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PEOPLE-CENTRED APPROACHES TO WATER AND ENVIRONMENTAL SANITATION

Community wells for sustainable irrigation in tank commands: A case study

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An optimization model has been formulated to maximize the net benefit from a tank command with conjunctive use of surface water from the tank and ground water from wells and community well in the tank area. The Kannangudi tank in Pudukkottai district, Tamil Nadu, India has been taken as the case study. Six crops were found in the command area and are considered for arriving the optimal cropping pattern. The study result shows that, the wells and community well in a tank command contributes to a sustainable irrigation and apparently maximize the net benefit from that tank command.

Introduction

Tamil Nadu state in India irrigates an area of about 0.91 M.ha through 39,200 tanks, which accounts for 17% of all tanks in the country. Apart from surface irrigation, the tank serves as a recharging structure for the underlying aquifer. In most of the tank system, the area near the tank (head reach) receives water for two crops, middle reach receives water for one full crop and tail reach area suffers from water shortage even for a single crop mainly due to the location of sluices at different levels. This situation in the tail reach and part of middle reach, can be managed by constructing a community well (well common to the farmers community in that area) and tapping the recharged ground water for irrigation.

In the recent past considerable attention has been paid to the integrated use of surface and ground water in large reservoir, but little work has been done in tank commands. For sustainable agriculture in the tank commands judicious use of water from different sources are essential.

Maknoon and Budges (1987) listed out the chronological development of the conjunctive use approach. Mohan and Jothiprakash (2003) listed out different types of conjunctive use based on possible combination of land, water and time. Some of the important works reported in conjunctive use modeling are Chandhry (1974), Lakshminarayanan and Rajagopal (1977), Chavez – Moral et al (1987), Kumar and Pathak (1989), Onta and Gupta (1991), Mohan and Arumugam (1992), Peralta et al (1995) Panda et al (1996), Jothiprakash et al (2002), Mohan et al (1998), Emch and Yeh (1998), Belainesh et al (1999).

In the present study, a linear programming model has been formulated for arriving optimal cropping pattern in a tank system. The model has been developed considering the conjunctive use of surface water from the tank and ground water from community wells, lying in the aquifer near the tank.

Model Development

A linear programming model suggested by Loucks et al. (1981) and Lakshminarayana and Rajagopalan (1977) has been used to allocate the available resources and to derive optimal cropping pattern in the tank command. The objective function and the constraints of the developed model are explained below.

The objective function is to maximize the net benefits incurred due to irrigation in the tank command and is given by

Max NB =

$$\sum_{z=1}^{Z}\sum_{i=1}^{N} B_i Ax_{zi} - \sum_{z=1}^{Z}\sum_{i=1}^{N} C_i Ax_{zi} - \sum_{z=1}^{Z}\sum_{t=1}^{12} C_{sw} SW_{zt} - \sum_{z=1}^{Z}\sum_{t=1}^{12} C_{gw} GW_{zt}$$

where, NB- Net benefit in rupees (Rs)
Bi- Benefit incurred from crop ‘i’
Ci- Cost of cultivation for crop ‘i’
i- No of crops: i=1,2,…,N
z- Sluice number:z=1,2 &3
Axzi- Area of ith crop under sluice ‘z’
t - Time period in months
Csw – Cost of surface water in Rs/Mm3 (Rs 1.5/m3, paid interms of land tax)
SWzt - Surface water release (Mm3) to sluice z in period t
Cgw – Cost of ground water in Rs/Mm3 (Rs 4.5/m3, paid interms of pumping cost)
GWzt- Ground water pumpage during time period ‘t’ in sluice ‘z’
The objective function is subjected to the following constraints.

Surface water storage constraints

The storage at any month should not exceed the maximum storage (0.65 Mm3) and minimum storage in all months.

$$S_t \le 0.65 \quad t=1,2,\ldots,12 \quad (2)$$

$$S_t \ge 0.005 \quad t=1,2,\ldots,12 \quad (3)$$

where, St- Storage in the tank during time period 't'.

