Tank performance and its impact on rural livelihoods of tank commands in Andhra Pradesh, India: a spatial analysis approach

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This study examines the impact of poor tank performance in Andhra Pradesh, India, focusing on non-system and system tanks. Data analysis reveals declining tank performance over the past three decades, with average performance at 58.39% for non-system tanks and 87.4% for system tanks in 2021. Non-system tanks show favourable gross farm revenue and water user association characteristics, with siltation negatively affecting the performance. System tanks benefit from better foreshore and water spread area maintenance, reducing siltation and encroachment issues. Recommendations include Government initiatives for desiltation, strengthening water user associations, and promoting less water-intensive crops to address tank performance challenges.

Keywords: Human-induced factors, non-system and system tanks, rural livelihoods, spatial analysis, tank performance model.

MANY regions of India employ tank irrigation to cultivate crops, primarily paddy, but its prevalence is highest in the South Indian states such as Andhra Pradesh, Karnataka, Tamil Nadu and Telangana. Even now, tanks account for 20–30% of the total net irrigated area in several districts of these states. Small bodies of water, i.e. tanks, have been an essential source of irrigation water in India for centuries. Tanks have offered excellent livelihood protection to rural populations for millennia. Due to the modest size of these tanks, the irrigable capacity (command area) of each tank is typically between 50 and 250 ha (refs 1–3).

Despite providing several indirect and direct benefits to the rural communities, especially farmers, India's total irrigated area from tank sources continues to decline. From 4.56 million hectares (m ha) in 1960–61 to 1.89 m ha in 2013–14, the area irrigated by tanks has decreased by around 59%. Andhra Pradesh, Karnataka and Tamil Nadu, where tank irrigation is still significant, irrigate a fair portion of land[4,5]. During 2019–20, the net tank-irrigated area accounted for 13.30% in Andhra Pradesh, 16.57% in Tamil Nadu and 6.16% in Karnataka of their total net irrigated area of 28.79, 26.72 and 40.32 m ha respectively[6].

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After independence, numerous new tanks were constructed in India while keeping in mind the significance of minor irrigation for the general growth of rural economy. The rapidly growing usage of groundwater irrigation, lower water inflow, encroachments in supply channels, inadequate water user's engagement in tank maintenance and administration, etc. all seem to be contributing to the poor performance of newly constructed tanks. Due to their limited access to resources, marginal and small farmers still face difficulty growing crops due to the loss in tank-irrigated land since they cannot afford to use groundwater, an alternative method of irrigation that is expensive[7,8].

Several studies have examined tank performance across India, particularly in Andhra Pradesh. Reddy *et al.*[9] presented a detailed account of several rank performance studies conducted over the decades in the country. Other studies demonstrated that tank performance declined during the Green Revolution in the mid-1960s (refs 10–12). No single factor has been identified as the cause for the poor performance of tanks, but institutional, physical and technological variables seem to have combined in most cases to bring about the decline in tank irrigation in India[13]. Studies on the recently launched Andhra Pradesh Community-Based Tank Management Project (APCBTMP) have also been conducted to analyse its overall impact on several parameters[14].

Unfortunately, the decrease in net tank-irrigated area that results from poor tank performance will primarily affect resource poor small and marginal farmers. The loss of budget friendly tank irrigation with the gain of expensive alternative, i.e. groundwater irrigation. In the near future, a persistent decline in tank performance may cause water shortage and the total disappearance of eco-friendly water sources, notably affecting marginal and small farmers.

In order to assess tank performance, find the reasons behind declining performance of tank-water resources and ways to replenish the available resources with estimates of influencing factors of tank performance, this study deals with two different tank irrigation systems, viz. non-system tank in Chittoor district and system tank in Srikakulam district, Andhra Pradesh. It explores the possibilities to improve the performance of tank irrigation, with the use of spatial data on water spread area and cropping pattern

