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Conjunctive use planning of surface and ground water resources

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Abstract

The quantity and quality of available water resources have been recognized as limiting factors in development of most of the arid and semi arid regions. Optimal use of available surface and groundwater, Shortages of surface water supplies have increased the need of groundwater development in many canal commands. In the present the feasibility of conjunctive use management is analyzed using a mathematical model in the Tungabhadra side channel irrigation command area of Krishna western delta in Andhra Pradesh, India. Demand and availability of water resources in the study area are evaluated considering both surface water and groundwater. A simple optimization model is presented to explore the possibilities of conjunctive use of surface and groundwater using linear programming model with various hydrological and management constraints, and to arrive at an optimal cropping pattern for optimal use of water resources for maximization of net benefits. The results indicate that conjunctive use options are feasible and can be easily implemented in the area.

Keywords: Surface water, ground water, conjunctive use, linear programming model and cropping pattern

Introduction

Agriculture sector in Andhra Pradesh uses more than 95% of harnessed water resources. Bulk of the State's irrigation development is on interstate rivers of Krishna and Godavari and there is increasing uncertainty of timing and availability of irrigation supplies due to irrigation developments by upstream states of Karnataka and Maharashtra. Conjunctive use is defined as the allocation of surface and groundwater in terms of quantity and quality so as to achieve one or more objectives while satisfying certain constraints. As irrigation is the major water used sector worldwide, with an average consumptive use of 70 percent, managing surface and groundwater resources in irrigation systems for optimal productivity under conditions of scarcity is an essential issue. Conjunctive use of surface and groundwater has not been given adequate attention in India. Till recently, planning for development and management of groundwater and surface water was done in isolation. Analysis of conjunctive use programmers in India reveals that in most of the cases, the optimal use of both surface and groundwater resources is not properly envisaged in reality. None of the states have formulated so far, a clear-cut operational plan for conjunctive use in any irrigation projects.

The Krishna delta irrigation system comprises of two components viz. Krishna Eastern Main Canal System (2.72 lakh ha ayacut) and Krishna Western Main Canal System (2.42 lakh ha ayacut). As per the Krishna Water Dispute Tribunal Award, 181.2 TMC of water is allocated to the Krishna Delta System, in which 162 TMC is used in kharif season only. The districts covered under Krishna Western Delta (KWD) are Guntur and Prakasam. The designed duty for KWD is 1287 ha/cumec or 91 acres/cusec. The study location for the present study, Tungabhadra Side (TS) Channel (Fig.1) was chosen based on the recommendations of Central Ground Water Department (2007) for exploring the scope for utilization of ground water use in conjunction with surface canal water.

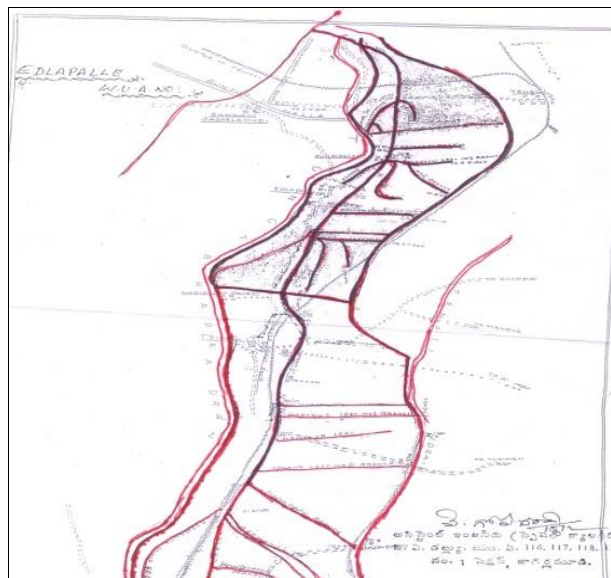


Fig 1: Map of Tungabhadra Side (TS) channel

Data and Methodology

Tungabhadra side channel takes off at 29.346th Km on left bank of Commamuru canal with a head discharge of 10.2 cumecs was considered for the study. It runs for a length of 18.961 Km and irrigates an extent of 9832 ha ac. Detailed investigations were carried out to study the existing condition of the channel. The existing bed level is far below the designed bed level throughout its length varying from 40cm to 90cm. This clearly indicates that earth is taken away from the bed of the channel but not due to scouring. There are 3 double lane bridges; 6 no. of single lane bridges, 4 cross drainage works - 4 Under Tunnels, 2 regulators, and 17 nos. of slab off take sluices and 30 nos. of pipe sluices on the channel.

