Indian Journal of Agricultural Sciences **92** (5): 648–51, May 2022/Article
https://doi.org/10.56093/ijas.v92i5.124792

Optimization of tank irrigation systems in the rainfed region of Andhra Pradesh

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Received: 22 July 2021; Accepted: 23 November 2021

ABSTRACT

In India, tank irrigation was one of the primary sources of irrigation for most part of the rainfed regions. However, as of 2017–18, only 2.45% of irrigated area is under tank irrigation. The present study intends optimization of tank irrigation systems through different optimal scenarios. The detailed information on required variables was collected using a structured questionnaire from farm households for the period 2017–18 in Ananthapur district, Andhra Pradesh. The Linear Programming model was applied for the optimization of tank irrigation systems. The results revealed that the gross cropped area (9%) and net return (25%) have increased under the improved scenario (cement lining of irrigation channel). Further, the adoption of improved irrigation methods minimizes water losses and enhances water use efficiency and yield. Thus, optimization of tank systems augments the food and livelihood security of tank users, especially small and marginal holders. Therefore, to minimize the detrimental impact of climate change and scarcity of water, traditional water bodies along with efficient technologies are crucial for optimization.

Keywords: Linear Programming, Optimization, Rainfed, Tank irrigation, Water Use Efficiency

Sustainable food production along with conservation of natural resources are the two key issues confronted by Indian agriculture. Several studies on the projection of food grain demand suggested an increase in food production to feed the growing population (Kumar 1998, Kumar *et al.* 2009). Indian agriculture predominantly depends on rainfed farming as it is a prime food supporting system and source of livelihood for millions of rural households. Rainfed agriculture accounts for more than 50% of the total gross cropped area, nearly 40% of food production, and supports two-thirds of the livestock population in the country (Venkateswarlu and Prasad 2012). However, the rainfed production system suffers from low productivity (GoI 2011) with seasonal and temporal variability of rainfall. To overcome water scarcity, tanks for irrigation are constructed across the rivers, streams, drainage channels and are managed by local communities (Shankari 1991, Palanisamy and Easter 2000, Palaniswamy 2006). Despite numerous economic, socio-cultural and ecological benefits, the role of tanks was diminished in the rural economy over the period (ADB 2006). The area irrigated by tank system has significantly declined from 4.5 million hectares (17.33% of the net irrigated area) in 1960–61 to 1.71 million hectares (mha) (2.45%) during 2017–18. Several studies highlighted that inadequate maintenance, deterioration of the physical structure, heavy seepage losses in the delivery system, heavy siltation, and private encroachments into tank foreshore were the major reasons for the decline in the performance of tanks (Palanisami and Easter 1984, Shankari 1991, Janakarajan 1993, Palanisami and Balasubramanian 1998, Raj and Sundaresan 2005, Palanisami 2006, Nehlin 2016).

Therefore, to ensure uninterrupted supply and optimum use of irrigation water, appropriate strategies need to be developed by considering all the factors for optimum management of tank irrigation systems (Arumugam and Mohan 1997). Optimization of tank systems using modern technologies not only increases the water supply but also complements the groundwater table and reduces the dependency on wells (Palanisami *et al.* 2008). The specific objective of the study is optimization of tank systems under different improved scenarios through the adoption of modern technologies and its impact on the availability of water, net return and cropping intensity.

MATERIALS AND METHODS

Present study was carried out at Ananthapur district of Andhra Pradesh state in India. Andhra Pradesh was a historically tank-based agrarian economy with the largest number of tanks in the country (Vth Minor Irrigation Census). More than 50% of livelihood depends on agriculture and tank irrigation was one of the major sources of irrigation.

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However, over the years tank systems in Andhra Pradesh have lost their importance and the area under tanks has significantly declined from 1.10 mha (30% of the total net irrigated area) in 1988–89 to 0.30 mha (11%) in 2017–18. Tank systems were operating below their optimum level (APCBTMP 2007), a wide gap has been observed between the designed and actual capacity of tanks. After realizing the importance of tanks, the state has started restoration of tank structures to enhance agricultural productivity and manage the tank system effectively.

