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HYDROLOGICAL VIABILITY ANALYSIS FOR MINOR IRRIGATION TANKS CASCADE SYSTEM USING REMOTE SENSING AND GIS

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ABSTRACT

Many of the Andhra Pradesh minor irrigation tanks are inter-connected cascades, allowing surplus flow of the upstream tanks and return flow from the upstream command area to reach straight away downstream tank. To increase the irrigation supply in downstream of command area, irrigation tanks are being used. There are several troubles of the irrigation tanks, such as reduction of design discharge as a result of silting of channel and tanks, deterioration of stone masonry channel, and encroachment of drainage courses and tank water spread leads to the decline of tank performance. Water Resources Department (WRD) is implementing Andhra Pradesh Integrated Irrigation and Agriculture Transformation Project (APIIATP) for improvement and management of minor irrigation tanks through community based approach with the funding of World Bank .The prediction of water availability in tank is important for the purpose of improving productive use of the water resources in a tank cascade system.The land use/land cover map was prepared using LISS-IV imagery. The drainage courses problems are identified in the tank cascade system by SOI 1: 50,000 scale toposheet & satellite image. The problems were found in the earthen channel, catchments and head works. For the identified problems, the remedial measures are suggested for improving the tank cascade system to restore it to its original condition.

Keywords: Toposheet, Satellite imagery, SCS-CN, Rainfall Data.

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Introduction

Tanks are traditional irrigation structures commonly situated in many parts of Indian sub-continent to capture monsoon runoff. A tank comprises the catchment area, feeder channels; water spread area, outlet structures (sluices), flood disposal structures (surplus weir) and command area. It is reported that more than 70 – 80 per cent of minor irrigation tanks need renovation to restore them for normal functioning. Tank Rehabilitation / Restoration / Renovation is termed as " the tanks which are dysfunctional are brought to normal functioning by way of undertaking works on breach closing, tank bund strengthening and repairs or reconstruction to sluices and weirs". Many tanks are found in the form of cascades, which is defined as a series of small and medium tanks that are connected at successive locations down in one single common water course (Madduma Bandara, 1985; Panabokke, 1999). These tanks are hydro-geologically and socio-economically interlinked in terms of storing, conveying and utilising water. If the hydrology of one or few tanks is altered by increasing either storage capacity through rehabilitation programmes or command area by developing new paddy lands, the entire cascade hydrology changes (Sakthivadivel et al., 1996). Such changes can also have a socio-economic impact on the surrounding communities dependent on the water availability of the system. Therefore, it is important to take the total tank cascade system rather than an individual tank into account when planning, development and operations of small tank systems are considered.

Levine (1996) analyses the fundamental reasons for the need to improve irrigation systems. He points out that the need for rehabilitation arises because of failures to adequately maintain irrigation systems. This problem is endemic throughout the world, but especially in the developing countries, due to severe constraints on the financial resources available for operation and maintenance. Many works have been done by various researchers for finding out the way and need to improve the performance of the tank system through rehabilitation process. Nowadays the GIS and Remote Sensing technology can be used for identification and mapping the problems in the catchment and command area of minor irrigation tank system. This paper describes briefly the role of GIS and Remote Sensing in the process of rehabilitation of tank cascade system. Toposheets are used to tank position along the drainage courses and catchment boundary. The changes in the linkage of tank cascade and land use due to natural and human activities can be observed and updated recorded using a combination of GIS and Remote Sensing technology.

Study Area

The study area covers Kavali mandal, Nellore district, Andhra Pradesh. The catchment boundary is taken from Geo-rectified SOI Map toposheet to study drainage and tanks all along the catchment. The study area covered in 57 N 13 SOI toposheet of 1: 50,000 scale. The study area covers 35.83 sq km. and located 79.8911 to 80.0011 East Longitude and 14.9241 to 14.9856 North Latitude (Figure 1).

