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Water supply strategies for higher land and water productivity in tank command areas of Southern India

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ABSTRACT

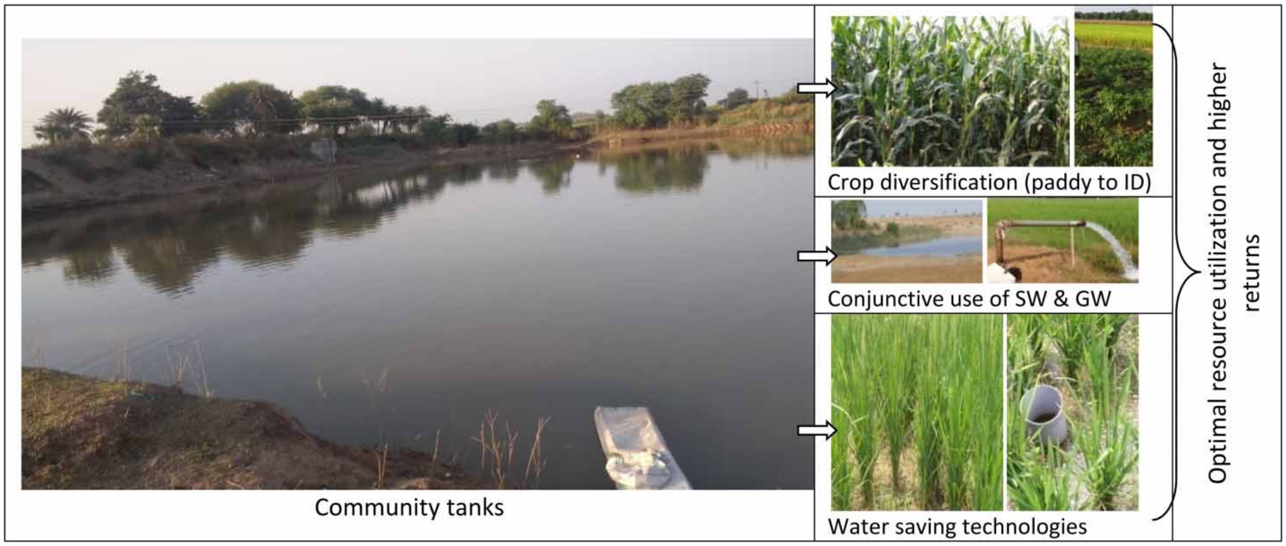
Tanks are one of the most important traditional sources of water for irrigation and other livelihood purposes in southern India. The present study was conducted to develop the strategies for enhancing the land and water productivity in tank command areas in the rain-fed regions of Telangana. Three strategies were identified, these strategies include change in the cropping pattern, water saving technologies and conjunctive use of tank with open well/bore well water. Due to change in cropping pattern from paddy to irrigated, dry crops like maize, chillies and cotton increased the cultural command area of the tanks by 79% and net reruns by 43%. The conjunctive use of tank water and well water is the better strategy for optimal resource use and higher returns in tank command areas. Results also showed that the alternate wetting and drying strategy in tank command areas increased the command area by 35%. These strategies can be implemented to increase the water use efficiency, cultural command area and net returns in the tank command areas of Southern India.

Key words: alternate wetting and drying (AWD), command area, conjunctive use, cropping pattern, tanks management, water saving

HIGHLIGHTS

- The change in cropping pattern from paddy to irrigated dry crops in tank command areas increased the cultural command area of the tanks by 79% and net reruns by 43%.
- The conjunctive use of tank water and well water is the better strategy for optimal resource use and higher returns in tank command areas.
- The alternate wetting and drying strategy in tank command areas increased the command area by 35%.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Generally, water is considered to be a relatively low-efficiency, low-value and highly subsidized in agriculture (FAO 1993). However, water is becoming more valuable with increased demands or competition between agriculture, industry and urbanization. Farmers are always on the losing side with this rapidly increasing competition due to the greater value of water in industry and municipalities. Increasing water scarcity has brought governments and farmers under pressure to rely on local water sources (Mushtaq *et al.* 2006).

Irrigation plays a vital role in agriculture to the Indian economy and it depends upon the monsoon rainfall (von Oppen & Subba Rao 1987). About 75–80% of annual rainfall is from the South-West monsoon season in India. According to the Indian statistics for 2021, the total land area under irrigation is about 64.7 million hectares (35%).

The other uses of tank water are fishing, aquatic products, supporting home gardens, livestock, brick-making, domestic uses such as drinking, cooking, bathing, washing, recreation and environmental uses, including recharging groundwater (GW), flushing contaminants and supporting wildlife (Karthikeyan & Palanisami 2011).