Assessment of surface and ground water resources in the study area

The data pertaining to surface water resources of TS channel was collected from irrigation department and the availability was estimated and presented in Table 1.

Table 1: Available surface water resources (canal water) in the study area

Sl. No.	Month	Discharge (cusec)	Discharge (m ³ /sec)	water allocated (ha m)	Seepage from main canal (ha m)	water allocated (ha m)
1	January	88.40	2.50	670.04	134.01	536.03
2	February	67.31	1.90	460.81	92.16	368.65
3	March	55.23	1.56	418.63	83.73	334.91
4	April	23.00	0.65	168.68	33.74	134.94
5	May	3.61	0.10	27.36	5.47	21.89
6	June	0.00	0.0	0.00	0.00	0.00
7	July	45.53	1.29	345.09	69.02	276.07
8	August	235.72	6.67	1786.72	357.34	1429.37
9	September	268.62	7.60	1970.40	394.08	1576.32
10	October	277.08	7.84	2100.22	420.04	1680.17
11	November	209.59	5.93	1537.44	307.49	1229.95
12	December	73.98	2.09	560.75	112.15	448.60

The data on ground water table fluctuations for 5 years in the TS channel command was collected and presented month wise in Table 2. From the fluctuations, the availability of ground water resources was estimated and substituted in the model.

Use of linear programming model

The model consists of objective function and a set of constraints. The linear programming technique has been used to formulate the conjunctive use optimization model, to arrive at the optimal allocation of surface and groundwater, to maximize the benefits within the framework of given constraints and designed cropping pattern (Ediwhayunan, 2002) ^[2]. One year planning horizon was considered with monthly planning period. In the present study, the MS office Excel based 'Solver' Add-in package is used to solve the model. The linear programming model was run for eight hypothetical scenarios, one including the existing average monthly (10 years average) available canal flow as the 100% surface water.

Table 2: Ground water table fluctuations in the TS channel command

Sl. No.	Year	Jan	Mar	May	July	Sept	Nov
1	2005	3.1	3.76	4.26	4.55	1	1.46
2	2006	2.56	2.92	2.92	3.6	0.9	1.26
3	2007	2.76	2.99	3.18	2.68	1.11	1.45
4	2008	2.96	1.2	3.36	3.83	0.87	1.03
5	2009	2.61	3.28	3.45	4.08	2.44	1.79
6	2010	2.97	3.59	3.7	3.51	0.68	0.96
7	2011	2.53	3.33	3.68	4.08	1.61	1.82

Table 3: Net profits per hectare as per the existing cropping pattern in the study area

Sl. No.	Crop	Minimum price Rs/quintal	Yield (kg/ha)	Total receipts (Rs/ha)	Cost of Cultivation	Net benefits (Rs/ha)
1	Paddy	900	5,500	49,500	29,500	20,000
2	Maize	1,000	4,000	40,000	15,000	25,000
3	Chilly	2,500	4,100	1,02,500	72,500	30,000
4	Black Gram	2,500	1,000	25,000	5,000	20,000

Source: www.indianstat.com

CROPWAT 8.0 model was used to estimate the crop water requirement of different crops grown in the study area. The

procedure of the usage of the model is not described in this research article.

