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A GIS-Based Analysis for Reservoir Sedimentation

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Abstract: ***A reservoir is an integral component of a water resources system with a designed life. Sedimentation is a major problem for a reservoir, it is not possible to stop the sedimentation process it could be controlled and some feasible measures could be adapted to minimize the sedimentation yield in a reservoir. Periodic evaluation of sediment deposition patterns and available capacity assessment plays an important role in water resources. Some conventional approaches such as hydrographic survey and inflow-outflow methods are available but are cumbersome, costly, and time-consuming. Due to the sedimentation process water spread area at various elevations keeps on decreasing, calculating the temporal change in the water spread area can be analyzed and an evaluation of the sediment deposition pattern could be done. In this study, a remote-sensing approach is adopted for the assessment of sedimentation. Multi-date remote sensing data (1RS-1B, L1SS II) provided information on the water-spread area of the reservoir, which is used for computing the sedimentation rate. The revised capacity of the reservoir between maximum and minimum levels is computed using the trapezoidal formula. The loss in reservoir capacity due to the deposition of sediments is computed.***

Keywords: Sedimentation; sediment yield; GIS; remote sensing; reservoir capacity

1. Introduction

Sedimentation is a process in which soil particles of the upper layer of the earth get eroded and Sediment particles originating from erosion processes in the catchment are propagated along with the river flow. When the flow of a river is stored in a reservoir, the sediment settles in the reservoir and reduces its capacity. Reduction in the storage capacity of a reservoir beyond a limit hampers the purpose for which it was designed. Thus assessment of sediment deposition becomes very important for the management and operation of such reservoirs. The important sources of the accelerated soil erosion and high concentrations of sediment in the Himalayan rivers are deforestation, road construction, mining, cultivation on steep slopes, and seismic activities The silt transported by the rivers and their tributaries is deposited in the reservoirs reducing the reservoir capacity of the reservoirs and affecting their useful life. As a result, environmentalists and water resources planners are very much concerned with this impact After the arrival of sediment-laden flow into a reservoir, the coarser particles settle first in the upper reach of the reservoir due to the decrease in the flow velocity. Subsequently, the finer sediment material deposits further into and along the reservoir bed. Sediment deposition into reservoirs built for hydropower generation has several major detrimental effects which include loss of storage capacity, damage of hydro equipment, bank erosion and instabilities, upstream aggradation, and effect on water quality. Assessment of reservoir sedimentation is part of the basic information needed for the operation of any reservoir an up-to-date knowledge of the sedimentation process and deposition would help in ensuring remedial measures are taken well in advance so that the reservoir operation schedules can be planned for optimum utilization.

After the construction and impoundment of a reservoir, there is a great need to continuously monitor it to:

a) know the quantity of actual annual storage loss in the reservoir due to sedimentation,
b) determine the spatial distribution of sediment deposition in the entire body of the reservoir,
c) update the elevation-area-capacity curve for efficient reservoir operation, and
d) undertake conservation measures at the reservoir and watershed levels.

2. Data Used

To estimate the actual silt deposits in the Reservoir, the historical record of annual maximum and minimum observed water levels is obtained from the dam authorities. Maximum variation in water level is observed, covering most of the live storage is selected for analysis. The hourly levels are recorded between 06:00 and 06:00 h and the mean daily value of the reservoir level is obtained by taking the average of 24-hour values. During the study year, the maximum reservoir level is to be observed, which gradually reduces and reaches the minimum level. The IRS-1B satellite data with high resolution is obtained from the National Remote Sensing Agency, Hyderabad, India. The reservoir water-spread area was covered with the help of a digital image processing technique. After browsing the data of the study area, cloud-free dates were identified and used in this study.

3. Methodology

The methodology adopted for this study involves pre-processing satellite data, identifying the water pixels and computation of the capacity of the reservoir. These are discussed in brief below. To quantify the volume of sediments deposited in the reservoir, the basic informationthat needs to be extracted from the satellite data is the water-spread area of the reservoirat different water elevations. In this study the satellite data were processed and analyzed using Digital Image processing for determining the water-spread area of the reservoir. Initially, a false color composite (FCC) of the satellite data is preparedand visualized. The FCCs of depicting maximum and minimum water- spread areas are obtained. The pixels representing water-spread area of the reservoir were clearly distinguishable in the FCC. For processing of satellite data generally it is necessary to geo-reference the images of different time periods when using the temporal satellite data of the same area. In fact, determination ofthe water-spread area in a reservoir did not require the geo-referencing of the different scenes. However, using the geo-referenced imageries, it was possible to overlay theremote sensing data of the different dates. Comparison of the change in the water-spread areaand shrinkage in the water-spread area with time at different water levels of reservoir.

