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

Karunakaran K. R[1] and Madhurima U[2,*]

[1]Professor & Head, Dept. of Social Science, AC&RI, Tamil Nadu Agricultural University, Kudumiyanmalai, Tamil Nadu, India

[2]Ph. D Scholar, Dept. of Agricultural Economics, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

Unedited version published online on 18/10/2023

This paper 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 per cent for non-system tanks and 87.4 per cent for system tanks in 2021. Non-system tanks show favorable gross farm revenue and water user association characteristics, while siltation negatively affecting 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.

Key words: Tank irrigation, tank performance, spatial analysis, tank performance model, human-induced factors.

Many regions of India employ tank irrigation to cultivate crops, primarily paddy, but its prevalence is highest in South Indian states such as Andhra Pradesh, Karnataka, Tamil Nadu and Telangana. Even now, tanks account for 20–30 per cent 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

[*] For correspondence (email: madhurimaupadhyay@gmail.com)

populations for millennia. Due to the modest size of tanks, the irrigable capacity (command area) of each tank is typically between 50 and 250 hectares[123].

Despite providing several indirect and direct benefits to the rural community, especially farmers, India's total irrigated area from tank sources continues to decline. From 4.56 million hectares in 1960–61 to 1.89 million hectares in 2013–14, the area irrigated by tanks decreased by around 59 per cent. Andhra Pradesh, Karnataka and Tamil Nadu where tank irrigation is still significant, irrigates a fair portion of land[45]. The net tank irrigated area accounted for 13.30 per cent in Andhra Pradesh, 16.57 per cent in Tamil Nadu and 6.16 per cent in Karnataka of their total net irrigated area of 28.79, 26.72 and 40.32 mha during 2019-20[6], respectively.

After independence, numerous new tanks were constructed while keeping in mind the significance of minor irrigation for the general growth of the 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 newly built tank's poor performance. Due to their limited access to resources, marginal and small farmers are still facing a difficult time growing crops due to the loss in tank irrigated land since they cannot afford to use groundwater, an alternative method of irrigation that is very expensive[78].

Several studies have examined tank performance across India, particularly Andhra Pradesh, where the current study is being undertaken, using field survey data a detailed account of several studies on tank performance[9]. Other studies demonstrated that tank performance dropped during the green revolution, in the mid-1960s[101112]. No single factor has been identified as the cause of the poor performance of tanks, but institutional, physical and technological variables appeared to have combined in the majority of cases to bring about the fall of tank irrigation in India[13].

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Studies on the recently launched Andhra Pradesh Community Based Tank Management Project (APCBTMP) have also been conducted in order to analyze its overall impact on several parameters[14].

Unfortunately, it seems that the decrease in net tank irrigated area that results from poor tank performance may primarily affect small and marginal farmers with limited resources who struggle to cultivate crops due to the decrease of the tank irrigated area since they cannot afford to use groundwater, an expensive alternative form of irrigation. In the near future, a persistent drop in tank performance may cause a water shortage and the total disappearance of existing eco-friendly water sources, which would notably affect the marginal and small size groups of the farming community.

As the matter of concern, the assessment of tank performance, reasons behind declining performance of tank water resources, ways to replenish the available resources with estimates of influencing factors of tank performance, this paper presents the study of two different tank irrigation systems of non-system in Chittoor and system tank in Srikakulam district to explore the possibilities to improve the performance of tank irrigation, with the use of spatial data on water spread area and cropping pattern for the last five years collected with the help of Remote Sensing & GIS tools along with primary and secondary data on human-induced factors that aid in declining tank performance of the tank systems of Andhra Pradesh. The specific objectives of the study are:

1. To study the general characteristics of study area non-system and system tanks.
2. To determine the mean value of influential factors and tank performance of study tanks
3. To estimate the association between influencing factors and tank performance of the study tanks.
4. To determine the impact of variables on tank performance under non system and system tanks.

