir, and the method of reservoir operation. The CIR is the ratio of reservoir storage capacity to mean annual inflow. A reservoir with CIR more than 50% is considered hydrologically large; it may have significant carry-over storage and the trap efficiency will also be large. Note that the sediment inflow depends on catchment area too. All other things remaining the same, a dam of the same capacity in the upper catchment will have a higher rate of silting compared to a dam of the same design but constructed lower down the valley.

The two principal factors mentioned above have a complete range of interplay. A reservoir having a small CIR and small sediment inflow and that having a large CIR and large sediment inflow may have more or less the same rate of sedimentation. Also, with high CIR and high sediment content in inflow, a high rate of silting can be expected. On the other hand, high CIR and low sediment content in inflows will result in a small rate of silting.

1.2 Trap Efficiency

The trap efficiency of a reservoir is the ratio of sediment retained in the reservoir to the sediment inflow. It primarily depends on the sediment characteristics, the detention time of the inflow, method of reservoir operation, and age of reservoir. A small reservoir on a large stream passes most of its inflow so quickly that the finer sediments are discharged downstream. A larger reservoir, on the other hand, may retain water for several years and the outflow from it may be completely devoid of suspended sediments. The trap efficiency of a reservoir decreases with age as the reservoir capacity is reduced by sediment accumulation. Thus complete filling of the reservoir may require a very long time.

The trap efficiency can be computed from the sediment inflow and outflow data. Brune (1953) analysed data from 44 reservoirs in the USA, 40 being normal ponded reservoirs with catchment areas varying from 0.098 sq. km to 478110 sq. km and the CI ratio ranging from 0.0016 to 2.05. This analysis revealed that the laws of sediment deposition are the same for all types of reservoirs, and the factors influencing the trap efficiency are independent of the size of the reservoir. Brune (1953) presented a set of envelope curve between CIR and trap efficiency.

2.0 Loss of Storage Capacity

Observations show that in the reservoirs which have small sluicing capacity with respect to normal floods and which have no upstream reservoirs, the siltation rate is comparatively high in the first 15-20 years and thereafter it falls off and may ultimately become negligible. From the data of reservoir capacity surveys, Shangle (1991) found that the sedimentation rates in major reservoirs (storage > 100 million m^3) in India that have completed more than 50 years of their useful life varied from 0.30 to 4.89 Ha-m/100 sq. km/year. The rate for those major reservoirs that have completed less than 50 years of their useful life varied from 0.34 to 27.85 Ha-m/100 sq. km/year.

The rate of siltation of a reservoir normally shows a falling trend with time. A plausible explanation is that the obstruction by the dam causes the dips and flanks of the storage basin to fill up with silt in early years. A stage comes when the river section adjusts itself to carry the normal discharge and disposal of suspended load in the area of the reservoir is harmonised with the condition of the flow. Besides, the progressive development of deltas above the reservoir helps in trapping of some of the silt load. Shrinkage and settlement of deposited silt also takes place with time due to superimposed loads of additional silt. This results in reduction in silt volume. However, a complete explanation of this behaviour is not available.

The consequences of reservoir sedimentation are gradual reduction in benefits from the operation of the reservoir. The extent of loss depends on the type and nature of purposes being served and the rate of loss of storage capacity. The loss may turn out to be really high when the replacement cost of the storage lost is considered.

2.2 Distribution of Sediments in Reservoirs

Sediment distribution in a reservoir is important and this aspect requires careful consideration in planning and design stages. The pattern of sedimentation helps in predicting the extent to which services will be affected at various times and the remedial actions to be taken. The designer is interested to know the height of sediment accumulation to fix up the sill elevation of the outlets, penstocks gate elevation, to estimate the region where delta would be formed and consequent increase in backwater levels. Finally, the pattern is necessary to plan for recreational facilities. Four types of distribution patterns of deposits have been identified:

Delta deposits: These deposits contain the coarsest fraction of the sediment load which is rapidly deposited in the zone of inflow.

Wedge-shaped deposits: These are thickest at the dam and become thinner moving upstream.

Tapering deposit: These occur when deposits become progressively thinner moving toward the dam.

Uniform deposits: The thickness of these deposits is more or less uniform in the reservoir. Such deposits are not very common.

