



RESEARCH ARTICLE

Assessing water use efficiency to evaluate economic performance across tank and groundwater irrigation systems

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Received: 04 August 2025; Accepted: 26 January 2026; Available online: Version 1.0: 04 June 2026

Cite this article: Malaisamy A, Rithika S, Raswanthkrishna M. Assessing water use efficiency to evaluate economic performance across tank and groundwater irrigation systems. Plant Science Today. 2026; 13(sp2): 1-14. <https://doi.org/10.14719/pst.11086>

Abstract

This study investigates the economic and socio-economic performance of three distinct irrigation systems: Farmers managed tank irrigation through Water Users Association (WUA), Water Resource Department (WRD)-managed tanks and groundwater irrigation (control area) in Pudukkottai district, Tamil Nadu. A sample of 240 farmers was selected equally from these three systems and extensive data were collected on household profiles, landholding patterns, asset and livestock inventories, water use efficiency (WUE), income sources, employment and total asset value. The analysis reveals that WUA-managed tank irrigation systems demonstrated superior outcomes in WUE, economic returns and employment generation compared to WRD-managed and groundwater-based systems. Paddy cultivation under WUA tanks recorded the highest WUE (263.60 kg m⁻³), significantly outperforming WRD tanks (117.37 kg m⁻³) and groundwater irrigation (189.35 kg m⁻³). Socio-economically, WUA and groundwater systems were characterised by a predominance of joint families and larger average landholdings, while WRD-managed systems showed higher proportions of nuclear families and small farmers. Annual income, asset value and employment generation were highest in the WUA-managed areas, pointing to the effectiveness of participatory irrigation management (PIM). In contrast, WRD systems showed relatively poorer performance in water productivity and employment, indicating issues in governance and institutional engagement. The groundwater system, while offering moderate performance, reflected higher reliance on livestock and groundwater infrastructure due to the lack of surface irrigation support.

Keywords: economic performance; groundwater irrigation; participatory irrigation management; tank irrigation system; water use efficiency

Introduction

Water is a vital resource for sustaining agricultural production, especially in semi-arid and dry sub-humid regions like Tamil Nadu, where rainfall is erratic and highly seasonal (1). The state's irrigation landscape is characterised by a complex mosaic of water sources ranging from centuries-old tank systems to increasingly dominant groundwater extraction (2). Historically, tank irrigation has been a cornerstone of agricultural development in Tamil Nadu, not only as a physical infrastructure but also as a community-managed institution (3). These tanks, often built centuries ago and linked with the socio-cultural fabric of the region, ensured equitable water distribution through traditional norms and local-level governance mechanisms (4). However, over the past few decades, tank irrigation systems have experienced a marked decline due to factors such as administrative neglect, land encroachment, siltation, lack of community participation and the rise of individualistic irrigation strategies centred around groundwater extraction (5). This shift in the irrigation paradigm has had far-reaching implications not only in terms of water use efficiency (WUE) and agricultural productivity, but also in the socio-economic structure and sustainability of rural livelihoods (6). Consequently, Tamil Nadu now faces an urgent need to evaluate

and compare the effectiveness of various irrigation regimes, namely, farmer-managed tanks under Water Users Associations (WUAs), state-managed tanks under the Water Resources Department (WRD) and groundwater-based systems across multiple performance indicators (7). The debate over centralised versus decentralised irrigation management has gained renewed attention in the context of participatory irrigation management (PIM) reforms, which seek to empower farmers through WUAs (8). While some studies have shown promising outcomes under PIM, especially in terms of equity, cost-sharing and maintenance efficiency, others point to weak implementation, lack of autonomy and poor institutional design as constraints limiting their potential. Conversely, WRD-managed tanks continue to be administered in a top-down bureaucratic fashion with minimal local involvement, often resulting in inefficiencies, delays and inequitable distribution of water, particularly between head and tail-end farmers (9). Groundwater-based irrigation, on the other hand, is highly individualised, flexible and responsive to farmers' needs, but it comes at the cost of over-extraction, energy-intensive pumping and long-term sustainability concerns. These divergent models of irrigation governance thus merit a comprehensive comparative evaluation, particularly through the lens of WUE, economic returns

and institutional performance.

In this context, the present study is grounded in the agrarian landscape of Pudukkottai district, Tamil Nadu, a region that presents a microcosm of the broader irrigation diversity in South India (10). Specifically, the study focuses on Illuppur Taluk and Annasaval Block, where tank irrigation coexists with groundwater systems and where interventions under both WRD and WUA-led management have been operationalised to varying degrees. The area provides a unique opportunity to examine the real-world functioning of these systems under similar agro-climatic conditions (11). One of the most critical aspects this study addresses is the performance of the WUA model, particularly in terms of its capacity to deliver economic and social benefits through collective water governance. Unlike the WRD system, where farmers often remain passive recipients of irrigation services, WUAs, when functional, offer a platform for farmers to make decisions on water allocation, scheduling, maintenance and conflict resolution (12). These participatory functions are theoretically expected to enhance ownership, accountability and local-level adaptation, leading to better outcomes in terms of water productivity, crop yield and rural employment (13). However, empirical assessments of such institutional models in Tamil Nadu remain sparse and scattered (14). Similarly, groundwater irrigation systems, though widespread, have not been systematically analysed from an economic performance standpoint, particularly regarding collective tank-based systems (15). This study attempts to fill these critical gaps by employing a comparative analytical framework that evaluates the socio-economic profiles of farmers, WUE, cost of irrigation, employment generated, asset ownership and crop productivity under each system.

The importance of this study also lies in its methodological design. A total of 240 sample farmers were selected across three irrigation systems: Farmer managed tank area (WUA), WRD-managed tank area and groundwater irrigation area (control), with 80 farmers chosen from each system, ensuring equitable representation from head and tail reaches within the command area. This allows for a nuanced understanding of intra-system equity, a dimension often overlooked in performance evaluations (16). The analysis is supported by structured surveys capturing data on family structure, education, operational landholding, irrigation infrastructure, employment generation, asset inventory and annual income sources (17). These socio-economic indicators are crucial in revealing the differentiated impact of irrigation regimes on farmer well-being, resilience and sustainability (18). Particular emphasis is placed on WUE, defined as kilograms of output per cubic meter of irrigation water used, as a central metric of economic and environmental performance (19). For paddy cultivation, the results demonstrate a significant variance in WUE: the WUA-managed system recorded 263.60 kg m⁻³, followed by groundwater irrigation at 189.35 kg m⁻³ and WRD-managed tanks at 117.37 kg m⁻³. These differences are not merely technical; they reflect the underlying institutional dynamics, collective behaviour and access to timely irrigation water. In terms of income, farmers under WUA management exhibited higher returns from agriculture, higher livestock income and better ownership of irrigation assets, further validating the economic viability of decentralised models (20). In contrast, WRD farmers showed dependence on wage labour and lower

asset positions, while groundwater farmers, despite moderate success in crop income, faced high costs related to borewell maintenance and energy use.

Furthermore, the study draws attention to how irrigation governance intersects with other socio-economic dimensions such as family type, literacy, asset ownership, mechanisation and livestock rearing (21). For instance, joint family systems were more prevalent in WUA and groundwater areas, which could potentially influence labour availability and investment patterns (22). The data also show that WRD areas had a higher share of nuclear families and small farmers, which may correlate with lower collective bargaining power and reduced capacity for shared infrastructure maintenance. These insights are critical for policy-making, as they demonstrate that irrigation systems do not operate in isolation but are embedded within broader social structures and livelihood strategies. The employment generated per household also varied across irrigation systems, with WUA-managed areas recording the highest average employment (224.8 man-days/year), followed by groundwater irrigation (218.5 man-days/year) and WRD-managed tanks (192.7 man-days/year). Such findings emphasise that irrigation performance should be evaluated not only in terms of crop output or WUE but also through its impact on rural employment and income diversification.

In light of these observations, the study aims to contribute to the ongoing discourse on irrigation reform, participatory governance and sustainable water management in India (23). It calls for a re-evaluation of centralised irrigation models like WRD and advocates for the strengthening of WUAs through legal, financial and technical support. At the same time, it recognises the limitations of over-dependence on groundwater and argues for integrated approaches that promote conjunctive use, groundwater regulation and community engagement in aquifer recharge efforts. The study also suggests that monitoring systems for WUE, farmer training programs on water budgeting and targeted subsidies for micro-irrigation infrastructure can further enhance the performance of all irrigation systems. By adopting a comparative lens, this research underscores the fact that irrigation governance is not a one-size-fits-all model; instead, it must be tailored to the institutional capacity, ecological constraints and socio-economic realities of each region (24). In conclusion, the introduction sets the stage for a detailed empirical investigation into how different irrigation systems affect water productivity, income generation and socio-economic transformation (25). It establishes the need for robust institutional models that not only manage water efficiently but also empower farmers economically and socially (26). As Tamil Nadu grapples with increasing water stress, climate change and agrarian distress, studies such as this are essential for informing grounded, evidence-based policies that can reconcile productivity with sustainability and equity in rural India.

