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Computation of runoff on tank cascade system using GIS

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Abstract

A study was conducted to compute the runoff in tank catchment using GIS databases. For the study 10 tank cascade system was selected in upper Noyyal river basin, Coimbatore region of Tamil Nadu. The tank catchment-wise map, soil and land use map were scanned, geo-referenced and digitized. The Thiessen polygons with rainfall data of three rain gauge stations were created. From the above, tank catchment-wise land use pattern, soil hydrological group with rainfall region were identified by superimposing the maps and the attributes were stored in dbf files, which can be opened by any database. These attribute values were directly taken in to Visual basic - 6.0 (used as a platform), Curve numbers and runoff of each tank catchments was calculated using Soil Conservation Service (SCS) curve number techniques. The actual part of runoff from streams of Noyyal River was also considered for the tank storage. The runoff was computed by Normal rainfall condition, deficit rainfall condition and surplus rainfall condition (based on IMD classification). The runoff calculated from GIS database was compared with observed runoff for each tank catchment. The number of fillings in each tanks was calculated based on the runoff generated from own catchment and found out none of the tanks was filled by its own catchment runoff for the entire season. Hence, there is a necessity to augment the storage position of all tanks from the external source of water supply *i.e.*, from Noyyal river.

Keywords: Tank, catchment, GIS, runoff, land use, soil

Introduction

India has the world's second largest irrigated area, accounting for about 43 M ha out of 329 M ha geographical areas. In the case of Tamil Nadu scenario, the gross irrigated area is dwindling and it has come down to about 3.2 M ha compared to 3.4 M ha during 1970's. The reduction in canal irrigated area is from 0.89 M ha during 70's to 0.80 M ha during the year 2000. The minor irrigation tanks shared nearly one third of irrigated area in the State during 70's i.e. nearly 1.0 M ha has reduced to just about 0.60 M ha now (Palanisami and Easter, 1984) ^[8]. Tanks would also be useful in reducing floods, recharging wells and providing drainage in high rainfall periods. In many areas tank irrigation is the only method to store rainwater, help farmers through the crop-growing period and provide stability to agricultural production. GIS plays a major role in developing the information system that is being adapted to the kind of decision and management activities. GIS with its capability of integration and analysis of spatial, temporal, multi-layered information obtained in wide variety of formats has proved to be an effective tool in planning the water resources planning activity. Rainfall – Runoff models and water balance models could be integrated with spatial and non-spatial data using GIS packages effectively.

Materials and methods

Study Area

Noyyal River originates from western ghats of Vellangiri hills of Coimbatore district, Tamil Nadu. The basin lies between North Latitude of $10^0 54^{\circ} - 11^0 19^{\circ} 3^{\circ}$ and East Longitude of $76^0 39^{\circ} 30^{\circ} - 77^0 5^{\circ} 25^{\circ}$ covering a total area of 3150 km². The river flows over a distance of 180 km. The part of the upper Noyyal river basin with an areal extent of 176.21 km² was selected for the study (as shown in Fig. 1). 0.5 per cent mineral matter. The mineral matter reported to be present in fair amount of calcium, phosphorus, iron, potassium, sodium and iodine.



Fig 1: Study area consist of tanks

Physiographic Characteristics Soil

There are five soil series found in the study area, namely Somayyanur series, Pilamedu series, Palathurai series, Noyyal series and Vellalur series. The soils of the study area fall in B and C hydrologic groups (as depicted in Fig. 2). The B type soil, which is of clay loam, is the predominant soil found in the study area.

Land use/Land cover

The Land use / land cover map was obtained from Institute of

Remote Sensing, Anna University, Chennai. The map was derived from IRS-LISS-IV data during the period of July 2000. The map were identified Six types land use/land cover pattern were identified in all ten tank catchments (as shown in Fig. 3), which include agricultural crop land, fallow or harvested land, agricultural salt affected land, cultivable land, built-up land, wasteland stony area, wasteland industrial area and water bodies. The agricultural crop land and cultivable land is the predominant land use type which occupies 77 % of the study area.



