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Restoration of Cascading Tank System Using Geoinformatics Technology

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ABSTRACT

In South India, tanks system is quiet ancient, meant for storing and supplying water towards multifunctional needs of the people. In Tamil Nadu, there are around 39,000 tanks with varying size and types. Over past few decades, irrigation rely on stable and reliable groundwater resources like dug and deep bore wells, consequently tanks lost their significance. Moreover, excessive siltation, improper maintenance and illegal encroachment further degraded the system. The deterioration factors are broadly categorised into problems in catchment, feeder channels and head works, eventually resulting in loss of storage capacity. The present study chiefly narrates an indirect method of estimating loss in storage capacity of tanks and the catchment problem, especially soil erosion and its induced downward siltation using geoinformatics technology. Using remotely sensed satellite data by measuring surface area of tank loss in storage capacity was estimated through a model relationship. Using Digital Elevation Model derived topographic wetness indices data, the catchment problem especially, soil erosion areas are identified and remedial measures are suggested. Under prevailing water crisis, it is essential to rehabilitate the tanks through which the surface water potential can be improved subsequently the groundwater quality and quantity will be enhanced.

Key words: Tank, storage capacity, soil erosion, topographic indices, remote sensing

INTRODUCTION

In South India, tanks system is quiet ancient, meant for storing and supplying water towards multifunctional needs of the people (Palanisami *et al*., 1997). Especially in water scarce region, tanks are used for a variety of productive and domestic uses, thus a vital resource for rural livelihood. In Tamil Nadu, alone there are around 33,000 tanks supporting 0.63 million ha of paddy fields. Amongst, especially those fringing deltaic regime of easterly flowing rivers like Palar, Vellar and Vaigai exhibits a typical cascading system of architect. In cascading system, taking advantage of gradient, a tank in the upper reach is interconnected to series of tanks in the down slope through feeder channels. Similarly, each of these are connected to their further down slope tanks, thus forming a network of cascading tank system. The surplus water gained during Monsoon in upper reach tank is effectively drained through feeder channels to tanks in the downward link. Once these get overflowed, the water will be regulated to the chains of tanks further down the link. Thereby, storm water is effectively retained within the watershed itself, playing indispensible role in agriculture and related activities. But recent statistics exemplifies a drastic decrease in net tank irrigated area from 38% during 1960-19.47% in 2000 (DEAR, 2009). Hence over past few decades, tanks have lost their significance. When a tank gets isolated from irrigation purpose, will become defunct (Baker, 1984). Added excessive erosion in the catchment and its induced downward reservoir siltation has reduced the storage capacity of tanks. Moreover, the silted supply channels, leaky embankments, illegal encroachment etc., has further degraded the system (Von Oppen and Subba Rao, 1987). Despite receiving adequate annual rainfall, owing to loss in storage capacity, most of storm water is being discharged out from the system as surface runoff. Hence under prevailing water crisis, it is time deserving to conserve the available water resource. But there is a lack in reliable data on location, size and storage capacity of small tanks. Ground based monitoring and measuring storage capacity of small tanks was laborious and time consuming. While remote sensing technology owing to its spectral, spatial, temporal and radiometric credibility have proven an effective tool in mapping and managing natural resources in general, water resources in particular. Using remotely sensed data, estimation of loss in storage capacity, demarcation of soil erosion zones and carving mitigation measures can be done precisely. By rehabilitating the system, surface water potential can be improved subsequently groundwater quality and quantity will also be enhanced.

MATERIALS AND METHOD

The study area encompasses Vellar watershed of Tamil Nadu, covering 930 km^2 vested by 850 tanks of varying size (Fig. 1). Mostly rain fed non-system while few are connected to streams. The area receives mean annual rainfall of 900 mm. Irrigation chiefly depends on tanks followed by tube wells and canals. But now suffers a critical status with regard to water supply especially for irrigation and other purpose due to degradation of the system. Most of the blocks comprising major part of the watershed are designated under semi critical category (Suresh, 2008).

