



3D Visualization of Reservoir and its Applications in Fisheries: A GIS Perspective

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Abstract

Reservoirs are water bodies created using a dam for storage of water. Natural process like erosion in the catchment area and the consequent deposition in various parts of reservoir gradually reduce the capacity of the reservoir. This silt deposition from the upland and surrounding areas poses a threat to the aquatic environment in general and fisheries in particular. Information about the quantity of the silt and the consequent reduction in the capacity of the reservoir is necessary for planning and operational purposes and the same can be estimated through scientific capacity surveys. It is also essential to identify the geomorphological characteristics of the bathymetric area of the reservoir for management of fisheries. This article reviews the research works carried out for development of three dimensional visualization of reservoirs in GIS platform for sustainable fishery management.

Keywords: Hydrographic survey, capacity study, TIN, DEM, 3D view, contour, bathymetric map, GIS

Introduction

Reservoir is the water body created in a river valley by construction of a dam. They are important features of the hydrology of river systems and are used for various purposes including storing of water for public uses, flood control, irrigation, hydro-power generation and fisheries. However, natural phenomenon like erosion in the catchment area and the consequent deposition of soil, mud and rock pieces in various parts of reservoir leads to siltation resulting in reduction in the capacity of the reservoir

(Bothale et al., 2003) and thus affecting the aquatic environment. Siltation is also the measure of the soil-erosion that takes place from the upland and basin area to the reservoir area. It is imperative to have the information on the extent of the silt and the subsequent reduction in the capacity of the reservoir for planning and developmental activities in reservoirs. The capacity of the reservoir is the volume of water the reservoir can hold, which invariably measures the health of the reservoir. The silt is an obvious threat to the aquatic environment including fish. Analysis of sedimentation data in the reservoir shows that reservoirs in India are losing its capacity at the rate of 0.30 to 0.92% annually and sedimentation in reservoir occurs in dead as well as live storage area, which ultimately results in reduction in useful storage region and affect the water utilization pattern of the reservoir (Rao & Raju, 2010). The sedimentation survey in the reservoirs in India dates back to 1870. However, the systematic survey was only conducted in 1958 when the Central Board of Irrigation and Power undertook a co-ordinated scheme of reservoir sedimentation. Under the 8th five year plan, Central Water Commission (CWC) started survey of 144 reservoirs of the country by following conventional techniques (CWC, 2001). In their recommendation, CWC asserted that the capacity survey needed to be done on regular basis once in 5 yrs for major reservoirs. Another important facet of the reservoir is the geomorphological characteristics, which provides insight on the bottom topography of the reservoir. Since reservoirs are formed due to inundation of land area, which may include forests, there may be unknown tree stumps and other obstructions at the bottom, which can foul the fishing gears.

All the above factors have implications on fisheries management in reservoirs. Understanding the capacity of the reservoir is essential to stipulate appropriate fishing system to be used for both

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capture and culture fishery. Information on bottom topography is essential in designing and developing suitable crafts and gears.

Geographic Information Systems (GIS) is an emerging technology that enables the analysis of spatial data, which are warehoused in a spatial database management system. Once the geographic relationships of data are determined, many types of analysis can be performed on individual or multi-layer data set, with unique theme in each layer. So, complex real life physical features can be modeled using digital spatial database, which constitute simplified thematic layers in a GIS platform.

The three dimensional visualization (3D view) of reservoir includes assessment of volume of the reservoir, estimation of the silt deposited and mapping of bathymetry derived from the spatial 3D dataset collected by the conventional methods or by using remote sensing techniques. This process will be more effective and robust if the spatial data is made available in a GIS platform. Development of 3D view of the reservoir in a GIS platform with the support of suitable spatial databases is one of the ways to monitor and facilitate the proper reservoir management including fisheries. It would be possible to have a sound perception on the bathymetric characteristics, extent of siltation and storage capacity of the reservoir using appropriate GIS tools.

Though 3D visualization has been widely used in various fields due to technological innovation, there has yet not been much advancement in technological application in 3D GIS. The additional factor in 3D GIS as compared to 2D GIS, where a feature or phenomenon is represented as an area of grid cells or as an area within a polygon boundary, is that volumes are also involved. This sort of features necessitates the handling of large amount of data in 3D GIS.