Small water reservoirs constructed behind the earthen dams are called tanks or ponds. On the basis of storage, capacity ponds are categorized as large, medium and small. Large ponds have a storage capacity of more than 10,000 m^3; medium ponds have a storage capacity between 1,000 and 10,000 m^3; while small ponds have a storage capacity of less than 1,000 m^3. These are vast in number, varied in size, provide a low-cost source for irrigation, have a small command area and are also predominantly managed by the farmers themselves (Narayanamoorthy & Suresh 2016). Tanks are not only useful for irrigation but also enrich the water table through percolation (Palanisami *et al.* 2008). An irrigation tank brought most of the water during the rainy season only. However, a small portion of tank water was obtained from direct precipitation and the remaining comes from the runoff of the catchment area (Balasubramanian & Selvaraj 2004). This runoff water contains a large number of dissolved materials and other organic and inorganic substances (Alexander & Mahalingam 2011). Tanks allow farmers to capture rainfall, store surplus water from irrigation canals and conserve water from other sources. These ponds allow the users to obtain water on-demand because of their built-in flexibility to store water close to water users (Loeve *et al.* 2001). Ponds have also proved to be helpful in reducing floods, and recharging and providing drainage in high rainfall periods (Anbumozhi *et al.* 2001).

Tanks have been one of the most important traditional sources of water for irrigation (Suresh Kumar & Palanisami 2020) and other livelihood purposes over the centuries in India (Narayanamoorthy 2007; Narayanamoorthy *et al.* 2021). Tank irrigation contributes significantly to agricultural production in many semi-arid areas in parts of South and South-East Asia (Palanisami 2006). The largest concentration of tanks is found in the southern states of Andhra Pradesh, Karnataka and Tamil Nadu and the union territory of Pondicherry, with nearly 60% of the total irrigated area coming under the tanks in India (Sakthivadivel *et al.* 2004). The tank irrigation system has a special significance to a large number of small and marginal scale farmers that essentially depend on tank irrigation because these systems are low-cost intensive and have a wider geographical distribution than large projects (Palanisami 2000).

The significance of ponds has not been explored much and also not much information is available on benefits generated by ponds in sustaining crop production (Biggs *et al.* 2017; Hill *et al.* 2018, 2021; Lopez-Felices *et al.* 2020). Very few studies were conducted on tank irrigation, tank silt application and de-silting of tanks. However, a detailed study needs to develop strategies for optimal utilization of land and water resources in tank command areas.

2. STUDY AREA

The present study was conducted at eight de-silted tanks in two districts of Telangana State, namely Warangal and Khammam of Southern India. These tanks belong to the basins of Godavari and Krishna, respectively. Warangal and Khammam districts are located in the Central Telangana zone. The normal annual rainfall of this zone is 800–1,150 mm. The minimum and maximum temperature of Warangal and Khammam are about 21–25 °C and 22–37 °C. The study area map is mentioned in Figure 1. The tank details are mentioned in Table 1.

3. METHODOLOGY

To calculate the water productivity, weather data like Rainfall, Temperature, Humidity, Wind speed and Sunshine hours were collected from the Telangana State Development Planning Society (TSDPS) and Research Stations of Warangal and Khammam districts.