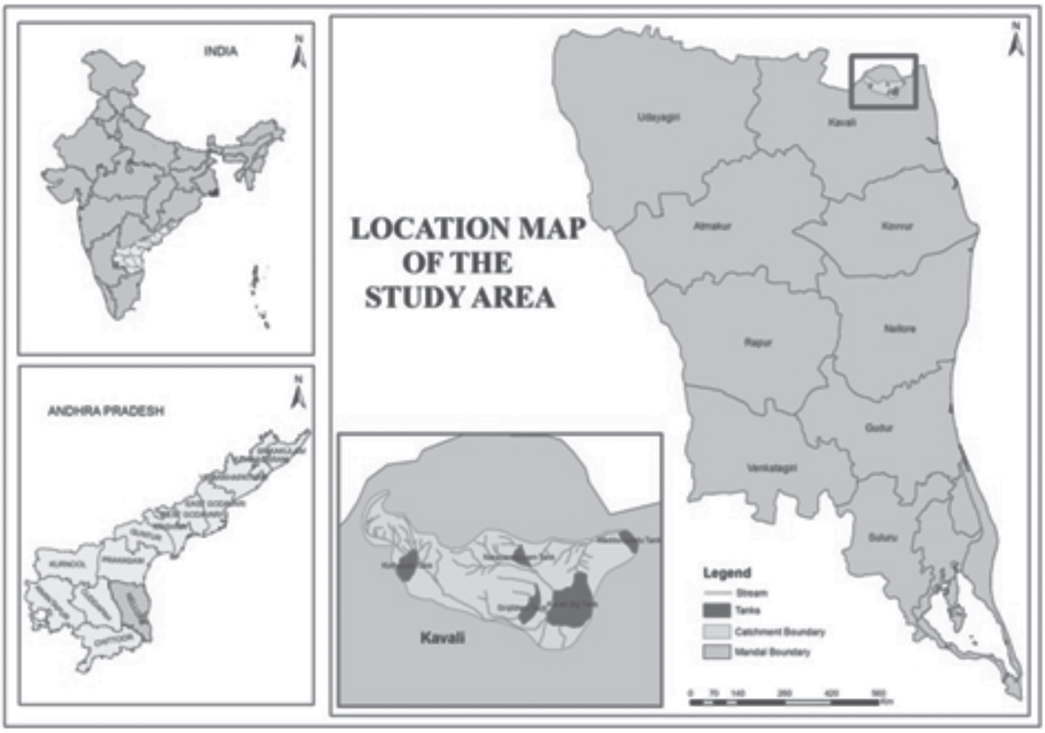


Figure 1 : Location Map

In this study, IRS-ID LISS-IV satellite data of 2016 have been used. The details are given in Table 1. In addition, SOI 57 N/13 toposheet of 1:50,000, hydrographic data and other collateral data are used.

Table 1 : Characteristics of IRS Satellite Data

Name of the satellite	Sensor resolution	Data of pass
IRS-P6	LISS-III –5.8 meters	24th January 2016

Methodology

The toposheet 57 N 13 is collected from the Survey of India and is digitized and then the study area is delineated in QGIS software. Further, the more tanks which are connected in a cascade manner are delineated, its catchment (Figure 3). The catchment of each tank is also delineated besides water spread area and number of inlet channels.

Figure 2: Methodology

Drainage

The surface drainage delineation is important to assess the hydrology of an area. Initially, rainfall received is absorbed by the soil and once it gets saturated it goes out as surface runoff. The surface runoff varies with surface conditions namely length and degree of slope, raggedness, soil texture and structure, cover conditions and lithology of the terrain. Every geographical area has a defined drainage system/ pattern that determines the groundwater potential (Gurtz, J.; Zappa, M.; Jasper, K).

The drainage of the study area is extracted through onscreen digitization from the toposheet 56 N/13 of 1:50,000. The drainage which includes streams, canals and tanks is covered in the study. Strehlar (1952) stream ordering has been followed, because it is universally accepted, in this catchment highest stream order is 3rd order.