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Materials and methods

Study location

Andhra Pradesh being the highest tank irrigated state displays substantial regional variations in the performance based on the types of tank irrigation system. There are two types of tank irrigation systems in the state: non-system tanks and system tanks. Changes in the filling pattern, cropping pattern and agricultural production system are significant among two different tank irrigation systems. The selected system tank is located at 83^{o} 75' E longitude and 18^{o} 60' N latitude in Srikakulam district of North Coastal Andhra region, connected to Thotapalli left canal of Nagavali river with multi-cropping pattern and water surplus production system while non-system tank in Chittoor district of Rayalaseema region, is located at 79^{o} 70' E longitude and 13^{o} 75' N latitude with mono or double cropping pattern, majority of the farmers followed water deficit and dry land based agricultural production system.

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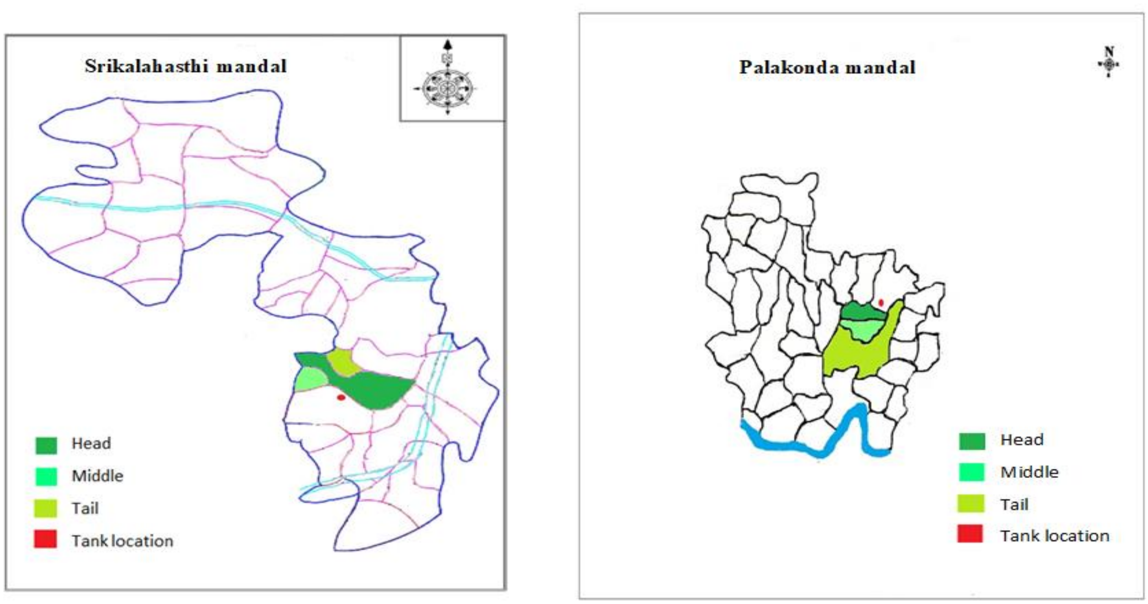

Figure 1 Geographical location of study tanks in Andhra Pradesh

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

Table 1 Classification of study area based on type of tank irrigation

Sl. No	Type of tank irrigation	Sample districts	Sample mandals	Sample villages	Sample respondents
1.	System tank	Srikakulam	Palakonda	Lumburu (Head)	30
				Garugubilli (Middle)	30
				Palakonda (Tail)	30
2.	Non-system tank	Chittoor	Srikalahasti	Uranduru (Head)	30
				Guntakindapalli (Middle)	30
				Maddiledu (Tail)	30
	Total				180

The respective command areas of the tanks are 389.49 ha and 273.17 ha. Both the tanks represent groundwater use intensity measured in terms of number of well irrigating per ha (0.67/ha) in non-system tank district of Chittoor. While the micro-irrigation (0.37/ha) sources domination in and around their system command area. Delayed onset and failure of monsoons, scarcity of water and variations in climatic parameters paved way for adaptation of mitigation and coping strategies by command area farmers. Marginal farmers are more prevalent in the tank command zones of both tanks with 48.7 per cent and 58.76 per cent of farmers of overall farming community (Table 2).

