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ABSTRACT

The tank system is quite ancient and meant for storing and supplying water for the multifunctional needs of the people. But the population explosion has driven humankind towards more stable and reliable groundwater resources like the dug and deep bore wells. Added excessive siltation, improper maintenance and illegal encroachment have further degraded the system. Hence over the past few decades, a drastic declination in the functionality of tanks has been noticed. Besides many, the storage capacity is considered the prime factor in dictating the functionality of a tank. Under the prevailing water crisis, it is time to rehabilitate the degraded tank system. For rehabilitation, data on the storage capacity of tanks is essential. But owing to its number and negligence, there is a lack of data availability. Hence the first step is to generate data on the storage capacity of tanks. Conventionally, the capacity is estimated by taking field measurements using survey instruments. Later by applying mathematical formulas, the capacity was assessed with minimum field measurements. Advanced technologies like DGPS, Total Station, SONAR, Remote Sensing, and LIDAR have simplified the estimation with minimum to nil fieldwork. The present paper briefly narrates various methods for estimating tank storage capacity.

Keywords— tank, storage capacity, surface area, linear regression

**I. INTRODUCTION**

 The minor reservoir is quite ancient and has been used in different regions of the world for centuries to store and supply water during times of surplus and scarcity respectively [1],[2]. The reservoirs satisfy the diverse needs of the communities, including the demands for agriculture, drinking water, and livestock, particularly in arid and semi-arid regions worldwide. Notably, during dry seasons, their function is critical in promoting the sustainability of rural communities and farmers and reducing social inequality gaps for 15% of the world's population [3]. There are approximately 2.9 million small reservoirs in semi-arid regions, with a total water surface area of 17,000 square kilometers and a seasonal storage capacity of 37,000 cubic kilometers. Their distribution and density across space are highly variable (0 to 420 reservoirs per 100 km2). Despite their relatively low storage capacity, minor reservoirs have a high socio-economic value due to their high density [4].

 But in recent decades, their functionality has declined [5],[6]. Several factors determine the functionality of a tank; among the most significant is its storage capacity. There is a considerable reduction in their capacity [7]. The primary cause of the decline in tank dead and live storage is catchment erosion and siltation [8]. As a result, tanks cannot store even the scarce resources currently available.

 Furthermore, considering the present water crisis, it is time to restore the system. Any such reclamation activities will necessitate critical data on the spatial distribution, original capacity, current capacity, and siltation level. In addition, periodic measurements are required to assess variations in their capacity. Unfortunately, such data are scarce because of their number and negligence. Thus, the primary task is to create a database. Generally, conventional in situ techniques such as survey instruments, echo sounders, sediment inflow-outflow quantification, etc., are in practice for capacity estimations. However, these methods necessitate extensive fieldwork and skilled labour, which are both expensive and time-consuming.

 Furthermore, due to their large number, periodic measurement and evaluation are time-consuming [9], [10]. Indirect methods, such as estimation from contours derived from topographic sheets, surface water spread area from satellite images, Lidar, and so on, have recently gained popularity due to minimal field work. Thus, the current paper comprehensively reviews various direct and indirect methods for measuring small reservoirs' storage capacity.

**II. DIRECT METHODS**

 In direct methods, tank storage capacity is estimated by measuring three parameters: length, width and depth. Survey instruments such as a dumpy level, levelling staff, tacheometer, and so on are commonly used for measurements. However, in recent times, advanced instruments such as an echo sounder, DGPS (Differential Global Positioning System), and Total Station are used for measuring and collecting data. Subsequently, capacity is calculated either manually or using conventional software such as surfer and geographic information system. [11], [12], [13]. On the contrary, the other method measures the volume of sediment flowing in and out of a reservoir. The silt retained within will then be calculated. The current reservoir volume is estimated by subtracting the volume of the silt retained from the reservoir's original volume [14], [15]. The above methods are applicable only when the tank is at its full capacity level (FTL) or water flows to and from the tank. In contrast, during the dry periods, instead of measuring the bathymetry, the depth of silt inside the tank bed is estimated by excavating pits and trenches in a grid pattern. Theisen polygon method will calculate the volume of silt inside the tank. The tank's present capacity is calculated by comparing it to its original volume [14]. Thus, the above methods estimate storage capacity for small reservoirs depending on time, instrument availability, and expertise. The direct methods used in the capacity estimation are detailed below.