S.No.	Stream	Count
1	1st order	49
2	2nd order	25
3	3rd order	5

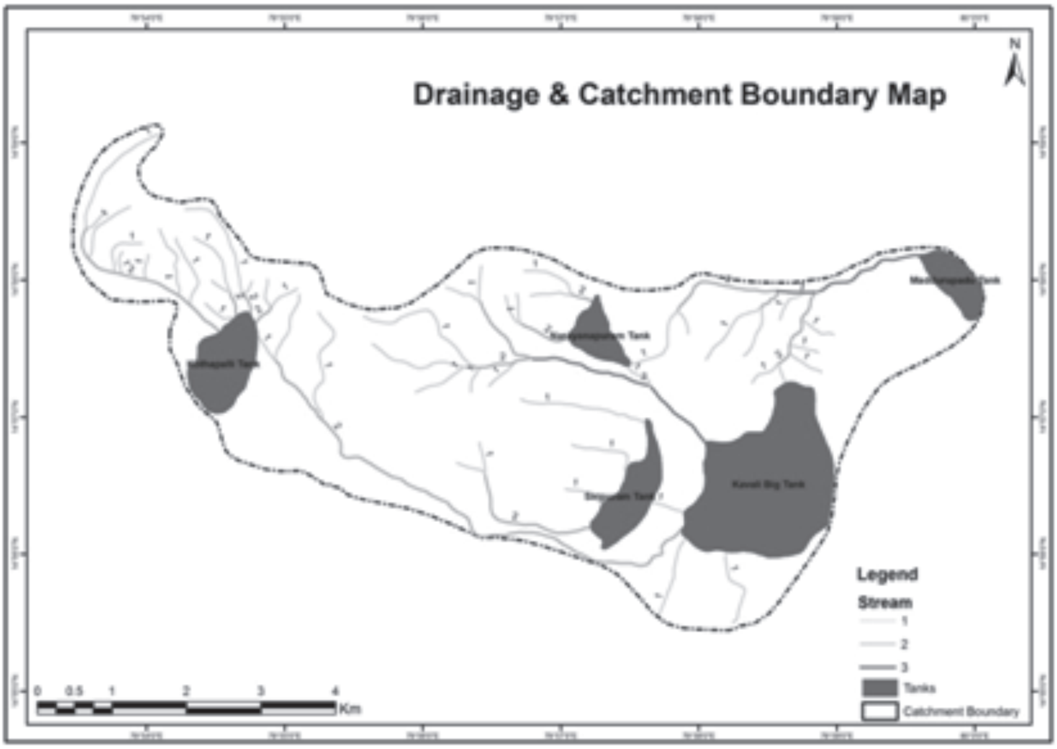


Figure 3: Stream Ordering and Catchment of the Study Area

Land Use / Land Cover

The LU/LC of the area are delineated through on screen digitization on IRS 1D LISS IV satellite image in QGIS. For Rabi season IRS-P6 LISS-IV satellite data of 24th January 2016 are used. Supervised classification technique has been implemented using the maximum likelihood algorithm and classifications procedure is applied on each scene separately using spectral reflectance and field knowledge. Before classifying the images using supervised classification technique, unsupervised classification was done to attain spectral signature of real land use and land cover. The maximum likelihood algorithm is used for different class segments with separate training data set. The entire study area is broadly divided into eight categories; namely agricultural land, scrub land, forest, wastelands, water bodies, built-up land and others (Table 2) and these are shown in Figure 4.