This article reviews the work done on three dimensional visualization of reservoir with special emphasis on GIS, for better fishery management, discussing the data models *viz.*, Triangulated Irregular Network (TIN), Digital Elevation Model (DEM) and the empirical model (MMF model).

GIS based models in reservoirs for 3D visualization

In comparison to the conventional 2D data, 3D data and its visualization require more sophistication in

real time data acquisition, visualization and simulation analysis. GIS is a strong automated spatial database management system capable of linking with real time data for spatial mapping and spatial analysis of data. For any 3D application, along with the spatial data, the attribute data pertaining to the spatial location, which could be based on different environmental parameters of the reservoir, are also to be collected and made available in GIS platform. Both spatial and attribute data can be generated through conventional hydrographic survey method or by the application of Remote sensing (RS) technology for the GIS. The GIS system allows faster data processing and comprehensive information generation in a map format for visual interpretation of data. The 3D GIS can revolutionize data processing capabilities using effective data analysis tools for geo-spatial information generation pertaining to geographical area under study. Models can be developed in graphical mode for easy visualization and interpretation of data, which can give us location specific information to address management dimensions with respect to the reservoir (Yong & Xiang-guo, 2005)

Two types of data models for terrain mapping and analysis in GIS for 3D visualization are Triangulated Irregular Network (TIN), a vector based data model and Digital Elevation Model (DEM), a raster based data model. These data models in a GIS platform can visualize the morphological characteristics of a terrain area. Though DEM and TIN cannot be used together in an operation, one can be converted in to another data model in GIS platform (Kang-Tsung Chang, 2006).

TIN (Triangulated Irregular Network)

Triangulated Irregular Network (TIN) model is a data model which approximates a terrain with a set of non-overlapping triangles in which each triangle assumes a constant gradient (Kang-Tsung Chang, 2006). It is a digital data model used in GIS for representing the surface. A TIN is a vector-based representation of the physical land surface or sea bottom, made up of irregularly distributed nodes and lines with three-dimensional coordinates that are arranged in a network of non-overlapping triangles. TIN is based on a Delaunay triangulation and is derived from the elevation data of a rasterized digital elevation model (DEM). It is an alternative to the regular raster of a DEM and is used in most of the GIS packages. An advantage of using a TIN

over a raster DEM in mapping and analysis is that the points of a TIN are distributed based on an algorithm that determines which points are most necessary for an accurate representation of the terrain. Data input is therefore flexible and fewer points need to be stored than in a raster DEM, with regularly distributed points. A TIN may be less suited than a raster DEM for certain kinds of GIS applications, such as analysis of slope and aspect pertinent to a surface. TIN is used for volumetric analysis of reservoir including capacity and sedimentation studies. A TIN comprises a triangular network of vertices, known as mass points, with associated coordinates in three dimensions connected by edges to form a triangular tessellation. Three-dimensional visualizations are readily created by rendering of the triangular facets. In regions where there is little variation in surface height, the points may be widely spaced whereas in areas of more intense variation in height the point density is increased. As TIN is widely used for volumetric analysis which is capable of calculating volume of a reservoir, the reservoir capacity can be calculated using this data model.

Kelly et al. (2009) illustrated how bathymetric and topographic survey of Loch Lomond reservoir, Santa Cruz County, California was carried out using multi beam side scan sonar and laser scanning (LiDAR) respectively to estimate the total water storage capacity using TIN data model. The spatial data of latitude, longitude and depth of water column are determined using GPS and echo sounder on a continuous mode along the transect of the hydrographic survey during FRL (Full Reservoir Level). This 3D data set is converted to 3D data of latitude, longitude and elevation from the LiDAR data of the reservoir. In order to represent accurately the reservoir bed surface using the available data, a Triangulated Irregular Network (TIN) model is created. A TIN model is a surface representation derived from irregularly spaced points of the 3D data. This surface model was used to calculate the volume of the reservoir using the GIS software. The estimation of silt was drawn from the volume of the reservoir in 2009 and the historic data of volume of the reservoir in 1998 when it started operational.