Fig 2: Soil Hydrological group map

Hydrology

The Noyyal sub-basin can be classified as "Leaf type" based on its shape and stream pattern. The river originates at an altitude of about 1800 m above MSL. This is a stream which is dry for long periods and the flow is taking place only during the monsoon periods. There are 44 tanks distributed within the basin. These tanks are mostly placed in series and in several lines forming a cluster. The capacities of each tank vary from 0.093 Mm³ to 52.270 Mm³. Only ten tanks were



selected in upper basin of the study area due to urbanized in lower region as shown in Fig. 1.

Topography

The toposheets (1:25,000 scales) of the study area were btained from SOI, Guindy, Chennai. The contours of 10 m interval were extracted from the toposheets. The total study area was covered in between 300 to 360 m contour level elevations.

Data Acquisition and Map Preparation Maps and hydrological data collection

The spatial map, hydraulic and hydrological data were collected from different sources viz., PWD (Water Resources Division), Coimbatore, Anna University (Remote Sensing Department), Chennai and local Village Administrative Office, Coimbatore.

Preparation of thematic maps

The following maps were scanned, geo-referenced, digitized and subsetted the study area. 1) Drainage base map 2) Soil map 3) Land use map 4) Map showing the tanks, catchments and ayacuts 5) Thiessen polygon map 6) Contour map from SOI Toposheet). There are three rainfall stations located within the study area viz., Union Office - Thondamuthur, Paddy Breeding Station (PBS) and Tamil Nadu Agricultural University (TNAU).

GIS Database Development

Geographical Information System (GIS) provided a medium to develop, store, analyze and visualize spatially distributed data. The features of the study area like topography, soil type, land use pattern and drainage pattern were obtained thematic maps were prepared. All the four thematic maps were superimposed namely tank–catchment wise map, soil hydrological group map, land use pattern map and thiessen polygon map. From these superimposed map tank catchmentwise land use pattern and soil hydrological group with rainfall region were identified and derived the attributes were stored in dbf files.

Direct Runoff Determination

Rainfall excess forms the main input to arrive the direct runoff. After flowing through the catchment, the excess rainfall becomes the direct runoff at the catchment outlet. There are many methods for estimating the volume and time distribution of rainfall excess. The Soil Conservation Service (SCS) developed a comprehensive procedure called as runoff curve number technique for calculating the abstractions and the rainfall excess. This method takes care of the heterogeneous nature of the catchment characteristics and antecedent soil moisture conditions over the catchment and it was chosen for the present study. The micro level changes of the catchment characteristics, such as the variations in soil and land use, which mainly control the surface runoff generation, are easily handled by this technique. From the GIS attributes values the runoff has been calculated for each tank catchments using SCS Curve number techniques.

Computation of water losses Evaporation losses

The evaporation losses were calculated by the following equation (IWMI research report 48, 2001) ^[6]. The daily evaporation data were collected from different meteorological stations. The evaporation losses were computed by multiplying the pan coefficient (0.85) and water spread area of each tank.

Evaporation losses $E(m^3) = E_p \times K_p \times A$ ------(1)

Where,

$$\begin{split} &E = Evaporation \ losses \ (m^3); \\ &E_P = Pan \ evaporation \ (m) \\ &K_p = Pan \ coefficient \ (0.85); \\ &A = Water \ Spread \ Area \ (m^2) \end{split}$$

Seepage and percolation losses

Seepage and percolation losses were estimated by deducting the evaporation loss from the total water lost from each tank daily (IWMI research report 48, 2001) ^[6]. The twenty days daily total water losses from each tank was measured during the month of September and February when there were no inflows and outflows in relation to the tank capacity. A graph was drawn based on the daily tank water losses and tank capacity and predicted linear equation for each tank to compute the seepage and percolation losses.