Table 4: Estimated monthly crop water requirement of different crops

Sl. No.	Month	Paddy (mm)	Maize (mm)	Black gram (mm)	Chillies (mm)
1	January	0	104.53	0	100
2	February	0	118.27	0	113
3	March	0	151.03	132	144
4	April	0	168.84	148	0
5	May	0	0	153	0
6	June	0	0	121	0
7	July	315.5	0	0	0
8	August	128.7	0	0	0
9	September	127.4	0	0	122
10	October	123.5	0	0	118
11	November	106.6	0	0	102
12	December	0	97.09	0	93
	Total	801.72	639.77	554	794

The objective function was formulated for maximizing the net benefits resulting from the cropping activity in the study area. The unit cost of surface water was calculated based on the available discharge at the outlet. The unit cost of surface water was considered the same for all the months during which the surface water is available. Cost analysis of groundwater was out based on the data obtained from the study area.

Net benefit maximization

The objective is to maximize the net benefit from different crops grown in the command area in different seasons, i.e. monsoon and non-monsoon seasons.

Maximum net annual benefits

$$\text{Maximize } Z = \sum_{i=1}^{nz} \sum_{j=1}^{nc} A_{ij} \times NB_j - \sum_{i=1}^{nz} \sum_{k=1}^{12} CST_i \times SW_{i,k} - \sum_{i=1}^{nz} \sum_{k=1}^{12} CGT_i \times GW_{i,k}$$

Where,

i is the number of zones of the study area ($i = 1, 2, \dots, nz$), j is the number of crops ($j = 1, 2, \dots, nc$), k is the number of months ($k = 1, 2, \dots, 12$), A_{ij} is the area under the crop in i^{th} zone (ha), Y_j is the yield of j^{th} crop (kg/ha), P_j is the price of j^{th} crop (Rs/kg), CCL_j is the total cost of cultivation for j^{th} crop excluding the cost of water, NB_j is the net benefits for j^{th} crop excluding the cost of water, CSC_i is the unit capital cost of surface water for i^{th} zone (Rs/ham), CSO_i is the unit operation and maintenance (O&M) cost of surface water for i^{th} zone (Rs/ha m), CST_i is the total unit cost of surface water for i^{th} zone (Rs/ha m), $SW_{i,k}$ is the surface water allocation for i^{th} zone during k^{th} time interval (ha m), CGT_i is the total unit cost of groundwater for i^{th} zone (Rs/ha m), $GW_{i,k}$ is the groundwater allocation for i^{th} zone during k^{th} time period (ha m).

Water requirement constraints

The total monthly water requirement for all the crops in each zone shall be met by surface and groundwater allocations. In the present investigation water requirement has been considered at the canal outlet. Therefore, constraints for water requirement for the crops can be written as

$$\sum_{j=1}^{nc} WR_{j,k} \times A_{i,j} = \sum_{i=1}^{nz} SW_{i,k} + GW_{i,k}$$

Where, WR_j , k is the water requirement of j^{th} crop for k^{th} time period (m), $A_{i,j}$ is the area of j^{th} crop for i^{th} zone (ha).

Area availability constraints

$$\sum_{k=1}^n A_{ijk} \leq TA_{ij} ;$$

Where, TA_{ij} = total cultivable command area of sector i in season j (ha)

Surface water availability constraints

$$\sum_{i=1}^{nz} \sum_{k=1}^{12} \frac{SW_{i,k}}{ES_{dmi} \times ES_{ci}} \leq \sum_{k=1}^{12} SWA_k$$

Where, $SW_{i,k}$ is the surface water allocation for i^{th} zone during k^{th} time interval (ha m), ES_{dmi} is the efficiency of the surface water system for distributaries and minors for i^{th} zone, ES_{ci} is the conveyance efficiency of canal for i^{th} zone, SWA_k is the surface water available at the head of canal (ha m) for k^{th} time interval (ha m).

Ground water availability constraints

The total water pumped annually from the groundwater resources of the study area should not exceed the annual recharge without allowing mining. Thus, the constraints on groundwater availability for all the zone of the study area can be written as:

$$\sum_{i=1}^{nz} \sum_{k=1}^{12} GW_{i,k} \leq \mu \times GWA$$

Where, $GW_{i,k}$ is the groundwater water allocation for i^{th} zone during k^{th} time interval (ha m), μ is the mining allowance (=1 when no mining is allowed), and GWA is the annual groundwater recharge.