Ground water constraints

The total ground water pumpage from the wells under each sluice in each month should not exceed the safe yield of the aquifer. These constrains are mathematically expressed as follows:

$$GW_{zt} \le Sy_z \quad t=1,2,\ldots,12 \quad (4)$$

where,

Syz - Safe yield of aquifer under sluice 'z',

Water allocation constraints

The quantity of irrigation water required for each crop in each month should be met with either from the surface water in the tank or from the ground water in the aquifer. These constraints are given as:

$$\sum_{i=1}^{N} NIR_{it} Ax_{zi} \ge \eta_s SW_{zt} + \eta_g GW_{zt}$$
$$t=1,2,\ldots 12 \quad z=1,2\&3 \quad (5)$$

where, NIRit – Net irrigation requirement for the crop 'i' during the month 't'

ηs- efficiency of the surface water irrigation (60%) and

ηg - efficiency of the ground water irrigation (85%)

Continuity constraints

The month to month relation of storage in the tank and releases are given by continuity equation and mathematically it is represented as

$$S_{t+1} = S_t + I_t - \sum_{z=1}^{Z} SW_{zt} - E_t - O_t$$
$$t=1,2,\ldots,12 \quad (6)$$

where , St+1 - Storage in the tank at time t+1

It - Monthly inflow into the tank during time t

Et - Evaporation in the tank during time t and

Ot - Surplus from the tank during time t

Overflow Constraints

If no constraint on overflow is provided then the linear programming model will result in overflow even when the reservoir storage is less than the capacity and hence the overflow constraint developed by Chavez-Morales et al (1987) is used in the present study. The overflow constraint is given by

$$O_t = S_t + I_t - \sum_{z=1}^{Z} SW_{zt} - E_t - S_{\max}$$
$$O_t \ge 0$$
$$t = 1,2,\ldots 12 \quad (7)$$

Along with the above constraints the total irrigation area constraints in each season, minimum irrigation area under each crop and non – negativity constraints are also incorporated.

Study area

Kannangudi tank in Pudukkottai district in Tamil Nadu, India has been selected as the case study. The basin is situated between 10°40'05''N latitude and 18°30'45'' longitude and it has an altitude of 92.650 m. above m.s.l. Kannangudi tank comes under the non-system tank (does not have any feeding canal from a river) (Mohanakrishnan, 1992) and it is situated North of Kannangudi village in Kulathur Taluk of Pudukkottai district and about 35 km from Trichy in Tamil Nadu, India. The catchement covers an area of 23.427 km2. This tank has a capacity of 0.65 Mm3 and serves 116.050 hectares through the three sluices. The area under sluice I, sluice II and sluice III is 30.980 ha, 73.42 ha and 13.235 ha respectively. The location of the study area is shown in Figure 1. High rainfall of 408.6 mm is experienced in North-east monsoon during the months of October, November and December. The annual rainfall in the study area is around 898.06 mm. The ground water is observed in 5 to 25 m depths below ground level. The main crop grown in the command area are Rice-Samba (Aug-Jan), Rice-Thaladi I (Jan-May), Rice-Thaladi II (May-Sep), Groundnut (May-Sep), Cotton (Mar-Aug) and Sugarcane (Annual).

Community well

Community wells are not new to Tamil Nadu. These wells are found in many villages mostly as drinking water wells rather than an as an irrigation well. This methodology of constructing a community well can be adopted in tank irrigation also. Usually the community wells are located in the head reach of the tank to harvest the unnoticeable ground water, which is wasted through the aquifer. This water can be conjunctively used with the surface water, when the water from the tank is insufficient to raise the crop. The community wells are managed by group of farmers. Thus making integrity among the farmers in water sharing. An informal rules and regulations for the operation of the community wells is available with the water users association. In the present study area only one community well is existing in the sluice III and is shown in Figure 1,all other wells are owned by individual farmers.

Table1. Monthly net irrigation requirements for various crops in the study area (mm)

Month	Rice			Groundnut	Cotton	Sugarcane
	Samba	Thaladi-I	Thaladi-II			
Jan	-	35	-	-	-	12
Feb	-	53	-	-	-	49
Mar	-	110	-	-	59	140
Apr	-	90	-	-	93	146
May	-	50	63	19	121	189
Jun	-	-	101	40	120	170
Jul	-	-	86	86	49	174
Aug	73	-	62	78	25	160
Sept	127	-	82	5	-	150
Oct	71	-	-	-	-	106
Nov	48	-	-	-	-	50
Dec	21	-	-	-	-	16
Annual	340	338	394	228	467	1362

