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PEOPLE-CENTRED APPROACHES TO WATER AND ENVIRONMENTAL SANITATION

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

V. Jothiprakash, S. Mohan and K. Kuppusamy, India

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.


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 Lakshminarayanan 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 =

\[ \sum_{z=1}^{Z} \sum_{i=1}^{N} B_i A_{xz} - \sum_{z=1}^{Z} \sum_{i=1}^{N} C_i A_{xz} - \sum_{z=1}^{Z} \sum_{r=1}^{12} C_{sw} S_{wz} - \sum_{z=1}^{Z} \sum_{r=1}^{12} C_{gw} G_{wz} \]

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 in terms of land tax)
SWzt - Surface water release (Mm3) to sluice in period t
Cgw – Cost of ground water in Rs/Mm3 (Rs 4.5/m3, paid in terms 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.

\[ S_t \leq 0.65 \quad t=1,2,\ldots,12 \quad (2) \]
\[ S_t \geq 0.005 \quad t=1,2,\ldots,12 \quad (3) \]
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 constrain are mathematically expressed as follows:

\[ GW_{zt} \leq Sy_z \quad t=1,2,\ldots,12 \quad (4) \]

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:

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

where, NIRit – Net irrigation requirement for the crop ‘i’ during the month ‘t’
\( \eta_s \) - efficiency of the surface water irrigation (60%) and \( \eta_g \) - 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

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

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
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

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

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 catchment 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 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.
Data base
The data required for this study was collected from 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.

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 141 constraints. This model is also solved using revised simplex method. The net benefit resulted from 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 141 constraints. 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

| Table1. Monthly net irrigation requirements for various crops in the study area (mm) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Month          | Rice            |                  |                  |                  |                  |
|                | Samba           | Thaladi-I        | Thaladi-II       | Groundnut        |                  |
| Jan            | -               | 12               |                  |                  |                  |
| Feb            | -               | -                | 149              |                  |                  |
| Mar            | -               | 59               | -                | 140              |                  |
| Apr            | -               | 93               | -                | 146              |                  |
| May            | -               | 121              | 189              |                  |                  |
| Jun            | -               | 101              | 40               | 120              | 170             |
| Jul            | -               | 86               | 49               | 174              |                  |
| Aug            | 73              | 86               | 49               | 174              |                  |
| Sept           | 127             | 78               | 25               | 160              |                  |
| Oct            | 71              | -                | 5                | 150              |                  |
| Nov            | 48              | -                | -                | 50               |                  |
| Dec            | 21              | -                | -                | 16               |                  |
| Annual         | 340             | 338              | 394              | 228              | 467             | 1362            |

| 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            | 12350            | 86              | 14330           |
| Thaladi-I       | 4076            | 12350            | -               | 8030            |
| Thaladi-II      | 4076            | 12350            | -               | 8030            |
| Groundnut       | 1729            | 9386             | -               | 6175            |
| Cotton          | 525             | 11115            | -               | 13560           |
| Sugarcane       | 98800           | 24700            | -               | 54340           |

| Table. 3 Monthly inflow into the tank (Mm³) |
|-----------------|-----------------|
| 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            |

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.
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

Contact address
Dr. V. Jothiprakash Senior Lecturer,
Dr. K. A. Kuppusamy, Professor
Department of Civil Engineering, National Institute of Technology, Tiruchirappalli, Tamil Nadu 620 015, INDIA
vprakash@nitt.edu
Dr. S.Mohan, Professor,
Environmental and Water Resources Engg Division
Dept. of Civil Engineering, Indian Institute of Technology, Madras, Chennai, Tamil Nadu 600 036, INDIA
mohan@civil.iitm.ernet.in