Seepage and percolation losses (m^3) = Total water losses (m^3) – Evaporation losses (m^3) ; ----- (2)

Soil Conservation Service Model

Runoff calculation using SCS method of abstractions

The hydrologic relation between the rainfall (P), soil storage (S) and direct runoff (Q) is given by the following equations (Hand Book of Hydrology, 1972) ^[4].

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)};$$
-----(3)

$$S = \frac{25400}{CN} - 254$$
.....(4)

Where,

Q = Runoff (mm)P = Rainfall (mm)

 $I_a = Interception = 0.3S$

Knowing CN for AMC II condition, CN for AMC I and AMC III conditions were evaluated as given below:

$$CN(I) = \frac{4.2 CN(II)}{10 - 0.058 CN(II)}; ----- (5)$$

$$CN(III) = \frac{23CN(II)}{10 + 0.13CN(II)} ----- (6)$$

Total Runoff
$$(m^3) = Q \times Area \dots (7)$$

The direct runoff from a catchment having multiple hydrologic soil-cover complexes can be found out in to weighted CN method. The weighted curve number was arrived for the whole catchment and the direct runoff was found out in which the direct runoff from individual soilcover complex was found out and then weighted to get the average depth of Q. The present study is concerned with the estimation of total volume of runoff from the catchments.

Linking between GIS output database and Platform

The GIS based output was linked with Visual basic programming language as considering as the back end tool to calculate the runoff. In this platform the input data are GIS based superimposed output attributes, SCS curve no. table, daily evaporation (mm), seepage & percolation losses and daily rainfall (mm) from different regions (PBS and TNAU) at three rainfall (normal, surplus and deficit) conditions. The runoff was computed from all the given input data and the output will be in the form of Tank-catchment wise runoff, rainfall, evaporation, and seepage & percolation losses in terms of daily (dd/mm/yyyy).

Computation of Runoff

The own catchment runoff of each tank was calculated from GIS output database and analyzed with three-rainfall condition. The rainfalls were selected based on IMD classification the normal rainfall (-19 to 19% of the mean rainfall of the study area), deficit rainfall (-20 to -59% of the mean rainfall of the study area) and surplus rainfall (+20 to +59% of the mean rainfall of the study area). The selected mean annual rainfall simulations were identified 708 – 802 mm (year of 1998), 471 – 505 mm (year of 1999) and 888 –

954 mm (year of 1997) for normal, deficit and surplus rainfalls.

Results and discussion

Tank catchment-ayacut wise map

The tanks catchments were identified and delineated with stream lines in the map (Fig.1). The tank area (water spread area), catchment area and ayacut area were obtained through attributes, which is stored as a dbf file. The water spread area and catchment area varies from 0.1620 to 1.0720 km² and 0.2041 to 4.610 km² respectively (Table 1).

Tank Id	Tank Name	Reported water spread area (km ²)	GIS derived data – water spread area from map (km²)	Percentage Absolute error $\frac{ obs - est }{obs} \times 100$	Reported Free catchment area (km ²)	GIS derived data – Catchment area from map (km²)	Percentage Absolute error $=\frac{ obs - est }{obs} \times 100$
1	Pudukulum	0.2120	0.2110	0.47	1.2160	1.2100	0.49
2	Kolarampathi	0.1760	0.1789	1.65	0.2670	0.2650	0.75
3	Narasampathi	0.5010	0.5020	0.20	1.6993	1.6990	0.02
4	Krishnampathi	0.7020	0.7120	1.42	2.1225	2.1220	0.02
5	Selvampathi	0.2850	0.2830	0.70	0.6543	0.6532	0.17
6	Sottandikuttai	0.2010	0.2020	0.50	1.5400	1.5325	0.49
7	Perur big tank	1.0740	1.0720	0.19	2.1481	2.1452	0.14
8	Selvachinthamani	0.1490	0.1490	0.00	0.5752	0.5732	0.35
9	Ganagnarayana usdan	0.1620	0.1620	0.00	0.2041	0.2035	0.29
10	Kumarasami	0.3800	0.3800	0.00	2.6100	2.5965	0.52

Table 1: Comparison of GIS derived and actual water spread area and catchment area of tanks

Soil hydrological group

From the soil series map, the hydrological group of soil was identified (Hand book of Hydrology, 1972)^[4]. Only two soil hydrological groups B & C were identified in the study area as shown in Fig. 2. The area of B & C soil hydrological group obtained through GIS were 131.435 & 44.99 km².