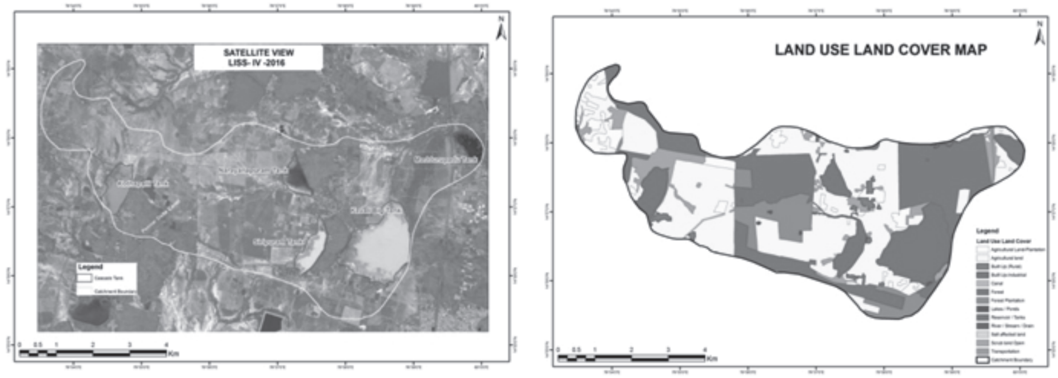


Figure 4: Division of Study Area

Table 2: Land Use / Land Cover Categories

S.No.	Class name	Km2	Percentage (%)
1	Transportation	0.030	0.085
2	Agricultural land-plantation	2.018	5.630
3	Built up (Rural)	0.439	1.224
4	Forest plantation	2.612	7.288
5	Lakes / ponds	0.029	0.081
6	Canal	0.044	0.123
7	River / stream / drain	0.132	0.367
8	Agricultural land	14.087	39.308
9	Built up-industrial	0.015	0.040
10	Reservoir / tanks	4.816	13.438
11	Salt affected land	0.004	0.012
12	Scrub land open	2.204	6.149
13	Forest	9.408	26.252
	Total count	35.838	100.000

Surface Runoff Estimation

Rainfall - Runoff modelling is an essential part in water resources planning and management.The soil conservation service curve number (SCS-CN) is a simulation model that analyses runoff volumes from the rainfall. It is one of the efficient methods to estimate direct runoff volume in unguaged catchments (Hawkins, 1993; McCuen, 2002; Michel et al., 2005; Ponce and Hawkins, 1996). It uses the curve number (CN) to determine the runoff volumes. Curve number varies with the terrain conditions. The SCS-CN method uses land use / land cover, soil information and antecedent soil moisture conditions of the catchment (Moore, R.J). The Ministry of Agriculture, Govt. of India, modifications suggested (1972, Handbook of Hydrology),to suit Indian conditions are included in the study. A brief account of inputs and formulae of the SCS method adopted for the current study is given in Figure 5.

a. Rain gauges in the neighbourhood of the tank catchment are taken and weighted average rainfall of catchment arrived using Thiessen polygons(Paik,K.;Kim,J.H).

b. Hydrological soil groups map is prepared based on soil classification map.

c. Integrating hydrological soil groups and land use / land cover information, a weighted curve number - CN (II) for each tank catchment is arrived based on curve number table.

SCS – Curve Method

The basic hypotheses of SCS method are:

a. Runoff starts after the primary abstraction, Ia, has been contented

b. The ratio of real preservation of rainfall to possible maximum retention(S) is equal to the ratio straight runoff to rainfall minus initial abstraction.

c. The first concept Ia is linked to S as $Ia = aS$ with the value of a being a function of antecedent moisture condition (AMC) and type of soil. The association between runoff depth Q (in mm) and rainfall P (in mm) in a rainfall event in the catchment for Indian conditions is given as

$$Q = \frac{(P-0.3S)^2}{(P+0.7S)} \quad ...(i)$$

(black and all other soil regions for AMC I)

$$Q = \frac{(P-0.1S)^2}{(P+0.9S)} \quad ...(ii)$$

(Black soil region for AMC-II & III)

$$\text{where } S = \frac{25400}{CN- 254} \quad ...(iii)$$

In which CN = a co-efficient called curve number

If P is less than 0.3, S in the runoff is taken as zero.

The curve number CN is a relative measure of retention of water by a given soil-vegetation-land use (SVL) complex and takes values from 0 to 100.

The curve number CN depends upon

- Hydrological soil groups
- Land use
- Antecedent moisture condition (AMC)

The definitions of AMC types (3 types), which depend upon the antecedent 5-day rainfall and upon whether the season is growing or a dormant one, are available and are shown in the following Table 3.