Using historic data pertaining to the capacity of the reservoir the assessment of silt over the respective period and consequently the rate of silt can also be assessed using TIN. This has got wide application on the impact study of reservoir environment which

has a bearing on the reservoir aquatic resources including fisheries. Volume being the measure of quantity of water, the performance of craft and gears to be used for different water columns can be achieved by fisheries experts. Capacity of reservoir is also decisive for many strategic programmes of aquaculture including fish stocking and harvesting in reservoir eco-system.

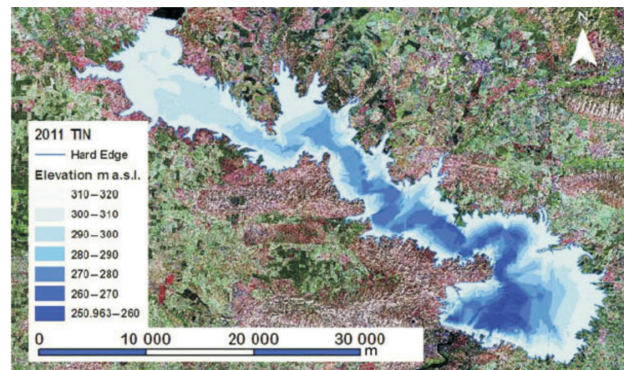


Fig. 1. A TIN surface Model of Mosul Reservoir of Iraq (source: https://www.researchgate.net/figure/256980084_fig11_Fig-11-Mosul-Reservoir-TIN-surface-model-generated-from-2011-bathymetric-survey)

A Digital Elevation Model (DEM) can be represented as a raster (a grid of squares, also known as a height map when representing elevation) or as a vector-based TIN. The TIN DEM dataset is also referred to as a primary (measured) DEM, whereas the Raster DEM is referred to as a secondary (computed) DEM. DEMs are commonly built using remote sensing techniques, but they may also be built from land surveying. DEMs are used often in Geographic Information Systems and are the most common basis for digitally-produced relief maps. The DEM could be acquired through techniques such as photogrammetry, LiDAR and land surveying. Older methods of generating DEMs often involve interpolating digital contour maps that may have been produced by direct survey of the land surface; this method is still used in mountain areas, where interferometry is not always satisfactory. Note that the contour line data or any other sampled elevation datasets (by GPS or ground survey) are not DEMs, but may be considered digital terrain models. A DEM implies that elevation is available continuously at each location in the study area.

The quality of a DEM is a measure of how accurate elevation is at each pixel (absolute accuracy) and

how accurately is the morphology presented (relative accuracy). This implies that if we have 3D data of bathymetric area of reservoir, GIS software can generate contour map and DEM of the bathymetry. DEM can visualize the bottom morphological characteristics of the reservoir area with high degree of perception. The digital characterization using DEM can be validated using proper ground truth at field level to the extent as possible during the Dead Storage Level (DSL), when water in the reservoir is bare minimum. This sort of digital mapping of bathymetric area with proper bathymetric characterization can enable us to visualize the geo-morphological characteristics of the reservoir area clearly. This information can help fishery experts to assess the performance of craft and gear for efficient sustainable fishing operation for optimum harvesting in the reservoir. Nature of bottom topographical area can help experts to a greater extent to identify suitable hotspots for certain species-specific cage culture programmes for sustainable fishery in the reservoir eco-system.