Table 2 Profile of the study tanks in Andhra Pradesh

Particulars	Non-system tank	System tank
Registered command area (ha)	389.49	273.17
System/non-system	Non – system tank	System tank
Number of wells and micro – irrigation sources in the	264	102

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command areas		
Well density (no of wells/ha)	0.67	-
Micro – irrigation source density (no. of sources/ha)	-	0.37

Source: Irrigation department and village administrative officers of concerned tanks and villages

Data and methodology

The required primary data from the 180 sample respondents were gathered using the well-designed pretested survey schedule while taking into account the indicated objectives. Data on the nature of water user's associations, farmer's participation in collective tank management, farm income and the kind of support offered by institutional agencies were gathered in order to evaluate the performance of the tanks under the two tank irrigation systems for 30 years' time period (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 gathered using RS & GIS tools to analyze cropping intensity (MODIS dataset) and water spread area (SENTENIL -1 SAR dataset) for both tank systems to determine the impact on tank performance.

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Tank performance model

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

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

Where,

Y= Tank performance (per cent/year)

a= intercept

X_1= Wells density or micro-irrigation source density (number/ha)

X_2= Filling pattern (number/year)

X_3= Water availability (days/year)

X_4= Encroachment level (per cent)

X_5= Siltation level (per cent)

X_6= Presence or absence of water user's associations (1 if present or 0 otherwise)

X_7= Farm income (rupees/ha)

X_8= Farmer's participation in WUA by financial or physical contribution (1 if present or 0 otherwise)

X_9= Government support (1 if present or 0 otherwise)

b_1, b_2, b_3, b_4, b_5, b_6, b_7, b_8 and b_9 are slope coefficients

Variables under tank performance model

Tank performance is defined as the per cent of actual cultivated area under a tank command to the registered or total command area under the tank as given by Palanisami and Jegadeesan[15], Kumar[16] and Kumar and Palanisami[17].

$$\text{Tank performance} = \frac{\textit{Actual cultivated area of the tank}}{\textit{Registered command area of the tank}} \times 100$$

Well density or micro-irrigation source density: Number of wells in non-system tank or number of micro-irrigation sources in system tank per hectare of command area.

Filling pattern: Number of times the tank gets filled up during a crop year.

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

Encroachment level: Percentage of water spread area and foreshore area encroached due to human factors.

Siltation level: Percentage of siltation in the tanks in each year over the years.

Water user's associations: Presence or absence of government or non-government water user's organizations or associations under the tank (1 if present or 0 otherwise).

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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 the tank (1 if present or 0 otherwise).

Government support: Assistance from institutional agencies in the form of financial support or any reclamation and maintenance measures were taken up in each year over the study period (if present 1 or 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 per cent, followed by 130.90 percent in the system tank command area. Cropping intensity was computed using MODIS Satellite Normalized Difference Vegetation Index (NDVI) data, which is useful for calculating vegetation indices, forecasting crop yields and monitoring the state of local and regional agricultural production. Each peak in an NDVI graph represents the maximum amount of vegetation or the number of crops in a cropping season (Figure 2). It was discovered that paddy-groundnut cropping pattern was followed in non-system tank while paddy followed by pulses, groundnut or sesame was cultivated in system tank with a minor percentage of annual crop sugarcane.