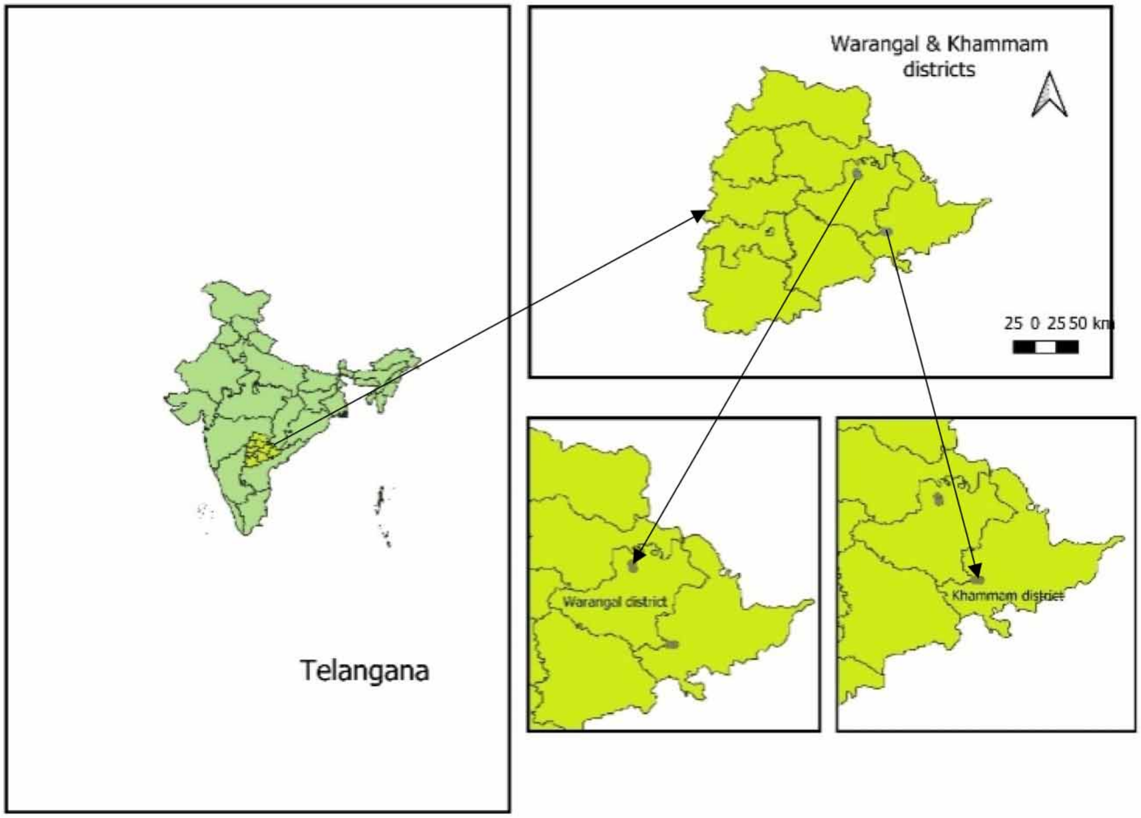


Figure 1 | Location map of the study area.

Table 1 | Details of the different tanks

S. No	Tank name	Village	Mandal	District	Latitude	Longitude
1	Oora Kunta	Bhagirthipet	Regonda	Warangal	18°16′13.88″	79°47′34.72″
2	Sammayya Kunta	Dumpillapally	Regonda	Warangal	18°17′17.27″	79°46′49.79″
3	Venkatadri Kunta	Thirumalagiri	Regonda	Warangal	18°13′43.86″	79°48′04.35″
4	Yellayya Kunta	Thirumalagiri	Regonda	Warangal	18°14′02.65″	79°48′24.51″
5	AamudalaCheruvu	Mucherla	Kamepally	Khammam	80°16′02.98″	17°23′14.21″
6	Thalla Kunta	Sathanugudem	Kamepally	Khammam	80°15′10.21″	17°23′21.94″
7	Gaddi Kunta	Pandithapuram	Kamepally	Khammam	80°12′53.06″	17°22′22.19″
8	Parusharam Kunta	Rukki Thanda	Kamepally	Khammam	80°12′53.12″	17°24′53.12″

For calculating water productivity, the water requirement (WR) of the different crops, which were grown in that command area, was calculated. The crops grown in the command area were paddy/rice, cotton, chillies, turmeric, maize, red gram and black gram.

The following three strategies were used to increase the water and land productivity, namely changing the cropping pattern, implementation of water saving technologies using alternate wetting and drying (AWD) and conjunctive use planning of surface water (SW) with GW resources. These strategies were solved by Linear Programming Solver Model.

3.1. Crop evapotranspiration (ET_c)

The crop evapotranspiration (ET_c) is calculated by using the following equation:

$$ET_c = K_c * ET_0 \tag{1}$$

where ET_c is the evapotranspiration of a specified crop (mm day^{-1}), K_c is the crop coefficient (dimensionless); ET_0 is the potential/reference evapotranspiration (mm day^{-1}).

3.2. Potential evapotranspiration (ET_0)

Reference evapotranspiration is calculated by using the Penman–Monteith Method. The following equation is used for calculating reference evapotranspiration:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (2)$$

where ET_0 is the reference evapotranspiration (mm day^{-1}); R_n is the net radiation at the crop surface (MJ m^{-2} day^{-1}); G is the soil heat flux density (MJ m^{-2} day^{-1}); T is the mean daily temperature at 2 m height (°C); u_2 is the wind speed at 2 m height (m s^{-1}); e_s is the saturation vapour pressure (kPa); e_a is the actual vapour pressure (kPa); $e_s - e_a$ is the saturation vapour pressure deficit (kPa); Δ is the slope of vapour pressure curve (kPa °C^{-1}); γ is the psychrometric constant (kPa °C^{-1}).

3.3. Effective rainfall

For calculating effective rainfall (ER), monthly average rainfall and consumptive use were needed. The ER of each individual crop was calculated by using the United States Department of Agriculture–Soil Conservation Service method by incorporating a slight modification in this method as suggested by Rao & Rajput (2008).

3.4. Water requirement

The WRs of available cropping patterns were found by using crop evapotranspiration and their ER. The total WR of crops grown in the Warangal and Khammam districts are shown in Table 2.

3.5. Linear programming model for proposed strategies

An optimization model called Linear Programming (LP) was used to develop the conjunctive use planning and changing in the cropping pattern for the selected tank command areas in Warangal and Khammam districts. A linear objective function for maximizing the net benefits and a set of constraints were used to run the LP in solver. A linear programming model (LPM) was developed for the assessment of conjunctive use options and changes in the cropping pattern according to Khare *et al.* (2006).