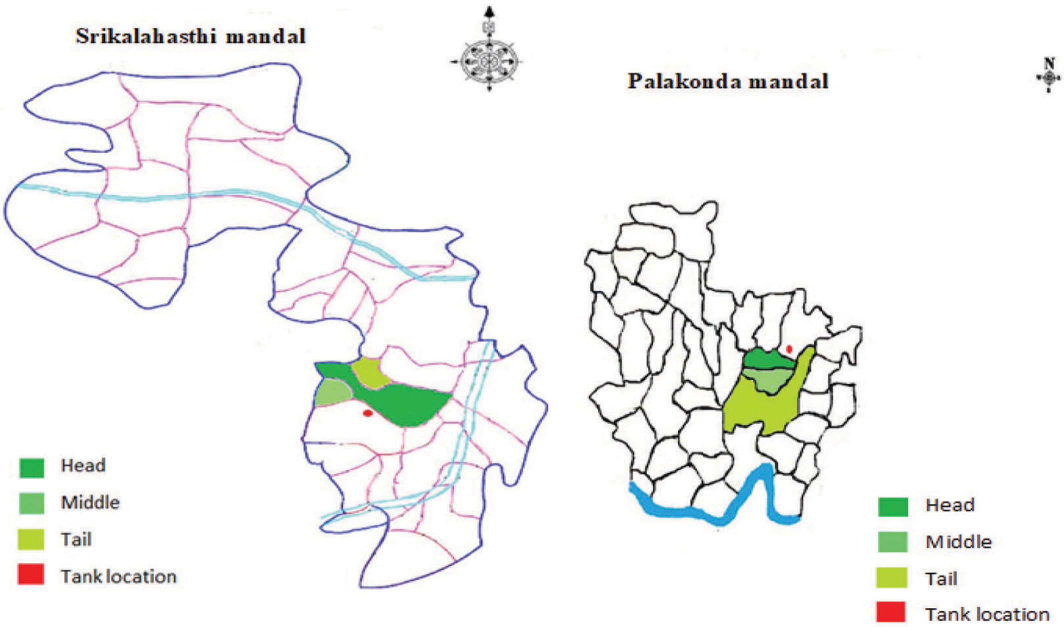

Figure 1. Geographical location of the study tanks in Andhra Pradesh, India.

for the last five years collected with the help of remote sensing (RS) and Geographic Information System (GIS) tools along with primary and secondary data on human-induced factors that aid in the declining tank performance of these tank systems in Andhra Pradesh. The specific objectives of the study are as follows: (i) To evaluate the general characteristics of the non-system and system tanks in the study area. (ii) To estimate the mean value of influential factors and tank performance of the study tanks. (iii) To identify the association between influencing factors and tank performance of the study tanks. (iv) To determine the impact of variables on tank performance under non-system and system tanks.

Materials and methods

Study location

Andhra Pradesh, being India's highest tank-irrigated state, displays substantial regional variations in tank performance based on the tank irrigation system. There are two tank irrigation systems in the state: non-system and system tanks. Changes in the filling pattern, cropping pattern and agricultural production system are significant among these tank irrigation systems. The selected system tank in this study is located at 83°75′E long. and 18°60′N lat. in Srikakulam district of the North Coastal Andhra region (Figure 1), connected to Thotapalli left canal of Nagavali river with multi-cropping pattern and water-surplus production system, while the non-system tank in Chittoor district of the Rayalaseema region is located at 79°70′E long. and 13°75′N lat. with mono- or double cropping pattern. The majority of the farmers followed a water-deficit and dryland-based agricultural production system.

Under each tank command area, a cluster of three villages was selected to represent the head, middle, and tail-end regions under the tank irrigation system. From each village, a random sample of 30 farmers was selected, making a total of 90 sample farmers under each tank command area and a grand total of 180 sample farmers from both tank command areas.

The respective tank command areas are 389.49 and 273.17 ha. Both tanks represent groundwater use intensity measured in terms of the number of wells irrigating per ha (0.67/ha) in the non-system tank district of Chittoor. Meanwhile, the micro-irrigation (0.37/ha) sources dominate in and around their system command area. Delayed onset and failure of monsoons, scarcity of water and variations in climatic parameters have paved the way for the adaptation of mitigation and coping strategies by command-area farmers. Marginal farmers are more prevalent in the tank command zones of both tanks at 48.7% and 58.76% of the overall farming community (Table 1).