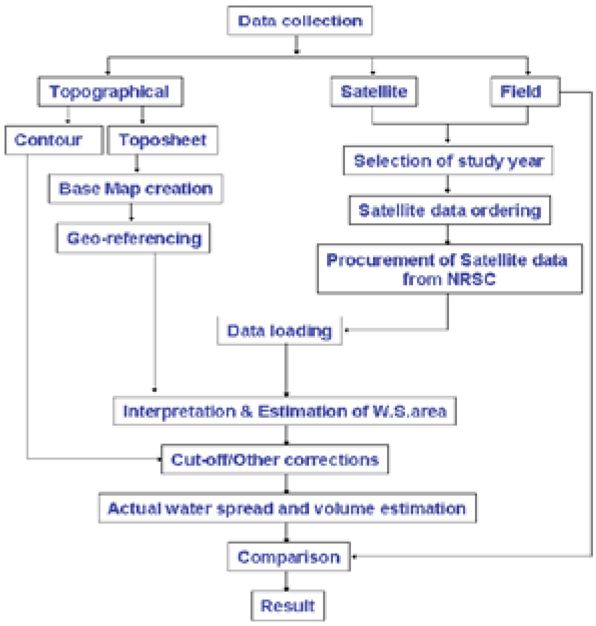

Figure 1: Brief methodology of Sedimentation Analysis

3.1 Identification of water pixels

In the visible region of the spectrum (0.4-0.7 urn), the transmittance of water is significant and the absorptance and reflectance are low. The absorptance of water rises rapidly in the NIR band, where both the reflectance and transmittance are low. At NIR wavelengths, water apparently acts as a black body absorber. Though the spectral signatures of water are quite distinct from other land uses such as vegetation, built-up areas, and soil surfaces, 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 the reservoir. To differentiate water pixels from the adjacent wetland pixels, a 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 analyzing the spectral reflectance of water pixels in various imageries, an algorithm was used to identify water pixels using data from different bands. The algorithm matches the digital number (DN) value of a pixel with that of water and then identifies whether a pixel represents water or not. In addition, it also checks for the normalized difference water index, *NDWI*, which can be defined as:

$$\text{NDWI} = (\text{Green} - \text{NIR})/(\text{Green} + \text{NIR})$$

For the differentiation of water pixels from the other land-use features, a generalized algorithm based on the information of different bands is adopted (Goel & Jain, 1998). Each pixel has a numerical value called a digital number (DN), that records the intensity of electromagnetic energy measured for the ground resolution cell represented by that pixel. Using the spectral information, the algorithm matches the signatures of the pixel with the standard signatures of water and identifies whether a pixel represents water or not. The spectral signature shows the reflectance/emittance pattern of any object at different wavelengths. The resulting images of water pixels were compared with the NIR images and the standard FCC and water spread area of the reservoir at different water elevations were obtained.

3.2 Removal of Discontinous Pixels:

It is required that the isolated water pixels surrounding the water-spread 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 the reservoir and need to be removed. To remove most of these unwanted pixels, a mask is generated from the edited water image. 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 were not part of the reservoir. Most of the discontinuous pixels could be removed in this step. However, some of the pixels that are discontinuous and lie within the mask still need to be edited. these clumped pixels should be removed so that only a continuous water-spread area remains in the water image.

3.3 Computation of Revised Capacity

For the computation of reservoir capacity between two consecutive reservoir elevations, usually three formulae, the Prismoidal formula, the Simpson formula, and the trapezoidal formula are used. Of these, the trapezoidal formula has been most widely used for the computation of capacity.

$$\boldsymbol{V} = \frac{\Delta \boldsymbol{H}}{\mathbf{3}}\left(\boldsymbol{A_1} + \boldsymbol{A_2} + \sqrt{\boldsymbol{A_1}.\boldsymbol{A_2}}\right)$$

where V is the volume between two consecutive levels,
$A_1$is the contour area at elevation1,
$A_2$is the contour area at elevation 2,
H is the difference between elevations1 and 2.

The volume of sedimentation deposit between two reservoir levels is computed from the difference between previous capacity survey and satellite-derived information. The water-spread area of the reservoir was calculated from satellite data and the level corresponding to the date of pass is collected from the project authority. From the elevation-area table, the original areas at the intermediate elevations are obtained by linear interpolation. From the known values of original and estimated areas at different elevations, the corresponding original and revised capacities are determined as mentioned above. The overall reduction in capacity between the lowest and the highest observed water level are obtained by adding the reduced capacity at all levels.

3.4 Advantages over Conventional Methods

The volume of sedimentation deposit between two reservoir levels is computed from the difference between the previous capacity survey and satellite-derived information. The water-spread area of the reservoir was calculated from satellite data and the level corresponding to the date of pass is collected from the project authority. From the elevation-area table, the original areas at the intermediate elevations are obtained by linear interpolation. From the known values of original and estimated areas at different elevations, the corresponding original and revised capacities are determined as mentioned above. The overall reduction in capacity between the lowest and the highest observed water level is obtained by adding the reduced capacity at all levels.

4. Conclusion

The application of remote sensing techniques for the estimation of sediment yield rate in the Reservoir is cost-effective and less time-consuming, as conventional methods are the most accurate one, but requires heavy cost and time. comparing both the results of the conventional method and the remote sensing method shows a difference in average sedimentation rate. The difference in sedimentation rate obtained using remote sensing data can be explained on the basis of accuracy in the determination of the water spread area and the mixing of water pixels with the land around the periphery of the reservoir.

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