Data base

The data required for this study was collected form Public Works Department, Pudukkottai district, Government of Tamil Nadu, India. The field data, regarding the cropping pattern, cost of cultivation, net benefit from the each crops were collected through socio-economic survey. Rice, Sugarcane, Cotton and Groundnut are the main crops being cultivated in the study area. Out of the above crops, rice occupies a larger portion of the command area. Monthly net irrigation requirement for each crop grown in the command area was estimated based on the methodology suggested by Doorenbos and Pruitt (1977). The evapotranspiration was estimated using FAO modified Penman method. The estimated NIR is listed in Table 1. The cropping details regarding yield, cost of cultivation, labour and fertilizer requirements for each crop is depicted in Table 2. The mean monthly inflow into the tank for the period of 10 years is shown in Table 3. From the probability studies it is found that 75% dependable inflow level has mostly zero inflow during most of the months, hence average inflow values are used in deriving the cropping pattern. From the water level fluctuation and specific yield method, it is found that the safe yield of the aquifer in sluice I is 1289 lph. The safe yield under sluice II and sluice III are 1394 and 1332 lph respectively.

Table 2 Net benefit calculation for each crop (Rs/ha)

Crop	Yield Kg/ha	Market value Rs/kg	Cost of cultivation Rs/ha	Net Benefit Rs/ha
Samba	3335	8		14330
Thaladi-I	4076	5	12350	8030
Thaladi-II	4076	5	12350	8030
Groundnut	1729	9	9386	6175
Cotton	525	47	11115	13560
Sugarcane	98800	0.8	24700	54340

Table. 3 Monthly inflow into the tank (Mm^3)

Month	Mean
Jan	0.11
Feb	0.04
Mar	0.07
Apr	0.14
May	0.13
Jun	0.10
Jul	0.18
Aug	0.08
Sep	0.36
Oct	0.10
Nov	0.02
Dec	0.18

Results and discussion

The revised simplex method was used to find the optimal cropping pattern, sluice releases, and ground water pumpage with one year as the planning horizon.

With above developed model, the optimal cropping pattern was determined for two different scenarios. One is without conjunctive use and other one is with conjunctive use. In the first scenario the model consisted of 66 variables and 105 constraints. The developed model was solved using revised simplex method. The net benefit resulted for this scenario is Rs. 11,57,895.33 ($1=Rs. 52). The optimal allocation of surface water from the tank is shown in Figure 2. The sluice wise release resulted from the model showed that the release in the sluice 2 is more than the other two sluices. For this scenario the area irrigated under sluice 1, sluice 2, and sluice 3 are 39.41ha, 63 ha and 13 ha respectively.

In the next scenario the model was solved with conjunctive use of surface water and ground water. This model consisted of 102 variables and 141constraints. This model is also solved using revised simplex method. The net benefit resulted from this scenario is Rs. 26,67,462.49 The increase in the net benefit in this scenario is due to cultivation of sugarcane. Whereas in earlier scenario (without conjunctive use) the sugarcane has not entered into the feasible solution region. The optimal allocation of surface water and ground water for the second scenario is also shown in Figure 2. From Figure 2 it can be seen that the surface water utilization in second case is less and also the total water used is less (sum of surface water and ground water) because of higher efficiency in using