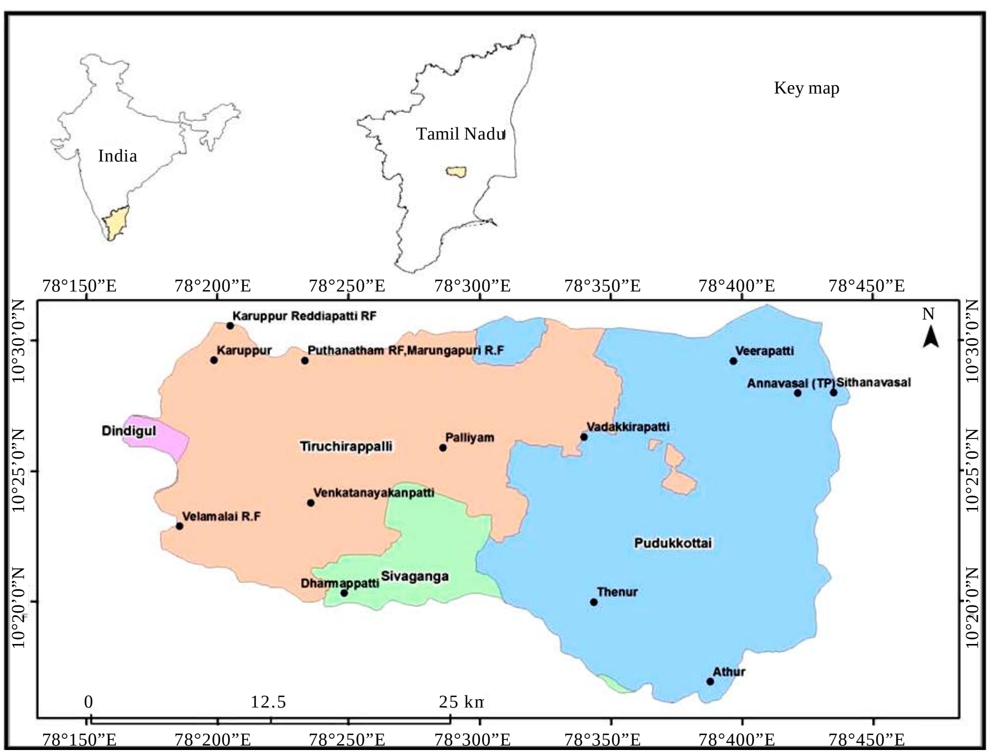

Fig. 1: Study area

The present study chiefly aims in estimating reduction in their storage capacity, identifying areas of soil erosion and thereby suggest appropriate remedial measures. The storage capacity of the tanks was estimated indirectly from its surface area. Firstly, using survey of India toposheets (1:50,000) surface water spread area of tanks were mapped. At time of inception, storage capacities of selected tanks were collected from state public works department. A Mathematical relationship has been established between surface area and storage capacity and based on it, actual storage capacity of all the tanks were derived from the surface area mapped using topographic sheets. In order to derive existing capacity, using remote sensed satellite data, present surface area was mapped and accordingly storage capacity was derived. By correlating, loss in storage capacity was estimated. Excessive siltation is the prime factor for reduction in storage capacity, hence in order to elucidate soil erosion prone areas, topographic indices derived from Digital Elevation Model data were used and accordingly remedial measures were suggested.

RESULTS AND DISCUSSION

The population explosion, its demanding food resources and improved standard of living has amplified the necessity of fresh water resources. It is essential to seek ways of achieving the most efficient and equitable utilization of the available limited resource. Even in those countries, where water resource is adequate due to over exploitation, facing series of environmental hazards including declination of water table. That too in developing nation like India, irrigation sector plays major role in GDP, where water is an essential resource. But the mismanagement not only reduces the resource also indirectly affects crop yield and soil wealth. Hence, it is vital to ensure a sustainable water management that too under prevailing water crisis, it is essential to rehabilitate the tanks. The remote sensing based assessment of loss in storage capacity and therefrom estimation of volume of siltation can be done periodically. By effective utilization, degraded tank system can be rehabilitated through which the surface water potential can be improved subsequently the groundwater quality and quantity can also be enhanced.