Data and methodology

The required primary data from the 180 sample respondents were collected using the well-designed pretested survey schedule while taking into account the indicated objectives (Table 2). Data on the nature of water user's associations (WUAs), farmer's participation in collective tank management, farm income and the kind of support offered by institutional agencies were obtained in order to evaluate the performance of the tanks under the two tank-irrigation

Table 1. Profile of the study tanks in Andhra Pradesh, India (2021–22)

Particulars	Non-system tank	System tank
Registered command area (ha)	389.49	273.17
Actual command area (ha)	168.22	208.77
Number of wells and micro-irrigation sources in the command areas	264	102
Well density (no. of wells/ha)	0.67	Absent
Micro-irrigation source density (no. of sources/ha)	Absent	0.37

Source: Irrigation Department and village administrative officers of the concerned tanks and villages.

Table 2. Classification of the study area based on the type of tank irrigation

Type of tank irrigation	Sample districts	Sample mandals	Sample villages	Sample respondents
System tank	Srikakulam	Palakonda	Lumburu (Head)	30
			Garugubilli (Middle)	30
			Palakonda (Tail)	30
Non-system tank	Chittoor	Srikalahasti	Uranduru (Head)	30
			Guntakindapalli (Middle)	30
			Maddiledu (Tail)	30
Total				180

systems for 30 years (1990–2021). The Irrigation Department and village administrative officers of the relevant tanks and villages provided information on well density or micro-irrigation source density, water availability, number of fillings, encroachment and siltation levels. Along with primary data, spatial data were also collected using RS&GIS tools to analyse cropping intensity (MODIS dataset) and water spread area (SENTENIL-1 SAR dataset) for both tank systems to determine their impact on tank performance.

Tank performance model

In addition to rainfall, a number of human-induced factors can have an impact on tank performance. Using 9 variables under each tank system for the previous 30 years (1990–2021), multiple linear regression analysis was conducted individually to assess the performance of the two tank irrigation systems, as shown below.

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7 + b_8X_8 + b_9X_9, \quad (1)$$

where Y is the tank performance (%/year), a the intercept, X_1 the well density or micro-irrigation source density (no./ha), X_2 the filling pattern (no./year), X_3 the water availability (days/year), X_4 the encroachment level (%), X_5 the siltation level (%), X_6 the presence or absence of WUAs (1 if present, 0 otherwise), X_7 the farm income (Rs/ha), X_8 the Farmer's participation in WUAs by financial or physical contribution (1 if present, 0 otherwise), X_9 the Government support (1 if present, 0 otherwise) and b_1–b_9 are the slope coefficients.

Variables under tank performance model

Tank performance is defined as the percentage of actual cultivated area under a tank command to the registered or total command area under the tank, as given in the literature[15–17].

$$\text{Tank performance} = \frac{\left(\begin{array}{c}\text{Actual cultivated}\\ \text{area of the tank}\end{array}\right)}{\left(\begin{array}{c}\text{Registered command}\\ \text{area of the tank}\end{array}\right)} \times 100.$$

Well density or micro-irrigation source density

The number of wells in a non-system tank or the number of micro-irrigation sources in a system tank per hectare of the command area.

Filling pattern: The number of times a tank gets filled up during a crop year.

Water availability: The number of days water will be available during a crop year.

Encroachment level: The percentage of water spread and foreshore areas encroached due to human-induced factors.

Siltation level: The percentage of siltation in a tank in each year over the years.

WUAs: The presence or absence of Government or non-Government water user organizations/associations for a tank (1 if present, 0 otherwise).

Farm income: The average gross farm income earned by sample farmers during a crop year.

Farmer's participation: Farmer's labour or financial contribution, or both, for maintenance of a tank (1 if present, 0 otherwise).