3.0 RESERVOIR SURVEYS

Sediments accumulated in an existing reservoir can be determined by periodically running sediment surveys. It is a direct measurement procedure to assess the volume and pattern of deposits. Sediment data collected during the surveys are analyzed to determine the specific weights of the deposits, their grain size distribution, sediment accumulation rates, and reservoir efficiencies. Recent advances in technology have considerable reduced the efforts to carry out reservoir surveys and analyze data.

The accuracy of these surveys is usually very high particularly if advanced equipment are used. It is possible to estimate the total sediment (bed and suspended) load being carried by the river. But such surveys do not provide any information about the variation of sediment yield with time and give only the total sediments accumulated since the last survey. This method does not provide sub-catchment wise sediment yield. Finally, to find the total sediment inflow, the information about sediment outflow is also needed.

The frequency of surveying the reservoirs depends on the sediment accumulation rate and cost of running a survey. Reservoirs with high accumulation rates are surveyed more often than those with lower rates. Generally, the reservoirs are surveyed every 3 to 10 years. Special circumstances may necessitate a change in the established schedule. A reservoir might be surveyed after a major flood that has brought in heavy sediment load. A survey may also be run following the closure of a major dam constructed upstream in the same catchment. An upstream dam reduces the free drainage area and hence reduction in the sediment inflow.

4.0 REMOTE SENSING APPROACH TO ASSESS RESERVOIR SEDIMENTATION

With the availability of high resolution satellite data at close temporal spacing, capacity surveys of reservoirs by remote sensing technique have become practical with acceptable accuracy. In India, the water level in a reservoir is near the FRL by the end of the monsoon season (September/October) before it gradually depletes to lower levels towards the end of the drawdown cycle (May/June). Due to deposition of sediments in the reservoir, the water-spread area at an elevation keeps on decreasing. Using the remote sensing approach, the water-spread area is determined at different reservoir levels and the revised elevation-capacity curve is prepared. By comparing the original and revised elevation-capacity curves, the amount of capacity lost to sedimentation can be assessed.

Clearly, the analysis for the water year with maximum variation in the reservoir water level will be most useful. The satellite imagery is analyzed using either visual or digital processing techniques and the water-spread area is delineated. Knowing the waterspread area for a particular image, the periphery of waterspread area is derived using various image processing techniques. Elevation values are assigned to each and contours corresponding to different waterspreads are overlaid to represent the revised conditions in the various zones. The reservoir capacity between two consecutive elevations is computed using the prismoidal formula and the revised elevation-capacity table is generated. A comparison of this table with the original table gives the capacity loss due to sedimentation in various zones of the reservoir.

5.0 CASE STUDY - THE BARGI RESERVOIR

The Bargi project is one of the major schemes which have been constructed on the Narmada River in Madhya Pradesh. Bargi is a composite earth and masonry dam, 5374.39 m long constructed near village Bargi in the Jabalpur district. This multipurpose project scheme is meant to serve for water supply for domestic and industrial purposes, irrigation and hydropower generation. The latitude and longitude of the dam are 22°56′30″ N and 79°55′30″ E respectively. The index map of the basin is presented in Figure – 1. The catchment area at the dam site is 14556 sq. km. The Bargi reservoir (now known as Rani Avanti Bai Sagar) has the maximum reservoir level, full reservoir level and the dead storage level at 425.70 m, 422.76 m and 403.55 m respectively. The gross, live, and dead storage capacities of the reservoir are 3.92 billion cubic meters (B Cum), 3.18 B Cum and 0.740 B Cum respectively. The reservoir has been classified as hilly according to the I.S. code no. 5477. The shape of the reservoir is almost longitudinal. Its longest periphery from the axis is about 80 km.

The average annual rainfall in the catchment up to Jamtara is 1414 mm; about 94% of this occurs during the monsoon season (July to October). The average annual inflow at the dam site is 7197 million cubic meters (M Cum). The dam was first impounded up to RL 407.5 m in the year 1988. No hydrographic survey has yet been carried out for the reservoir.