Land use/land cover map

The land use map of the tanks is depicted in Fig.3. Eight types of land use patterns were identified in the study area. Out of eight land use patterns, only six were identified in all the chosen ten tank catchments viz., agricultural crop land, fallow or harvested land, agricultural salt affected land, cultivable land, built-up land and water bodies. The areas under various land use patterns viz., Agricultural cropland, Agricultural salt affected land, built up land, cultivable land, fallow/harvested land, water bodies, wasteland stony area and wasteland built up areas were 57.25, 10.66, 11.65, 11.87, 79.04, 3.45, 2.63 and 0.02 km² respectively. Fallow / harvested land was the predominant land use pattern in the study area and was followed by Agricultural cropland. The area of each land use pattern varied from 0.0033 to 0.7763 km².

Thiessen Polygon

The Thiessen polygon with rainfall data of three rain gauge stations were created (Fig 4.). The area of influence under the three of rain gauge stations regions namely Thondamuthur, PBS, TNAU are 74.90, 44.25 & 57.32 km² respectively.

Superimposing of all thematic maps

Tank catchment-wise land use pattern and soil hydrological group with rainfall region were identified by superimposing the four thematic maps of tank catchment, soil hydrological group, land use pattern and Thiessen polygon. The superimposed map of all the above four thematic maps and database is presented in Fig.5 and Table 2. All the ten tanks were located within the area influence of two rainfall stations namely Paddy Breeding Station (PBS) and Tamil Nadu Agricultural University (TNAU). Out of ten tanks, four tanks namely Pudukulum, Kolarampathi, Narasampathi and Krishnampathi are situated in the area of influence of PBS rainfall station and the remaining six tanks namely Selvampathi, Perur big tank, Perur kuttai, Ganagnarayana usdan and Selvachinthamani and Kumarasami are located under the area of influence of TNAU rainguage station.



Fig 4: Thiessen polygon

Fig 5: Super imposed maps

Sub		Area of soil group (km ²)									
Sub Cotobmonto ID	Tank Name	Soil hyd.	Built up	Agricultural crop	Fallow/harveste	Water	Agricultural salt	Cultivable			
Catchinents ID		group	land	land	d land	bodies	affected land	land			
11	Pudukulam	B&C	0.0000	0.1519	0.0000	0.0000	0.0000	0.0000			
12	Kolarampathi	В	0.0000	0.1538	0.0276	0.0033	0.0000	0.0000			
13	Narasampathi	В	0.0000	0.7320	0.7763	0.1896	0.0000	0.0000			
14	Krishnampathi	B&C	0.1778	0.5278	0.1221	0.0877	0.0000	0.0000			
15	Selvampathi	B&C	0.0000	0.4312	0.0204	0.2022	0.0000	0.0000			
16	Perur kuttai	B&C	0.0614	0.0000	0.2275	0.0000	0.0027	0.0000			
17	Perur tank	В	0.2711	0.8084	0.1667	0.0068	0.7146	0.1856			
18	Selvachinthamani	В	0.0598	0.4730	0.0000	0.0419	0.0000	0.0000			
19	Perur Usdan	В	0.0344	0.0000	0.1300	0.0000	0.0395	0.0000			
20	Kumarsami	С	0.2612	0.2211	0.0517	0.0000	0.0000	0.0000			

Table 2: GIS derived data from superimposed thematic maps (four maps)

Tank catchment wise slope

The tank catchment slope was identified by overlaying the tank catchment map with slope map (one per cent average slope interval thematic map) as shown in Fig. 6. The attributes of this map showed that the percentage of slope varied from 1

to 1.71 for all the ten tank catchments. From the output results, it was decided that the SCS curve number techniques could be used for runoff calculation of these tank sub-catchments.