Storage capacity loss estimation: Reservoir capacity is estimated conventional by in situ measurements using survey instruments, echo sounders etc. Direct ground based surveys, especially for small tanks owing to its number are laborious and time consuming, therefore indirect methods with minimum field measurement are adopted all around. By measuring width, throwback and maximum depth, mathematical models were developed for capacity estimation (Nelson, 1996). Even though the above method comprises minimum ground survey, it is cumbersome to execute for hundreds of small tanks in a catchment. Hence exclusive indirect methods are developed wherein surface area, otherwise water spread area of a tank is taken as base for computation. The method relies on the fact that the water spread of reservoirs varies with respect to different levels of sedimentation. Initially capacity will be calculated using ground based measurements for different water levels. For periodical assessment, based on the measured data in correlation with surface area of water spread in the reservoirs, estimation will be done. Initially topographic maps and aerial photographs were used for mapping surface area (Meigh, 1995). Recently satellite data owing to its various spectral resolution water boundaries were mapped precisely (Goel and Jain, 1996; Rodrigues *et al.*, 2007; Hui *et al.*, 2008, Ran and Lu, 2011). In these methods, original capacity will be calculated using ground based measurements and a model relationship is established between the surface area and storage capacity (Jain and Goel, 2002). Mostly capacity surveys by 'remote sensing techniques' are adopted for major reservoirs while few attempts were

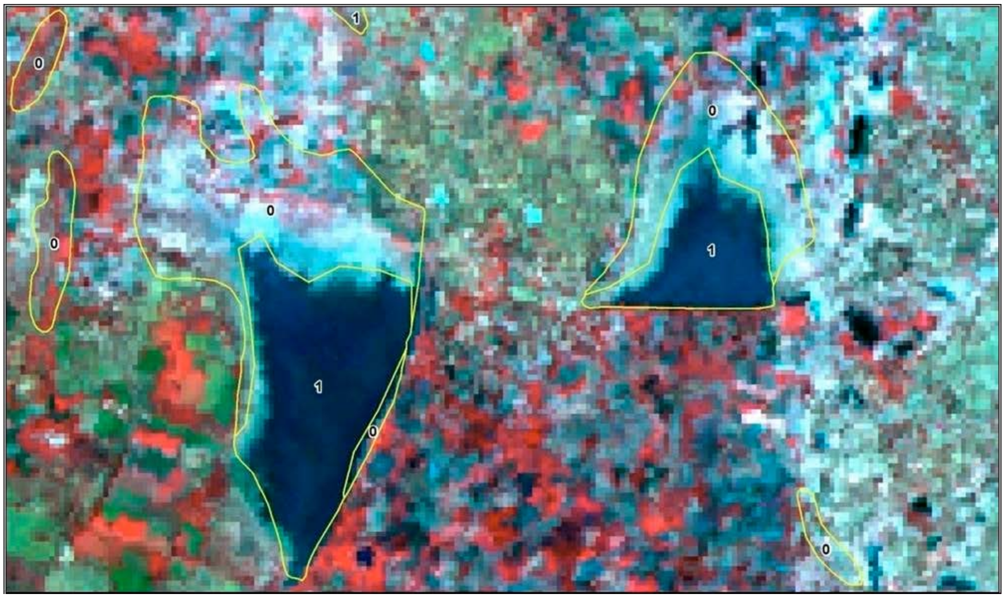

Fig. 2: LANDSAT data showing present surface of tanks

made for small reservoirs (Liebe *et al*., 2005; Sawunyama *et al*., 2006). Hence, present study chiefly aims at mapping small tanks using remote sensing data and calculate their surface areas using GIS, establish a model relationship between surface area and storage capacity and thereby estimate loss in its capacity.