5.1 Data Availability

For the Bargi reservoir, the historical record of annual maximum and minimum observed levels was obtained from the dam authorities. Maximum variation in water level (406.00 m to 421.45 m) was observed in the year 1996-97, covering most of the live storage zone (403.55 m to 422.76 m). Therefore, the period from October 1996 to June 1997 was selected for analysis.

The multispectral data of IRS-1C satellite, LISS – III sensor were used in this study. Bargi reservoir water-spread was covered in one scene of Path 100 and Row 56 of satellite. Based on the status and availability of remote sensing data and the time spacing in-between the satellite data, nine scenes were obtained for the following dates of pass: 10.10.96, 03.11.96, 27.11.96, 07.02.97, 03.03.97, 27.03.97, 20.04.97, 14.05.97, and 07.06.97. The water levels on these days were obtained from the dam authorities.

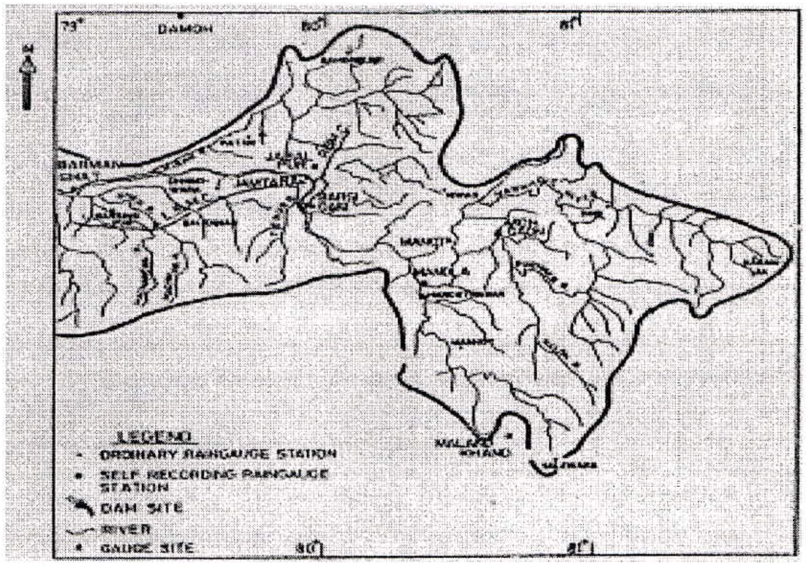

Fig. 1 Index map of catchment of Bargi project.

5.2 Interpretation and Analysis

The basic output from the remote sensing analysis is the waterspread area on the date of satellite pass. Two techniques of remote sensing interpretation, viz., visual and digital, are used for waterspread delineation. Visual techniques are based purely on the interpretative capability of the analyst and it is not possible to use the information of different bands after the generation of visual product. Around the periphery of the waterspread area, the wetland pixels appear very similar to the water pixels and it becomes difficult to visually judge whether a pixel near the periphery is water or land. Using digital techniques, the information of different bands can be utilised to the maximum extent. In this study, digital processing was carried out using the ERDAS/IMAGINE image processing software. The steps of analysis are described in the following.

5.3 Import, Visualisation and Geo-referencing

The data of IRS-1C satellite and LISS-III sensor for nine different dates were received from NRSA on CD-ROM and were imported in the ERDAS system. The pixel size of the processed data was 24 m. A false colour composite (FCC) of 3, 2 and 1 Bands combination was prepared. The water-spread area (except at the periphery) of the reservoir was quite distinct and clear in the FCC. Reservoir water-spread area was free from clouds and noise in all the nine imageries.

The multi-temporal remote sensing images are first geo-referenced to a master map. Using the geo-referenced images, the waterspread areas at different time periods can be compared and revised contours can be overlaid. First, the drainage pattern of the area around and within the reservoir waterspread was digitised from 1:50,000 scale toposheets of the Survey of India (SOI). The toposheets of higher scale were not available. The drainage pattern was rasterised and resampled in Polyconic projection to a pixel size of 24 m (same as remote sensing data). In the similar way, the original contours of the catchment upstream of the dam site were digitised. The contours on these toposheets were available for elevations of 400 m, 420 m, 440 m and 460 m.