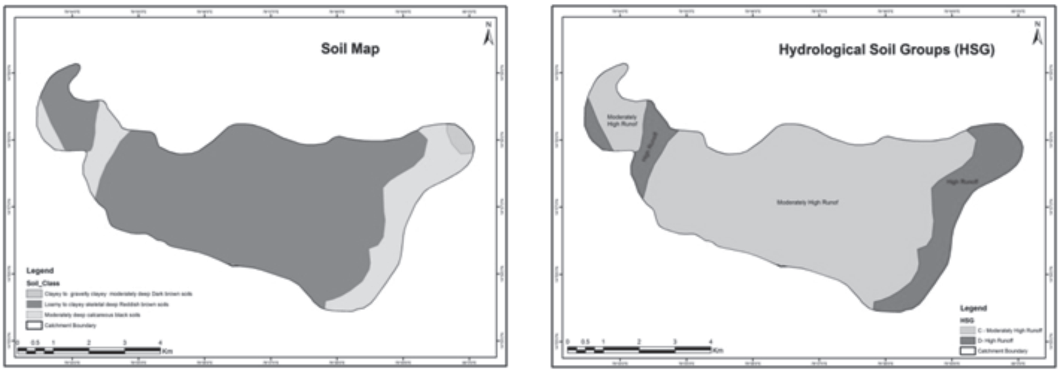
Table 3: Antecedent Moisture Conditions (AMC)

AMC type	5 days total rain in previous season	
	Dormant	Growing
1	13 mm less than	36 mm less than
2	13 to 28 mm	36 to 53 mm
3	28 mm more than	53 mm more than

The determination of CN for AMC Type 2 (CN (2)) can be determined for hydrologic soil cover complexes and land use based on the curve numbers.The curve numbers CN (3) for AMC Type 3 and CN (1) for AMC Type (I)) can be computed by using the following equations:

$$CN(1) = \frac{(4.2CN(2)}{(10\text{-}0.058CN(2)}$$

$$CN(3) = \frac{(23CN(3)}{(10+0.13CN\ (2)}$$



(a) Soil texture (b) Hydrological soil groups

Figure 5: Inputs and Formula of the SCS Method

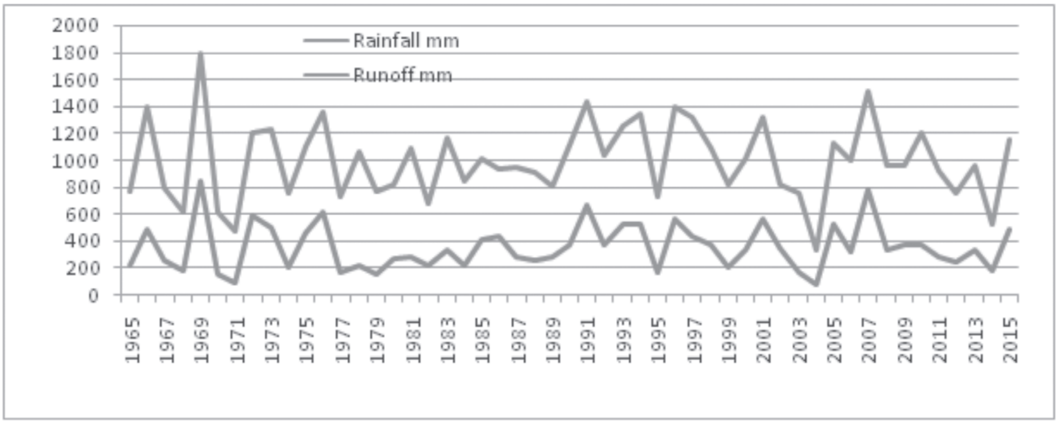
Total curve number was assigned using the unique land use and hydrological soil group. The ratio of total curve number and its corresponding area gives the weighted curve number(WCN).This generated weighted curve number is a factor for runoff estimation. 75 per cent dependable yield was estimated for each tank in the cascade using SCS curve method.The tank-wise details are as follows.

