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# WATER BALANCE STUDY AND CONJUNCTIVE WATER USE PLANNING IN IRRIGATION CANAL COMMAND AREA - A REMOTE SENSING PERSPECTIVE

**V. VENKATESHWAR RAO**
*Water Resources Group, National Remote Sensing Agency, Hyderabad, Andhra Pradesh*

**A.K. CHAKRABORTI**
*Water Resources Division, Indian Institute of Remote Sensing, Dehradun, Uttar Pradesh*

***Abstract*** *Water budgeting of the D-36 and D-36A distributaries confined between Peddavagu, Korutla Vagu and Kakatiya main canal of SriRam Sagar Project Command area was conducted using remote sensing derived crop areas, landuse/landcover, irrigation tank inventory, source-wise irrigated areas, etc., together with the conventional meteorological, canal flow and well inventory data. Recharge and water balance in the study area indicate that the net recharge to aquifer is negative to the tune of 254 ha.m. resulting in fall of ground water table by 0.79 m during 1992-93. However, normalised groundwater recharge and water balance estimates indicate an impending water logging problem with an annual ground water table rise of 0.35 m. In view of existing water management practices, a conjunctive water use plan of rotational utilization of groundwater and canal water is suggested.*

## INTRODUCTION

Water budgeting helps to evaluate the net available water resources pertaining to both surface and subsurface and to assess the impact of existing water utilization pattern and practices. The need for accurate and reliable information on crop inventory, land use pattern, land cover, soils, source-wise distribution of irrigated areas, irrigation tank inventory etc. have often precluded quantitative description and analysis of various processes that describe the water resources regime in any irrigation command. The emergence of remote sensing as a tool for providing the above base line information in space and time is both cost and time effective. This information together with the conventional meteorological, canal flows, and well inventory data can be used as input to the various existing empirical, semi-empirical and conceptual models to understand the components of water budgeting and thus aid in developing guidelines for planning sustainable use of groundwater resource in conjunction with surface water resources in an irrigation command area.

The Groundwater Estimation Committee (Ministry of Irrigation, 1984) recognised the availability of groundwater potential in major irrigation projects and recommended specific empirical constants to estimate the recharge from conveyance and distribution system of these projects. These constants are now routinely applied by the various government agencies to estimate the groundwater potential of region. The methodology is based on such specific empirical constants which are modified based on objective information derived from satellite remote sensing data and field data for conducting water balance of study area. Remote sensing derived area estimates of major agricultural crops, source-wise irrigated areas, landuse/land cover and water yield estimates from the irrigation tanks, etc. are used together with the conventional field data as the inputs to estimate various components of water balance and groundwater recharge estimation.

## STUDY AREA

Study area is confined by two tributaries viz. Peddavagu and Korutla Vagu of river Godavari and the Kakatiya main canal of SriRam Sagar project with a gross command area of 6800 ha in Karim Nagar district of Andhra Pradesh. The climate is semi-arid and the average annual rainfall of the study area is 948 mm. Irrigation system in the study area comprises of canals, wells, dug-wells and tanks. D-36 and D-36 A are the two distributaries commanding 3644 and 137 acres. Red soils (sandy loam and sandy clay loam) are predominant covering an area of about 65 per cent of the total extent, while black soils (clay and silty clay) occupy about 35 per cent. The major crops grown are paddy, maize, turmeric sugarcane, ground nut and other crops. Groundwater occurrence is fair to moderate and the quality of groundwater is good to fair for both irrigation and drinking.

## ASSESSMENT OF NET GROUNDWATER RECHARGE

The net regional recharge ($R_n$) to groundwater during any time period is:

$$R_n = R_g \pm Q_g - Q_p \qquad (1)$$

where $R_g$ is gross recharge to groundwater basin; $Q_g$ is groundwater inflow /outflow to neighboring areas; and $Q_p$ is groundwater extraction through wells. The gross recharge ($R_g$) to groundwater basin is:

$$R_g = R_e + R_c + R_d + R_t + R_{ci} + R_{wi} + R_{ti} \qquad (2)$$

where $R_e$ is recharge due to rainfall; $R_c$ is recharge due to seepage from major distributaries; $R_d$ is recharge due to seepage from minor distributaries; $R_t$ is recharge due to percolation from irrigation tanks; $R_{ci}$ is recharge due to percolation losses from canal irrigated areas; $R_{wi}$ is recharge due to percolation from well irrigated areas; and $R_{ti}$ is recharge due to percolation losses from tank irrigated areas.