Next, image–to–image registration was carried out for all the images. Each imagery was georeferenced with its subsequent date image. The results were checked for all the images by displaying two images at a time one over the other and comparing the two using the SWIPE facility. The match between the images was satisfactory. After image–to-image registration, the resulting images were georeferenced with the drainage map. All the images were georeferenced with the drainage map using the similar model, since all of them were already georeferenced with each other. The FCC of georeferenced image of Bargi reservoir of 10 October, 1996 is shown in Figure – 2. The water-spread image of June 07, 1997 is overlaid on this image to have a view about the overall waterspread variation in this analysis.

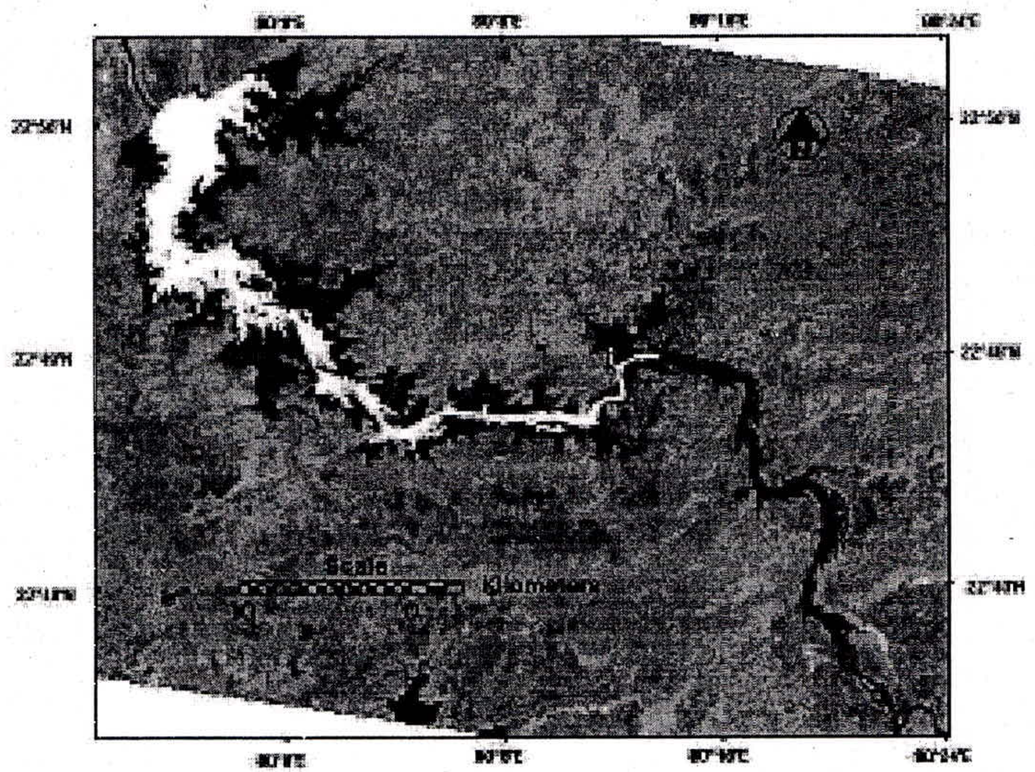

Fig. 2 Near-infrared image of Bargi Reservoir on 10 October 1996 overlaid with water-spread image (white) of 7 June 1997.

5.4 Identification of Water Pixels

This is the basic output of the remote sensing interpretation and is the most important part of analysis. In the visible region of the spectrum (0.4 - 0.7 μm), the transmittance of water is significant and the absorptance and reflectance are low. The absorptance of water rises rapidly in the near-IR where both, the reflectance and transmittance are low. At near-IR wavelengths, water apparently acts as a black body absorber. Though the spectral signatures of water are quite distinct from other land uses like vegetation, built-up area and soil surface, the identification of water pixels at the water/soil interface is very difficult and depends on the interpretative ability of the analyst. Deep-water bodies have quite distinct and clear representation as compared to shallow water. Shallow water can be mistaken for soil while saturated soil can be mistaken for water, especially along the periphery of reservoir. To differentiate water pixels from the adjacent wetland pixels, comparative analysis of the digital numbers in different bands was carried out. The methodologies, commonly used in digital processing are classification, thresholding and modeling.