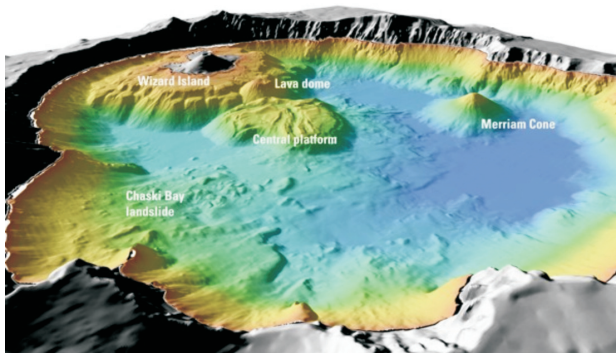


Fig. 2. A digital elevation model (DEM) of Crater Lake of Western United States (Source: https://en.wikipedia.org/wiki/Crater_Lake)

Oklahoma Water Resource Board (OWRB, 2009) conducted a hydrographic survey of W.R Holway Reservoir in early February of 2009. The purpose of this survey was to produce a new elevation-area-capacity table for W.R. Holway Reservoir that would aid in a dependable yield determination conducted by the United States Army Corps of Engineers (USACE). The process of surveying the reservoir was by GPS and acoustic depth sounding technology that are incorporated into a hydrographic survey vessel. As the survey vessel travels across the lake surface, echo-sounder gather multiple depth values for every second and the positional value of latitude and longitude is collected using GPS. The

depth values along with positional data were stored in a computer system connected online. The data were edited after removing the data noise and average depth were converted to elevation reading based on the height of the lake water level on the day on the hydrographic survey. Accurate estimate of area-capacity of the lake was estimated by building a 3D model of the reservoir using TIN data model derived from the 3D data collected and corrected from the hydrographic survey. The bathymetry of the reservoir was drawn using the DEM data model generated.

DEM represents a regular array of elevation and quality of DEM determines the accuracy of terrain (Kang-Tsung Chang, 2006). In fact DEM data model is used to assess the terrain features of a geographical area. In reservoir modeling studies, 3D data collected can be used to generate DEM by which the bathymetric characteristics of reservoir area can be identified by terrain analysis of the reservoir area. The characterization of bathymetric features can be validated using field level survey for ground truth when water level is minimum. The terrain analysis of the bathymetry of reservoir sketches the morphological nature of the reservoir area including the bottom topographical features. This information will help us to select the craft and gears to be used for sustainable management of reservoir fishery, the topographic characteristics also help us to identify the natural and congenial habitat (hotspots) for aquatic animals for breeding and sustenance. This sort of information can be harnessed for development of sustainable aquaculture programmes including cage culture in reservoir eco-system.

Morgan et al. (1984) presented a simple empirical model for predicting annual soil loss from field-sized areas on hill slopes. It provides a stronger physical base than the universal soil loss equation (USLE). However, it retains the advantages of an empirical approach regarding ease of understanding and availability of data. The model was validated by the authors in the year 1984, using erosion plot data for 67 sites in 12 countries and then applied to simulate erosion over a 100 year period in Malaysia under shifting cultivation. Since then, several researchers have used the model successfully in a wide range of field. The basic concept of MMF model is that the soil erosion can be divided in two phases: water and sediment. The sediment phase of the model involves two processes *viz.*, rate of splash detachment of soil particles and

other for estimating the transport capacity of overland flow.

A study was conducted to visualize Malampuzha reservoir of Kerala in a three dimensional perspective by Centre for Water Resource Development and Management (CWRDM), Kozhikode (Venugopal et al., 2010). In this study, the rate of sedimentation and consequent reduction in storage was estimated using MMF model (Morgan et al, 1984) for computing the sediment output from the selected basin. The MMF model was used for predicting soil erosion in steeper basins on the hill slopes. The database of this study is based on the following data layers *viz.*, Annual rainfall, soil moisture content, bulk density of top soil, rooting depth, slop rainfall and crop cover management factors. The land use classification was carried out using IRS LISS III of 2005 (supported by Erdas Imagine 8.7). The data layers were integrated in ArcGIS 9.2 and soil erosion output was computed. The study estimated that the annual discharge of sediments to the Malampuzha reservoir is about 67 000 t year⁻¹ implying the fact that the impact of sedimentation on the reservoir capacity is quite significant.

MMF model is used to assess the silt accumulated in the reservoir. The siltation aspect of the 3D visualization of reservoir is addressed by this empirical model. The life of the reservoir depends on the rate of silt, which enable us to assess the extent of environmental degradation of the reservoir aquatic system which in turn affects the fishery eco-system.