In light of these gaps, the present study aims to conduct a comprehensive comparative assessment of three irrigation systems WUA-managed tanks, WRD-managed tanks and groundwater-based irrigation to understand how differences in institutional arrangements influence WUE, economic performance and socio-economic outcomes at the farm level. Specifically, this study seeks to: (i) evaluate the economic and agronomic performance of the three irrigation regimes, (ii) analyse variations

in WUE across systems and (iii) examine their impacts on employment generation, income distribution, asset position and household-level socio-economic characteristics. By articulating these objectives, the study positions itself to generate empirical insights for strengthening irrigation governance and improving water productivity in water-scarce regions (27).

The findings of this study carry strong practical relevance for agricultural extension and water-resource policy. For extension agencies, the results highlight the need to promote participatory water management practices, farmer training on water budgeting and adoption of efficient irrigation methods tailored to each system. For policymakers, the study provides evidence to guide interventions such as strengthening WUAs, improving WRD governance through farmer engagement and regulating groundwater extraction while encouraging conjunctive-use strategies (28). By demonstrating how institutional frameworks shape water productivity and economic resilience, the study offers actionable insights for designing policies that enhance efficiency, equity and sustainability in irrigation-dependent farming communities (29).

Design of the study

Selection of study area

The present study was conducted in the Pudukkottai district of Tamil Nadu, specifically in Illuppur Taluk and Annasaval Block, where tank and groundwater irrigation systems are widely practised. Two tanks in Illuppur taluk of Pudukkottai, Parambur big tank managed by farmers through collective action, where there was an active WUA, which ensures the equity in distribution of tank water between head and tail reach farmers and Killikkudi big tank managed by WRD [passive or defunct WUA], where there usually exists a conflict between head and tail reach farmers for irrigation water, were chosen purposively for the comparative analysis of the institutions governing the management and use of tank water for irrigation purposes. Along with this, farmers who had no access to an irrigation tank were also chosen as a control area to find the economics of conjunctive use and draw meaningful results. Eighty sample farmers were selected randomly in each tank management regime and control area. Total data was collected from 240 sample farmers for the research problem identified. The distance of the channel was divided into two halves and was demarcated as the head and tail reach.

Data collection tools and period

Primary data were collected using a structured and pre-tested questionnaire administered to the sample farmers. The questionnaire covered household characteristics, landholding details, irrigation practices, crop production, employment, income sources, livestock and asset ownership and farmers perceptions regarding irrigation management. In addition to the questionnaire survey, personal interviews and field observations were conducted to ensure accuracy and cross-verification of responses. A total of 240 farmers were interviewed 80 from WUA-managed tanks, 80 from WRD-managed tanks and 80 from the groundwater-irrigated control area, with equal representation from head- and tail-reach farmers within tank commands. The data were collected during the 2023–2024 agricultural year, covering both the rainy (Samba) and summer (Navarai) seasons.

Data analysis

The data collected from the field survey were coded, tabulated and analysed using descriptive statistical techniques. Frequencies, percentages, averages and cross-tabulations were employed to describe the socio-economic profile of farmers, irrigation practices, asset positions, employment levels and income patterns across the three irrigation systems. This descriptive approach is appropriate for extension and rural development research, where the objective is to characterise farmers' livelihoods, resource conditions and institutional environments rather than perform inferential or hypothesis-testing statistical procedures.

Tools of analysis

Descriptive analysis

The simple average and percentage analyses were used to examine the socio-economic characteristics of the sample farm and household characteristics such as age, educational status, farming experience, size of operational land holdings, livestock inventory and farm assets inventory. To assist in the interpretation of findings, descriptive statistical measures, such as percentages and averages, were calculated wherever necessary.

Water use efficiency

The WUE formula is used to measure how effectively irrigation water is converted into agricultural output. It is calculated as the ratio of crop yield to the amount of water used for irrigation, both expressed on a per-hectare basis (30). A higher WUE indicates better water productivity, meaning more yield is obtained with less water. A lower WUE suggests inefficient water use, possibly due to losses, poor irrigation methods, or suboptimal crop management. Water use efficiency (WUE), which is calculated as follows,

$$\text{WUE (kg/m}^3\text{)} = \frac{\text{Crop yield (kg/ha)}}{\text{Water used (m}^3\text{/ha)}}$$

The WUE is expressed in kilograms per cubic metre (kg m^{-3}), where crop yield is measured in kilograms per hectare (kg ha^{-1}) and total water used is measured in cubic metres per hectare ($\text{m}^3 \text{ha}^{-1}$).

Where,

WUE = Water use efficiency (kg m^{-3})

Crop yield = total yield of crop (kg ha^{-1})

Water used = total irrigation water used in cubic metres per hectare ($\text{m}^3 \text{ha}^{-1}$)

Results and Discussions

Socio-economic characteristics of the respondent farmers

To better understand the social and economic perspectives of the profile of the sample farmers, the general characteristics of the farmers of both tank irrigation management institutions and groundwater irrigation, namely family type, family composition, age distribution, literacy level, farming experience, size of land holding, livestock and farm assets inventory, are presented in this section.

Family type of sample farmers

The size of family labour in farming is determined by the type of family, including nuclear and joint families. The sample respondent's family type is analysed and shown in Table 1.

Table 1. Type of family among sample farmers (%)

Sl. No.	Family type	Farmers managed tank area (WUA)	WRD managed tank area	Groundwater irrigation (control area)
1	Nuclear family	38 (47.50)	52 (65.00)	33 (41.25)
2	Joint family	42 (52.50)	28 (35.00)	47 (58.75)
	Total	80 (100.00)	80 (100.00)	80 (100.00)

Figures in parentheses indicate per cent of the respective total. WUA - Water Users Association, WRD - Water Resource Department.

The data showed that the WUA-managed areas, joint families, constitute a slightly higher proportion (52.50 %) compared to nuclear families (47.50 %). This suggests that community-managed irrigation systems may encourage or benefit from joint family structures, which often provide greater labour availability and collective decision-making capacity. In contrast, the WRD-managed areas show a different trend, with a significant majority of farmers (65.00 %) belonging to nuclear families and only (35.00 %) from joint families. This may indicate a shift toward more individual or nuclear family-based farming systems in areas managed by government agencies, where participation in collective decision-making is minimal. In the control area, farmers who utilise the groundwater had the majority (58.75 %), while nuclear families accounted for (41.25 %). This could reflect a greater need for labour sharing and cost distribution in managing private groundwater sources. This indicates that the joint family was predominant in groundwater irrigation and WUA-managed areas. On the other hand, the nuclear family type was dominant in the WRD-managed areas.

Family composition of sample farmers

Family size affects the farm management choices, as well as the pattern of income and expenditure. Therefore, information on family composition is presented in Table 2. The table showed that in the WUA-managed tank area, families have a moderate size (average 4.43), with a balanced proportion of males (39.44 %), females (32.96 %) and children (27.60 %), indicating a stable labour force for farming and water management. The WRD-managed area shows smaller families (average 3.68) and a higher proportion

of children (37.97 %), suggesting a higher dependency ratio and limited adult labour. In groundwater-irrigated control area has the largest family size (average 4.86), with a higher share of females (35.99 %). This showed the highest family size of 4.86 in groundwater irrigation.

Age distribution of sample farmers

Age is a significant factor influencing farm-level decisions, particularly with irrigation practices and technology adoption. The age distribution of sample farmers across the three irrigation management systems reveals a clear dominance of the 41–50 age group. In the WUA-managed tank area, the majority of farmers (65.00 %) fall within this age group, followed by above 50 years (22.50 %) and only below 40 years (12.50 %). A similar trend is observed in the WRD-managed tank area, where 71.25 % of farmers are aged between 41–50 years, 16.25 % are below 40 years and only 12.50 % are above 50 years. In the groundwater-irrigated control area, 66.25 % of farmers are in the 41–50 age group, 18.75 % are below 40 years and 15.00 % are above 50 years. Table 3 indicate that middle-aged farmers (41–50 years) dominate across all irrigation types, suggesting that this group is most actively involved in managing farm operations and irrigation decisions. The relatively lower share of younger farmers (below 40 years) across all systems reflects limited youth participation in agriculture, while the declining share of older farmers (above 50 years), especially in WRD areas, may indicate generational transitions or reduced physical involvement in farming tasks. These results shows that the 41–50 age group appears to be the most engaged demographic in irrigation management across the study areas.