Surface area mapping: Surface area of tanks were mapped and converted into digital data using ArcGIS 9.3 software. Amongst 850 tanks in the study area, tanks having surface area more than 0.5 km^2 (405 tanks) were considered for further analysis. In order to map, the present surface area of the tanks, post Monsoon IRS IC satellite data has been used. Since, it is a post monsoon data, tanks will be with its full capacity and hence the periphery of its water spread has been considered as its present surface area. The tank map prepared earlier was superposed over the satellite data and the present water spread has digitized and in order to differentiate the original surface area with that of the present area, an ID of 0 and 1 has been given respectively (Fig. 2). In ArcGIS, using calculate geometry tool, the surface area of each tanks for both of its original and reduced water spreads were calculated and databases were generated. The perusal of data shows that most of them have significantly lost their surface area to an extent of more than 50-60% (Fig. 3).

Estimation of storage capacity: By in situ measurements, bathymetric mapping is done by measuring depth of the reservoir bed from water surface and therefrom storage capacity is derived. By comparing it with actual reservoir capacity data computed during its commission, capacity loss is calculated. Several indirect methods are used for estimating small reservoir storage capacities. Generally Mid area and Trapezoidal methods were used to estimate storage capacity from mapped surface area. The surface area based reservoir estimation is done by establishing a model relationship between capacity and surface area and the general formula is $C = mA^n$, where C is the capacity of tank (m^3), A is the surface area of tank (m^2) and m and n are calibration constants.

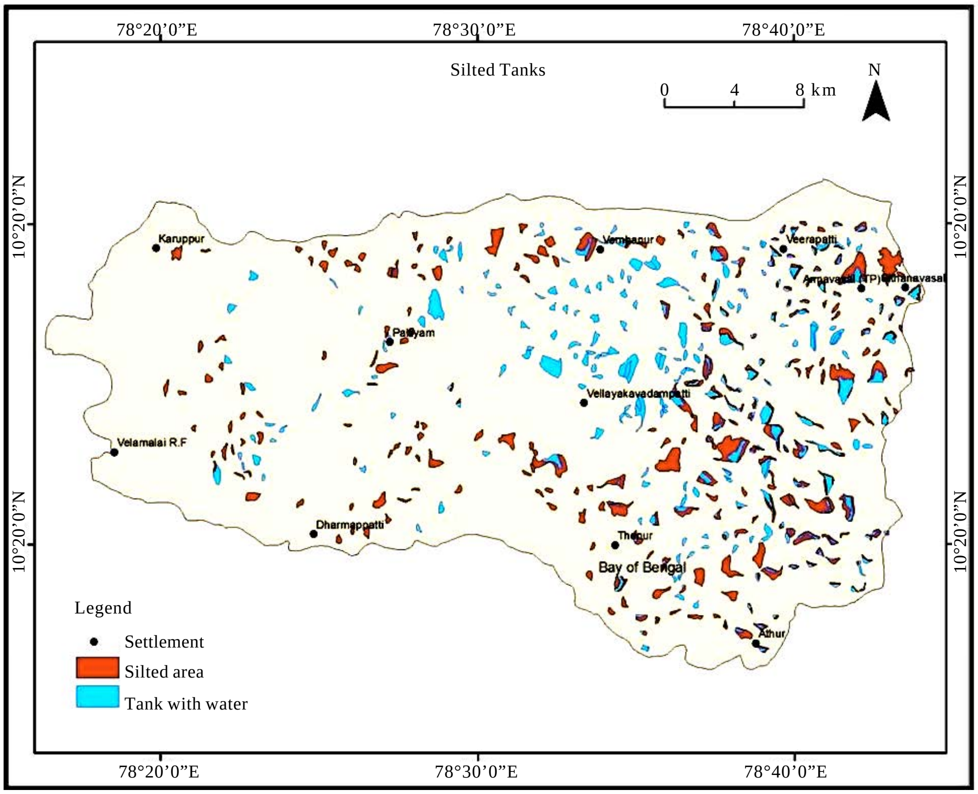

Fig. 3: GIS layer showing present surface area and silted zones

Table 1: Collateral data on surface area and capacity of selected tanks

Tank No.	Surface Area(m^2)	Capacity (m^3)
1	172933.71	52710.19
2	101946.48	41431.04
3	352341.50	125292.63
4	159984.94	48763.40
5	44230.73	11234.60