Crop area constraints

Depending upon socio-economic needs of the area these constraints are applied. These constraints have been imposed on each individual crop such that

$$A_{ij} = p_{ij} \times CCA_i$$

Where, p_{ij} is the percentage of j^{th} crop in i^{th} zone with respect to CCA of i^{th} zone, i.e., ratio of area under j^{th} crop in i^{th} zone and CCA of i^{th} zone.

Results and Discussion

The linear programming model was used to investigate the different integrated conjunctive water use policy options. The linear programming model was run for eight hypothetical scenarios, one including the existing pattern of utilizing the 100% surface water. The hypotheses assumed for running the LP model are listed below. 1) 100% surface water + 100% ground water. 2) 100% surface water only 3) 90% surface + 100% ground water 4) 90% surface water only. 5) 80% surface water + 100% ground water 6) 80% surface water only 7) 70% surface water + 100% ground water 8) 70% surface water only. This type of analysis is highly essential in planning for crop shifts or crop planning purpose in the entire TS channel command area in co-ordination with all the line Departments namely Agriculture and Irrigation Departments.

From Figure 2, it is obvious that there is a need of ground water

during December to April and in July month in the project area. April to June are summer fallow months showing no water usage. From August to November, the surface water availability is more and if the water is efficiently used, more area downstream could be brought under cultivation. Model gave more area for cultivation with more or less same profit for the crops compared to the earlier scenario showing the advantage of going for the use of ground water. April to June are summer fallow months showing no water usage. There is a net reduction of 7% in the area under production and net benefits when compared to the ideal scenario. (Fig.4)

Model gave less area for cultivation for the crops compared to the earlier scenario showing the drastic reduction in the net benefits and area under production with the reduction in the surface water availability by 10% and without ground water usage. (Fig.5) There is almost a net reduction of 35% the area under production and also in the net benefits in the similar tune when compared to the ideal scenario. Model gave less area for cultivation and as well fewer net benefits for the crops compared to the earlier conjunctive use scenario showing the advantage of going for the use of ground water. There is a reduction of 14.3% area under production and net benefits compared earlier scenario i.e., 80% surface water 100% ground water (Fig.6).

A drastic reduction in the area under production and net benefits will be encountered under situations of. 44% reduced canal flows and no ground water pumping (Fig.7). Model gave less area for cultivation for the crops compared to the earlier scenario showing the advantage of going for the use of ground water. There is a reduction of 22% in area allocation for production consequently 22% is the reduction in net benefits when compared to the ideal situation (Fig.8). Model gave less area for cultivation for the crops compared to the earlier scenario showing the advantage of going for the use of ground water.

There is almost a net reduction of 50% in the area allocation for production and consequently affecting reduction 50% net benefits when 70% of canal water is available in the command and no ground water is utilized (Fig.9).

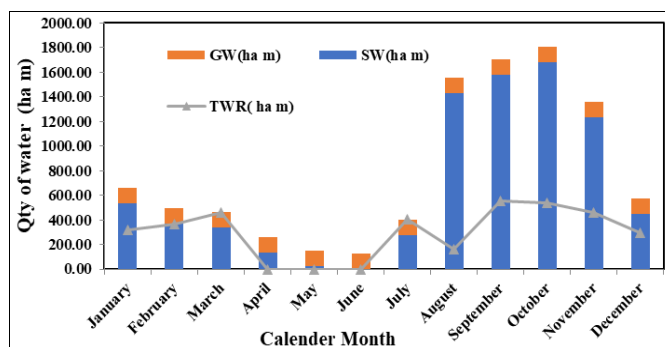


Fig 2: Optimal allocation of surface and ground water for the proposed cropping pattern (100% surface and 100% ground water)