Table 2. Family composition of sample farmers (%)

Sl. No.	Particulars	Farmers managed tank area (WUA)	WRD managed tank area	Groundwater irrigation (control area)
1	Number of males	140 (39.44)	86 (29.15)	129 (33.16)
2	Number of females	117 (32.96)	97 (32.88)	140 (35.99)
3	Number of children	98 (27.60)	112 (37.97)	120 (30.85)
	Total	355 (100.00)	295 (100.00)	389 (100.00)
	Average family size	4.43	3.68	4.86

Figures in parentheses indicate per cent of the respective total. WUA - Water Users Association, WRD - Water Resource Department.

Table 3. Age distribution of sample farmers (%)

Sl. No.	Particulars	Farmers managed tank area (WUA)	WRD managed tank area	Groundwater irrigation (control area)
1	Up to 40 years	10 (12.50)	13 (16.25)	15 (18.75)
2	41–50	52 (65.00)	57 (71.25)	53 (66.25)
3	More than 50 years	18 (22.50)	10 (12.50)	12 (15.00)
	Total	80 (100.00)	80 (100.00)	80.00 (100.00)

Figures in parentheses indicate per cent of the respective total. WUA - Water Users Association, WRD - Water Resource Department.

Literacy level of sample farmers

The literacy level of farmers enhances the production and productivity of farms with technology adoption. The literacy levels of sample farmers across the three irrigation management systems are presented in Table 4. In the WUA-managed tank area, the highest proportion of farmers were degree holders (33.75 %), followed by those with secondary education (22.50 %) and primary education (18.75 %). Illiterates accounted for only 10.00 %, indicating a relatively educated farming community in this system. In the WRD-managed tank area, the majority of farmers had secondary education (27.50 %), followed closely by degree holders (27.50 %) and primary education (22.50 %). Illiteracy formed a small share at 6.25 %, showing a similar trend of relatively high literacy among farmers. In the groundwater-irrigated control area, farmers with primary education were the highest (25.00 %), followed by degree holders (30.00 %) and secondary education (21.25 %). The percentage of illiterates was slightly higher in this group (13.75 %) compared to the other two systems but remained low. Thus, it could be concluded from the given table that most farmers across all irrigation systems have attained at least primary or secondary education, with a notable shareholding of degrees. The presence of illiterates remains minimal, suggesting that the majority of farmers are equipped with basic literacy skills, which can facilitate the adoption of modern farming practices. Degree holders are particularly notable in the WUA and control areas, indicating potential for greater awareness and participation in irrigation management and farm decision-making.

Farming experience of sample farmers

Farming experience has a great impact on yield and profit, with technological adoption resulting in high production and productivity and the results are presented in Table 5. The distribution of farming experience among the sample farmers

across different irrigation systems. In the WUA-managed tank area, the majority of farmers (35.00 %) had 31–40 years of experience, followed by those with more than 40 years (30.00 %) and 21–30 years (27.50 %). Farmers with less than 20 years of experience accounted for only 7.50 %, indicating that most participants were experienced cultivators. In the WRD-managed tank area, the highest proportion of farmers (37.50 %) had more than 40 years of farming experience, followed by 21–30 years (30.00 %). Farmers with 31–40 years of experience constituted 22.50 % and those with up to 20 years formed only 10.00 %. This suggests a strong presence of highly experienced farmers in WRD-managed areas. In the groundwater-irrigated control area, farmers with more than 40 years of experience were also the largest group (33.75 %), closely followed by 21–30 years (31.25 %). Farmers with 31–40 years of experience made up 21.25 % and those with up to 20 years formed 13.75 % of the sample. This confirms that farmers with over 40 years of experience are dominant in all irrigation systems, reflecting a mature and experienced farming population. The prevalence of long-term farming experience may contribute positively to resource management, technology use and sustainable agricultural practices across the study area.

Size of land holdings of sample farmers

The size of land holding details is given in Table 6. It could be seen from the table that the average land holding size of both the farmers managed tank area, the WRD managed tank area and groundwater irrigation was 2.35 ha, 2.29 ha and 1.94 ha respectively; it was highest in the farmers managed tank area. Among the farmers managed tank area, the medium-sized farms were high with a proportion of 43.75 %, followed by large-sized farms and small-sized farms with 11.25 % and 27.50 % respectively. The average size of land to small, medium and large farms in farmers-managed tanks was 1.50 ha,

Table 4. Literacy rate of sample farmers (%)

Sl. No.	Particulars	Farmers managed tank area (WUA)	WRD managed tank area	Groundwater irrigation (control area)
1	Illiterates	8 (10.00)	5 (6.25)	11 (13.75)
2	Primary	15 (18.75)	18 (22.50)	20 (25.00)
3	Secondary	18 (22.50)	22 (27.50)	17 (21.25)
4	Higher secondary	12 (15.00)	13 (16.25)	8 (10.00)
5	Degree	27 (33.75)	22 (27.50)	24 (30.00)
	Total	80 (100.00)	80 (100.00)	80 (100.00)

Figures in parentheses indicate per cent of the respective total. WUA - Water Users Association, WRD - Water Resource Department.

Table 5. Farming experience of sample farmers (%)

Sl. No.	Particulars	Farmers managed tank area (WUA)	WRD managed tank area	Groundwater irrigation (control area)
1	Up to 20 years	6 (7.50)	8 (10.00)	11 (13.75)
2	21–30	22 (27.50)	24 (30.00)	25 (31.25)
3	31–40	28 (35.00)	18 (22.50)	17 (21.25)
4	More than 40 years	24 (30.00)	30 (37.50)	27 (33.75)
	Total	80 (100.00)	80 (100.00)	80 (100.00)

Figures in parentheses indicate per cent of the respective total. WUA - Water Users Association, WRD - Water Resource Department.

Table 6. Size of land holding of sample farmers (%)

Sl. No.	Particulars	Farmers managed tank area (WUA)		WRD managed tank area		Groundwater irrigation (control area)	
		No.	Average in ha	No.	Average in ha	No.	Average in ha
1	Marginal farmers (< 1 ha)	14 (17.50)	0.60	18 (22.50)	0.66	22 (27.50)	0.54
2	Small farmers (1–2 ha)	22 (27.50)	1.50	36 (45.00)	1.42	3 (37.50)	1.38
4	Medium farmers (2–4 ha)	35 (43.75)	2.70	22 (27.50)	2.75	24 (30.00)	2.35
5	Large farmers (more than 4 ha)	9 (11.25)	4.55	4 (5.00)	4.80	4 (5.00)	4.20
	Total	80 (100.00)	2.35	80 (100.00)	2.29	80 (100.00)	1.94

Figures in parentheses indicate per cent of the respective total. WUA - Water Users Association, WRD - Water Resource Department.

2.70 ha and 4.55 ha respectively.

In the WRD-managed tank irrigation, small farms were high, followed by medium farms and marginal farms with proportions of 45.00 %, 27.50 % and 22.50 % respectively. The average size of land for marginal, small, medium and large farms in the tank irrigation was 0.66 ha, 1.42 ha, 2.75 ha and 4.80 ha respectively.

In groundwater irrigation, small farms were the highest, followed by medium farms, marginal farms and large farms with proportions of 37.50 %, 30.00 %, 27.50 % and 5.00 % respectively. The average size of land for marginal, small, medium and large farms in groundwater irrigation was 0.54 ha, 1.38 ha, 2.35 ha and 4.20 ha respectively. The results showed that medium-sized farms were high in farmer-managed tank irrigation, small farms were high in WRD-managed tank irrigation and small farms were high in groundwater irrigation. Also, the average size of land holding was high in the farmers managed tank area.

Livestock and farm assets inventory

The livestock composition across different irrigation systems provides valuable insights into the farmers livelihood strategies in response to irrigation availability. The WRD-managed tank area recorded the highest share of livestock (335 animals), followed by the WUA-managed tank area (373 animals) and the groundwater-irrigated control area (234 animals) (Table 7). Among the livestock types, sheep and poultry birds accounted for the largest proportions across all regions, with sheep representing 40.75 %, 44.78 % and 38.46 % of total livestock in the WUA, WRD

and control areas respectively. Similarly, poultry birds made up 40.49 %, 39.40 % and 41.46 % in the same order, showing their popularity as low-cost, income-generating assets. Crossbred cows were notably higher in the groundwater control area, contributing 9.40 % of total livestock, compared to 8.06 % in the WRD-managed and 8.04 % in the WUA-managed areas. This indicates that in areas with limited surface water availability, farmers rely more on high-yielding livestock such as crossbred cows to support their livelihoods. Draught animals (bullock pairs) were found only in the control area, albeit minimally (0.43 %), while buffaloes and goats were present in small numbers across all systems.