3.5.1. Changing in the cropping pattern under the command area of the tank

LP technique was used to develop the changing in the cropping pattern to reach an optimal allocation of SW to maximize the net benefits for given constraints and cropping pattern. The amount of SW supplied to the field was constant but crops may vary.

Table 2 | Water requirement of different crops under the selected tanks in Warangal and Khammam districts

District		Warangal		Khammam	
S.No	Season	Crop	Water requirement (m³ ha^{-1})	Crop	Water requirement (m³ ha^{-1})
1	Kharif season	Paddy	8,282	Paddy	8,706
2	Rabi season	Paddy	9,999	Paddy	8,916
		Maize	2,878	Maize	2,196
		Red gram	4,874	Red gram	5,067
		Black/green gram	2,008	Black/green gram	1,686
		Onion	4,137	Tomato/cucumber	5,620
				Brinjal	5,721
3	Annual crop	Cotton	6,342	Cotton	5,850
4		Chillies	8,877	Chillies	7,829

3.5.1.1. Objective function. The objective function was developed by considering net benefits and area of the cropping pattern subjected to SW constraints mentioned below as:

$$\text{Max } Z = \sum_{i=1}^{n} A_i * \text{NB}_i \quad (3)$$

where A_i is the area of the ith crop (ha); $i = 1, 2, \ldots n$. NB_i is the net benefits of the ith crop (Rs ha^{-1}).

3.5.1.2. Total water availability constraint. The total crop WRs of different crops were satisfied with the available SW resources. The total volume of irrigation water depends on the area and the demands of the different crops. The following constraint equation is also formulated to run the Linear Programming Problem (LPP) of changing in the cropping pattern model.

$$(A_i * \text{CWR}_i) \leq \text{SW} \quad (4)$$

where A_i is the area of the ith crop (ha); $i = 1,2, \ldots n$. CWR_i is the crop water requirement of the ith crop (m); SW is the amount of surface water available in the command area (ha m).

3.5.1.3. Land area constraints

$$\sum A_i \leq TA_k \quad (5)$$

where TA_k is the total area available for cultivation in different seasons, ha; A_i is the area of the ith crop (ha); $i = 1,2, \ldots n$.

3.5.1.4. Non-negativity constraints

$$\text{SW}_{i,k} \geq 0, \forall, k, i \quad (6)$$

$$A_{i,k} \geq 0, \forall, k, i \quad (7)$$

3.6. Conjunctive use of SW (tank water) and GW resources in tank commands

3.6.1. GW assessment

For assessing GW, we have to know the number of open wells and bore wells in the command area, and also the working hours of the pump, motor horsepower and discharge of the pump. The available GW under each tank is listed in Table 5.

The different crops grown under the tank commands were paddy (kharif and rabi), chillies, cotton, maize, green gram, black gram and red gram. Total command area of the tanks and total water availability of the tanks are shown in Table 8.

The LP technique was used to develop the conjunctive use modelling to reach an optimal allocation of surface and GW to maximize the net benefits for given constraints and cropping patterns.

3.6.2. Objective function

The objective function was developed considering net benefits and area of the cropping pattern subjected with surface and GW resources mentioned below as:

$$\text{Max } Z = \sum_{i=1}^{n} A_i * \text{NB}_i \quad (8)$$

where A_i is the area of the ith crop (ha); $i = 1, 2, \ldots\ldots\ldots\ldots\ldots\ldots n$. NB_i is the net benefits of the ith crop (Rs ha^{-1}).

3.6.3. Water availability constraints

The total crop WRs of different crops were satisfied with the available surface and GW resources. The total volume of irrigation water depends on the area and the demands of the different crops. The available surface and GW applied to the crops with different combinations. The following constraint equation is also formulated to run the LPP of the conjunctive use model:

$$SW_{i,k} \leq TASW \tag{9}$$

$$GW_{i,k} \leq TAGW \tag{10}$$

$$(A_i * CWR_i) \leq (SW + GW) \tag{11}$$

where A_i is the area of the ith crop (ha); TASW is the total available surface water in the command area (ha m); TAGW is the total available groundwater in the command area (ha m); CWR_i is the crop water requirement of the ith crop (m); $SW_{i,\,k}$ is the surface water available for ith crop and kth season in the command area (ha m); $GW_{i,\,k}$ is the groundwater available ith crop and kth season in the command area (ha m).

3.6.4. Non-negativity constraints

$$SW_{i,k} \geq 0, \forall, k, i \tag{12}$$

$$GW_{i,k} \geq 0, \forall, k, i \tag{13}$$

$$A_{i,k} \geq 0, \forall, k, i \tag{14}$$

3.7. Implementation of water saving technologies

These water saving technologies were used to save the water content and increase in the command area under the tanks. Several method were used to save the water but AWD method was used in this study. The field was subjected to periodical drying and re-flooding which will reduce the water use.