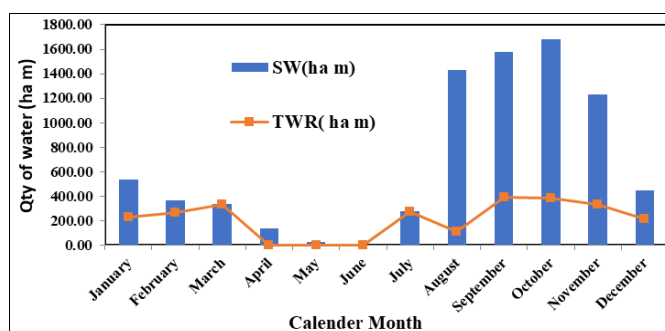


Fig 3: Optimal allocation of surface water for the proposed cropping pattern (100% surface water only)

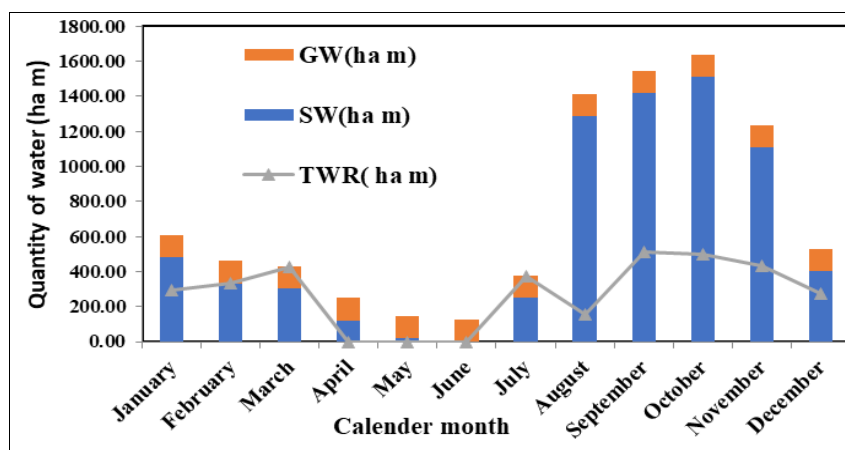


Fig 4: Optimal allocation of surface water for the proposed cropping pattern (90% surface and 100%ground water utilization)

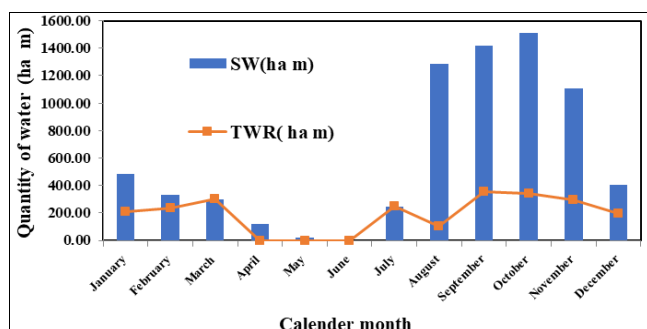


Fig 5: Optimal allocation of surface water for the proposed cropping pattern (90% surface water only)

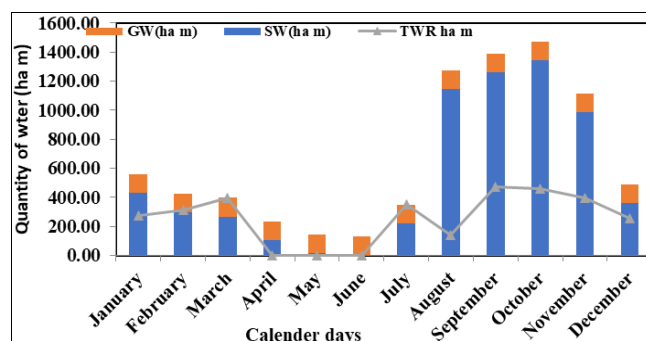


Fig 6: Optimal allocation of surface water for the proposed cropping pattern (80% surface and 100%ground water utilization)