After analysing the spectral reflectance of water pixels in various imageries, an algorithm was used to identify water pixels using data of different bands. The algorithm matches the signatures of a pixel with that of water and then identifies whether a pixel represents water or not. In addition, it also checks for the *Normalised Difference Water Index* ((B2-B3)/(B2+B3)) which is created as a separate image. In all the images, it is found that the NDWI for water is either equal to or greater than 0.44. The algorithm checks for following condition for each pixel. If the condition is satisfied, then the pixel is recorded as water, otherwise not:

> *"If the DN value of near-IR band (B3) of a pixel is less than the DN value of the red band (B2) and the green band (B1), and the NDWI is ≥ 0.44, then it is classified as water otherwise not".*

Since the absorptance of electromagnetic radiation by water is at maximum in the near-IR spectral region, the DN value of water pixels is appreciably less than those of other land uses. Even if the water depth is very shallow, the increased absorptance in the Band 3 causes the DN value to be less than Band 2 and Band 1. This condition differentiates the water pixels from other pixels. The condition was applied in the form of a model in the ERDAS/IMAGINE software and the model runs were taken with images of different dates. The resulting images of water pixels were compared with the near-IR images and the standard FCC. The results were found to be satisfactory in all the cases. The biggest advantage of this method was that it avoided the necessity of selecting different limits in different images as required in density slicing.

5.5 Removal of Discontinuous Pixels

The main objective of calculating the water-spread area is to determine the revised contour area at the elevation of the water surface. Since the contour area represents the continuous area, it is required that the isolated water pixels surrounding the waterspread area and/or located within the islands be removed from the interpreted water image. Similarly, the water pixels downstream of the dam do not form part of reservoir and need to be removed.

To remove most of these unwanted pixels, a mask was generated from the edited water image of October 10, 1996. The water image of this date was manually edited to remove the discontinuous pixels and the downstream river pixels. Next, the water images corresponding to remote sensing images of all dates were obtained by applying the model as mentioned above. The mask was superimposed and all the pixels outside the mask were treated as if they are not part of the reservoir. Most of the discontinuous pixels could be removed in this step. However, some of the pixels that were discontinuous and lie within the mask, still needed to be edited. To remove these pixels, a GIS utility known as "CLUMP" was used. An 8-connected clump image was formed for all the water images. This utility created a clump around the discontinuous pixels and assigned different values to different clumps. Using the "MODELER" option, these clumped pixels were removed so that only continuous water-spread remained in the water image.

5.6 Removal of Extended Tail and Channels

The main river at the tail end of the reservoir and numerous small channels join the reservoir from different directions around its periphery. Water in these channels is classified as water. However, the elevation of water in these channels and the main river remain higher than the water surface of the reservoir. So, the extended tail and channels must be removed from the point of termination of spread. The selection of truncation point is subjective and may be based on the difference between the water levels in the subsequent date imageries.

In the present case, there were no extended channels around the periphery of the reservoir. Further, there was no need to identify the tail end in eight out of nine imageries except for the image of October 1996. In eight imageries, the termination of water spread was obvious.

5.7 Derivation of Revised Contours

After finalising the waterspread area for a particular image, the periphery of the waterspread area was derived using various digital processing techniques. First, the islands within the spread area and the diagonally connected pixels were removed. This was achieved using the

CLUMP, in the same way, as was done for removing the discontinuous water pixels. Then, three different kinds of filters, namely Edge Detection, Horizontal and Vertical were convoluted with the total waterspread image. After obtaining the final peripheral pixels, the elevation values were assigned to them using the MODELER. The revised contours of the reservoir water-spread, as obtained from remote sensing analysis are presented in Figure – 3.