3.7.1. Alternate wetting & drying

This study was conducted at WALAMTARI farm, Rajendranagar, Hyderabad. For this study, a Bowmen tube (Figure 2(a) and 2(b)) was used made of Poly Vinyl Chloride (PVC) having 30 cm length and 15 cm diameter installed in the field. It had perforations on side walls of 20 cm by drilling holes of 5 mm in diameter spaced 2 cm apart. This perforated portion was buried in the soil so that 10 cm protruded from the soil surface. Soil from inside the tube was removed so that the bottom of the tube was visible. When the tube water level dropped 10 cm below the soil surface, then the field was flooded again to a depth of 5 cm for meeting crop water demands. The number of days of drying period without standing water in a rice field in AWD irrigation practice before re-flooding varied from 1 to 7 days depending on the soil type, weather conditions and crop growth stage. This irrigation system of periodic drops in pond water level and re-flooding was repeated during the life cycle of rice.

4. RESULTS AND DISCUSSION

The results obtained from the implementation of strategies (i) change in cropping pattern, (ii) conjunctive use of tank water with well water and (iii) water saving technologies to increase the land and water productivity under the tank command areas are presented below.

4.1. Implementation of change in the cropping pattern

The total WR of crops grown in Warangal and Khammam districts of Telangana state of Southern India are presented in Table 2. From Table 2, it is observed that paddy crop requires 18,280.60 m^3 ha^{-1} of water followed by chillies (8,876.90 m^3 ha^{-1}); cotton (6,341.50 m^3 ha^{-1}); red gram (4,874.20 m^3 ha^{-1}); onion (4,137.30 m^3 ha^{-1}); maize (2,877.60 m^3 ha^{-1}) and black/green gram (2,008.30 m^3 ha^{-1}) in Warangal district. In Khammam district, paddy crop requires 17,621.81 m^3 ha^{-1} of water followed by chillies (7,828.50 m^3 ha^{-1}); cotton (5,850.10 m^3 ha^{-1}); brinjal (5,720.90 m^3 ha^{-1}); tomato/cucumber (5,620.00 m^3 ha^{-1}); red gram (5,067.00 m^3 ha^{-1}); maize (2,196.40 m^3 ha^{-1}) and black/green gram (1,686.00 m^3 ha^{-1}). It shows that crop WRs for irrigated dry crops were less than the paddy in both Warangal and Khammam districts. Part of the WR for paddy during the kharif season was met from, rainfall due to that paddy requiring less water during the kharif season.

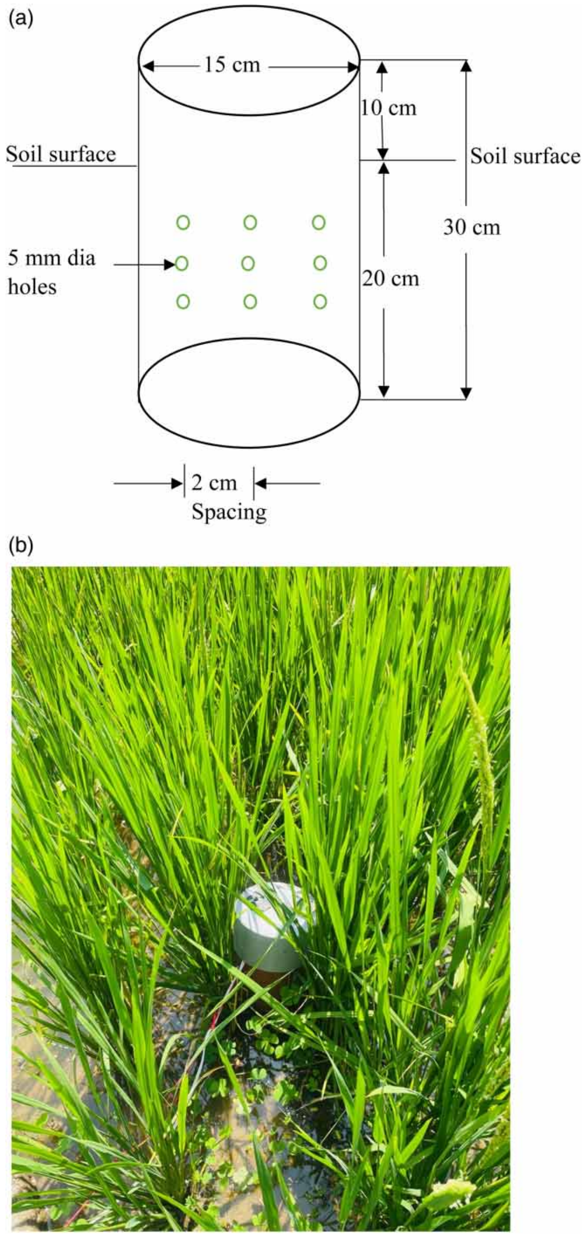


Figure 2 | (a) Schematic diagram of Bowmen tube. (b) Installation of Bowmen tube in Paddy field.