Table 4: Tank -75% Dependable Yield Estimation (Monsoon)

Graph: Kothapalli Tank - Monsoon rainfall and runoff (mm)

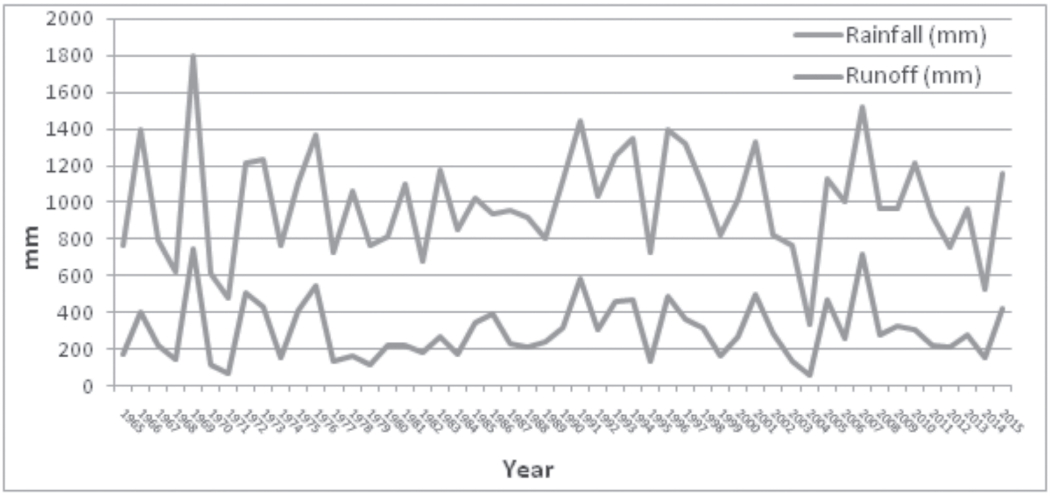
75% yield in mm - 164.58
75% yield in mcft - 82.65

Graph: Narayanapuram Tank - Monsoon rainfall and runoff (mm)



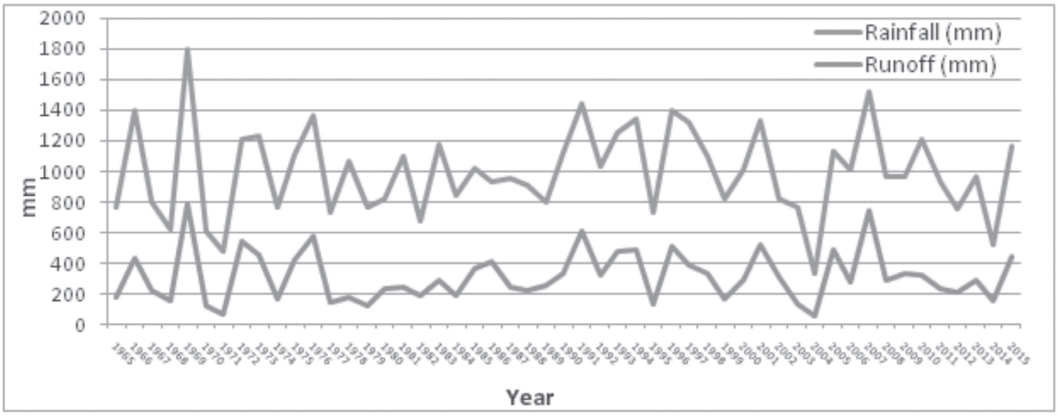
75% yield in mm - 212.84
75% yield in mcft - 13.43

Graph: Siripuram Tank - Monsoon rainfall and runoff (mm)