Contour map is a map illustrated with contour lines, the imaginary lines joining the geographical points on a map of equal elevation. Contour map of a terrain area give a feel of the nature of the terrain area with 3D visualization of the geographic area. The quantitative estimate of capacity of reservoir and 3D visualization of bathymetric area of the reservoir in a digital format is possible by generating TIN and DEM data from the contour maps. Thus contours, which are derived from 3D data collected from the reservoir also serves as an input to GIS for developing 3D visualization. There are software exclusively used for 3D visualization of reservoir using contour maps.

Kerala Engineering Research Institute (KERI, 2006), Peechi made an attempt to quantify the sedimentation taken place in Malampuzha reservoir of Kerala. In their study in 2005 "Sedimentation studies in

Malampuzha Reservoir using Integrated Bathymetric System", it is reported that the quantity of silt was 31 Mm³, during the last 50 yrs. The study also states that the sedimentation per year was 0.27% and the water spread area of the reservoir area increased from 22 to 26.88 sq.km, an increase of 22.2% from original. Navisoft & Surfer 8.0 were used as bathymetric survey softwares for data recording and processing and bathymetric data at an interval of 200 m to cover the entire reservoir. The survey was conducted after setting a data logging software to record the reading at 5 m interval with speed of the boat 3 to 4 kn. Depth of water and corresponding location was recorded using echo sounder and GPS connected online with the system. The maximum depth of water near the dam side calculated was 25.29 m.

Remote sensing data is another source of input to GIS for 3D visualization study. Remote sensing technology is a well-established and cost effective technology in natural resource mapping and management. At present, high resolution satellite imageries are available through India Remote Sensing (IRS) satellites and through other agencies. These satellite data can be utilized for developing the base

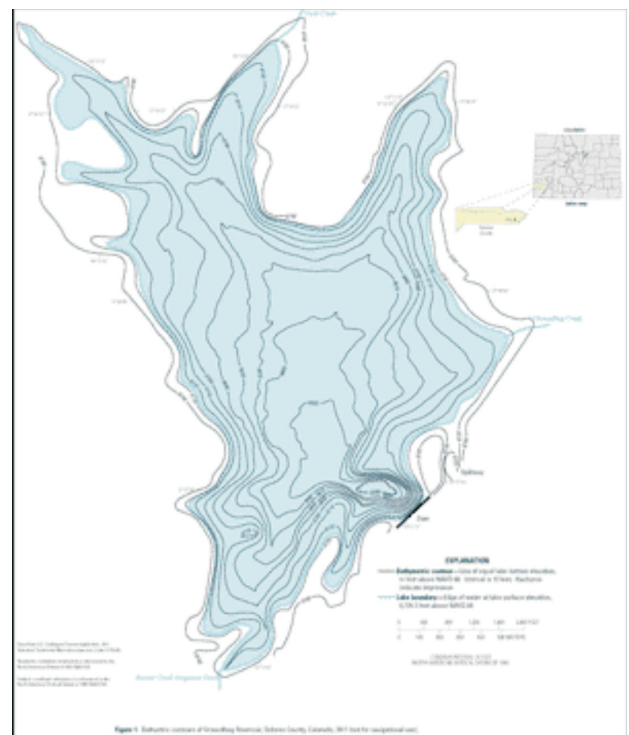


Fig. 3. A bathymetric contour of Groundhog reservoir of south west Colorado, USA (source: <http://pubs.usgs.gov/sim/3202/contents>)

map as well as for mapping the water spread area and can also be used to a limited extent for 3D visualization of reservoir by carrying out volumetric analysis including the assessment of sedimentation. The reduction in storage volume results from decrease in water spread area due to sedimentation at different elevations. So capturing water spread area at various operating levels would help in estimating the current reservoir storage and comparison with original storage would provide the loss in storage due to sedimentation. Hence, satellite remote sensing has a vital role to play in assessing the capacity and sedimentation of the reservoir, owing to its synoptic and repetitive view, Rao et al. 2010). Volume of reservoir at different water level can also be calculated using Herone's formula in the operational zone of the reservoir using water spread area data available from remote sensing data (Sharma et al., 2013).