All the components in Eq. (2) can be estimated using the Remote Sensing derived command area inventory and the recommendations of the Groundwater Estimation Committee of the Ministry of Irrigation (1984), with some modifications based on field observations. The specific percentage allowances for the various recharge components estimated are as follows (Rao and Chakraborti, 1995):

(i) Recharge from rainfall ($R_e$) is estimated as 12.5% of the annual rainfall.

(ii) Recharge due to seepage losses from major distributary at 3.5 cumecs per million sq. m. estimated to be 11% of water delivered.

(iii) Recharge due to seepage from minor distributaries ($R_d$) at 3.5 cumecs per million sq. m. estimated to be 9% of water delivered.

(iv) Recharge due to percolation from Irrigation Tanks ($R_t$) is 25% of live storage capacity.

(v) Recharge due to seepage from canal irrigated areas ($R_{ci}$) at 35% of water delivered at the outlets is 639.57 ha.m.

(vi) Recharge due to seepage from well irrigated areas ($R_{wi}$) at 30% is 60.80 ha.m.

(vii) Recharge due to seepage from tank irrigated areas is 40 percent; as recommended by the groundwater estimates committee is 287 ha.m.

(viii) In addition to above, seepage losses from paddy fields contribute 3 mm $d^{-1}$ for 120 days. Results are presented in Table 1.

**Table 1** Gross Recharge components to Groundwater in the study area in 1992-93

| S.No. | Sources of Recharge | Recharge (ha.m) |
|---|---|---|
| 1. | Recharge from Rainfall ($R_e$) | 518.73 |
| 2. | Recharge from D-36 & D-36A major distributaries ($R_e$) | 172.80 |
| 3. | Recharge from minors ($R_d$) | 125.80 |
| 4. | Recharge from Irrigation Tanks ($R_t$) | 191.20 |
| 5. | Recharge from canal irrigated areas ($R_{ci}$) | 639.57 |
| 6. | Recharge from Tank irrigated areas ($R_{ti}$) | 287.04 |
| 7. | Recharge from areas irrigated by wells ($R_{wi}$) | 601.80 |
| | Total | 2536.34 |

Volume of groundwater ($Q_p$) extracted in the year 1992-93 in Eq. (1) is estimated from well inventory data of the area using average annual drafts for each type of well operating in the region. The sub-surface inflow or outflow of groundwater across the aquifer boundaries ($Q_p$) can not be directly estimated. Hence, it is calculated as residue from the annual (Crop year) water balance equation.

$$(P+I)=\left(ET+E+Q_g+Q_s+Q_P \pm \Delta S_s \pm \Delta S_m \pm \Delta S_g\right) \quad (3)$$

where P is precipitation over the region; *I* is sum of irrigation water applied over the region by the canal system ($Q_c$), groundwater ($Q_p$) and irrigation tank water ($Q_t$); ET is evapotranspiration; E is soil evaporation from the uncultivated areas; $\Delta S_m$ is change in soil moisture storage; $\Delta S_s$ is change in surface water storage; and $\Delta S_g$ change in groundwater storage.

All the above components are expressed in depth units (mm) for the area of 6800 ha. Weighted rainfall estimated using Theissen Polygon method using daily rainfall records of 5 raingauge stations located in and around the area, is used to estimate rainfall for the year 1992-93. Satellite remote sensing derived water yield estimates (Rao and Chakraborti, 1995) from irrigation tanks together with the monthly canal releases at the off take point and groundwater extraction during 1992-93 are used to obtain value of *I*.