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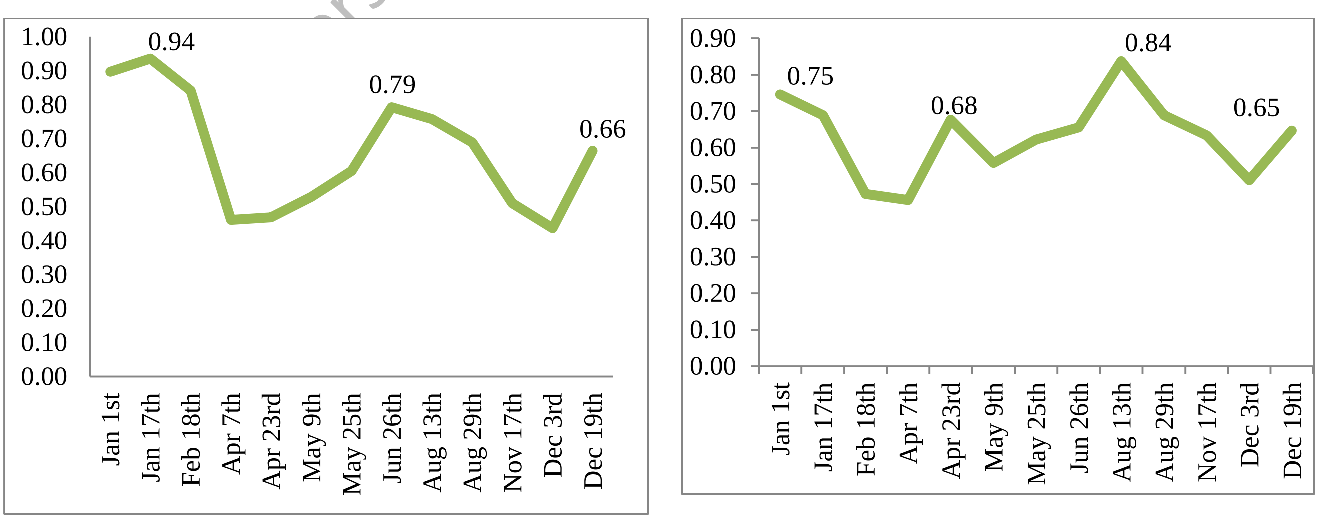

Figure 2 NDVI under non-system and system tank command areas

Spatial data for water spread area was collected using SENTENIL – 1 SAR dataset of strip-map images for 5 years (2017 – 2021, August month). The water spread area under non-system tank recorded 65.20 ha, 37.17 ha, 53.30 ha, 38.77 ha and 36.53 ha over past 5 years (Figure 3) while under system tank, the spatial water spread area distribution recorded 3.86 ha, 1.24 ha, 1.24 ha, 3.42 ha and 6.83 ha, respectively (Figure 4).