However, Remote sensing technology can well be applied for sedimentation assessment only in the operational zone of the reservoir whereas the same in the dead storage area can be effectively done using hydrographic survey only. This emphasizes the fact that remote sensing technology provides a supplementary role for 3D visualization of reservoir. The volumetric analysis can be treated using functional relation of elevation of water level, water spread area and volume of water column in the reservoir using remote sensing data.

Remote Sensing Technology was applied to assess the sedimentation in the operation zone of the Bargi reservoir in the Narmada basin, which was impounded in the year 1989 (Anon, 2000). The remote sensing data of IRS- 1C satellite and LISS-III sensor were acquired for 9 different days for the year 1996-97 and the revised water spread area was extracted. The original elevation-area-capacity curves and reservoir levels on the nine days are obtained from the dam authority. Using the trapezoidal formula, the revised capacity between the maximum (421.45 m) and minimum (406.00 m) observed level were obtained. The result of the study revealed that the available capacity in the zone of study (406 to 421.45 m) has reduced by 26.67 Mm³ from the original capacity of (2585.56 Mm³). The sedimentation rate in the zone of study come out to be 0.023 ha-m sq km yrs⁻¹.

Reservoir capacity survey using remote sensing can be considered as a supplement to conventional

survey. Being convenient, cost effective and less time consuming, capacity of reservoir may be updated in every 3-5 yr using remote sensing technique, while conventional hydrographic survey can be conducted at an interval of 10 to 15 yr for reliable baseline data (Mani et al., 2007).

3-D visualisation of reservoir has been conceptualized and modeled using the concepts of TIN, DEM, MMF models, by incorporating the three dimensional data of latitude, longitude and elevation collected through hydrographic survey or using remote sensing imagery pertaining to that water body area. The 3D analysis of reservoir area facilitates volumetric analysis of the water bodies to assess the capacity of the reservoir and the extent of silt in the water body area. This sort of visualization elicits the nature of the bathymetry of the under-water area which is other-wise unknown to all including the planners, policy makers and researchers. This information is a pre-request for all planning and research studies, for better management of reservoirs in general and fishery in particular. The spatial data collected through survey and other remote sensing techniques can be optimally made use of, if it is put in a GIS platform. A spatial database with latest geo-spatial technology can revolutionize modeling studies for a high- end research output. A true sense of 3D-digital reservoir will only emerge with a versatile geo-database mounted in a GIS platform, in the sense that it will be a virtual spatio-temporal model worth the salt. A 3D-digital reservoir in a GIS platform provides strong spatial analysis, data management, 3D visualization in both volumetric and bathymetric sense. With combination of real time attribute and geographic data, it supports spatial information inquiry, attribute data inquiry and data management and it can monitor and simulate different hydrologic phenomena like flood submergence, drought condition. This sort of information can facilitate all kinds of management programmes including dam engineering management, disaster management and fisheries management. Volumetric analysis could quantify and monitor the phenomenon of siltation of reservoir which has direct impact on environment. Bathymetric analysis in a sound GIS platform could enable fishery researchers to identify the suitable gears to be used at different geographic locations. A sound knowledge on the bottom morphology of the reservoir could help in identification of hotspots for different species.

Development of Spatial database of fisheries resources of reservoir in a GIS platform will help us to include more environmental parameters into this spatial database. The water quality parameters like nutrients and pH-values can be included in the database. Proper data collection on these water quality parameters can help us to generate spatial mapping of these parameters which will make the GIS model more informative and meaningful for proper monitoring of the reservoir. Being spatial data warehoused temporally, real-time monitoring and optimum exploitation of the dynamic ecosystem is also envisaged. Development of Fishery Resource Information System for a judicious decision support is the need of the hour for better use of the water body. In India, where the capture fishery is stagnating in the marine sector, it is the need of the hour to increase the inland fish production. As the lone hope in the present scenario of enhanced fish production lies in culture fishery of inland water bodies, the productivity of reservoir fishery could be the better alternative, which can be improved upon by replicating this type of 3D visualization for all potential reservoirs for optimum resource management through spatial modeling studies.

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