Overall, the findings reveal that farmers in the control area rely more on productive livestock (like crossbred cows) to compensate for the limited irrigation, whereas those in conjunctively irrigated systems (WUA and WRD) show relatively more diversified livestock holdings. The WRD-managed tank area showed slightly higher livestock possession than the WUA-managed area, likely due to water scarcity at the tail-end, compelling farmers to depend more on livestock. These trends affirm that the availability of irrigation water is inversely related to livestock dependency, as assured water supply reduces the need for supplementary income through animal husbandry.

The farm assets inventory of the sample farmers across the three irrigation systems reflects their access to mechanisation and infrastructure that support agricultural operations. As shown in Table 8, the highest number of assets was recorded in the control area (281), followed by the WRD-managed tank area (218) and the

Table 7. Livestock inventory of sample farmers in the study area (%)

Sl. No.	Particulars	Farmers managed tank area (WUA)		WRD managed tank area		Groundwater irrigation (control area)	
		No.	Average in ha	No.	Average in ha	No.	Average in ha
1	Bullock pairs	0 (0.00)		0 (0.00)		1 (0.43)	
2	Cows	14 (3.75)		7 (2.09)		10 (4.27)	
3	Crossbred cows	30 (8.04)		27 (8.06)		22 (9.40)	
4	Buffaloes	1 (0.27)		1 (0.30)		2 (0.85)	
5	Sheep	152 (40.75)		150 (44.78)		90 (38.46)	
6	Goats	25 (6.70)		18 (5.37)		12 (5.13)	
7	Poultry birds	151 (40.49)		132 (39.40)		97 (41.46)	
	Total	373 (100.00)		335 (100.00)		234 (100.00)	

Figures in parentheses indicate the percentage of farmers possessing the livestock. WUA - Water Users Association, WRD - Water Resource Department.

Table 8. Farm assets of sample farmers in the study area (%)

Sl. No.	Particulars	Farmers managed tank area (WUA)	WRD managed tank area	Groundwater irrigation (control area)
1	Wooden /M.B. ploughs	5 (2.32)	7 (3.21)	10 (3.56)
2	Power tillers	8 (3.72)	7 (3.21)	5 (1.78)
3	Tractor and accessories	11 (5.11)	9 (4.13)	7 (2.49)
4	Sprayers	75 (34.89)	78 (35.78)	71 (25.27)
5	Irrigation pumps (IP Set)	43 (20.00)	47 (21.56)	53 (18.86)
6	Borewells	35 (16.28)	32 (14.68)	84 (29.89)
7	Farm buildings	31 (14.42)	27 (12.39)	38 (13.52)
8	Cattle shed	7 (3.26)	11 (5.04)	13 (4.63)
	Total	215 (100.00)	218 (100.00)	281 (100.00)

Figures in parentheses indicate the percentage of farmers possessing those farm assets. WUA - Water Users Association, WRD - Water Resource Department.

WUA-managed tank area (215). Among all assets, sprayers were the most widely possessed across all systems, 34.89 % in WUA, 35.78 % in WRD and 25.27 % in the control area, indicating widespread use for pesticide and weedicide application.

Irrigation pumps (IP sets) were also common, accounting for 20.00 % in WUA, 21.56 % in WRD and 18.86 % in the control area. Notably, borewells were significantly higher in the control area (29.89 %), compared to 16.28 % in WUA and 14.68 % in WRD areas, reflecting the control area's greater dependency on groundwater sources. This corresponds with the higher number of borewells and electric pump sets typically used in such systems. The possession of tractors and power tillers was slightly higher in the WUA-managed area (5.11 % and 3.72 % respectively), indicating greater use of mechanisation compared to WRD (4.13 % and 3.21 %) and control areas (2.49 % and 1.78 %). Traditional implements like wooden or MB ploughs were found in small proportions across all systems, but slightly more in the control area (3.56 %). Farm buildings and cattle sheds were relatively evenly distributed, with a slightly higher presence in the control area, reflecting better storage or livestock housing infrastructure.

Thus, it could be inferred that mechanised assets like tractors and power tillers are more prevalent in the WUA-managed areas, while the control area shows greater investment in groundwater infrastructure such as borewells. The widespread presence of sprayers across all systems highlights the universal need for plant protection measures. These patterns indicate that asset ownership is influenced by the type of irrigation system and resource availability, shaping the technological and infrastructural profile of farming in the region.

Economic performance of both tank irrigation management institutions and groundwater irrigation

Economic performance of productivity of crops, annual income of farmers, employment of farmers and asset position of farmers for tank and groundwater irrigation are presented in this section.

Water use efficiency (WUE) of crops

The average WUE of major crops was studied by dividing the total output by the total inputs in the farm production. The average productivity of crops for both tank and groundwater irrigation is

Table 9. Water use efficiency of major crops for the Water User Association managed tank irrigation

Sl. No.	Crops	WUE (kg m ⁻³)
1	Paddy	263.60
2	Groundnut	87.58
3	Millets	33.91
4	Pulses	25.06
5	Gingelly	47.35

WUE - Water Use Efficiency.

Table 10. Water use efficiency of major crops for the Water Resource Department-managed tank irrigation

Sl. No.	Crops	WUE (kg m ⁻³)
1	Paddy	117.37
2	Groundnut	59.68
3	Millets	30.73
4	Pulses	22.50
5	Sugarcane	32.24

WUE - Water Use Efficiency.

Table 11. Water use efficiency of major crops for groundwater irrigation

Sl. No.	Crops	WUE (kg m ⁻³)
1	Paddy	189.35
2	Groundnut	37.12
3	Millets	25.17
4	Pulses	17.10
5	Gingelly	42.68
6	Banana	27.16
7	Vegetables	10.06

WUE - Water Use Efficiency.

discussed in the given table 9, 10 and 11 respectively.

The superior performance of the WUA-managed system can be attributed to stronger farmer participation and collective decision-making (31). Functional WUAs ensure timely water release, equitable distribution between head- and tail-end farmers, regular maintenance of field channels and conflict resolution mechanisms. These governance practices improve irrigation reliability, reduce water losses and ultimately enhance crop yield and WUE compared with the WRD system, where governance tends to be more top-down and less responsive to field conditions (32, 33).

Water use efficiency (WUE) for Water Users Association-managed tank irrigation

Water use efficiency of major crops for the WUA managed tank irrigation. The analysis of crop productivity under WUA-managed tank irrigation reveals notable differences in WUE among major crops cultivated in the command area. Paddy exhibited the highest WUE (263.60 kg m⁻³), indicating its strong responsiveness to controlled and timely irrigation practices ensured by the WUAs. Groundnut recorded the second highest WUE (87.58 kg m⁻³), reflecting its moderate water requirement and effective utilisation of soil moisture in tank-fed conditions. Millets (33.91 kg m⁻³), pulses (25.06 kg m⁻³) and gingelly (47.35 kg m⁻³) showed comparatively lower WUE values, largely due to their lower biomass production potential and partial dependence on supplementary irrigation (Table 9). Nevertheless, these crops remain essential for sustaining crop diversification and improving soil health. Overall, the results demonstrate that WUA-led water allocation, channel maintenance and participatory decision-making significantly contribute to improved irrigation efficiency and enhanced water productivity across crops in tank-irrigated systems (Fig. 1).

Water use efficiency (WUE) for Water Resource Department-managed tank irrigation

Water use efficiency of major crops for the WRD-managed tank irrigation. The WUE of major crops cultivated under the WRD-managed tank irrigation system shows a distinct pattern similar to that of WUA-managed systems, with paddy recording the highest WUE at 117.37 kg m⁻³ (Table 10). Groundnut ranked second with a WUE of 59.68 kg m⁻³, reflecting its relatively efficient use of limited irrigation water. Millets (30.73 kg m⁻³), pulses (22.50 kg m⁻³) and sugarcane (32.24 kg m⁻³) exhibited comparatively lower WUE values, which can be attributed to their varying crop duration, biomass potential and water demand characteristics. Although these crops require either moderate or supplementary irrigation, their lower WUE indicates differences in field-level water management and crop response under the departmental irrigation structure. Overall, the variations highlight the need for improved water allocation and crop planning to enhance productivity and optimise the use of scarce tank water

resources (Fig. 2).

Water use efficiency for groundwater irrigation

Water use efficiency of major crops for groundwater irrigation. The productivity performance of major crops under groundwater irrigation also revealed substantial variations in WUE (Table 11). Among the crops, paddy recorded the highest WUE at 189.35 kg m⁻³, indicating its strong response to assured and controllable groundwater availability. Groundnut exhibited the second-highest WUE (37.12 kg m⁻³), followed by millets (25.17 kg m⁻³), pulses (17.10 kg m⁻³), gingelly (42.68 kg m⁻³), banana (27.16 kg m⁻³) and vegetables (10.06 kg m⁻³). The relatively lower WUE of several crops under groundwater irrigation reflects differences in crop characteristics, irrigation frequency and farmers water management practices. When compared across the three irrigation systems, WUA-managed tanks, WRD-managed tanks and groundwater irrigation, it is evident that paddy and groundnut consistently demonstrated the highest WUE. This suggests that these crops are more capable of converting available water into higher productivity across varying irrigation environments, highlighting their suitability and economic advantage under diverse water regimes (Fig. 3).