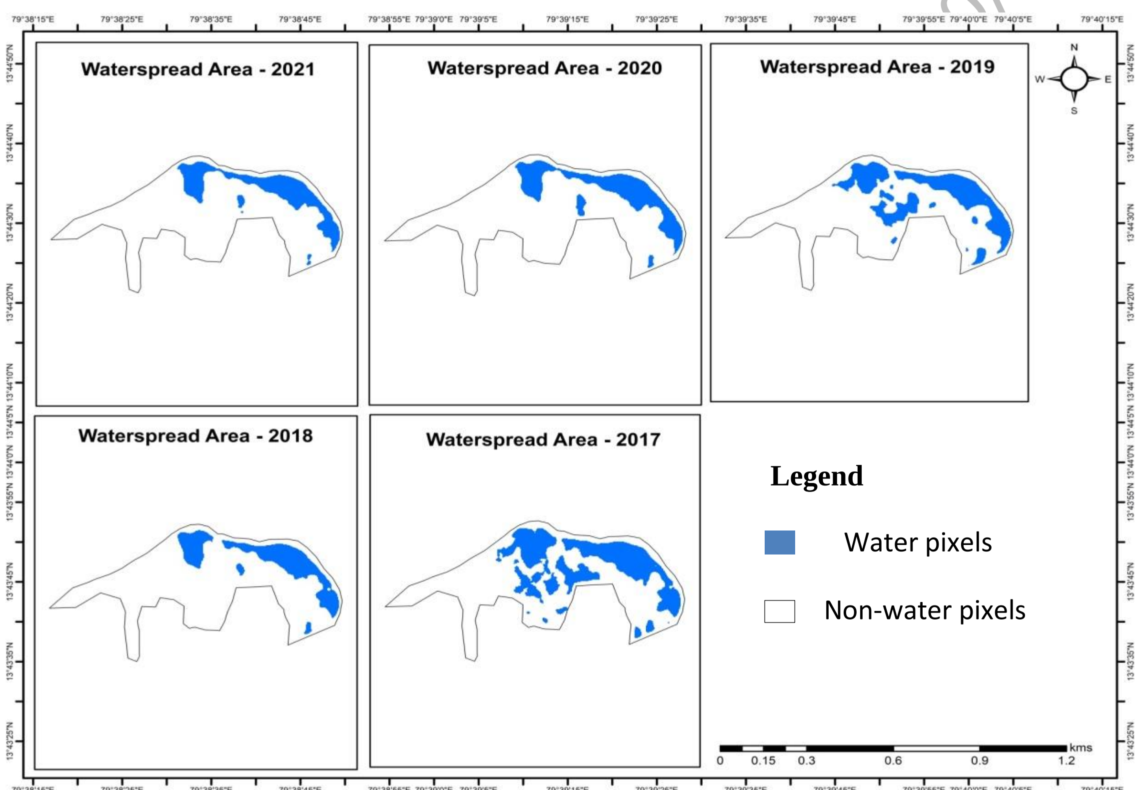

Figure 3 Spatial water spread area of non-system tank in Andhra Pradesh (August)

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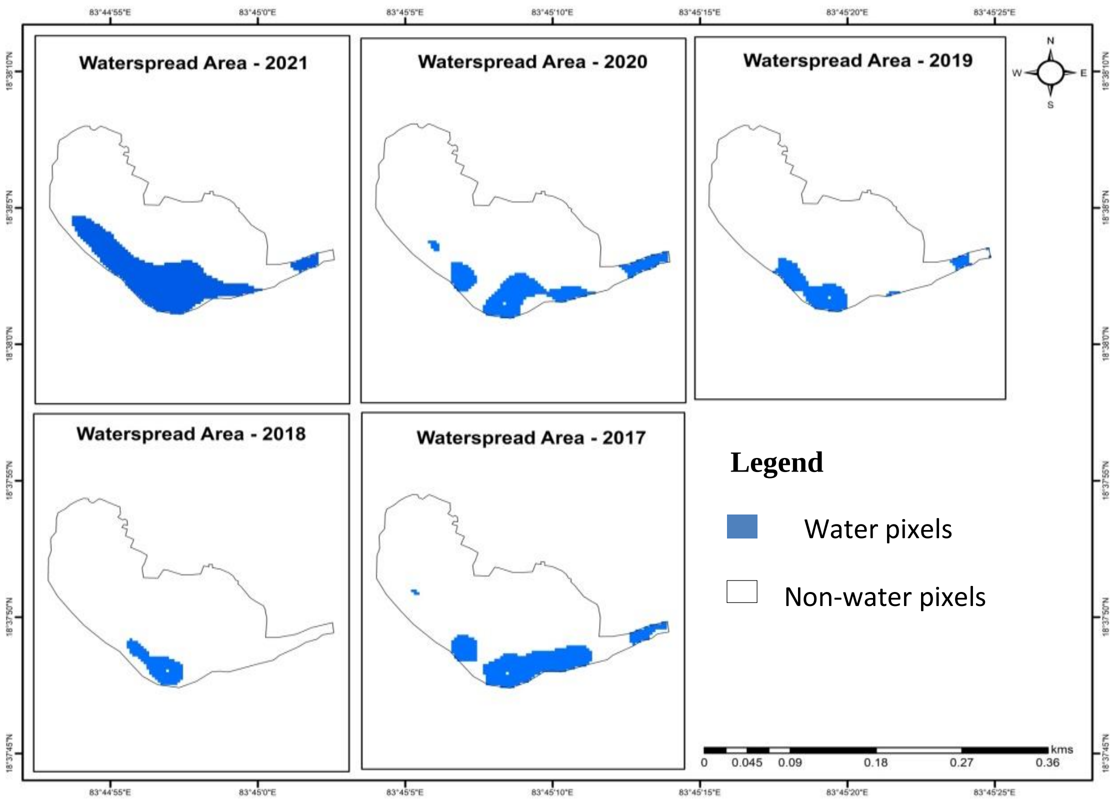

Figure 4 Spatial water spread area of system tank in Andhra Pradesh (August)

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Results and discussion

Tank performance has an impact on agricultural patterns, household economies and eventually, the tank economy of the region and 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, analyzed and addressed in this section.