The results obtained from the change in cropping pattern are presented in Tables 3 and 4. From Table 3, it is observed that the due to a change in cropping pattern from paddy to irrigated dry crops, like maize, chillies and cotton, increased the cultural command area (CCA) of the tanks in Warangal District by 67–83% and net returns by 32–47% (USD 1,323 to 1,465 ha^{-1}). In Khammam district, due to a change in cropping pattern from paddy to irrigated dry crops, like maize, chillies and cotton, increased the CCA of the tanks by 73–92% and net returns by 36–48% (USD 1,272 to 1,543 ha^{-1}). On average due to changes in cropping pattern, the CCA of the tanks was increased by 79% and net returns by 43%. The irrigated dry crops like maize, chillies and cotton require less water compared to paddy due to the CCA of the tanks increasing significantly. Commercial crops like chillies and cotton provided higher net returns in comparison to paddy, and net returns under each tanks increased due to changes in cropping pattern. Similar results were also reported by Palanisami (2006). Lift irrigation schemes, an alternative cropping system to paddy, increased the command area by three to four times. (Rao *et al.* 2012). The use of pressurized irrigation systems in command areas, which could increase irrigation efficiency and water productivity

Table 3 | Optimal cropping pattern, CCA and net returns under various tanks in Warangal district

S No.	Tank name	Existing cropping pattern in ha	CCA (ha)	Net returns (USD ha^{-1})	Optimal cropping pattern	CCA (ha)	Net returns (USD ha^{-1})
1	Orrakunta	Kharif: Paddy – 23.5, Rabi: Paddy – 23.5, Cotton: 6; Chillies: 4	50.70	898	Kharif: Paddy – 14.35, Rabi: Maize – 41.3, Cotton: 22.5; Chillies: 10.7	88.85 (75)	1,323 (47)
2	Sammayya Kunta	Kharif: Paddy – 6, Rabi: Paddy – 6, Cotton: 2; Chillies: 2.12	16.12	1,023	Kharif: Paddy – 5.74, Rabi: Maize; 11.52, Cotton: 5.42; Chillies: 4.28	26.96 (67)	1,349 (32)
3	Venkatadri Kunta	Kharif: Paddy – 5, Rabi: Paddy – 5, Cotton: 2; Chillies: 1.9	15.90	1,002	Kharif: Paddy – 4.33, Rabi: Maize – 12.46, Cotton: 4.78; Chillies: 3.23	24.80 (78)	1,465 (46)
4	Yellayya Kunta	Kharif: Paddy – 8.16, Rabi: Paddy – 8.16, Cotton: 3; Chillies: 3	24.32	982	Kharif: Paddy – 7.56, Rabi: Maize – 21.76, Cotton: 7.85; Chillies: 3.64	40.81 (83)	1,368 (39)

Table 4 | Optimal cropping pattern, CCA & net returns under various tanks in Khammam district

S No.	Tank name	Existing cropping pattern in ha	CCA (ha)	Net returns (USD ha^{-1})	Optimal cropping pattern	CCA (ha)	Net returns (USD ha^{-1})
1	Aamudala Cheruvu	Kharif: Paddy – 20.07, Rabi: Paddy – 20.07, Cotton: 5; Chillies: 3	53.14	1,044	Kharif: Paddy – 13.89, Rabi: Maize – 43.20, Cotton: 23.97; Chillies: 11.35	92.43 (92)	1,543 (48)
2	Thalla Kunta	Kharif: Paddy – 6.09, Rabi: Paddy – 6.09, Cotton: 0.75; Chillies: 1.25	14.18	941	Kharif: Paddy – 3.69, Rabi: Maize – 11.49, Cotton: 6.38; Chillies: 3.02	24.58 (73)	1,376 (46)
3	Gaddi Kunta	Kharif: Paddy – 7.62, Rabi: Paddy – 7.62, Cotton: 1.5; Chillies: 1.25	19.99	933	Kharif: Paddy – 5.09, Rabi: Maize – 18.83, Cotton: 8.77; Chillies: 4.16	33.87 (88)	1,272 (36)
4	Parasuramuni Kunta	Kharif: Paddy – 18, Rabi: Paddy – 18, Cotton: 6; Chillies: 3.52	45.52	992	Kharif: Paddy – 12.1, Rabi: Maize – 37.61, Cotton: 20.89; Chillies: 9.88	80.48 (77)	1,467 (48)

CCA, cultural command area.
Note: values in parenthesis indicates the percentage increase.

and save water, increased the CCA of the canal system in Eastern India (Panda *et al.* 2018). The crop diversification from paddy to other irrigated dry crops significantly increased the water use efficiency, water productivity and net returns in the command areas and also increased the cultural command areas.