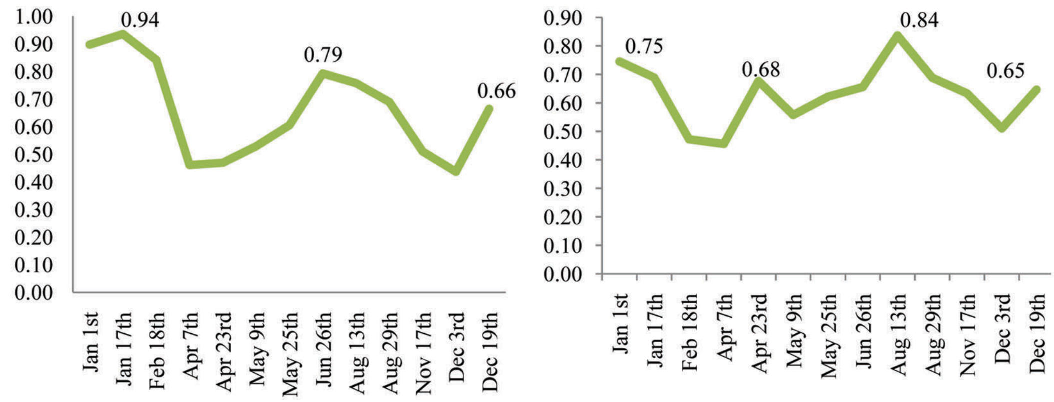

Figure 2. NDVI under non-system and system tank command areas.

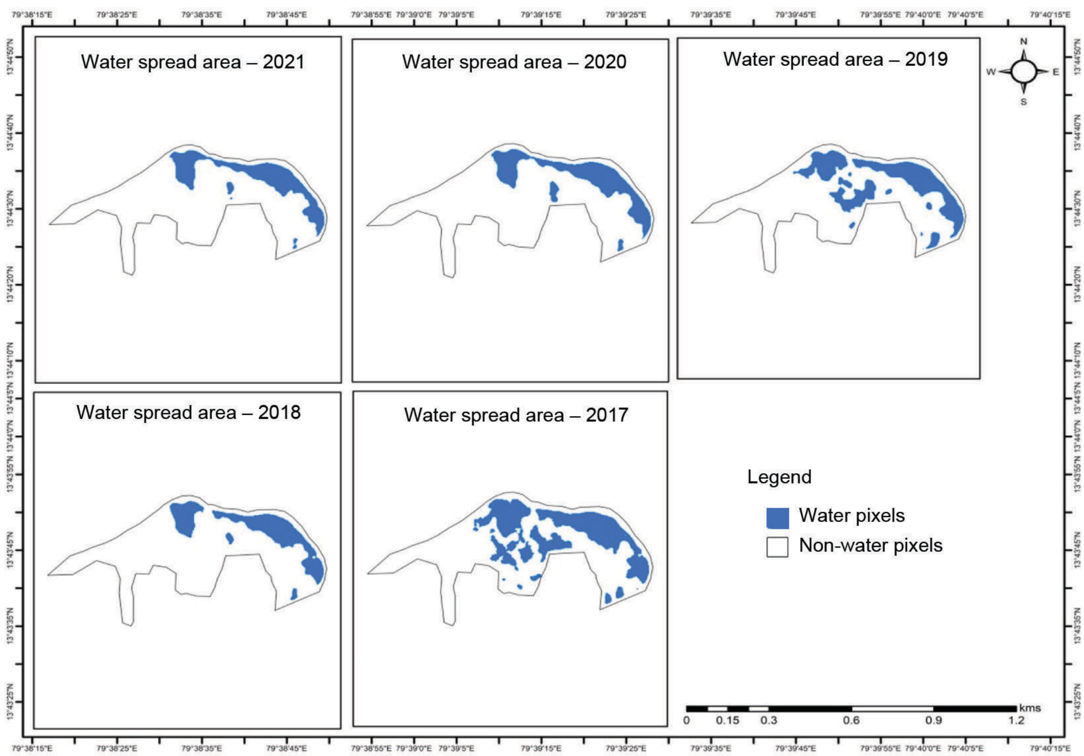

Figure 3. Spatial water spread area of a non-system tank in Andhra Pradesh (August).

Government support: Assistance from institutional agencies in the form of financial support or any reclamation and maintenance measures are taken up during each year over the study period (if present 1, 0 otherwise).

Cropping pattern and water spread area under tank irrigation systems

The average cropping intensity in the non-system tank command region was 135.18%, followed by 130.90% in the system tank command area. Cropping intensity was computed using MODIS normalized difference vegetation index (NDVI) data, which are useful for calculating vegetation indices, forecasting crop yields, and monitoring local and regional agricultural production. Each peak in the NDVI graph represents the maximum amount of vegetation or the number of crops in a cropping season (Figure 2). It was observed that paddy–groundnut cropping pattern was followed in the non-system tank, while paddy followed by pulses, groundnut or sesame were cultivated in the system tank with a minor percentage of annual crop sugarcane.