Annual income of both tank irrigation management institutions and groundwater irrigation

Household income distribution across irrigation systems. The sample farmers were classified into three groups based on their annual income. The farmers with an annual income of 0.5–2.5 lakh were considered as the low-income group, annual income between 2.5 lakh and 5 lakh was considered as the medium-income group and annual income more than 5 lakh was considered as the high-income group. The medium income farmers had more proportion among all three, viz, farmers managed tank irrigation, WRD managed tank irrigation and groundwater irrigation, with 53.75 %, 43.75 % and 43.75 % respectively (Table 12). This was followed by the high-income group in all three irrigation systems with 33.75 %, 28.75 % and

Table 12. Annual income of both tank irrigation management institutions and groundwater irrigation farmers (₹ lakhs)

Sl. No.	Annual income	Farmers managed tank area (WUA)	WRD managed tank area	Groundwater irrigation (control area)
1	Low income (0.5 – 2.5 L)	10 (12.50)	22 (27.50)	17 (21.25)
2	Medium income (2.5 – 5 L)	43 (53.75)	35 (43.75)	35 (43.75)
3	High income (more than 5 Lakh)	27 (33.75)	23 (28.75)	28 (35.00)
	Total	80 (100.00)	80 (100.00)	80 (100.00)

Figures in parentheses indicate per cent of the respective total. WUA - Water Users Association, WRD - Water Resource Department.

Table 13. Income sources of both tank irrigation management institutions and groundwater irrigation farmers (₹ lakhs)

Sl. No.	Particulars	Farmers managed tank area (WUA)	WRD managed tank area	Groundwater irrigation (control area)
1	Crop income	6.21 (94.95)	3.76 (93.53)	4.50 (94.14)
2	Livestock income	0.15 (2.29)	0.13 (3.23)	0.13 (2.72)
3	Off-farm income	0.05 (0.77)	0.03 (0.75)	0.05 (1.05)
4	Non-farm income	0.13 (1.99)	0.10 (2.49)	0.10 (2.09)
	Total income	6.54 (100.00)	4.02 (100.00)	4.78 (100.00)

WUA - Water Users Association, WRD - Water Resource Department.

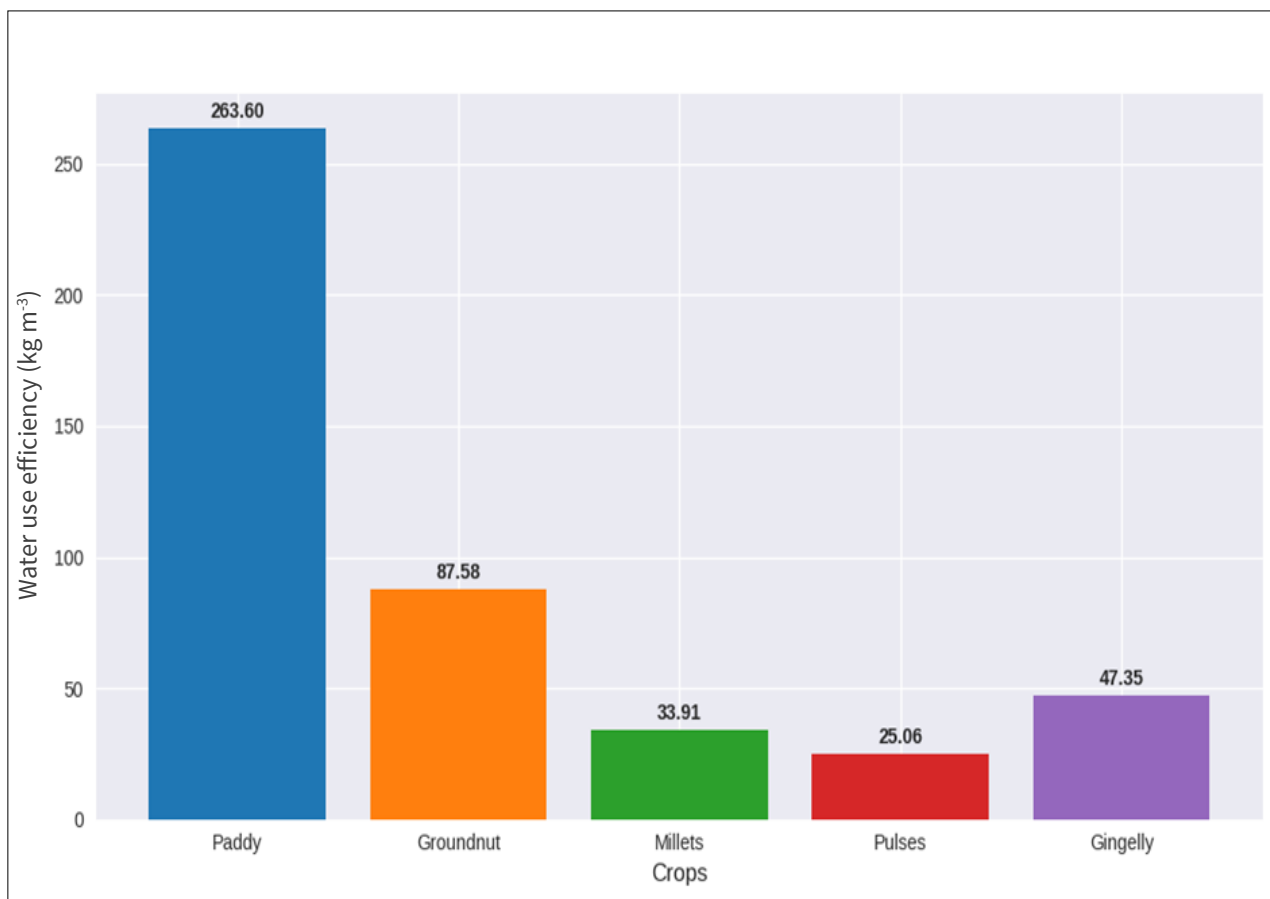


Fig. 1. Water use efficiency of major crops for the Water User Association managed tank irrigation.