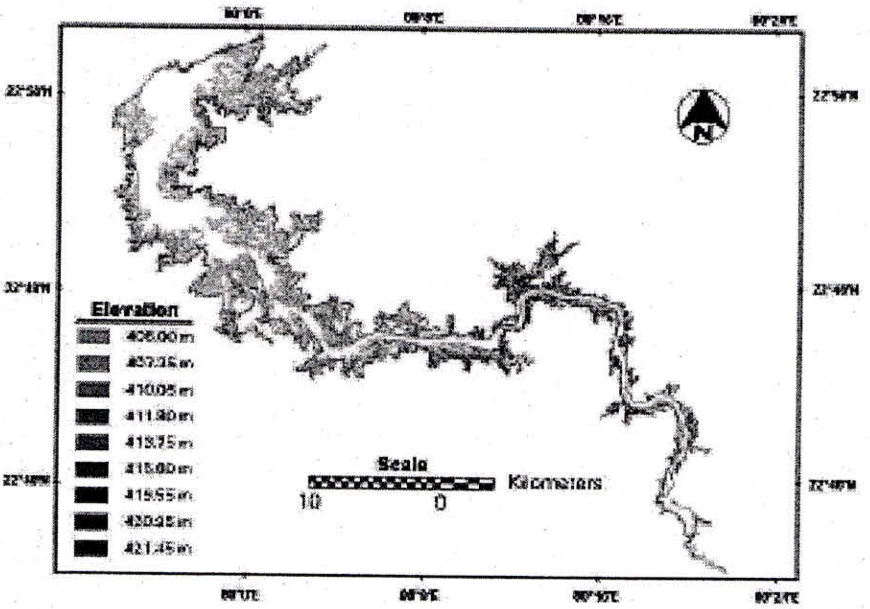

Fig. 3 Revised contours of Bargi Reservoir.

5.8 Calculation of Revised Capacity

After finalising the waterspreads of all the images, the histograms were analysed and the water pixels in each image were recorded. Water spread area at any elevation was obtained by multiplying the number of water pixels by the size of one pixel (24m x 24m). Reservoir capacity between two consecutive reservoir elevations was computed using the prismoidal formula:

$$V = \Delta H\,[A_1 + A_2 + \sqrt{(A_1 * A_2)}\,]/3$$

where, V is the volume between two consecutive elevations 1 and 2; A_1 and A_2 are contour areas and ΔH is the difference between elevation 1 and 2. The original elevation-capacity table before the impoundment of dam (1988) was obtained from the Reservoir Operation & Maintenance manual of the Narmada Valley Development Department, Govt. of Madhya Pradesh. From the original elevation-capacity table, the original capacity at the intermediate elevations (reservoir elevations on the dates of satellite pass) was obtained by linear interpolation. The revised volume was compared with the original volume in each zone and the difference between the two is the capacity loss due to sedimentation.

The cumulative revised capacity of the reservoir at the lowest observed level (406.00 m) was assumed to be the same as the original cumulative capacity (1010.00 M Cum) at this elevation. Above this level, the cumulative capacities between the consecutive levels were added up so as to arrive at the cumulative revised capacity at the maximum observed level (421.45 m). The calculation is presented in Table - 1.

Table - 1

Calculation of Sediment Deposition in Bargi Reservoir Using Remote Sensing

Date of Satellite Pass	Reservoir Elevation (m)	Revised Area (R.S.) (Mm^2)	Original Volume (Mm^3)	Revised Volume (R.S.) (Mm^3)	Original Cumulative Volume (Mm^3)	Revised Cumulative Vol. (R.S.) (Mm^3)
10.10.96	421.45	256.190			3595.833	3568.89
			139.966	126.65		
03.11.96	420.95	250.430			3455.867	3442.24
			391.904	341.64		
27.11.96	419.55	237.680			3063.963	3100.60
			860.072	837.84		
07.02.97	415.60	187.530			2203.891	2262.76
			306.907	325.72		
03.03.97	413.75	164.842			1896.984	1937.04
			262.161	297.29		

27.03.97	411.80	140.405			1634.823	1639.75
			213.942	227.24		
20.04.97	410.05	119.580			1420.881	1412.51
			290.028	286.39		
14.05.97	407.35	093.112	120.853	116.12	1130.853	1126.12
07.06.97	406.00	079.106	1010.00	1010.000	1010.000	1010.000

5.9 Remote Sensing Data Verification

Peng et al. (2006) proposed a method for RS data verification. It consists of the distance verification and the land and water border verification. For the distance verification, the difference between the distance of two points on the topographic map and the distance of the same two points on RS image data is compared. However, for the land and water border verification, it is a primary task that water surface area based on RS data is compared with the covered region of the contour in the topographic map at the same contour or corresponding water level.