Spatial data for water spread area were collected using SENTENIL-1 SAR dataset of strip-map images for 5 years (2017–21, August). The water spread area under non-system tank recorded 65.20, 37.17, 53.30, 38.77 and 36.53 ha respectively, over the past 5 years (Figure 3), while under

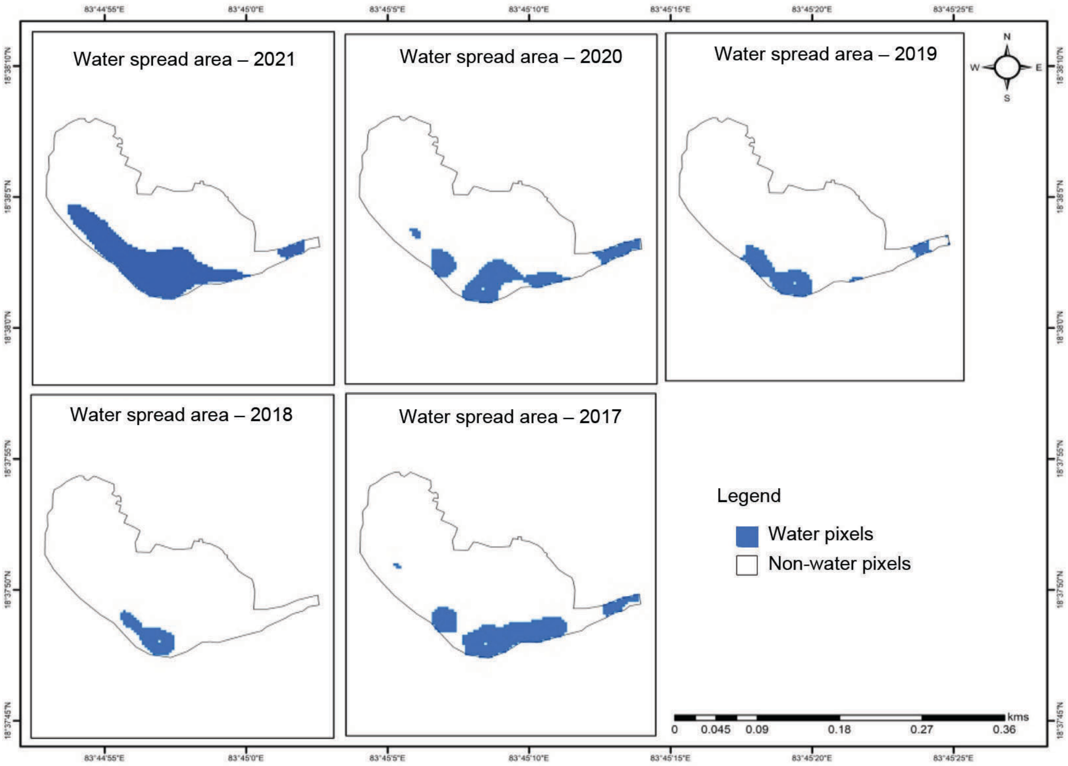

Figure 4. Spatial water spread area of a system tank in Andhra Pradesh (August).

system tank, the spatial water spread area distribution recorded 3.86, 1.24, 1.24, 3.42 and 6.83 ha respectively (Figure 4).

Results and discussion

Tank performance impacts agricultural patterns, household economy and eventually, the tank economy of a region/ state. A variety of factors influence tank performance in a given region. Some of the influential aspects that have a substantial impact on tank performance are examined, analysed and addressed in this section.