Meigh (1995) mapped surface area of small farm ponds using topographical maps in Botswana and estimated its capacity by establishing a power relationship. Recently satellite images are effectively utilized in estimating capacity of small reservoirs (Sawunyama *et al*., 2006).

The establishment of correlation between area and volumes of reservoirs is the vital element in remote sensing based storage estimation. To develop a relationship between tank capacity and surface area, collateral data were collected on capacity and surface area for five tanks within study area from Public Works Department (Table 1).

Since the terrain is almost flat with very gentle slope and other parameters like loithology, rainfall are common and moreover the selected tanks are located sporadically within the study area, the obtained relationship can be utilized to estimate the capacity of other tanks in the study area. The data on original capacity and surface area were transformed into log equations and plotted by notionally keeping log capacity in y-axis and log area in x-axis (Fig. 4).

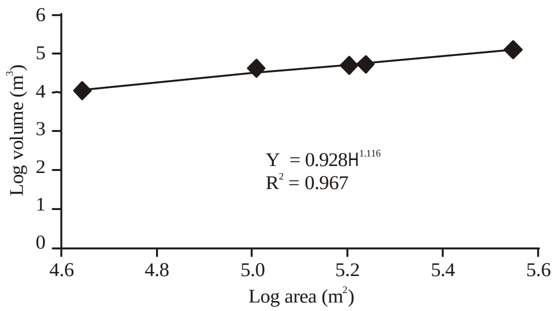

Fig. 4: Log area-log volume plot

The regression line drawn from linear regression analysis shows that there is good correlation between the surface area and capacity (R2 = 0.980). Using basic logarithmic principle, the values derived from the regression equation were used to relate capacity and area which is given by $V = 0.9278A^{1.116}$. From the above derived equation, original and present storage capacities of tanks were calculated for 450 tanks. The overall capacity is respectively 24.78 and 18.83 thousand m^3. The same shows that overall there is a reduction in capacity of about 5.95 thousand m^3.

Soil erosion: The above result clearly exhibits a reduction in storage capacity to the tune about 25% in the study area. Reduction is attributed to extensive erosion in the catchment and its resultant sedimentation in the downward reservoir. Despite soil erosion is a natural geomorphic process, in order to rehabilitate the degrading tank system, it is essential to identify erosion prone zones. By carving appropriate measures, silt can be arrested in the catchment itself and thereby siltation can be minimized. In general soil erosion is assessed through empirical methods which are more generalized. Nowadays, DEM (Digital Elevation Model) derived topographic indices provided better results in demarcating erosion prone areas (Milevski, 2008).

Amongst, relevant topographic indices namely Topographic Wetness Index (TWI) and Slope Length Steepness Factor (LS) using ASTER DEM 30 m resolution data and (NDVI) using Landsat ETM data were derived. Topographic Wetness Index (TWI) is the ratio between upstream area and slope, largely indicate distribution of runoff and soil moisture in the watershed. In combination with slope indicates erosion areas too. Hence, it plays a vital role in recognizing soil erosion and distributed hydrological model of watersheds (Zinko *et al*., 2005).

Slope Length Steepness factor (LS) includes combined effect of slope length and slope gradient (S), one of the major factors exemplifies soil loss intensity based on the terrain conditions. Generally soil erosion increases with increase in slope length and gradient. The slope length steepness factor is calculated using formula (LS) = L*S where, Length (L) = $1.4(\text{Aspect}/22.13)^{0.4}$ and Steepness (S) = $(\text{Sin } \beta/0.0^{896})^{1.3}$.