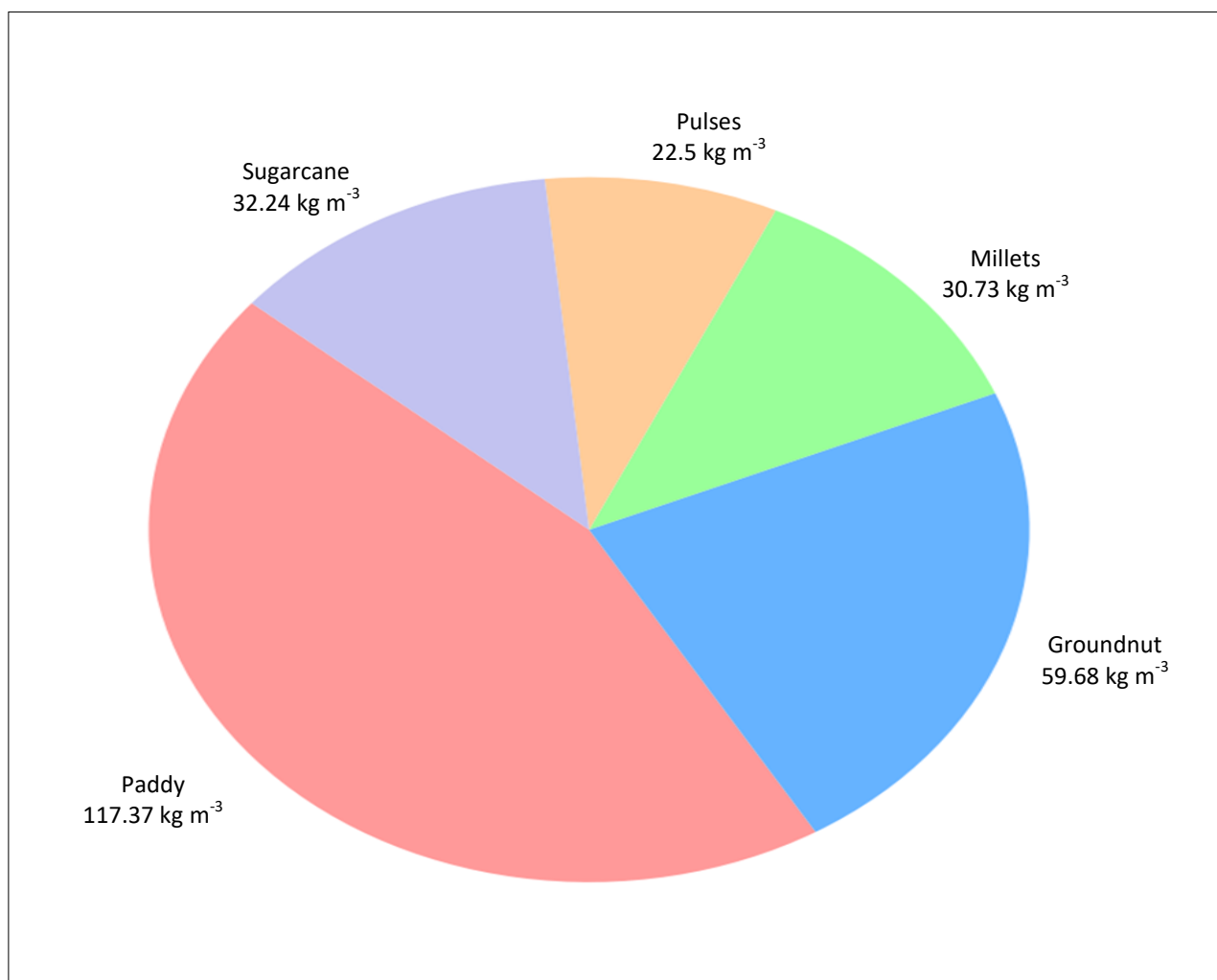


Fig. 2. Water use efficiency of major crops for the Water Resource Department-managed tank irrigation.

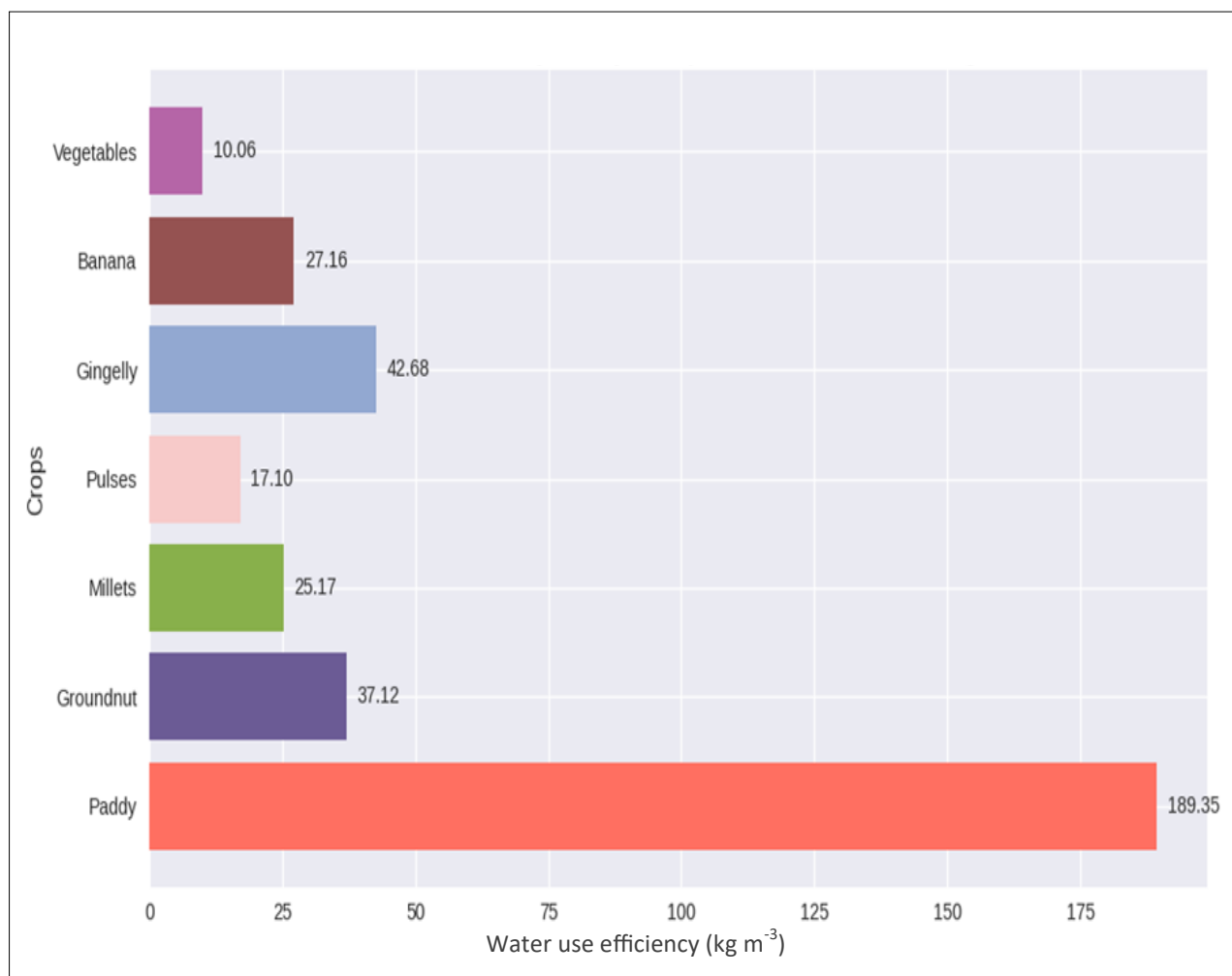


Fig. 3. Water use efficiency of major crops for groundwater irrigation.

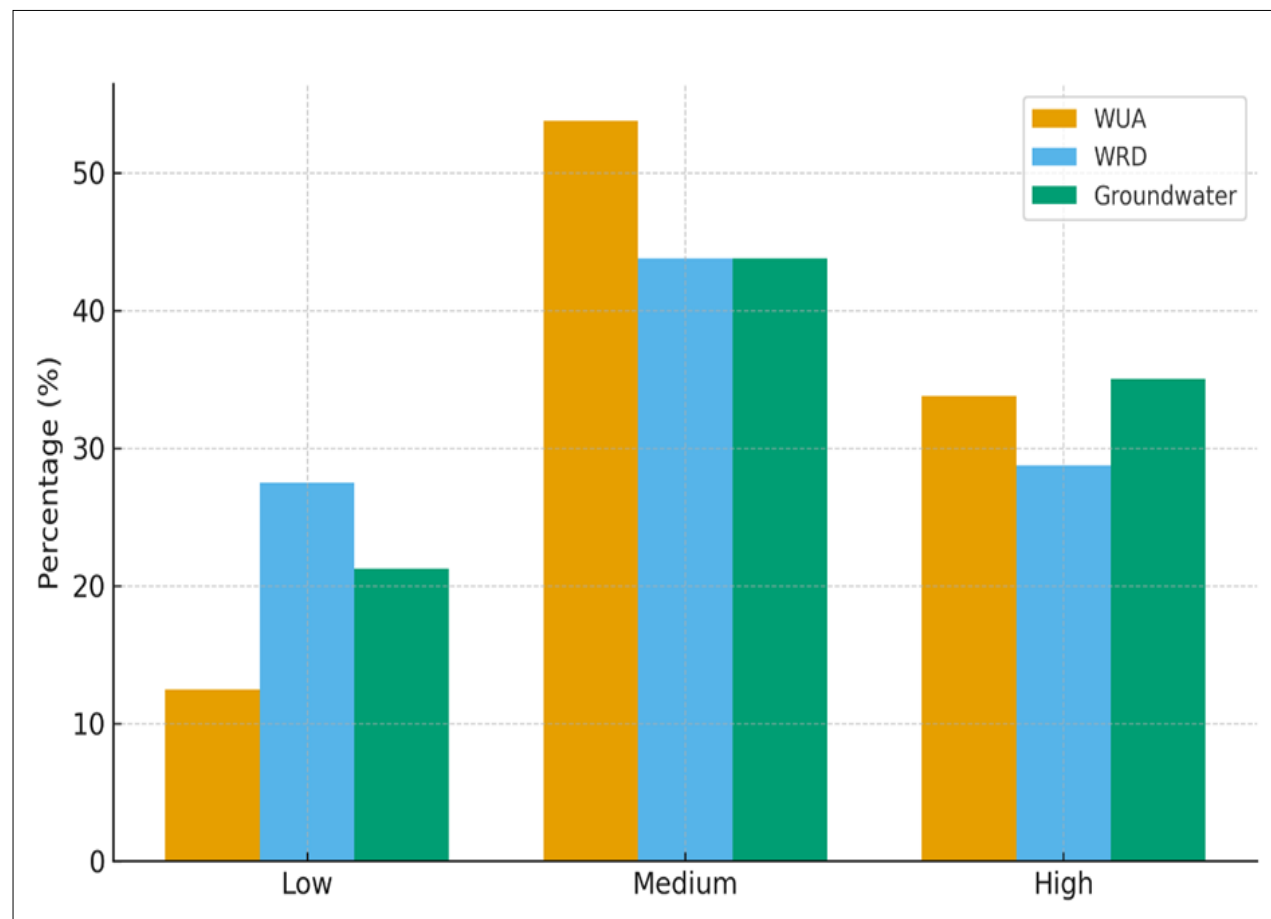


Fig. 4. Household income distribution across irrigation systems.