General characteristics of non-system and system tanks in the study area

The actual command area of the tank was 168.22 ha, spread across 540 farm households. Therefore, a single farmer would have only 0.31 ha of land to produce and support his/ her family. Currently, the tank has only one filling, while it had 1.5 fillings 10 years ago. In addition, 40% of siltation and 20% of encroachment in the foreshore region have reduced water availability during the crop season to just 60 days (with good rainfall). It is possible to increase the number of days of water availability for improved agricultural output in the command area by increasing the number of fills. The overall reliance of the command area on rice agriculture and a small area devoted to groundnut production (dryland) has resulted in perilous conditions due to inadequate maintenance, paucity of inputs and decreased water availability. The tank receives water storage with the start of good rainfall, which lasts just 3–4 months. Farmers have relied on groundwater irrigation by digging additional wells to overcome adversities over time. In the last 30 years, the number of wells in the command area has increased from 100 to 200. Each well covers the water needs of 2–3 farmers or 1.18 ha of land (Table 3).

Under the system tank, the actual command area is 208.77 ha, which is shared by 485 farmers. Consequently, a farmer may cultivate on less than 1 ha, i.e. 0.43 ha of land. During a crop season, the tank water supply is more, and water is accessible for 120 days (4 months). Statistically, the higher water supply in the system tank compared to the non-system tank is significant. Reduced fillings per crop season from 3.5 (before 10 years) to 2.5 has resulted in less water availability for irrigation. A 40% encroachment on the shoreline and a 25% siltation of the water spread area affected the overall amount of water available. While encroachment impairs the function of a tank as a whole, siltation is less of a problem in a system tank than in a non-system tank. Farmers began using micro-irrigation to overcome irrigation water shortages to reduce crop failures and yield losses due to the lack of water. With each source providing 2.08 ha of the command area, the number of sources had grown from 60 to 100 over the years (Table 3).

Table 3. General characteristics of study tanks in Andhra Pradesh during 2021–22

Particulars		Tank scenario	
Tank type		Non-system	System
Actual command area (ha)		168.22	208.77
Tank performance		43.18	76.42
No. of households in the command area		540	485
No. of fillings	10 years before	1.5	3.5
	2021–22	1	2.5
Water availability (days)	10 years before	90	150
	2021–22	60	120
Encroachment (%)	10 years before	15	20
	2021–22	20	40
Siltation (%)	10 years before	25	18
	2021–22	40	25
No. of wells or micro-irrigation sources	1991–2000	115	60
	2001–10	150	86
	2011–21	200	100

Source: Irrigation Department and village administrative officers of the concerned tanks and villages.

Table 4. Mean value of influential variables affecting the performance of the study tanks during 2021–22

Variables	Non-system tank	System tank
Tank performance (%/year)	58.39	87.40
Actual cultivated area (ha)	227.42	238.75
Well density or micro-irrigation source density (no./ha)	0.67	0.34
Number of fillings (no./crop year)	1.45	4.25
Water availability (days/crop year)	103.75	156.40
Encroachment (%)	8.76	2.03
Siltation (%)	13.80	2.14
Presence of WUAs (%)	53	65
Farm income (lakh rupees/ha)	2.11	3.66
Farmer’s participation (%)	65	68
Government support (%)	59	50

Note: WUAs, Water user’s associations.
Source: Authors’ own estimates from the survey and secondary sources of information.

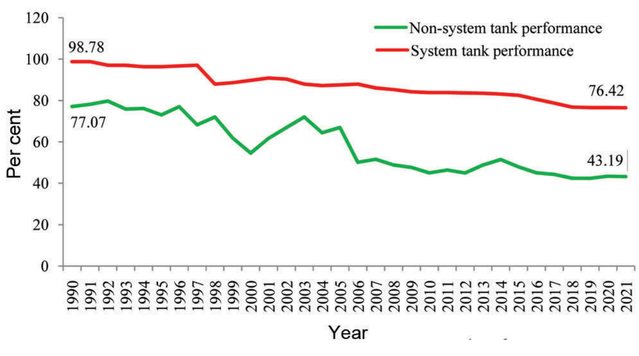

Figure 5. Trend lines of non-system and system tank performances over the years (1990–2021).

Mean value of influencing factors and tank performance

The mean value of tank performance and other variables impacting the same were evaluated (Table 4). Average levels of encroachment and siltation were lower in the system tank due to proper maintenance and operation in the tank bed and foreshore area.

The mean value of tank performance for the non-system tank during 2021 was 58.39% (Table 4 and Figure 5), compared to 87.40% for the system tank. This difference is statistically significant. Farmers expressed an increased siltation problem in the non-system tank as a result of social forestry, which hampered tank performance. Similar results were obtained in a study by Palanisami and Jegadeesan[15], in which social forestry was found to exacerbate the problem of siltation in tank beds and foreshore areas, thus impacting the overall performance of tanks.