Vegetation indices are used to discriminate vegetation for that of soil and water. Amongst various indices, Normalized Difference Vegetation Index (NDVI) is a method uses red (0.6-0.7 μm) and near-infrared (NIR) region (0.7-1.5 μm) of the electromagnetic spectrum (Holm *et al*., 1987). The algorithm subtracts NIR reflectance value of a pixel to that of red reflectance value of the corresponding pixel and divides it by sum of the above values. The result is a numerical value ranging in value from -1 to 1. In general, extreme negative values are interpreted as water, while values around zero as barren soil and values above 0.6 are considered as vegetation.

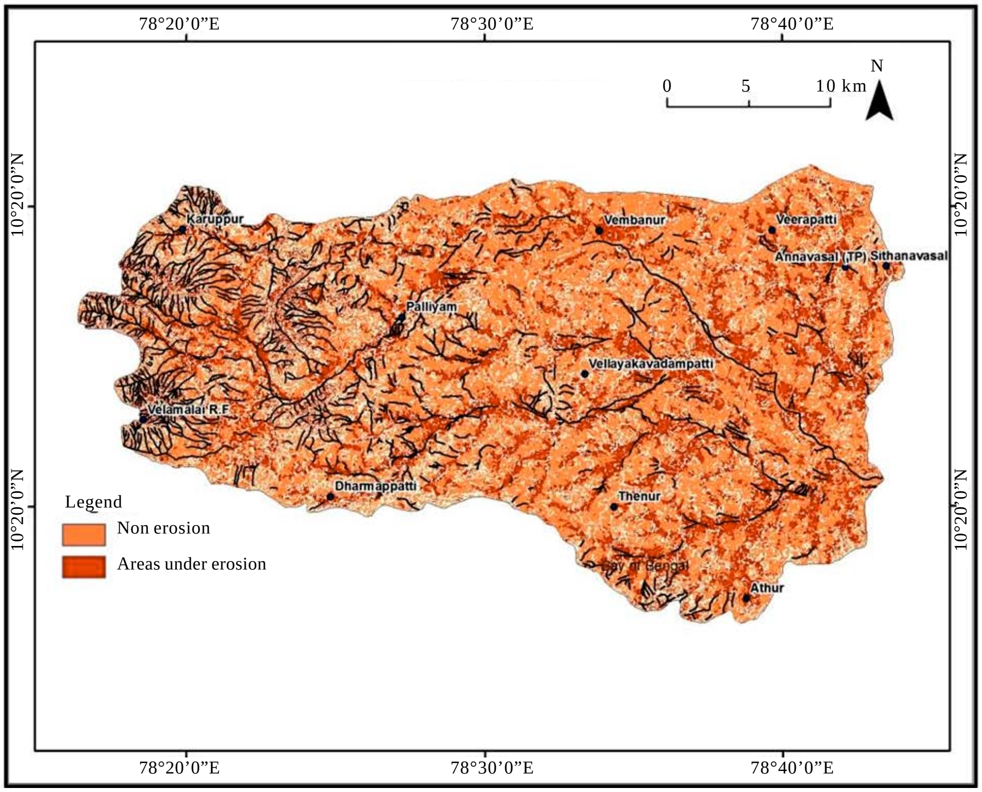

Fig. 5: Soil erosion prone areas

The digitally derived above erosion related spatial parameters were added using raster addition tool in ArcGIS. The resulted value ranges from (-)108 to (+) 57. The negative values indicate areas of deposition while the positive values are areas prone to erosion. For effective management, the data has been regrouped into to two classes (Fig. 5) as erosion prone areas (0-57) and non-erosive areas (0 to -108).

Form the above it is evident that western parts of the watershed is prone to more erosion. Similarly, along the first and second order drainages and the supply channels are susceptible to erosion. Based on the derived output site specific remedial measures viz., Gully plugging, afforestation, silt trapping, check damming can be adopted thereby silt can be restored consequently siltation of downward reservoir can be minimized.

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