Fig 6: Tank catchment wise slope.

Water losses components Estimation of evaporation losses

The evaporation losses were minimum in rainy season (June to August and October to December) due to low evaporation rate and it was maximum during January to May due high evaporation rate. Depending upon the tank capacity and monsoons, the losses varied from 300 to 1200 m³/day. The daily evaporation losses were incorporated into the model by deducting the quantum of evaporation losses from tank capacity during the running of the model.

Computation of seepage and percolation losses

The daily water losses of all the tanks were calculated during monsoon periods when there was no inflow, outflow and no rainfall conditions. The seepage and percolation losses were found out by subtracting/deducting the evaporation losses from the total losses. This commonly observed trends and linear equations were arrived at in all the ten tanks and presented in Table 3. The linear equation was obtained (Table 3.) for seepage and percolation losses and volume of tank storage of all the ten tanks. The seepage and percolation losses varied depending on the tank storage volume. The analysis indicated that tank seepage rate was less than 2 per cent for all the tanks. The seepage and percolation losses varied from 789.11 m³ (Ganagnaraya usdan tank with minimum storage volume of 7822.72 m³) to 31281.69 m³ (Kumarasami tank with maximum storage volume of 1554625.38 m³). The equations showing the relationship between the storage volume and the seepage and percolation losses for each tank are given below.

Table 3: Computation of Seepage and Percolation Losses

Pudukulum	Y = 0.0262x + 923.55	$R^2 = 0.95$
Kolarampathi	Y = 0.0288x + 1452	$R^2 = 0.93$
Narasampathi	Y = 0.003x + 1560	$R^2 = 0.82$
Krishnampathi	Y = 0.0229x + 1866.9	$R^2 = 0.92$
Selvampathi	Y = 0.0125x + 902.82	$R^2 = 0.76$
Sottandikuttai	Y = 0.0831x - 561.65	$R^2 = 0.86$
Perur big tank	Y = 0.003x + 2015.5	$R^2 = 0.71$
Ganagnarayana usdan	Y = 0.063x + 296.28	$R^2 = 0.93$
Selvachinthamani	Y = 0.0897x + 1005.5	$R^2 = 0.87$
Kumarasami	Y = 0.0163x + 2252.6	$R^2 = 0.94$

Where,

Y = Seepage and percolation losses (m³)

x = Tank storage volume (m³)

R² at 5 % significance level

Runoff Determination

Tank catchment-wise land use pattern and soil hydrological group with rainfall region were identified by superimposing the maps and the attributes were stored in dbf files. These attribute values were directly taken into Visual basic - 6.0 as a back end database program. The input form of updating the database was given in Fig. 7. The calculated output runoff was displayed in the form of Tank-catchment wise runoff, rainfall, evaporation, and seepage & percolation losses in terms of daily (dd/mm/yyyy) as depicted in Fig. 8. In addition that another module has designed for each thematic layer wise output results (map with data) also obtained through this platform as shown in Fig. 9.