Association among variables and tank performance

Table 5 shows the results of the estimation of partial correlation coefficients and the relevant variables impacting tank performance. The findings show that the filling pattern under non-system tank set-up is positively significant, contributing to the tank performance by 77.4%. The encroachment, however, is found to be negatively significant. Water availability in the study area had reduced by 40%, from 90 to 60 days. The average gross farm income also boosted tank performance significantly (Table 5). Each farm used more available tank water after adopting a diverse crop and farming plan, which improved tank performance. The association variable for water users was positive and significant. The eradication of encroachment and siltation problems has been made possible by the effective management and maintenance of WUAs.

The tank performance was positive and significantly influenced under the system tank set-up by variables like filling pattern and number of water available days (Table 5). Water supply and availability can be increased through better foreshore and water spread area management, which would reduce the levels of siltation and encroachment. It has been demonstrated that the tank performs significantly better with Government support.

Improvements in well density and micro-irrigation sources were found to have a negative impact on tank performance in both the non-system and system tank scenarios, indicating that poor tank performance has resulted in more tubewells, an increase in the adoption of micro-irrigation systems, and an increase in water utilization by groundwater irrigation to sustain the net irrigated area of Andhra Pradesh. Thus, reviving the tank irrigation system could achieve double the benefits of more recharge for increasing micro-irrigation systems and increase the net tank irrigated area in the study districts of the state. The collateral studies in the literature yield comparable results[12,17,18].

Tank performance and its determinants

To quantify the influence of the above-mentioned factors on tank performance, excluding rainfall, a linear relationship was mapped between tank performance and the factors, including well density, filling pattern, water availability, encroachment levels, siltation levels, presence of WUAs, farm income, farmers' participation and Government support.

Table 5. Correlation between variables and performance of the study tanks

Independent variables	Correlation value	
	Non-system tank	System tank
Well density or micro-irrigation density	–0.829	–0.925
Number of fillings	0.774**	0.943**
Water availability days	0.659	0.839**
Percentage of encroachment	–0.627**	–0.045
Percentage of siltation	–0.757	–0.623
Presence of WUAs	0.5702**	0.2401
Average gross farm income	0.874**	0.892
Farmer's participation	0.231	0.163
Government support	0.105	0.141**

Note: **Indicates significance at 0.05% level of significance.
Source: Authors' own estimates from the survey and secondary sources of information.

Tank performance under the non-system tank scenario

Table 6 shows that the variables evaluated from the study explain about 90% of the variation in tank performance. As expected, encroachment levels were found to be unfavourable and considerable in the non-system tank performance. The inclusion of WUAs, on the other hand, had a favourable and significant effect on tank performance.

The existence of formal or informal water user groups and the availability of financial resources facilitate the repair and maintenance of tank beds and enhance the water spread area, hence reducing encroachment and siltation levels. Also, multiple cropping patterns and farming methods help farmers diversify their income and use the water in their tanks more efficiently. Collateral studies of Karunakaran and Palanisami[19] revealed that despite the decline in net tank irrigated area in Tamil Nadu, tank irrigation had a significant positive impact on cropping intensity, the revival of which will enhance the livelihoods of tank command farmers.

Tank performance under the system tank scenario

The variables examined for analysis explained more than 90% of the variation in tank performance under the system tank. Compared to non-system tanks, siltation levels in the foreshore and water spread area of the system tank were found to be negatively impacting tank performance, whereas filling pattern and number of water available days were found to be positively significant influencing tank performance (Table 7).

Farmers believe that a minimum of 3–4 fillings are essential for successful yield since 2.5 fillings offer water for 120 days. Furthermore, because 25% of silt in the tank water distribution area is collected, more than three fills are required to maintain appropriate water delivery to the fields while also increasing the number of days of water availability.