4.2. Implementation of conjunctive use

The available GW under each tank command area was worked out and is presented in Table 5. From the table, it is observed that the tank command areas have open wells ranging from 10 to 35 and 1_15 bore wells ranging from 1 to 15. The GW availability with these wells range from 6.44 to 21.55 ha m. Among all these tanks, Aamudala Cheruvu tank has the highest GW availability for pumping. The higher water availability is mainly due to more open and bore wells. It also implied that due to SW available in Amudala Cheruvu the GW recharge was better, and therefore there was more wells and enhanced the GW availability. The percolation pond was found to be the most appropriate structure for GW recharge Abraham & Mohan 2015. The SW harvesting structures increase the recharge capacity of the wells.

Table 5 | Amount of groundwater available under each tank

Tank name	Open wells	Pumping hours	Bore wells	Pumping hours	Discharge (lpm)	Total volume (ha m)
Oora Kunta	30	5	10	6	450	12.48
Sammayya Kunta	20	5	3	6	450	18.53
Venkatadri Kunta	15	5	5	6	450	9.46
Yellayya Kunta	25	5	10	6	450	15.51
Aamudala Cheruvu	35	5	15	6	450	21.56
Thalla Kunta	10	5	1	6	450	6.44
Gaddi Kunta	20	5	10	6	450	12.48
Parasuramuni Kunta	30	5	5	6	450	18.53

lpm, litre per minute.

The results obtained from the strategy on the implementation of conjunctive use in tank command areas are presented in Tables 6 and 7. From Table 6, if only 90% of the SW and 10% of the GW is supplied, then 22.55 ha area is cultivated with net returns of USD 8,207.40 ha^{-1} under the tank of Oora Kunta compared with other scenarios. When 50% of the SW and 50% of the GW is supplied, then a 9.62 ha area is cultivated with net returns of USD 3,498.90 ha^{-1} under the tank of Sammayya Kunta compared with other scenarios. When 10% of the SW and 90% of the GW is supplied, then a 7.42 ha area is cultivated with net returns of USD 2,700.24 ha^{-1} under the tank of Venkatadri Kunta compared with other scenarios. When 60% of the SW and 40% of the GW is supplied, then a 12.36 ha area is cultivated with net returns of USD 4,500.06 ha^{-1} under the tank of Yellayya Kunta compared with other scenarios in Warangal district. From Table 7, if 90% of the SW and 10% of the GW are supplied to the field, then 20.58 ha area is cultivated with net returns of USD 7,487.70 ha^{-1} under the tank of Aamudala Cheruvu; 6.35 ha area is cultivated with net returns of USD 2,310.13 ha^{-1} under the tank of Thalla Kunta; and 20.67 ha area is cultivated with net returns of USD 7,521.93 ha^{-1} under the tank of Parasuramuni Kunta compared with other scenarios. When 90% of the GW and 10% of the SW are supplied, then 7.42 ha area is cultivated with net returns of USD 3,619.11 ha^{-1} under the tank of Gaddi Kunta compared with other scenarios in Khammam district. From both Tables 6 and 7, for chillies CCA decreased by 5–27% with higher net benefits under each tank in the conjunctive use planning.

The chillies crop was the most economical to cultivate under the command area in each scenario. In general, the application of 100% of SW and GW is not possible in field practice. For most of the tanks, the conjunctive use strategy, i.e. 90% of the SW and 10% of the GW, is the best for maximum returns with optimal resources. However, it can vary from 90 to 40% of the SW and from 10 to 50% of the GW depending upon the resource availability. These results are in line with Unami & Kawachi (2005), Sakurai & Palanisami (2001) and Satish Kumar *et al.* (2012). The conjunctive use of

Table 6 | Conjunctive use for selected tanks in Warangal district

Tank name	% SW	% GW	Total available water (ha m)	Crop	Area (ha)	Net returns (USD ha^{-1})
Oora Kunta	100	0	29.71	Chillies	23.44	8,528.32
	0	100	18.53	Chillies	14.61	5,320.30
	90	10	28. 59	Chillies	22.55	8,207.40
Sammayya Kunta	100	0	11.81	Chillies	9.38	3,412.02
	0	100	12.49	Chillies	9.85	3,585.77
	50	50	12.18	Chillies	9.62	3,498.90
Venkatadri Kunta	100	0	8.96	Chillies	7.06	2,570.92
	0	100	9.46	Chillies	7.46	2,714.61
	10	90	9.41	Chillies	7.42	2,700.24
Yellayya Kunta	100	0	15.51	Chillies	12.41	4,516.22
	0	100	15.65	Chillies	12.30	4,475.82
	60	40	15.59	Chillies	12.36	4,500.06

SW, surface water; GW, groundwater.

Table 7 | Conjunctive use for selected tanks in Khammam district

Tank name	% SW	% GW	Total available water (ha m)	Crop	Area (ha)	Net returns (USD ha^{-1})
Aamudala Cheruvu	100	0	30.24	Chillies	21.83	7,943.90
	0	100	21.56	Chillies	15.56	5,662.92
	90	10	28.50	Chillies	20.58	7,487.70
Thalla Kunta	100	0	8.04	Chillies	6.48	2,357.14
	0	100	6.44	Chillies	5.19	1,887.17
	90	10	7.88	Chillies	6.35	2,310.13
Gaddi Kunta	100	0	11.08	Chillies	8.93	3,248.39
	0	100	12.49	Chillies	10.05	3,660.30
	10	90	12.35	Chillies	9.94	3,619.11
Parasuramuni Kunta	100	0	26.33	Chillies	21.30	7,751.47
	0	100	18.53	Chillies	14.99	5,456.06
	90	10	25.55	Chillies	20.67	7,521.93

SW, surface water; GW, groundwater.