35.00 % respectively. Finally, low-income farmers were a very of less number in all three systems, with 33.75 %, 28.75 % and 35 % in each group. These results show that the table that medium-income group farmers were a large proportion in all three irrigation systems (Fig. 4).

Income sources of both tank irrigation management institutions and groundwater irrigation

The different sources of income of sample farmers are given in Table 13. The income sources were classified into crop income, livestock income, off-farm income and non-farm income. It could be seen from the table that crop income had the highest share of 94.95 %, 93.53 % and 94.14 % for farmers managed tank irrigation, WRD managed tank irrigation and groundwater irrigation respectively. In farmers managed tank irrigation, livestock income was the next highest source of income at 2.29 %, followed by non-farm income and off-farm income, at 0.77 % and 1.99 % respectively. In the WRD, managed tank irrigation, livestock income shares the second most with 3.23 %, followed by non-farm income and off-farm income with 2.49 % and 0.75 %. In the groundwater irrigation, farmers earn more from livestock sources with 2.72 %, followed by non-farm income and off-farm income with 2.09 % and 1.05 %. This confirms from the above table that in all three irrigation systems, crop income was dominant and almost all other income sources were of negligible proportion.

Employment position of both tank irrigation management institutions and groundwater irrigation

The employment distribution across major agricultural operations under different irrigation systems is presented in Table 14. Among all activities, planting operations generated the highest employment, accounting for 39.80 % in the WUA-managed tank area, 43.48 % in the groundwater-irrigated control area and 22.50 % in the WRD-managed tank area. This highlights the labour-intensive nature of planting, especially in groundwater-reliant systems where timely crop establishment is crucial. Intercultural operations such as weeding and earthing up contributed significantly to employment, particularly in the WRD-managed tank area (38.75 %) and WUA-managed area (24.27 %). In contrast, the control area had a relatively lower share at 18.48 %. Field preparation accounted for 21.25 % of employment in the WRD area, followed by 14.13 % in the control area and 11.65 % in WUA-managed tanks, indicating the importance of pre-sowing operations in WRD-managed fields. Other activities, such as application of fertiliser and manure, pesticide application and harvesting, contributed relatively less to total employment across all systems. Their combined share remained below 20 % in each irrigation regime, reflecting their shorter duration or mechanisation.

In terms of overall employment generation, the WUA-managed tank area recorded the highest total (103 man-days), followed by the control area (92 man-days) and the WRD-managed tank area (80 man-days). This indicates that community-managed irrigation systems like WUAs provide greater employment opportunities, likely due to more intensive and

Table 14. Employment position of both tank irrigation management institutions and groundwater irrigation farmers (man days ha⁻¹)

Sl. No.	Particulars	Farmers managed tank area (WUA)	WRD managed tank area	Groundwater irrigation (control area)
1	Field preparation	12 (11.65)	17 (21.25)	13 (14.13)
2	Planting	41 (39.80)	18 (22.50)	40 (43.48)
3	Application of fertiliser & manure	12 (11.65)	7 (8.75)	10 (10.87)
4	Application of pesticides	5 (4.86)	3 (3.75)	6 (6.52)
5	Intercultural operations	25 (24.27)	31 (38.75)	17 (18.48)
6	Harvesting	8 (7.77)	4 (5.00)	6 (6.52)
	Total	103 (100.00)	80 (100.00)	92 (100.00)

Figures in parentheses indicate per cent of the respective total. WUA - Water Users Association, WRD - Water Resource Department.

Table 15. Asset holdings of both tank irrigation management institutions and groundwater irrigation farmers (₹ lakhs)

Sl. No.	Particulars	Farmers managed tank area (WUA)	WRD managed tank area	Groundwater irrigation (control area)
1	Land	108.12 (98.14)	74.38 (97.53)	104.31 (98.38)
2	Buildings	0.12 (0.11)	0.06 (0.08)	0.07 (0.07)
3	Machineries	1.02 (0.93)	0.96 (1.26)	0.95 (0.89)
4	Livestock	0.91 (0.82)	0.86 (1.13)	0.70 (0.66)
	Total	110.17 (100.00)	76.26 (100.00)	106.03 (100.00)

Figures in parentheses indicate per cent of the respective total. WUA - Water Users Association, WRD - Water Resource Department.

participatory agricultural practices. These results show that irrigation type significantly affects labour distribution, with WUA and groundwater systems offering more employment than WRD-managed areas.

Asset position of both tank irrigation management institutions and groundwater irrigation

The asset composition of farmers across the three irrigation ecosystems, WUA-managed tank area, WRD-managed tank area and groundwater-irrigated (control) area, is detailed in Table 15. The data reveal that land constitutes the dominant asset, accounting for 98.14 % in the WUA-managed area, 97.53 % in the WRD-managed area and 98.38 % in the control area. This dominance highlights the central role of land in the overall asset structure of farming households, regardless of irrigation source. Machinery held the second-highest share of asset value, contributing 0.93 % in WUA-managed tanks, 1.26 % in WRD-managed tanks and 0.89 % in the control area. Although the differences are marginal, WRD-managed tank farmers showed slightly higher investment in machinery, likely due to reliance on mechanised operations to offset water uncertainties. Livestock assets contributed 0.82 %, 1.13 % and 0.66 % in WUA, WRD and control areas respectively, indicating a relatively higher dependency on livestock in the WRD-managed area. The value of buildings remained negligible across all areas, contributing less than 0.12 % of total assets. In terms of total asset value, farmers in the WUA-managed tank area had the highest overall asset base (₹110.17 lakhs), followed by the control area (₹106.03 lakhs) and the WRD-managed tank area (₹76.26 lakhs). This indicates that farmers under WUA management possess a stronger asset position, likely due to better water governance and participatory resource use. This indicates that land remains the predominant asset across all irrigation regimes, while the WUA-managed system supports higher overall asset accumulation, underscoring the economic advantage of community-managed irrigation structures.

Conclusion

This study provides empirical evidence on the differential performance of irrigation systems in the Pudukkottai district, Tamil Nadu. It demonstrates that community-managed irrigation systems through Water Users Associations (WUAs) are more effective in delivering higher water productivity, better income distribution and greater employment opportunities than Water Resource Department (WRD)-managed or groundwater-based systems. The WUA-managed areas recorded the highest water use efficiency (WUE) for all major crops, particularly paddy, which achieved nearly twice the efficiency compared to WRD-managed tanks. Farmers under WUAs also had larger landholdings, higher literacy rates, more mechanised assets and stronger asset positions, indicating robust farm economics supported by participatory governance. On the other hand, WRD-managed tanks, despite being under formal government supervision, performed sub-optimally in WUE and economic returns. Weak institutional engagement, conflicts between head and tail farmers and passive WUAs may contribute to these limitations. The groundwater control area showed moderate performance, bolstered by investments in borewells and livestock but constrained by over-reliance on depleting aquifers. The findings

suggest that strengthening WUAs and adopting decentralised, participatory water management can significantly enhance economic and environmental outcomes. At the same time, WRD-managed tanks require urgent institutional revitalisation, including functional WUAs, equitable water distribution mechanisms and farmer engagement. For groundwater systems, conjunctive use strategies, regulatory frameworks and investments in recharge structures are essential for long-term sustainability. This indicates that irrigation governance plays a pivotal role in shaping farm-level outcomes. The WUA model emerges as a promising approach to achieving inclusive, efficient and sustainable agricultural water management in water-scarce regions.

Key quantitative findings

The study clearly demonstrates the superior performance of the WUA-managed tank irrigation system compared with both WRD-managed tanks and groundwater-based irrigation. The WUE was significantly higher under the WUA system, with values for major crops such as paddy and groundnut exceeding those of WRD and groundwater systems by substantial margins. Farmers under WUA management also recorded higher crop yields, better income levels and improved irrigation reliability. Furthermore, socio-economic indicators such as asset position, employment generation and operational efficiency consistently favoured the WUA system, reaffirming the value of participatory irrigation management (PIM).

Policy and practical implications

The findings highlight the critical role of empowered WUAs in strengthening irrigation governance. Policies that support farmer participation, transparent water allocation and decentralised decision-making can directly enhance water productivity and reduce conflicts in tank irrigation systems. Extension agencies should prioritise training farmers in water budgeting, canal maintenance and collective governance practices to sustain WUA performance. At the institutional level, integrating WRD officials with WUA committees and promoting coordinated maintenance can strengthen hybrid governance models. The results underscore the importance of scaling participatory irrigation models to other tank systems in water-scarce regions to improve both equity and efficiency.