Sampling and analytical framework: The data used in this study was collected from the Chatram tank of Anantapur district. Information on the area, yield, cost and return of various crops grown under the command area of the tank for the agricultural year 2017–18 was collected. The information related to the physical structure of the tank was obtained from the water resource department, Government of Andhra Pradesh. The registered ayacut of the tank is about 117 ha whereas present ayacut is only 43.72 ha (37.36%) of the command area. The gap between registered and present ayacut is 73.68 ha (62.97%). Therefore, the present ayacut of the tank system can be improved through the adoption of varying optimal irrigation systems.

Model formulation: Linear Programming (LP) is a powerful optimization tool for the allocation of scarce resources under a different set of constraints (Jain *et al.* 2017). LP model has been formulated for both *rabi* and *kharif* to maximize the net returns, optimum use of water by keeping all other resource as constraints.

Mathematical specifications of the model: Mathematically, model specification presented by equations 1–6 is followed by equation wise description (Jain *et al.* 2017).

$$\text{Max } Z = \sum_{c=1}^{n} (Y_c P_c - C_c) A_c \quad (1)$$

$$\sum_t \sum_c a_{tc} A_c \leq NS_t - OA_t \quad (2)$$

$$A_c \geq \min_c \quad (3)$$

$$A_c \leq \max_c \quad (4)$$

$$\sum_c w_c A_c \leq TWA \quad (5)$$

$$A_c \geq 0 \quad (6)$$

Where, Z is the total net return; Y_c is yield/ha of crop c, P_c the price received for the crop c; C_c is cost of cultivation of crop c (₹/ha); A_c is the area under cultivation of crop c; A_{tc} is absence (0) or presence (1) of the crop c in the month; t; NS_t is net sown area during month t; OA_t is area under perennial crops; $Amin_c$ and $Amax_c$ are minimum and maximum area limits for crop c respectively; w_c refers to actual water requirement per ha for crop c; TWA refers to tank water available limit.

The objective is to maximize the net returns based on the optimum crop plan under different scenarios. The RHS of the equation 1 represents the total net revenue obtained from the crops under different optimal scenarios. The net return from different crops has been assessed in different improved optimal scenarios, viz. Cement channel lining of tanks over conventional earthen lining and Improved irrigation methods over conventional methods. The LP model has been performed using General Algebraic Modeling System (GAMS) software.

Land constraint: Optimum use of land for each month has been incorporated as a separate constraint equation (equation 2). This ensures that the total cropped area under selected crops in each month should be less than the net sown area (NS_t) minus the area under perennial (OA_t) crops. A crop calendar matrix was prepared to represent the months covered by each crop from its sowing to harvesting.

Minimum and maximum constraints: One of the major limitations of LP while using for optimization of crop planning is it captures only the supply side and ignores the demand of the region. As a result, a single crop may cover a larger area or null or negligible area. To overcome such undesirable estimation of LP, the minimum and maximum area of the crops has been incorporated as separate constraints in the model (equations 3 and 4). The area constraint for selected crops has been estimated based on the expert elicitation method and the existing land area allocations. In the model, the selected crops are paddy, groundnut, maize, chilli, mulberry, and ragi in both *kharif* and *rabi*.

Tank water constraints: Water is a scarce resource hence the tank water usage should be less than or equal to tank water available for agriculture (TWA) to ensure its sustainability. Tank water constraint is added as a separate equation in the model (equation 5).

RESULTS AND DISCUSSION

Existing scenario of farms under the tank: The gross cropped area under the existing scenario of the tank system is about 43.71 ha. Rice and maize are the two major crops cultivated during the *kharif* followed by groundnut and mulberry. In *rabi*, due to inadequate availability of irrigation maize, groundnut, and surprisingly rice are the major crops cultivated under the tank command area. About ₹474691 of total net return is generated from the tank command area for both the seasons under the existing scenario. A maximum share in return has been observed in the case of chilli crop as the highest premium price received in the market.