GIS based Tank Information System	ition System - E <u>x</u> it	[Runoff]								_ 8 > _ 8 >
	_									
Catchment no	14	•	Year	[1997	•				
	<u> </u>	iay)		<u>C</u> lear		E <u>x</u> it				
	Date	Rainfall CNo	Depth	Runo	off Runo	(f_WS)	_			
	1/1/1998	0	0	0	0	0				
	1/3/1998	0	0	0	0	0				
	1/4/1998	0	0	0	0	0				
	1/5/1998	0	0	0	0	0				
	1/6/1998	0	0	0	0	0				
	1/8/1998	0	0	0	0	0				
	1/9/1998	0	0	0	0	0				
	1/10/1998	0	0	0	0	0				
	1/11/1998	0	0	0	0	0				
	1/12/1998	0	0	0	0	0				
	1/13/1998	0	0	0	0	0				
	1/14/1998	0	0	0	0	0				
	1/15/1998	U	0	0	0	U				
	1/15/1338	0	0	0	0	0				
	1/18/1998	0	0	0	0	0				
	1/19/1998	0	0	0	0	0				
	1/20/1998	0	0	0	0	0				
	1/21/1998	0	0	0	0	0				
	1/22/1998	0	0	0	0	0				
	1/23/1998	0	0	0	0	0				
	1/24/1998	0	0	0	0	0				
	1/25/1998	0	0	0	0	0				
	1/26/1998	0	0	0	0	0				
	1/27/1998	0	0	0	0	0	T			
	1 17/6/10081			m						





Fig 7-9: Runoff estimation by VB platform

Runoff model validation

Initially the calculated runoff of each tank in southwest and northeast monsoon, year of 2003 was compared with observed runoff as shown in Fig. 10. Ten to twenty per cent deviation was obtained for all the ten tanks. Subsequently, different simulations like normal rainfall, surplus rainfall and deficit rainfall conditions with various water storage positions in tanks were carried out and obtained minimum deviations (10 to 20 %).



Fig 10: Runoff validation

Runoff and tank capacity

The total runoff calculated from each catchment for normal rainfall, surplus rainfall and deficit rainfall was compared with each tank water level and calculated the no. of fillings of each tank (Table 4). None of the tanks was filled from their own catchment runoff for entire year at different rainfall conditions. Hence, there is a necessity to augment the storage position of all tanks from the external source of water supply i.e from Noyyal river.

Sub	Tank	Capacity Runoff (m ³		No. of Runoff (m ³)		No. of	Runoff (m ³) at	No. of
Catchments ID	Name	(m3)	normal rainfall	fillings	surplus rainfall	fillings	deficit rainfall	fillings
11	Pudukulam	94766.72	17708.26	0.19	32424.91	0.34	6952.93	0.07
12	Kolarampathi	182633.68	17760.25	0.10	23577.48	0.13	6295.31	0.03
13	Narasampathi	1666746.27	213538.20	0.13	281155.05	0.17	87091.10	0.05
14	Krishnampathi	213761.19	133345.06	0.62	173994.54	0.81	58149.88	0.27
15	Selvampathi	276805.97	118168.25	0.43	117947.69	0.43	50108.31	0.18
16	Perur kuttai	121267.61	17628.92	0.15	42097.28	0.35	14994.89	0.12
17	Perur tank	1434213.04	70128.28	0.05	252411.86	0.18	70059.09	0.05
18	Selvachinthamani	83606.56	23683.50	0.28	72459.89	0.87	22072.08	0.26
19	Perur Usdan	226661.86	9961.00	0.04	27214.48	0.12	8888.31	0.04
20	Kumarsami	554625.38	46185.00	0.08	95362.34	0.17	40249.30	0.07

Table 4: Runoff computation and No. of fillings from each tank at different rainfall condition

Conclusions

The cultivable area in tank catchment is decreasing day by day and in some parts changed the cropping pattern is also one of the reasons to increase the demand. The farmers cultivated with high water requirement crops and hence increased the water demand. Most of the tanks in these regions are dry except during monsoon seasons and encroached the tank feeder channel of tanks catchment.

The runoff was computed by GIS techniques will be more precision method than other conventional methods. The basic principle involved in this study is, the runoff computed based on each separate polygon wise and finally it will be added as cumulative output runoff. Moreover as per the studies, none of the tank has been filled by its own catchments runoff for the entire season. Hence, there is a necessity to augment the storage position of all tanks from the external source of water supply i.e from Noyyal river. Depending upon the available water supplies during normal and deficit years, alternate crops with less water requirement atleast in some of the parts have to be suggested as a completion, apart from introducing water saving irrigation methods like drip, sprinklers etc in order to match the water supply and demands.

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