6.0 DISCUSSION OF RESULTS

The results show that the revised capacity in the zone under consideration (between RL 406.00 m and 421.45m) is 2558.89 M Cum while the original capacity as calculated and envisaged in the project before the impoundment of the dam was 2585.56 M Cum. Thus, it can be inferred that 26.67 M Cum of the capacity has been lost to sedimentation in the zone under study in a period of 8 years (1989 to 1996). The year 1988 was not considered because the impoundment of dam in that year was only up to 407 m. Thus, the rate of sedimentation in the reservoir comes out to be 3.33 M Cum per year.

The results of this study were compared with the sedimentation study report prepared by Central Water Commission. In this study, the trap efficiency of 95% was assumed. Based on the upstream developments, the report predicted that the total sediment trapped in the reservoir would be 5746.5 ha-m during the period 1989 to 1993 and 5655.0 ha-m during the period 1994 to 1999. Thus, the total sediment that will get trapped in the whole of the reservoir (367 m to 422.76 m) during the period from 1989 to 1996 will be 8574 ha-m. The results of the present study show that 2667 ha-m of sediment has deposited in the zone from 406.00 m to 421.45 m. The height of dead storage zone of this reservoir (367.00 m to 403.55 m) is about 36.5 m while that of live storage zone (403.55 m to 422.76 m) is 19.21 m. The tail portion of the Bargi reservoir is quite significant as compared to the main body of the reservoir. Since the reduction in velocity in the tail portion of this reservoir is only marginal, the sediment carrying capacity does not reduce appreciably resulting in the transportation of most of the sediments towards the main reservoir and their deposition at greater depths.

It is important to note that the accuracy of assessment of sedimentation depends on the accuracy of the original capacity table. The Bargi reservoir has a dendritic shape with a number of narrow but long branches jutting out at many places, in addition to the main tail. It is possible that at the time of original survey, many of these tails were ignored in the calculation of capacity.

7.0 ADVANTAGES & LIMITATIONS OF REMOTE SENSING APPROACH

The conventional methods, such as hydrographic surveys, are laborious, costly and time consuming. Due to these reasons, the hydrographic surveys of reservoirs are being conducted at a frequency of 2 to 15 years, although the recommended frequency is 5 years. Remote sensing technique has been found to be a useful, cost and time effective tool to estimate capacity loss.

The major limitation of the remote sensing based approach is that the revised capacity below the lowest observed level and above the highest observed level can not be determined. From the point of view of operation of reservoir, this limitation is not very significant. Since the reservoir rarely goes below the minimum drawdown level in normal years, the interest mainly lies in knowing the revised capacity and the sediment deposition pattern within the live storage zone. However, if the sedimentation in the entire reservoir is to be found, the hydrographic survey within the waterspread area corresponding to the lowest observed elevation could be carried out. This will decrease the quantum of efforts in hydrographic survey.

Note that the estimation of sedimentation by remote sensing is highly sensitive to: a) the accuracy in determining the waterspread area, b) the accuracy of water level information, and c) the accuracy of the original elevation-area-capacity table.

8.0 CONCLUDING REMARKS

The remote sensing technique is time and cost effective and convenient approach to estimate the elevation-area-capacity curves for a reservoir. The application of this approach has been demonstrated through a case study of Bargi reservoir. The results of the study demonstrate that the available capacity in the zone of study (406.00 m to 421.45 m) has reduced by 26.67 M Cum from the original capacity (2585.56 M Cum). The sedimentation rate in the zone of study comes out to be 0.023 ha-m/sq. km/year.

In many studies, water pixels are identified using digital processing techniques such as density slicing, classification or modelling of multi-spectral data. These techniques need subjective interpretation. Accuracy in the identification of water pixels and selection of tail end affect the accuracy of sedimentation assessment using remote sensing. In this study, the procedure to remove the discontinuous pixels and the derivation of contours has been automated to a considerable extent. There is an urgent need to develop a generalised algorithm for the identification of water pixels. Further, the satellites of higher spatial resolution are now becoming available and the same must be utilised to increase the accuracy of the waterspread determination. Remote sensing images can be chosen at closer time intervals so that maximum number of elevations within the zone of variation can be covered.

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