Scenario 1: Cement lining *vis-à-vis* conventional earthen lining of tank channel: In the existing scenario, irrigation channels of the tank are conventional earthen lined. However, it is observed that earthen-lined channels are having low conveyance efficiency and a significant amount of water loss is expected (Sen *et al.* 2018). Therefore, cement lining to the irrigation channel will minimize the water losses and thereby increase the conveyance efficiency. Thus, under an improved scenario, the cement lining of irrigation channels is recommended. According to the Food and Agriculture Organization (FAO), conveyance efficiency for an earthen lined channel is only about 60% whereas for a cement-lined channel is about 90%. Therefore, nearly 30% of water loss can be minimized by using a cement channel. Therefore, nearly 30% of water loss can be minimized by using a cement channel. The saved water can be used to expand additional irrigation area which was previously not under irrigation.

Table 1 represents the optimization of the tank, where cement lining channels (improved scenario) were used instead of earthen lined channels (existing scenario). According to the LP approach, the gross cropped area of the tank command area can be increased from 43.71–47.60 ha. The additional area of 3.89 ha (9%) can be made available for irrigation by cement lining to the channels. Further, optimal allocation of the additional area is observed for rice, groundnut, chilli, and *rabi* maize crops. The total additional net revenue generation of the command area has increased by ₹118913 (25%) by replacing earthen-lined channels (existing scenario) with cement-lined channels (improved scenario). Meijer *et al.* (2006) estimated about 50% of seepage loss is reduced annually through the concrete lining of irrigation canals. Further, Ashfaque *et al.* (2013) evaluated Dadu canal lining in Pakistan, result showed a reduction in seepage losses (40–50%) and higher conveyance efficiency (70–90%), thereby increasing in cropping intensity. Further, cement channels also help in the equitable distribution of irrigation water to all stakeholders in the command area (Meijer *et al.* 2006). Therefore, under an improved scenario, an increase in cropped area and net return are mainly due to the availability of additional water for irrigation and thereby additional area should be brought under irrigation.

Scenario 2: Adoption of improved irrigation practices *vis-a-vis* conventional irrigation practices: Not all the water supplied from the tank is utilized by the plants. Water losses in the fields are caused by surface runoff and deep percolation, as a consequence plants are unable to absorb the water. Hence, only a part of the water is utilized by the plants for growth and other metabolic activities leading to low field application efficiency. In the existing scenario of the tank command area, conventional flood irrigation methods are practiced by the farmers. However, these methods are having low field application efficiency and a significant amount of water loss is observed in the field. Therefore, by the adoption of improved methods of irrigation, a significant amount of water loss can be avoided and field application efficiency can be improved (up to 90%). Under the improved scenario, the system of rice intensification (SRI) method is recommended for the cultivation of rice crop and drip irrigation for other crops of the tank command area. The application efficiency can be increased by 90% and 13841 mm (35%) water in the tank command area can be saved.

Table 2 furnishes changes in the area, yield and net return under an improved scenario of tank command area by using the LP approach. As expected, the gross cropped area has increased by 8.55 ha (19.56%) more than the existing scenario. The additional area is allocated for the cultivation of rice, groundnut, maize and chilli crops. Further, it is observed that yield of all crops has also increased by 10–30% than the existing scenario. The total additional net gains from the adoption of improved irrigation methods is ₹702391 (48%) more than that of existing methods of irrigation. These results are expected due to the fact that water and energy productivity is significantly high in improved irrigation methods than the conventional methods (Suresh and Palanisami 2010). Further, an increase in the net return of the command area is attributed to an increase in yield and water use efficiency (Qureshi *et al.* 2001, Namara *et al.* 2005).