For the annual water balance (for the crop year June-May) both $\Delta S_s$ and $\Delta S_m$ may reasonably be assumed to be zero. However, satellite imageries of 5th May 1992 and 8th May

1993 were digitally analysed to examine change in areas. It is found to be 27.4 ha. in May 1992 and 27.1 ha. in May, 1993. Hence, the change in surface water storage during 1992-93 is assumed to be zero. $\Delta S_g$ is calculated from data of premonsoon (April/June) water levels of observation wells distributed over the study area. A value of 0.04 is used as specific yield (Ministry of Irrigation, 1984) for the granitic hard rock unconfined aquifer of the area.

In estimating ET, a distinction is made between evapotranspiration from irrigated and unirrigated areas for each crop. It is presumed that the ET from the irrigated cropped areas both in monsoon & non-monsoon season occurs at potential rate. For the unirrigated crops, ET is limited by maximum available soil moisture at the beginning of the season in the effective rootzone of crops. Normally it is taken as 80 percent of ET (PET or ET crop) from irrigated areas in Kharif-season and 60 percent of ET from irrigated area in Rabi season. Evaporation from uncultivated areas (E) is calculated using Ritchie's equation (Ritchie, 1972)

$$E = ET_o t^{-1/2} \tag{4}$$

where $ET_o$ is the reference evapotranspiration; and t is the time after the last rain in days.

In the monsoon season, when the soil is frequently wetted, E is estimated to be about 50% of $ET_o$ by this formula. In other season it is about 25% (Oct-Feb) and 10% (March-June) of $ET_o$. Remote Sensing derived land use-land cover information together with the basic soil information of the study area are used in GIS environment for estimating area of each land cover in each one of the hydrologic soil groups forming input to USDA Soil Conservation Service (SCS) model to estimate surface runoff (Q).

Once all the terms of the annual water balance equation except $Q_g$ are known, this quantity is determined (Table 2) as a residual of Eq. (3). The net annual recharge and the corresponding water table rise can therefore be estimated (Table 3) using Eqs. (1) and (2). Comparison with the observed water table rise during the year 1992-93 show (Table 3) that the estimates of the water balance and net regional groundwater recharge are realistic.

**Table 2** Annual water balance in the study area for the year 1992-93

| S.No. | Water Balance Component | Quantity (mm) |
|---|---|---|
| 1 | Rainfall (P) | 622 |
| 2 | Canal supplies ($Q_c$) | 229 |
| 3 | Groundwater draft ($Q_w$) | 233 |
| 4 | Irrigation tank supplies ($Q_t$) | 133 |
| 5 | Total Input | 1216 |
| 6 | Evapotranspiration (ET) | 363 |
| 7 | Evaporation (E) | 299 |
| 8 | Pumpage ($Q_w$) | 233 |
| 9 | Change in ground storage ($\Delta S_g$) | -32* |
| 10 | Surface Run-off ($Q_s$) | 175 |
| 11 | Total Output | 1038 |
| 12 | Groundwater Outflow ($Q_g$) | 178 |

* '-' sign indicates falling water table.

**Table 3** Comparison of computed and observed water table in the study area

| Gross groundwater recharge (Rg) (ha.m.) | Groundwater outflow (Qp) (ha.m) | Groundwater draft (Qg) (ha.m.) | Net groundwater recharge (Rn) (ha.m.) | Equivalent fall in water table (m) | Observed water table fall (m) |
|---|---|---|---|---|---|
| 2536 | 1210.0 | 1580 | 245 | 0.093 | 0.79 |

## RESULTS AND DISCUSSION

A systematic analysis of irrigation water demand in relation to available canal supplies, groundwater and irrigation tank water is undertaken in the present study by comparing monthly and seasonal canal water availability with the corresponding demand for water from CCA (Culturable Command Area) of D36 and D-36A distributaries and from the total cropped area. The balancing role of groundwater as an additional resource and for increasing the reliability of system operation is also examined. The analysis of groundwater recharge and water balance study are examined in this context to investigate the scope for possible conjunctive water use in the study area.