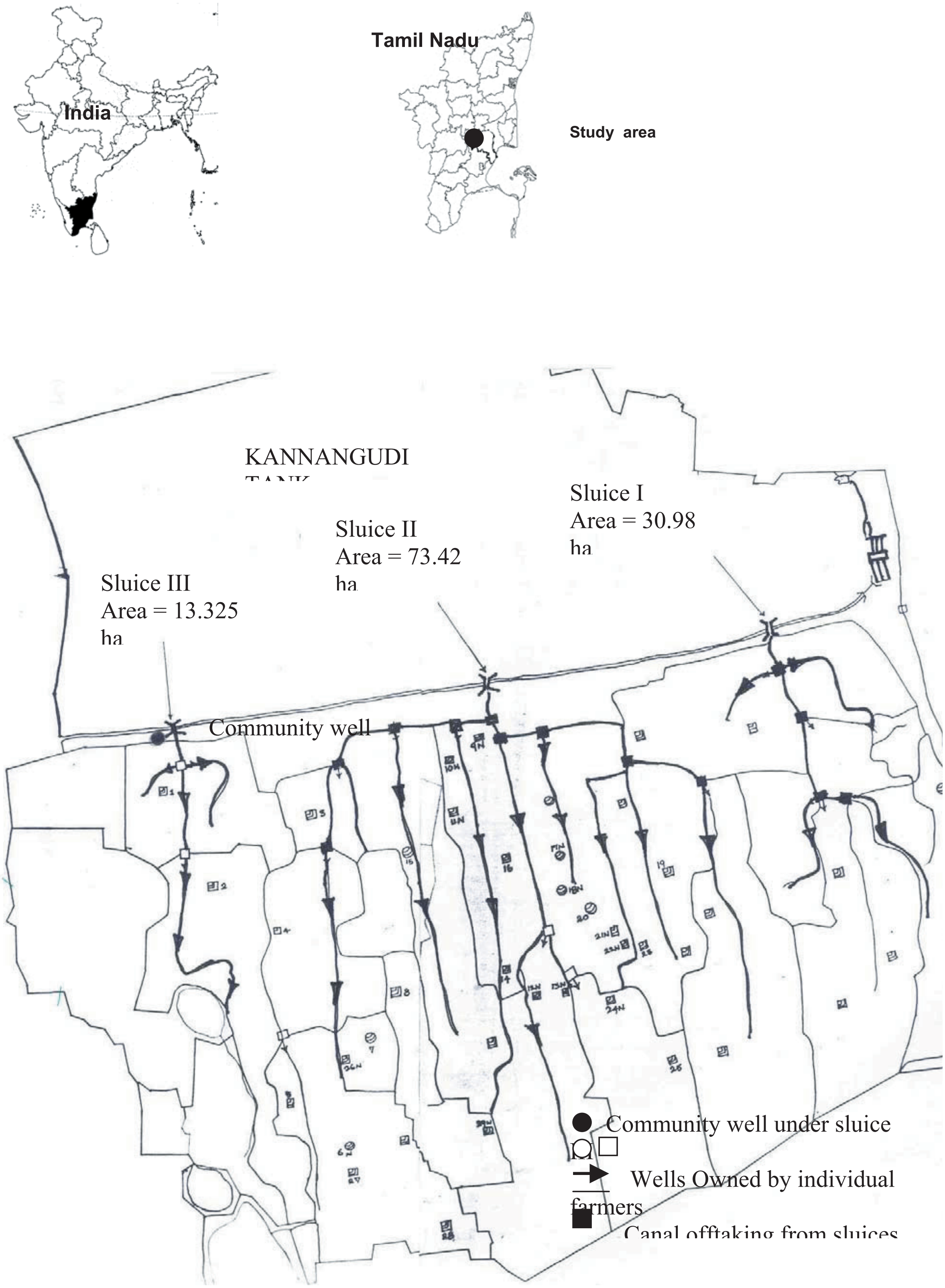

Figure 1. Location of the study area and community wells

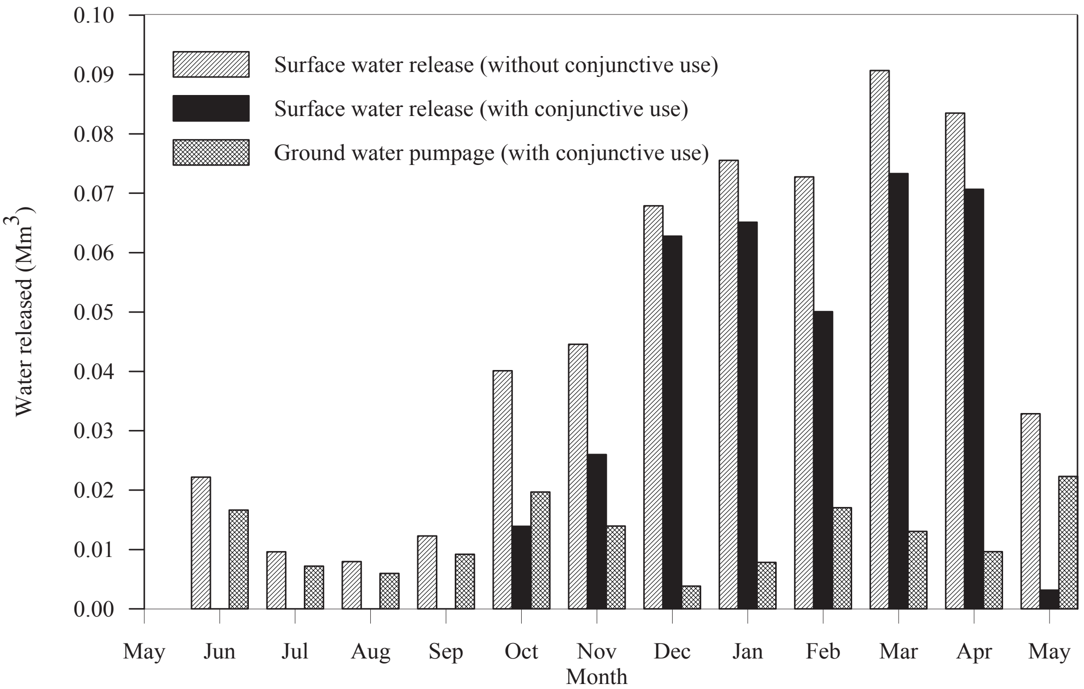

Figure 2. Optimal utilisation of surface water and ground water (with and without conjunctive use)

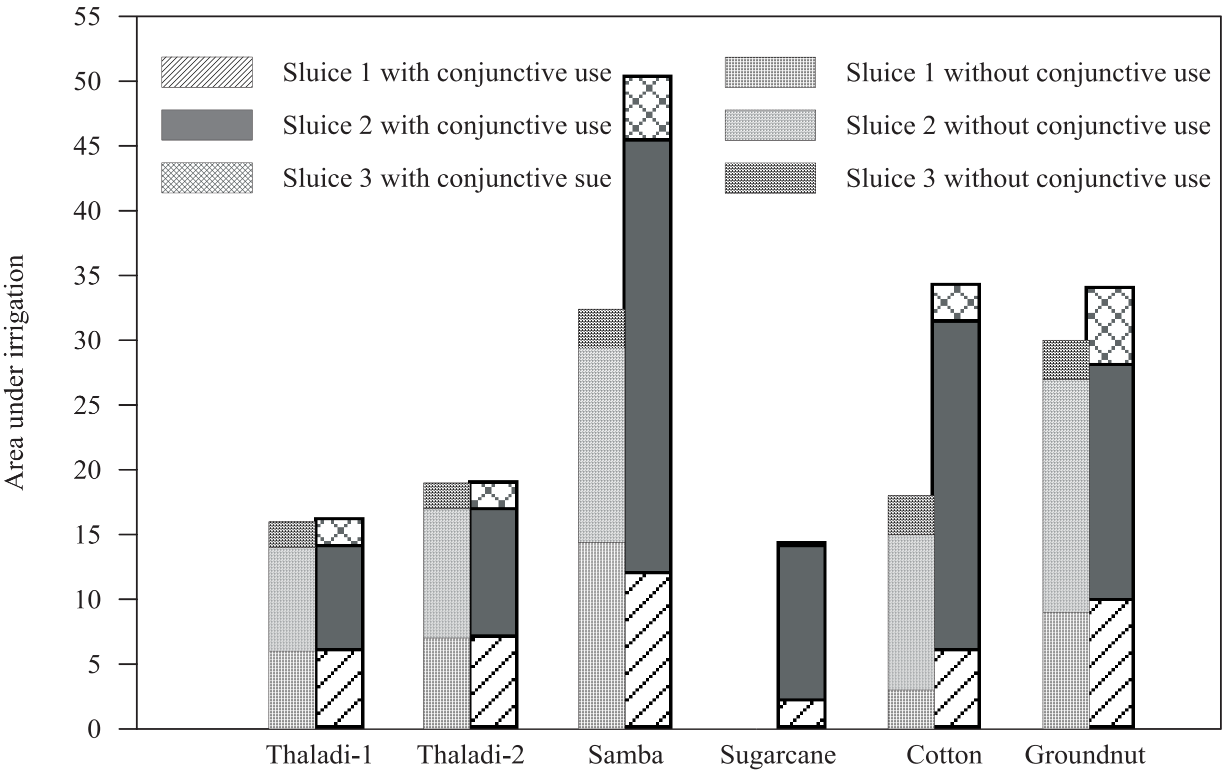

Figure 3. Optimal cropping pattern resulted from LP model with and without conjunctive use.

the ground water. For this scenario the area irrigated under sluice 1, sluice 2, and sluice 3 are 40.96 ha, 106.84 ha and 19.47 ha respectively. The optimal cropping pattern with conjunctive use and without conjunctive use resulted from the present linear programming model is shown in Figure 3. The sugarcane, which is a cash crop has entered the feasible solution with conjunctive use. Thus conjunctive use of surface water and ground water has increased the area under irrigation and also increased the net benefit in the tank commands. The model shows that conjunctive use is inevitable for sustainable irrigation in tank commands.