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

The tank's actual command area was 168.22 hectares, spread across 540 farm households. Therefore, a single farmer would have only 0.31 hectares of land to produce and support his family. Currently, the tank has only 1 filling, while it had 1.5 fillings 10 years ago. In addition, 40 per cent of siltation and 20 per cent of encroachment in the foreshore region reduced the crop season's water availability 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 tank command area's overall reliance on rice agriculture and a tiny area devoted to groundnut production (dry land) resulted in a perilous condition due to inadequate maintenance, paucity of inputs and decreased water availability. The tank receives water storage with the start of good rains, which lasts just three to four months. Farmers relied on groundwater irrigation through the digging of 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 two to three farmers or 1.18 hectares of land (Table 3).

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

Particulars		**Tank Scenario**	
Tank		**Non-system tank**	**System tank**
Actual command area (ha)		168.22	208.77
Tank performance		43.18	76.42
No. of households in 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 (per cent)	10 years before	15	20
	2021-22	20	40
Siltation (per cent)	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 concerned tanks and villages

Under system tank, the actual command area is 208.77 hectares, which is shared by 485 farmers. Consequently, a farmer may often cultivate on less than 1 ha i.e. 0.43 ha, of land. During a crop season, the tank water supply is greater 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

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significant. Reduced number of fillings per crop season to 2.5 from 3.5 (before 10 years) resulted in less water availability for irrigation. A 40 per cent encroachment on the shoreline and a 25 per cent siltation of the water spread area both had an effect on the overall amount of water available. While encroachment impairs the function of the tank as a whole, siltation was less of a worry in a system tank than in a non-system tank. Farmers began using micro-irrigation to overcome irrigation water shortages in order to reduce crop failures and yield losses brought on by a lack of water. With each source providing 2.08 ha of command area, the number of sources had grown from sixty to one hundred over the years (Table 3).

Mean value of influencing factors and tank performance

As depicted in Table 4, the mean value of tank performance and other variables impacting tank performance are investigated. Average levels of encroachment and siltation are lower in system tank due to proper maintenance and operation in tank bed and foreshore area.

Table 4 Mean value of influential variables affecting tank performance under study tanks during 2021-22

Variable	Non-system tank	System tank
Tank performance (per cent/year)	58.39	87.40
Actual cultivated area (ha)	227.42	238.75
Well density or micro-irrigation source density (number/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 (per cent)	8.76	2.03
Siltation (per cent)	13.80	2.14
Presence of WUA (per cent)	53	65
Farm income (Lakh rupee/ha)	2.11	3.66
Farmer's participation (per cent)	65	68
Government support (per cent)	59	50

Note: WUA – Water User's Association
Source: Author's own estimates from the survey and secondary sources of information

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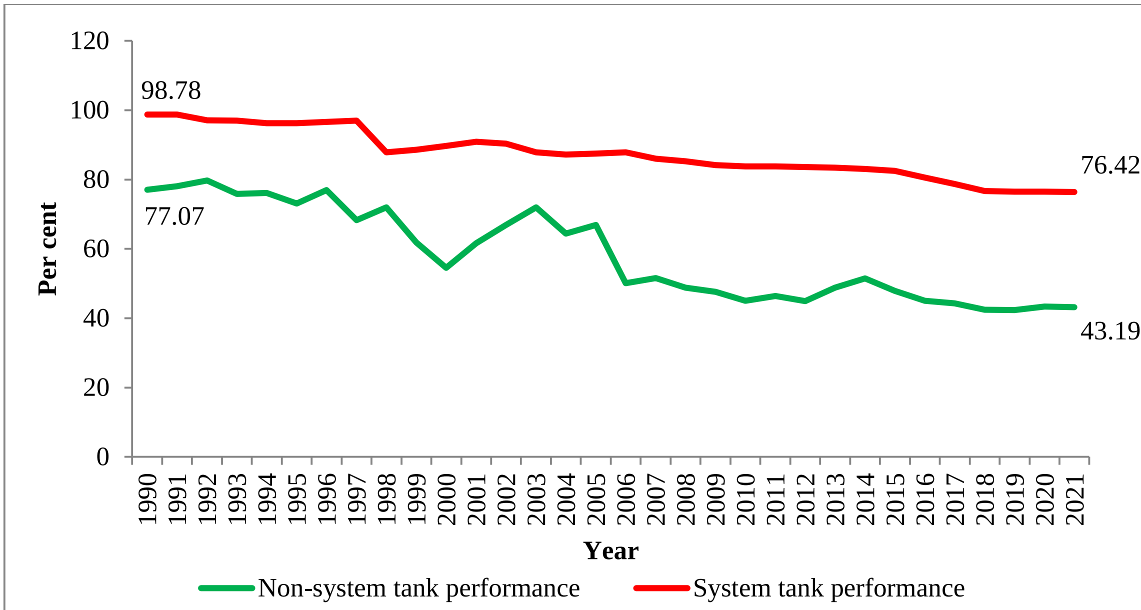