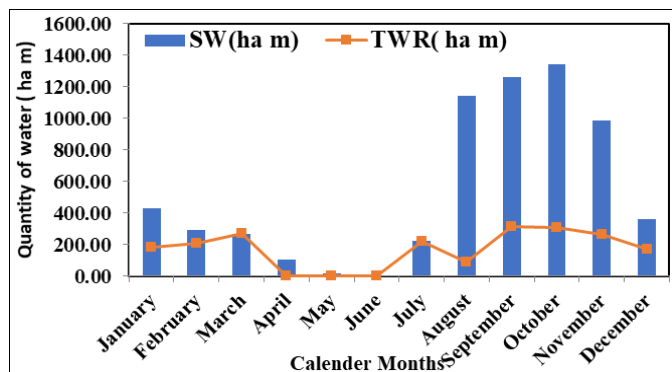


Fig 7: Optimal allocation of surface water for the proposed cropping pattern (80% surface only)

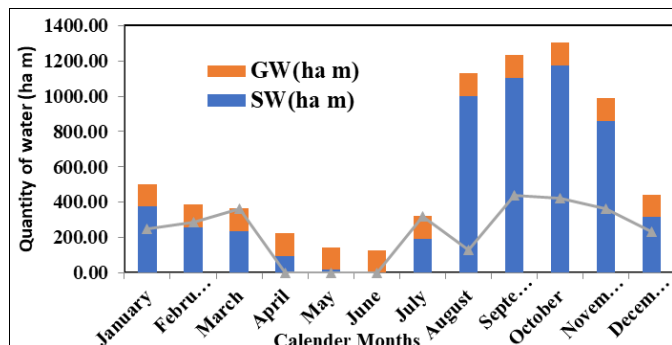


Fig 8: Optimal allocation of surface water for the proposed cropping pattern (70% surface and 100% ground water utilization)

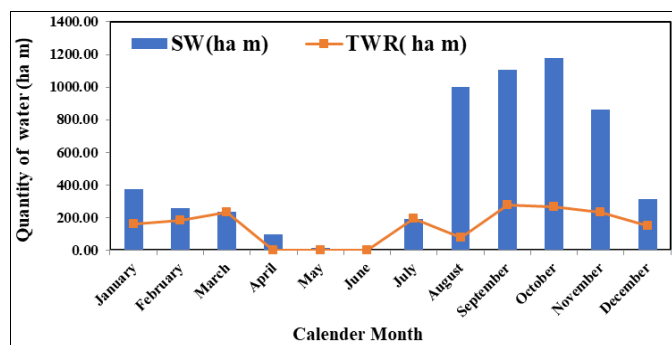


Fig 9: Optimal allocation of surface water for the proposed cropping pattern (70% surface water only)

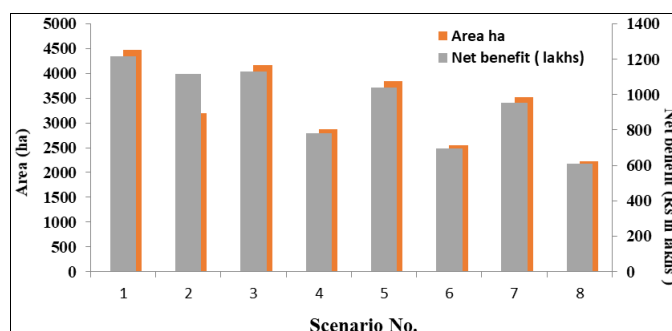


Fig 10: Net profit and area allocation by the model under various scenarios

Conclusion

This type of conjunctive use planning exercise would enable one to plan for crop shifts under extreme situations of reduction of canal flows. Out of all the eight hypothetical scenarios assumed, it is found a reduction of -7%, 14.5% and 21% in net profit and area under production while using 90%, 80%, 70% of surface

water respectively when conjunctively used with ground water in the command area as against first scenario (100% surface and 100% ground water) Out of all the eight hypothetical scenarios assumed, it is found a reduction of 35%, 44% and 50% in net profit and area under production while using 90%, 80%, 70% of surface water resources alone, respectively as against the first scenario (100% surface and 100% ground water). This type of exercise would enable one to plan for crop shifts under extreme situations of reduction of canal flows. This type of study with little exercise, with different more other cropping choices matching the water requirements could enable better planning in any command area

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