The primary focus of this study is on the optimization of the tank irrigation system in the rainfed region of India. To enhance the water use efficiency and maximize the net return, two optimum scenarios were developed, viz. cement lining to irrigation channel and adoption of improved water management techniques. According to the linear programming model, cement lining to irrigation channel leads to expansion of cropped area and increase in net return in the tank command area. Similarly, the adoption of improved irrigation methods has a positive effect on yields, net returns and cropping intensity under tank irrigation. Thus, in devising strategies for restoration of tanks, the adoption of improved irrigation techniques such as drip sprinkler irrigation systems, the system of rice intensification (SRI) need to be taken into account in the study region. Overall, the study points towards minor irrigation development in India, particularly restoration of tank irrigation system. Optimization of tank systems augments the food and livelihood security of tank users, especially small and

Table 1 Change in the area and net return of cement lining channel *vis-a-vis* earthen lining channel

Particular	Area (ha)		Difference	Total Net Return (₹)		Difference
	Cement channel	Earthen channel		Cement channel	Earthen channel	
Kharif						
Rice	12.41	10.12	2.29 (22.63)	121802	99358	22444 (22.59)
Groundnut	6.07	6.07	-	46458	46458	-
Maize	6.07	10.12	-4.05 (-40.02)	44029	73370	-29341 (-39.99)
Chilli	5.00	3.24	1.76 (54.32)	237500	153900	83600 (54.32)
Ragi	1.22	2.02	-0.80 (-39.60)	5984	9949	-3965 (-39.85)
Mulberry	2.83	4.05	-1.22 (-30.12)	13462	19238	-5776 (-30.02)
Rabi						
Rice	3.00	2.02	0.98 (48.51)	22104	14883	7221 (48.52)
Groundnut	6.00	2.02	3.98 (197.03)	52170	17564	34606 (197.03)
Maize	5.00	4.05	0.95 (23.46)	49375	39994	9381 (23.46)
Total	47.60	43.71	3.89 (8.90)	592884	474691	118193 (24.90)

Values in parenthesis indicate % change over existing scenario.

Table 2 Change in area, yield and net return under improved irrigation method *vis-a-vis* conventional irrigation method

Particular	Area (ha)		Yield (kg/ha)		Total Net Return (₹)	
	Conventional method	Improved method	Conventional method	Improved method	Conventional method	Improved method
Kharif						
Rice	10.12	13.00 (28.46)	4200	4620 (10.00)	99358	154284 (55.28)
Groundnut	6.07	6.07	1080	1240 (15.00)	46458	37410 (-19.44)
Maize	10.12	10.14 (0.20)	3950	4660 (18.00)	73370	76195 (3.85)
Chilli	3.24	5.00 (54.32)	8500	10030 (18.00)	153900	288775 (87.64)
Ragi	2.02	1.22 (-39.60)	2350	2350	9949	5984 (-39.85)
Mulberry	4.05	2.83 (-30.12)	13500	17550 (30.00)	19238	12682 (-34.08)
Rabi						
Rice	2.02	3.00 (48.51)	3500	3850 (10.00)	14883	29829 (100.42)
Groundnut	2.02	6.00 (197.03)	1570	1800 (15.03)	17564	44170 (151.48)
Maize	4.05	5.00 (23.46)	4950	5840 (18.00)	39994	53063 (32.68)
Total	43.71	52.26 (19.56)			474691	702391 (47.97)

Values in parenthesis indicate % change over existing scenario.

marginal holders in the region. Further, to minimize the detrimental impact of climate change and scarcity of water, traditional water bodies (irrigation tanks) could be considered and restored with improved technologies.

REFERENCES

Arumugam N and Mohan S. 1997. Integrated decision support system for tank irrigation system operation. *Journal of Water Resources Planning and Management* **123**(5): 266–73.

Ashfaque A M, Khalifa Q L, Agha, Pathan F H, Kanya L K, Sadiq A S, Kanwal K P, Rabia S and Kameran A. 2013. Design and evaluation of dadu canal lining for sustainable water saving. *Journal of Water Resource and Protection* **5**: 689–98.