Figure 5 Trend lines of non-system and system tank performance over the years (1990 – 2021)

The mean value of tank performance for non-system tank during 2021 was 58.39 per cent (Table 4 and Figure 5), compared to 87.40 per cent for system tank and this difference is statistically significant. Farmers expressed an increased siltation problem in non-system tank as a result of social forestry, which hampered the tank performance. Similar results were discovered in research conducted 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

The results of the estimation of partial correlation coefficients for tank performance and the relevant variables impacting tank performance are shown in Table 5. The findings showed that filling pattern under non-system tank setup are positively significant, contributing to the performance of the tank by 77.4 per cent. The encroachment, however, was determined to be negatively significant. The water availability in the research area was reduced by 40 per cent, from 90 to 60 days. The average gross farm income was a further factor that boosted tank

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performance significantly (Table 5). Each farm used more available tank water after adopting a diverse crops and farming plan, which improved tank performance. It was discovered that the association variable for water users was positive and significant. The eradication of the encroachment and siltation problems is made possible by effective management and maintenance of WUAs.

Table 5 Correlation between variables and tank performance of study tanks

Sl. No	Independent variables	Correlation value	
		Non-system tank	**System tank**
1	Well density or micro-irrigation density	-0.829	-0.925
2	Number of fillings	0.774**	0.943**
3	Water availability days	0.659	0.839**
4	Per cent of encroachment	-0.627**	-0.045
5	Per cent of siltation	-0.757	-0.623
6	Presence of WUA	0.5702**	0.2401
7	Average gross farm income	0.874**	0.892
8	Farmer’s participation	0.231	0.163
9	Government support	0.105	0.141**

Note: ** indicates significance at 0.05 per cent level of significance
Source: Author’s own estimates from the survey and secondary sources of information

The performance of the tank was shown to be positive and significantly influenced under system tank condition by variables like filling pattern and number of water available days (Table 5). Water supply and availability might be increased through better foreshore and water spread area care, which would reduce levels of siltation and encroachment. It has been demonstrated that the tank performs significantly better with the government's support.

Improvements in well density and micro-irrigation sources were discovered to have a negative impact on tank performance in both the non-system and system tank scenarios, indicating failure in better tank performance resulting in the erection of more tube-wells, an increase in the

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adoption of micro-irrigation systems, and an increase in water utilization by ground water irrigation to sustain the state's net irrigated area. Thus reviving tank irrigation system could achieve double benefits of more recharge for increasing micro-irrigation systems and increase the net tank irrigated area in the study districts. The collateral studies of Kumar and Palanisami[17], Palanisami *et al.*[18] and Palanisami and Meinzen-Dick[12] yield comparable results.

Tank performance and its determinants

In order to quantify the influence of these factors on tank performance, excluding rainfall, a linear relationship is mapped between tank performance and factors including well density, filling pattern, water availability, encroachment levels, siltation levels, presence of WUA's, farm income, farmers' participation and government support.

Tank performance under non-system tank scenario

Table 6 shows that the variables evaluated from the study explain about 90 per cent of the variation in tank performance. As expected, encroachment levels were found to be unfavorable and considerable in non-system tank performance. The inclusion of water user's association, on the other hand, had a favorable and significant effect on tank performance.