A. **Survey Instruments**

 Survey instruments like tacheometer, levelling staff, tape, plummet, and dummy level is used to generate the tank's bathymetric profile. Previously, the water column was measured using a rowboat plummet at predefined grid locations. Later, a tachometric survey with a stadia rod was used for better horizontal and vertical control [12]. In recent years, the global positioning system (GPS), which provides precise coordinates of the measuring stations, has been used in conjunction with the measurements [13]. The contours were generated manually or using software such as a surfer using the derived depth data. Lineu [16], conducted a field survey to determine the storage capacity of small reservoirs in the Brazilian Savannah region. He divided the tank area into evenly spaced grids and measured the reservoir depth with a plummet from a boat and GPS coordinates. The data was then extrapolated using the kriging interpolation method, and a 3D model was generated using surfer software to estimate the reservoir volume. Nowadays, volume estimations are automated using Geographic Information System (GIS) software by converting the point data into a triangulated irregular network [17].

B. **Geometrical Method**

 The above methods need extensive field measurement, while the mathematical model enables the volume computation with minimum fieldwork.

**a. Based on Mathematical Formula**

Generally, measurements are made on reservoir width, throwback, and maximum impounded water depth. Then computations are done by using mathematical formulas [12]. The width is the maximum width of the reservoir. At the same time, the depth is the difference in elevation between the lowest point in the tank bed and the highest point, the spillway crest level, and the throwback is the distance between the dam and the point where the river enters the tank. The general formula for estimating the storage capacity of small tanks using the above-measured parameters is given by

 $C = K1 x K2 x D x W x T$ (1)

Where C is the reservoir capacity (m3), K1 and K2 are constants that depend on the valley cross section, D is the difference in elevation between the lowest point in the reservoir bed and the spillway crest level, and W is the width (m) of water surface at the spillway crest level. T is the distance from the dam wall along the reservoir axis to where the river enters (m).

**b Based on Geometrical Formula**

If a tank has a well-defined geometrical shape, its capacity can be computed based on simple geometrical formulas [18, [19]. For tanks with "square" and "rectangular" shapes, the formula is given by volume = length x width x depth, and for circularly shaped tanks, the formula is

 $volume=3.14 ×radius^{2} ×depth$. (2)

The length, radius and width were measured inside the reservoir while its depth was at the appropriate water level. In general, the height of the sluice from the tank bottom is taken as depth. In the case of "triangular" shaped tanks, the estimation is based on whether the triangle has a square or 90° angle for one of its corners. If a 90° angle is present, then the formula is:

$Area =\frac{1}{2}x length x width$ (3)

and if the sides are unequal, then the formula is:

 $Area=√(S(S-A) )×(S-B)×(S-C)$ (4)

Where S = 1/2 (A+B+C) and A, B and C are the lengths of the sides. Then by the measured depth with the above-derived area, the volume is computed. Despite measuring the depths in the field, they were also estimated using topographic sheets by the following three methods, namely (i) from cross sections, (ii) from spot levels and (iii) from contours.

C. **Echo sounder**

 If the area and depth of the reservoir are too large, then the hydrographic survey is conducted using echo sounders [20]. It uses acoustic waves, and based on the travel time, the water column's depth is measured, thereby preparing the bathymetry. Now, the sounding is equipped with computerized data collection software and GPS (global positioning systems). Using the digital acoustic bathymetric sounders and global positioning systems, the Kansas Biological Survey department [21] generated maps on the bottom profile of the reservoirs in the Kansas Biological reserve for comprehensively assessing and monitoring the reservoirs. Nowadays, a higher acquisition rate than single beam echosounder is achieved by multiple beam ecosystems, airborne laser systems and airborne electromagnetic systems [22].