Challenges and the way forward

The amount of rainfall is a significant factor in determining the tank catchment area water levels, ultimately improving or reducing the actual command area for tanks, especially under rainfed/non-system tanks. Variations in seasonal rainfall (excess, less, or untimely) pose a serious challenge to the overall agricultural production and yield, as more than 65% of this is contributed by the southwest monsoon in

Table 6. Impact of variables on performance under non-system tank scenario in Andhra Pradesh

Variables	Coefficients	Standard error	*t*-Ratio
Constant	11.21	23.17	0.48
Well density (no./ha)	–0.05	0.05	–1.01
Fillings (no./crop year)	16.97	12.82	1.32
Water availability (days/crop year)	0.13	0.19	0.67
Encroachment (%)	–1.36***	0.49	–2.80
Siltation (%)	–0.21	0.37	–0.57
WUAs (%)	5.51**	2.03	2.72
Farm income (Rs/ha)	0.00015**	0.00	2.34
Farmer's participation (%)	1.40	2.43	0.58
Government support (%)	0.59	1.71	0.34
Adjusted R^2	0.90		
F-statistics	33.75***		
No. of observations	30 (1990–2021)		

Note: ***, **Indicate significance at 0.01% and 0.05% level of significance.
Source: Authors' own estimates from the survey and secondary sources of information.

Table 7. Impact of variables on performance under system tank scenario in Andhra Pradesh

Variables	Coefficients	Standard error	*t*-Ratio
Constant	41.14	22.03	1.87
Micro-irrigation density (number/ha)	0.05	0.12	0.45
Fillings (no./crop year)	4.06**	1.51	2.65
Water availability (days/crop year)	0.13***	0.06	2.06
Encroachment (%)	–1.56	0.96	–1.56
Siltation (%)	–3.82**	1.53	–2.51
WUAs (%)	0.98	1.04	0.94
Farm income (Rs/ha)	1.01	0.00	0.07
Farmer's participation (%)	0.49	0.88	0.56
Government support (%)	0.69	0.90	0.77
Adjusted R^2	0.91		
F-statistics	37.34***		
No. of observations	30 (1990–2021)		

Note: ***, **Indicate significance at 0.01% and 0.05% level.
Source: Authors' own estimates from the survey and secondary sources of information.

the state. To mitigate yield loss, adoption of short- or medium-term crop varieties, less water-intensive crops suitable for agro-climatic regions and reliance on supplementary micro-irrigation water sources can be encouraged. Excess of social forestry was found to be another factor under the non-system tank that posed a heavy siltation challenge with the reduction of water storage capacity in the tank. Under the system tank, siltation and waterlogging problems were registered due to heavy rainfall and improper maintenance, leading to decreased tank performance over the decades. Effective deslitation measures with participatory water management will improve water storage capacity and filling pattern, while proper maintenance of supply channels will bring the equitable distribution of tank water across the tank command area farms under both tank systems. Human-induced factors like encroachment in the foreshore area and tank bed can be mitigated by imposing serious penalties and pricing under the surveillance of the Irrigation Department officials of the concerned tanks. Strengthening WUAs will benefit the command area farms to avoid demand–supply gaps, encroachment problems, improving the number of water availability days and particularly improvement in the socio-economic structure of tail-end farms under both tank systems.

Conclusion and future perspectives

The present study in Andhra Pradesh compared non-system and system tanks, revealing a consistent decline in the water spread area of the non-system tank from 65.20 to 36.53 ha, attributed to weather, encroachment and siltation. Encroachment and siltation levels increased in both tank systems, resulting in reduced water availability. During the study period, tank performance declined for the non-system tank from 77.07% to 43.18% and for system tanks from 98.78% to 76.42%, due to climatic and human-induced factors. Fillings and water availability showed a strong positive correlation with tank performance, reaching 77.4% for the non-system tank and over 80% for the system tank. Encroachment negatively affected the non-system tank, while average gross farm revenue and WUAs contributed positively.

Optimization of tank water resources between the non-system and system tanks with effective measures of desiltation and encroachment will bring improvements in tank performance and livelihoods of tank command area farmers. Sustainability in water use can be brought about by carefully using tank water supplemented with subsidized micro-irrigation sources. The inclusion of major areas under less water-intensive crops (coarse cereals under the non-system tank and pulses and millets under the system tank) in similar agro-climatic regions will help mitigate the water scarcity conditions of tank system commands.

Conflict of interest: The authors declare that there is no conflict of interest.

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