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

Variables	Coefficients	Standard error	t - ratio
Constant	11.21	23.17	0.48
Well density (number/ha)	-0.05	0.05	-1.01
Fillings (number/crop year)	16.97	12.82	1.32
Water availability (days/crop year)	0.13	0.19	0.67
Encroachment (per cent)	-1.36***	0.49	-2.80
Siltation (per cent)	-0.21	0.37	-0.57
WUA (per cent)	5.51**	2.03	2.72
Farm income (₹/ha)	0.00015**	0.00	2.34

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Farmer's participation (per cent)	1.40	2.43	0.58
Government support (per cent)	0.59	1.71	0.34
Adjusted R^2	0.90		
F - statistics	33.75***		
No. of observations	30 (1990-2021)		

Note: ***, ** indicates significance at 0.01 and 0.05 per cent level of significance
Source: Author's own estimates from the survey and secondary sources of information

The existence of formal or informal water user groups and availability of financial resources facilitates to take-up repair and maintenance of tank-bed and enhance the water spread area, hence reducing encroachment and siltation levels. Also multiple-cropping pattern and farming methods help farmers to 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 contributed for significant positive impact on cropping intensity, revival of which will enhance the livelihoods of tank command farmers.

Tank performance under system tank scenario

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

Table 7 Impact of variables on tank 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 (number/crop year)	4.06**	1.51	2.65
Water availability (days/crop year)	0.13***	0.06	2.06

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Encroachment (per cent)	-1.56	0.96	-1.56
Siltation (per cent)	-3.82**	1.53	-2.51
WUA (per cent)	0.98	1.04	0.94
Farm income (₹/ha)	1.01	0.00	0.07
Farmer's participation (per cent)	0.49	0.88	0.56
Government support (per cent)	0.69	0.90	0.77
Adjusted R^2	0.91		
F - statistics	37.34***		
No. of observations	30 (1990 – 2021)		

Note: ***, ** indicates significance at 0.01 and 0.05 per cent level
Source: Author's own estimates from the survey and secondary sources of information

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Farmers believe that a minimum of 3 to 4 fillings is essential for a successful yield since 2.5 fillings offer water for 120 days. Furthermore, because 25 per cent of the silt in the tank's water distribution area has 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 rain-fed/non-system tanks. Variations in seasonal rainfall (excess or less or untimely) poses a serious challenge on overall agricultural production and yield as more than 65 % is contributed from south-west monsoon of the state. To mitigate the yield loss, adoption of short or medium term varieties of crops, less water intensive crops suitable to agro-climatic regions, reliance on supplementary micro-irrigation water sources can be enhanced. Excess of social forestry was found to be another factor under non-system tank that paved heavy siltation challenge with reduction of water storage capacity in the tank. Under system tank, siltation and water logging problems were registered due to heavy rains and improper maintenance led to decline in tank performance over the decades. Effective deslitation measures with participatory water management will bring improvement in water storage capacity and filling pattern and proper maintenance of supply channels will bring equitable distribution of tank water across the tank command area farms under both the tank systems. Human induced factors like encroachment in the foreshore and tank-bed area can be mitigated by imposing serious penalties and pricing under the surveillance of irrigation department officials of concerned tanks. Strengthening of water user's associations will benefit the command area farms to avoid demand-supply gaps, encroachment problems, improving number of water availability days and particularly improvement in socio-economic structure of tail end farms under both the tank systems.

Conclusions and future perspectives

The study in Andhra Pradesh compared non-system and system tank, revealing a consistent decline in the water spread area of non-system tanks from 65.20 ha to 36.53 ha, attributed to weather, encroachment and siltation. Encroachment and siltation levels increased in both tank types, resulting in reduced water availability. Over the study period, tank performance declined for 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 non-system tank and over 80% for system tank. Encroachment negatively affected non-system tank, while average gross farm revenue and water user associations contributed positively.

Optimization of tank water resources among 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 by careful usage of tank water supplemented with subsidized micro-irrigation sources. Inclusion of major area under less water intensive crops (coarse cereals under non-system tank, pulses and millets

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under system tank) in similar agro-climatic regions will mitigate water scarcity situations of tank system commands.

Declaration

Authors have declared that no competing interests exist.

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