Asian Development Bank (ADB). 2006. Rehabilitation and management of tanks in India: A study of select states. Asian Development Bank, Philippines.

GOI. 2011. Report of the XII Plan Working Group on Natural Resource Management and Rainfed Farming. Planning Commission, New Delhi.

Jain R, Kingsly I, Chand R, Kaur A P, Raju S S, Srivastava S K and Singh J. 2017. Farmers and Social Perspective on Optimal Crop Planning for Ground Water Sustainability: A Case of Punjab State in India. *Journal of the Indian Society of Agricultural Statistics* **71**(1): 75–88.

Janakarajan S. 1993. In search of tanks: Some hidden facts. *Economic and Political Weekly* **28**(26): 53–60.

Kumar P. 1998. Food Demand and Supply Projection for India, Agricultural Economics Policy Paper: 98–01. *Indian Agricultural Research Institute*, New Delhi.

Kumar P, Joshi P K and Birthal P S. 2009. Demand projection for food grains in India. *Agriculture Economic Research Review* **22**(2): 237–43.

Meijer K, Eline B, Denie A and Irna V M. 2006. Impacts of concrete lining of irrigation canals on availability of water for domestic use in southern Sri Lanka. *Agricultural Water Management* **83**: 243–51.

Namara R E, Upadhyay B and Nagar R K. 2005. Adoption and Impacts of Microirrigation Technologies: Empirical Results from Selected Localities of Maharashtra and Gujarat States of India. Research Report 93, *International Water Management Institute,* Colombo, Sri Lanka.

Nehlin M. 2016. Management of local irrigation systems and stakeholder perceptions in southern Tamil Nadu, India. MSc thesis in Environmental Management and Physical Planning at the Department of Physical Geography, Stockholm University.

Palanisami K. 2006. Sustainable management of tank irrigation systems in India. Water Technology Centre, Tamil Nadu Agricultural University, India.

Palanisami K R and Easter K W. 2000. *Tank Irrigation in the 21st Century*. Discovery Publishing House, New Delhi.

Palanisami K and Balasubramanian R. 1998. Common property and private prosperity: Tanks vs private wells in Tamil Nadu. *Indian Journal of Agricultural Economics* **53**(4): 600–11.

Palanisami K and Easter W. 1984. Irrigation tanks of south India: Management strategies and investment alternatives. *Indian Journal of Agricultural Economics* **39**: 214–23.

Palanisami K, Gemma M and Ranganathan C R. 2008. Stabilization value around water in tank irrigation systems. *Indian Journal of Agricultural Economics* **63**(1): 126–34.

Qureshi M E, Wegener M K, Harrison and S R Bristow K L. 2001. Economic evaluation of alternate irrigation systems for sugarcane in the Burdekin delta in North Queensland, Australia. *Water Resource Management*, pp. 47–57. C A Brebbia, K Anagnostopoulos, K Katsifarakis and A H D Cheng (Eds). WIT Press, Boston.

Raj A B S and Sundaresan D. 2005. Declining trend in tank irrigated area: Is there a way to arrest? *Fourth IWMI-Tata Annual Partners Meet*, Anand, February 2005.

Sen R, Fahmida M, Akter I and Milufarzana. 2018. Determination of Conveyance Loss through Earthen Channel by Cutthroat Flume. *International Journal of Hydraulic Engineering* **7**(1): 11–14.

Shankari U. 1991. Tanks: Major problems in minor irrigation. *Economic and Political Weekly* **26**(39): A115–A24.

Suresh K D and Palanisami K. 2010. Impact of drip irrigation on farming system: Evidences from Southern India. *Agricultural Economics Research Review* **23**: 265–72.

Venkateswarlu B and Prasad J V N S. 2012. Carrying capacity of Indian agriculture: Issues related to rainfed agriculture. *Current Science* **102**(6): 882–88.