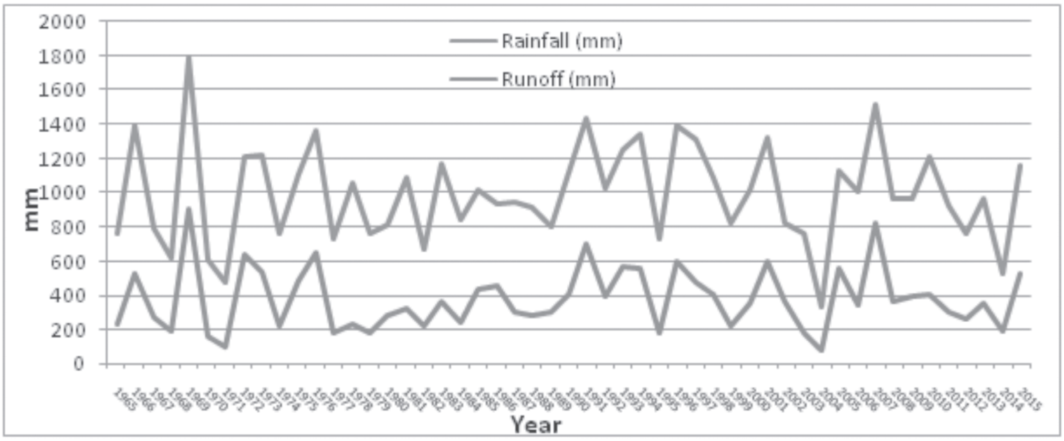
75% yield in mm - 174.69 ,
75% yield in mcft - 29.91

Graph: Kavali Big Tank - Monsoon rainfall and runoff (mm)



75% yield in mm - 188.73
75% yield in mcft - 247.04

Graph: Madhurapadu Tank - Monsoon rainfall and runoff (mm)



75% yield in mm - 233.61
75% yield in mcft - 64.95

Results and Discussion

The objective of the study is to map the land use/land cover of the study area, to have detailed information on the spatial variation to identify the problems in the drainage course of the tank cascade system through GPS survey and to suggest suitable analysis to measure the base data.

The minor irrigation tank system components consist of drainage course, catchments, tank bund, sluice and surplus weir locations.The problems identified are excessive weed growth-choaking of sections of canal, thereby reducing the velocity of flow and causing the deposition of sediment, silt accumulation, aquatic weed growth in water submerged areas is a problem because some of this growth eventually reaches the canals.

Total curve number was assigned using the unique land use and hydrological soil group. The ratio of total curve under and its corresponding area gives the weighted curve number (WCN).This generated weighted curve number is a factor for runoff estimation. Demand calculated 10 acres per one mcft of water. 75% dependable yield was estimated for each tank in the cascade using SCS curve method.The tank-wise details are as follows.

Table 5: Cascade Tanks Analysis Results

S.No.	Village	Name of Tank	Ayacut in Acres	Registered Area (Sqkm)	Catchment Yield (Mcft)	75% Dependable Mcft per acre)	Demand (0.15 (Mcft)	Balance Yield	Status
1	Narayanapuram	Narayanapuram Tank	160.80	1.79	13.43	24.12	-10.69	Viable (Feeding source - Pennar delta canal)
2	Kothapalli	Kothapalli Tank	370	11.04	82.65	55.50	27.15	Viable
3	Siripuram	Siripuram Tank	163	4.85	29.91	24.45	5.46	Viable
4	Kavali	Kavali Big Tank	1856	32.93	247.04	278.40	-31.36	Viable (Feeding source - Pennar delta canal)
5	Madhurapadu	Madhurapadu Tank	109	7.82	64.95	16.35	48.60	Viable

Conclusion

To meet the water demand in Ayacut area, improved irrigation system with proper maintenance is required to increase agriculture production and rising environmental concerns. Changing institutions and management within irrigation systems are now viewed as a catchment area and tank improvement process.This study is conducted towards hydrological viability of minor irrigation tank system. It was found that most of the irrigation tanks do not receive the surplus water from the upstream tanks.Through rainfall, runoff and GIS tracking over the drainage course and tank system, the problems were identified and suitable remedial measures were suggested for augmenting more water to the tank cascade hydrologic system. For optimum utilisation of financial resources it is suggested to receive and restore only those tanks that are hydrologically viable.Hence it is recommended that the rehabilitation of irrigation tank system is very essential. In this study, the and GIS and GPS are proved to be the most effective tools in discerning tank cascade water system.

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