### Status of Water Management and Implications for Conjunctive Water Use

Following are the observations from the supply-demand study conducted (Rao and Chakraborti, 1995) using satellite derived command area inventory:

1. It is observed that the contribution to the total irrigated area from various sources of irrigation i.e., canals, wells and tanks are 40, 41 and 19 percent, respectively during the year 1992-93.
2. It is observed that for the net sown area, the total available irrigation water from all the sources is 38.50 MCM, where as the requirement is 41.74 MCM, resulting in a deficit of 3.2 MCM in 1992-93. This emphasises the need for balancing the role of groundwater in conjunction with the proper regulation of canal flows so as to avoid surplus/deficit situations during various time periods (months) during the crop year (1992-93).
3. It also brings out the fact that the cropping pattern in canal command area show a large deviation from the designed cropping pattern, eventually leading to mismanagement of canal waters. This is reflected in the reduction of the total command which is 820 ha. in 1992-93, whereas the designed command is 1512 ha. The impact of this deviance is also reflected in the monthly supply-demand study resulting in deficits in the months of July and April due to the large area under paddy crop though there exists a surplus of 4.34 MCM in canal supplies.

From groundwater recharge study it can be seen that return irrigation from canal irrigated areas contribute 25 percent of gross recharge. Well and Tank irrigated areas contribute 24 percent and 11 percent respectively. The contribution from rainfall is around 20%. The annual net groundwater recharge is found to be negative to the tune of 254 ha-m resulting in a fall of groundwater table by 0.79 m. In the event of normal rainfall (rainfall during 1992-93 is 622 mm, which is 34 per cent less than average annual rainfall), contribution at the rate 12.5 percent of annual rainfall to recharge would result in higher contribution to gross recharge. Normalised values of the recharge estimates indicate that there will be around 100 ha.m. net recharge available as additional potential which could cause water table rise by 0.35 m.

The twin objectives of conjunctive water use, namely lowering the water table to control water logging and augmenting the canal supplies while increasing their reliability, are incompatible unless at least two additional factors are included. The first is the depth of water table as primary design variable and the second significant factor is that canal water and groundwater must be used rotationally in different time periods. The rotational periods will be unequal and will vary with irrigation system and aquifer conditions. The operation of surface and groundwater system in successive periods will to increased storage (increased flows in canals) in both surface and subsurface reservoirs and to improvements in overall water use efficiency.

From the groundwater budgeting and supply-demand study, the following rotational cycle of conjunctive water use is suggested in the study area. Deficit for irrigation water in the month of July is due to non-adherence to the design cropping pattern. Hence, original cropping pattern envisaged in the design is to be restored so that a large area can be brought under irrigation (under ID crops) and to meet the over all deficit of 2.7 MCM in 1992-93. The aquifers are to be pumped to pre defined limit (between 3 m to 6 m is suggested based on historical well inventory data of the study area) at this stage to lower water table and to meet the transplanting requirement of paddy in this month before operating canals. Huge requirement in this month can be met by the monsoon rainfall besides groundwater. Next canals should be run for 40-50 days, this will once again raise the water levels, which is lowered in the next cycle by abstraction from the aquifer. This also meets the high requirement during September-October months in the study area. This cycle can be repeated to meet excess demand in December during Rabi Paddy transplantation. This rotational cycle of conjunctive water use not only eliminate intra and inter seasonal imbalances in supply-demand but also lead to additional development of groundwater potential which ensure improved water management and brings more area under assured irrigation.

## CONCLUSIONS

Remote sensing derived command area inventory is successfully used in conducting and validating groundwater budgeting in the study area. Water budgeting indicates that the net recharge to aquifer is negative to the extent of 254 ha. m. But, the normalised groundwater balance estimates indicate the impending water logging situation. A conjunctive water use plan of rotational utilization of groundwater and canal water is suggested based on existing water management practices.

The design of conjunctive water use schemes in irrigation projects needs to be based on an understanding of the interactions between the surface water and groundwater system of the area. This is done as discussed in this paper. However, further similar study needs to be conducted for at least 3 to 4 years to draw more realistic conjunctive water use strategies in the study area.

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