 D. **Pit Method**

 Instead of measuring the water column, the amount of silt inside the tank was calculated, especially during the dry seasons. The thickness of sediments in the tank floor was initially measured by excavating pits or trenches in a grid pattern. The area of influence of each pit was then calculated using the Thiessen polygon interpolation method, and the quantity of silt in each polygon was calculated by multiplying it by the sediment thickness. The total volume of sediment trapped within the tank was determined [23]. Later, the capacity loss was calculated by comparing it to the original volume

E. **Inflow-out flow method**

 In the inflow-outflow method, the sediment load was measured at both points where the river enters and leaves the tank. The data is collected daily or during its peak discharge period. Then using mathematical models like HEC-6, GSTARS, FLUVIAL, TABS, etc. [14], [24], the variation in the sediment load supplied in and out of the tank was estimated, and therefrom the amount of sediment deposited within the reservoir was computed. By correlating with the original storage, the loss was calculated.

F. **Differential Global Positioning System**

 As a recent advancement, the differential global positioning system (DGPS) is used to measure the tank profile's elevation. The measurements are made along a series of cross sections perpendicular to the longitudinal axis of the reservoir. The survey provides data as point information comprising its geographical location and elevation concerning the mean sea level. Later, using conventional GIS software, the triangulated irregular network (TIN) was generated and there from the volume of the tanks was estimated [25].

G. **SONAR**

 The advanced hydrographic instrument SONAR (Sound Navigation and Ranging) accurately estimates the storage capacity. The survey-grade hydrographic sonar is coupled with survey-grade RTK-GPS (Real-time kinematic global positioning system). The integrated instrument records bathymetric, GPS, and timestamps for each location. Hydrographic software was later used to estimate the elevation of the water column, bathymetry, and total storage capacity. [26], [27].

**III. INDIRECT METHODS**

In the case of small tanks, owing to their number and size, the estimation using the above direct methods will be time-consuming and uneconomical. Hence indirect methods are preferred in computing their storage capacities.

A. **Elevation-based computation**

 This method uses topographic sheets to map contours for the tank bed. Then a planimetered cross along the longitudinal section of the tank axis is prepared. The tank's volume between the contours was calculated by multiplying the area between the successive contours with the above elevation difference. Similarly, capacity is derived for consecutive contours and the full tank level using the highest and lowest contour values (Sawunyama et al., 2006). Later, an elevation-area table will be prepared for different water levels. Whenever capacity estimates are required, the above table can be used by simply noting the water level data from the site's water level indicator. But the method needs large-scale topographic maps for preparing high-resolution contours. The above elevation-based computation can be further classified as follows

a. **Mid-Area method**

 As stated earlier, contours were used for calculating the capacity. The areas between the successive contours are computed from the cross-section. The distance between the contours, namely the contour interval, is measured, and the capacity is calculated using the given formula.

 $C= \sum\_{i=1}^{n}(\frac{A\_{i}+A\_{\left(i+1\right)×dh}}{2})$ (5)

Where C= Reservoir capacity, Ai =Surface area at contour interval i, AA+I =Surface area at the next contour level above contour level 1 and dh = contour interval. This method is suitable for small contour intervals.

b. **Prismoidal method**

 In this method, the shape of the tank is assumed as a pyramid. Considering the water surface as its base, the capacity enclosed by two successive contours is calculated using the prismoidal formula.

 $V= L x 1/(A1 + A2)$ (6)

c.**Trapezoidal method**

 Amongst the above methods, the trapezoidal formula was widely used to compute capacity (Goel and Jain, 1996). In this method, the tank is assumed as a trapezium, and the formula for calculation is

$V= \frac{H}{3}(A\_{1 }+ A\_{2 }√(A\_{1 }× A\_{2 }))$ (7)

where V = volume between two consecutive levels, A1 = contour area at elevation, A2 = contour area at elevation 2 and dh = difference between elevations 1 and 2.