Table 8 | Increase in the command area with implementation of AWD under selected tanks

			Existing data		AWD			
S. No	District	Tank name	Total available water (ha m)	Total command area (ha)	Water saved per hectare (ha m ha^{-1})	Total water saved (ha m)	Total available water (ha m)	Increased command area (ha)
1	Warangal	Oora Kunta	29.71	30.35	0.34	10.40	40.11	40.97
2		Sammayya Kunta	11.88	10.12	0.41	4.16	16.04	13.66
3		Venkatadri Kunta	8.96	8.90	0.35	3.14	12.1	12.02
4		Yellayya Kunta	15.65	14.16	0.39	5.48	21.13	19.11
5	Khammam	Aamudala Cheruvu	30.24	23.07	0.46	10.58	40.82	31.14
6		Thalla Kunta	8.04	8.09	0.35	2.81	10.85	10.92
7		Gaddi Kunta	11.08	10.12	0.34	3.89	14.97	13.67
8		Parasuramuni Kunta	26.33	27.52	0.41	9.22	35.55	37.20

water from rain, tanks and GW reserves, supported by proper monitoring, could improve the resilience and productivity of traditional tank irrigation systems (Siderius *et al.* 2015). The conjunctive use of canal water and well water reduced the gaps between supplies and demands (Rao & Rajput 2009). The conjunctive use of tank water and well water is the better strategy for optimal resource use and higher returns in tank command areas. This strategy needs to be incorporated into the minor irrigation policy framework.

4.3. Implementation of water saving technologies

The results obtained from the strategy on the implementation of water saving irrigation technology, i.e. AWD in paddy fields, are presented in Table 8. From Table 8, it is observed that with the implementation of AWD, the CCA increased from 30.35 to 40.97 ha (34.99%) under Oora Kunta (tank); 10.12 to 13.66 ha (34.98%) under Sammayya Kunta; 8.90 to 12.02 ha (35.05%) under Venkatadri Kunta and 14.16 to 19.11 ha (34.95%) under Yellayya Kunta in Warangal district. With the implementation of AWD, the CCA increased from 23.07 to 31.14 ha (34.98%) under Aamudala Cheruvu; 8.09 to 10.92 ha (34.98%) under Thalla Kunta; 10.12 to 13.67 ha (35.07%) under Gaddi Kunta and 27.52 to 37. 20 ha (35.17%) under Parasuramuni Kunta in Khammam district of Telangana. The results revealed that the CCA of the tanks increased by approximately 35% over the original CCA of the tanks.

Application of AWD saved 35–40% of the irrigation water compared to flooded rice, which might be due to the reduced number of irrigations and their frequencies (Sridhar *et al.* 2020). The saved water can therefore bring the excess area under paddy cultivation. AWD method of irrigation is promising in paddy cultivation in irrigation projects and tank command areas and it saves irrigation water, which can bring additional command area. The researchers Chen *et al.* (2022) and Ruensuk *et al.* (2021) also reported the positive aspects of the AWD method of irrigation. AWD technique can also reduce greenhouse gas emissions from paddy fields (Kumar & Rajitha 2019; Ishfaq *et al.* 2020; Chen *et al.* 2022). The AWD method of irrigation is a climate resilient practice and conserves natural resources. This technology needs to be upscaled in irrigation and tank command areas to reduce the gap between water demands and supplies and enhance water use efficiency and water productivity.

5. CONCLUSION

The results indicated that the CCA was increased in the rabi season under both districts, while the paddy crops were replaced with irrigated dry crops. The irrigated dry crops (maize, cotton, green gram, black gram and red gram) required lesser water compared to paddy. Due to the change in cropping pattern from paddy to irrigated dry crops, like maize, chillies and cotton, the CCA of the tanks increased by 79% and net reruns by 43%. Paddy crop was cultivated only in kharif season with the contribution of 100% surface water; but there is no increment in the rabi season and it affects the net returns and water use efficiency. Implementation of the AWD method saves water (35–40%) and increases the CCA in paddy growing areas. It is found that the AWD method is good for paddy cultivated areas under the tank command areas. Application of 100% SW and GW is not possible in field practice and so a combination of SW and GW was suggested for maximum net benefits with the utilisation of different conjunctive use planning. These strategies can be implemented to increase the water use efficiency, CCA and net returns in the tank command areas of Southern India. These strategies need to be incorporated into the minor irrigation policy frameworks.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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