Conclusion

An optimization model has been developed to derive optimal cropping pattern in a tank command with and without conjunctive use. It was found that the conjunctive use has increased the net benefit by cultivating the cash crop, because of availability of the ground water throughout the year. This ground water available is the recharged water from the tank. The net benefit without conjunctive use is Rs. 11,57,895.33 ($1=Rs. 52) and from the conjunctive use scenario is Rs. 26,67,462.49 Thus it is necessary to practice conjunctive use of surface and ground water under tank commands also for their sustainability.

References

Belaineh, G. Peralta, RC; Hughes, TC. (1999) “Simulation / Optimization Modelling for Water Resources Management”, Journal of Water Resources Planning and Management, Vol.125, No.3, pp 154 162.

Chandhry, MT. (1974) “Optimal conjunctive use model for Indus basin. Journal of the Hydraulics Division, ASCE, Vol. No.5, pp.667 - 687.

Chavez-Morales, J., M.A. Marino, and E.A. Holzapfel. (1987), “Planning Model if Irrigation District”. Journal of Irrigation and Drainage Engineering 113, No.4: 549-564.

Doorenbos, J., and Pruitt, W.O, (1977) Guidelines for predicting Crop Water Requirements, FAO Irrigation and Drainage Paper No 24. Food and Agricultural Organization of the United Nations, Rome, Italy.

Emch, PG and Yeh, WWG. (1998) “Management model for conjunctive use of coastal surface water and ground water”. Journal of Water Resources Planning and Management Vol. 124, No.3, pp.129-139.

Jothiprakash V. K.A. Kuppusamy, K. Sasireka and P. Shanmuganathan (2002) “Ground water harvesting through community wells for sustainable irrigation in tank commands” Proceedings of the international conference on Water and Waste Water Perspectives of Developing Countries, IIT Delhi, pp597 – 602.

Kumar R, and S. K. Pathak (1989) Optimal crop planning for a region in India by conjunctive use of surface and ground water, Water Resources Development, Vol. 5, No2, pp 99-105.

Lakshminarayana, V., and S.P. Rajagopalan (1977) Optimal cropping pattern for basin in India, Journal of the Irrigation and Drainage Division, ASCE, 103(IR1), 53 - 70.

Loucks, D.P., J.R. Stedinger, and D.A. Haith (1981) Water resources systems planning and analysis, Prentice-Hall, Inc, Englewood Cliffs, New Jersey.

Maknoon, R and S.J. Burges, (1987) “Conjunctive Use of Ground and Surface Water”. Management and Operations: 419-424.

Mohan S, and N. Arumugam (1992) A stochastic optimization model for irrigation planning, Proceedings of the International conference on optimization models and their application, National University of Singapore, Singapore, pp 657-663.

Mohan S, and V. Jothiprakash (2003) Development of priority based policies for conjunctive use of surface and ground water, Water International, Vol. 28, No2, pp 254-267

Mohan S, H. Raman, and K. Nagarajan (1998) Stochastic linear programming model for irrigation planning, Journal of Indian Water Resources Society, Vol. 18. No3. pp 28-34.

Onta, PR and Gupta, AD. (1991) “Multistep planning model for conjunctive use of surface and ground water resources”, Journal of Water Resources Planning and Management, Vol.117, No.6, pp: 662 – 678.

Panda, S.N., S.D. Khepar, and M.P. Kaushal. (1996) “Interseasonal Irrigation System Planning for Waterlogged Sodic Soils”. Journal of Irrigation and Drianage Division 122, No.3 : 135-144.

Peralata, RC, Cantiller, RRA and Terry, JE (1995), Optimal large scale conjunctive water use planning, Case Study: , Journal of Water Resources Planning and Management, Vol.121, No.6, pp.471 478.

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