B. **Surface Area based computation**

 The above methods are applicable for medium and large reservoirs. But in the case of small tanks, the capacity estimation will be cumbersome and time-consuming owing to their number and size. Whereas a linear relationship can be established between the tank's surface area and storage capacity, and thus, for any available surface water spread, its capacity can be computed. Since the surface area can be precisely mapped from the satellite images, the estimation can be done without field measurements. The added advantage of this method is that the estimates can also be done even for date-back periods using the respective satellite images.

 Further, the above-derived relationship can be extended even for the nearby tanks, provided they should be within the same hydro-geographical condition. Initially, the surface area and capacity were measured in the field for a few tanks, and an empirical equation was derived through linear regression analysis. The storage capacity was derived by substituting the water spread area in the equation.

 The general equation for computing capacity from the area is given by a power relationship as follows [28], [29]

$Storage Capacity C = a×A^{b}$ (8)

Where C = the reservoir capacity (m3); A = the surface area (m2); a and b = calibration constants based on the reservoir characteristics.

 At the same time, Mitchell [30] carried out a linear regression analysis between the log area/ log capacity of 12 reservoirs in the Zimbabwe region and derived a power relationship as follows$ C = 2.646×A^{1.5}$C. Similarly, Meigh [31] developed a power relationship $C = 7.381×A^{1.251}$(R2 = 93.1%) for estimating the reservoir capacity in Botswana. While Liebe [32] assessed and monitored the reservoirs in the Upper East Region of Ghana, mapped the surface area using satellite images and calculated their capacity periodically using the power relationship equation $C = 0.00857×A^{1.4367}$

 Similarly, Rodrigues [16] estimated the storage capacities of small reservoirs in the Brazilian Savannah region using Landsat ETM satellite data. Further, he correlated the results with the field measurements, observed a deviation in the results, and attributed the same to the resolution of the satellite image. Sawunyama [12] carried out a remote sensing based storage capacity estimation in 12 small reservoirs of Mzingwane catchment, Zimbabwe. Thus, from the above studies, it is evident that the storage capacity can be easily estimated by mapping the surface area. The difference in the constant value is attributed to the variation in the reservoir profile, climatic conditions and the spatial resolution of satellite data used.

**IV. FUTURE POTENTIAL**

 However, subtle field measurements are essential in the above methods, whether by preparing 3D or surface area-based models. While the recent advancement in remote sensing technology, namely the LIDAR (Light Detection and Ranging), provides data on the water surface and bottom profile more precisely. Airborne sensors transmit laser light of both NIR (1040 - 1060 nm) and Blue- green region (approximately centred at 532 nm). Due to its longer wavelength, the NIR region gets reflected from the water surface. The green region transmits through the water body and, after interacting with the bottom, gets reflected. The reservoir's bottom profile is generated based on its travel time.

 Further, based on the difference in the travel time between NIR and the Green band, the thickness of the water column is determined. LIDAR data can be collected at night because it is an active system, not dependent on passive solar illumination. But the above technology is costly and thus is not affordable for developing and underdeveloped nations. Nowadays, Waterbody mapping can be done precisely as well as on a large scale using the increasing availability of high-resolution earth observation (EO) datasets in conjunction with machine learning (ML) classification models [33].

Similarly, a sonar device fitted to a remotely operated vehicle (ROV) can improve the resolution and accuracy of s measurements and reduce labour and safety requirements. Technologies like UAVs help acquire high-resolution images of tanks during the dry period, which can be used to generate a terrain model and an EAC curve for these tanks. Thus, different techniques have different advantages and disadvantages depending on the requirements and applications, and it is up to the applicants to decide which technology best suits the given conditions.

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