Study limitations and recommendations for further research

This study is limited to a sample from a single district and relies on data from one agricultural year, which may not capture spatial or temporal variability in water availability, institutional performance and crop outcomes. Future research should consider multi-year panel data, expand the analysis to additional districts and agro-ecological regions and incorporate hydrological assessments of tank storage and groundwater dynamics. Comparative studies that combine economic analysis with remote sensing-based water accounting would further strengthen the understanding of irrigation efficiency across institutional and groundwater systems.

Acknowledgements

The authors acknowledge and are grateful to the Indian Council of Social Science Research (ICSSR), Government of India, New Delhi for funding this research study.

Authors' contributions

AM conceived the overall research idea and provided guidance. SR designed the study framework, drafted the manuscript and performed the statistical analysis. MR supervised the study and coordinated the manuscript preparation. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used Quill Bot tool to paraphrase the sentence and Grammarly to improve the language and readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

References

- Adhikari R, Singh A, Math S, Raizada A, Mishra P, Reddy K. Augmentation of groundwater recharge and water quality improvement by water harvesting structures in the semi-arid Deccan. *Curr Sci*. 2013;105:1534–42.
- Alexander JJ, Mahalingam B. Sustainable tank irrigation: An irrigation water quality perspective. *Indian J Sci Technol*. 2011;4(1):22–6. <https://doi.org/10.17485/ijst/2011/v4i1.5>
- Amarnath J, Saranya S. An economic analysis of sustainability in Namakkal district of Tamil Nadu. *Wyno Acad J Agric Sci*. 2014;2(1):1–18.
- Ashok K, Sasikala C. Farmers' vulnerability to rainfall variability and technology adoption in rain-fed tank irrigated agriculture. *Agric Econ Res Rev*. 2012;25(2):267–78. <https://doi.org/10.1177/0971344120120208>
- Banks E, Simmons C, Love A, Shand P. Assessing spatial and temporal connectivity between surface water and groundwater in a regional catchment: Implications for regional-scale water quantity and quality. *J Hydrol*. 2011;404(1-2):30–49. <https://doi.org/10.1016/j.jhydrol.2011.04.017>
- Bortolini L, Maucieri C, Borin M. A tool for the evaluation of irrigation water quality in the arid and semi-arid regions. *Agronomy*. 2018;8(2):23. <https://doi.org/10.3390/agronomy8020023>
- Farid I, Abbas M, Bassouny M, Gameel A, Abbas H. Indirect impacts of irrigation with low-quality water on the environmental safety. *Egypt J Soil Sci*. 2020;60(1):1–15. <https://doi.org/10.21608/ejss.2019.15434.1294>
- Feleke E, Assefa E, Zeleke T. Effects of small-scale irrigation on household income and its implications for livelihood sustainability in the drought-prone Central Rift Valley of Ethiopia. *J Sustain Dev Afr*. 2020;22(1):1–12.
- Heathwaite A. Multiple stressors on water availability at global to catchment scales: Understanding human impact on nutrient cycles to protect water quality and water availability in the long term. *Freshw Biol*. 2010;55:241–57. <https://doi.org/10.1111/j.1365-2427.2009.02368.x>
- Helmus A, Fernald A, VanLeeuwen D, Abbott L, Ulery A, Baker T. Surface water seepage effects on shallow ground-water quality along the Rio Grande in Northern New Mexico. *J Am Water Resour Assoc*. 2009;45(2):407–18. <https://doi.org/10.1111/j.1752-1688.2008.00293.x>
- Kajisa K, Palanisami K, Sakurai T. Effects on poverty and equity of the decline in collective tank irrigation management in Tamil Nadu, India. *Agric Econ*. 2007;36(3):347–62. <https://doi.org/10.1111/j.1574-0862.2007.00212.x>
- Krishna Kumar S, Hari Babu S, Eswar Rao P, Selvakumar S, Thivya C, Muralidharan S, et al. Evaluation of water quality and hydrogeochemistry of surface and groundwater, Tiruvallur District, Tamil Nadu, India. *Appl Water Sci*. 2017;7(5):2533–44. <https://doi.org/10.1007/s13201-016-0447-7>
- Legesse L, Ayele A, Tasewu W, Alemu A. Impact of small scale irrigation on household farm income and asset holding: Evidence from Shebedino District, Southern Ethiopia. *J Resour Dev Manag*. 2018;43(1):24–36.
- Li J, Ma W, Renwick A, Zheng H. The impact of access to irrigation on rural incomes and diversification: Evidence from China. *China Agric Econ Rev*. 2020;12(4):705–25. <https://doi.org/10.1108/CAER-09-2019-0172>
- Molden D, Burton M, Bos M. Performance assessment, irrigation service delivery and poverty reduction: Benefits of improved system management. *Irrig Drain*. 2007;56(2-3):307–20. <https://doi.org/10.1002/ird.313>
- Palanisami K, Flinn J. Evaluating the performance of tank irrigation systems. *Agric Syst*. 1988;28(3):161–77. [https://doi.org/10.1016/0308-521X\(88\)90049-2](https://doi.org/10.1016/0308-521X(88)90049-2)
- Palanisami K, Flinn J. Impact of varying water supply on input use and yields of tank-irrigated rice. *Agric Water Manag*. 1989;15(4):347–59. [https://doi.org/10.1016/0378-3774\(89\)90051-6](https://doi.org/10.1016/0378-3774(89)90051-6)
- Prabhakaran R, Seetharaman S. Evaluation of groundwater suitability for irrigation and drinking purposes in the Olakkur block, Villupuram district, Tamil Nadu, India. *J Appl Geochem*. 2020;22(2):153–8.
- Sakurai T, Palanisami K. Tank irrigation management as a local common property: The case of Tamil Nadu, India. *Agric Econ*. 2001;25(2-3):273–83. <https://doi.org/10.1111/j.1574-0862.2001.tb00207.x>
- Sharif M, Ashok K. Impact of groundwater over-draft on farm income and efficiency in crop production. *Agric Econ Res Rev*. 2011;24(2):291–300. <https://doi.org/10.1177/0971344120110212>
- Sivasubramaniyan K. Performance of irrigation in Tamil Nadu: A macro perspective. Chennai: Madras Inst Dev Stud; 2016.
- Randhir OT. Productivity variation and water use in farms of the Madurantakam tank-fed area of Chengalpattu district, Tamil Nadu. *Indian J Agric Econ*. 1990;45(1):59.
- Van Oel PR, Mulatu DW, Odongo VO, Meins FM, Hogeboom RJ, Becht R, et al. The effects of groundwater and surface water use on total water availability and implications for water management: The case of Lake Naivasha, Kenya. *Water Resour Manag*. 2013;27(9):3477–92. <https://doi.org/10.1007/s11269-013-0359-3>
- Zhou Q, Deng X, Wu F, Li Z, Song W. Participatory irrigation management and irrigation water use efficiency in maize production: Evidence from Zhangye City, Northwestern China. *Water*. 2017;9(11):822. <https://doi.org/10.3390/w9110822>
- Kumar N, Singh A, Bansal N. Evaluating the performance of participatory irrigation management in semi-arid regions of India: A case study of WUAs. *Water Policy*. 2022;24(3):345–60.
- Tiwari P, Bekele S. Community-driven irrigation governance and equity outcomes in smallholder systems. *Int J Water Resour Dev*. 2021;37(7):1120–38.
- Narayanamoorthy A. Revitalizing tank irrigation institutions: Policy reforms for efficient water governance in India. *Irrig Drain*. 2023;72(1):45–59.
- Ali M, Rahman S. Determinants of water-use efficiency in smallholder rice cultivation under climate variability. *Agric Water Manag*. 2022;268:107658.
- Devaraj R, Palanisami K. Assessing WUE in tank-fed paddy systems: Evidence from Tamil Nadu. *J Water Clim Change*. 2021;12(6):2280–91.

30. Saravanan V, Jayakumar M. Surface-groundwater interactions in tank-irrigated landscapes and implications for sustainability. *Hydrol Sci J*. 2023;68(2):314–28.
31. Bronson K, Ghosh A. Reimagining tank irrigation for climate-resilient agriculture in South Asia. *Environ Res Lett*. 2024;19(1):015004.
32. Choudhary R, Raghav P. Collective action for sustainable water governance: Lessons from farmer-led institutions. *Water Int*. 2024;49(2):203–21.
33. Aryal J, Gautam D. Community water management and institutional effectiveness in irrigation command areas. *Sustainability*. 2022;14(4):2239.

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Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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