Water Resources Management with Special Reference to Tank Irrigation with Groundwater Use

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Introduction

Tanks have existed in India from time immemorial and have been an important source of irrigation, especially in the southern peninsular. Kings, Zamindars and even the British rulers built many tanks in the eighteenth and nineteenth centuries. Though they are found in all parts of the country, tanks are concentrated in the southern states, such as Andhra Pradesh, Karnataka and Tamil Nadu, where they provided the largest source of irrigation until the mid-sixties. There are more than 39,000 tanks in Tamil Nadu state alone, with varying sizes and types and about 90% of them are rain-fed depending mainly on rainfall runoff for tank storage and irrigation. The area irrigated by tanks has been continuously declining from 0.9 to 0.5 million ha during the past 40 years and the share of the tanks in the total irrigated area has declined from 37% in the 1960s to 20% in the 2000s. Even though the share of tanks is decreasing part of it is replaced with groundwater irrigation in the tank command areas. Besides variation in rainfall and tank filling, several factors such as siltation, encroachment, and channel obstruction have reduced the tank irrigated area over the years. Also, over the years, increasing dug well irrigation in the tank commands has complicated the water allocation and management in the tanks (Palanisami and Easter 2000).

There are as many obstacles to tank irrigation as there are benefits, due to the large number of tanks and the differences in water demand, managerial experiences and investment needs for maintenance. In 2 out of 10 years the tank receives normal or excess rainfall; in 3 out of 10 years scanty rainfall results in tank failure; and in 5 out of 10 years deficit rainfall results in reduction of crop yields. Some tanks are reported to be functioning for irrigation only in normal/excess rainfall years and not so in poor/low-rainfall years. Since about 90% of the tanks are nonsystem or rain-fed the effect on area reduction will be more significant (Palanisami et al. 1997).

Over the years, farmers started supplementing tank water with well water, particularly in deficit years. There are tanks now acting as groundwater recharge ponds, and also meeting domestic and livestock water needs in the tank command areas where they use only groundwater. In about 10% of the tanks with adequate number of wells in the command area, the irrigated area has increased to 80%. However, due to constraints in the development of wells, the number of wells, for example, for every 4 ha, ranges from less than one to two wells, and the threshold level will be about one well for every 4 ha in a normal year, which will vary in different locations. In most cases, the tanks are having wells below the threshold level. It is also reported in a few cases that a larger number of wells above the threshold level will also affect the tank performance in terms of poor cooperation in operation and maintenance (O&M) of the tanks. In recent times, a major function of some tanks has changed from a primarily storage for surface irrigation to a groundwater recharge structure. However, these tanks do still play a major role in providing domestic water supply for humans and drinking water supply for the livestock population. Farmers, especially the rich and powerful, in the command area of these tanks now use dug wells or tube wells to irrigate their lands. Thus changing water use patterns in the command area of these tanks requires completely different management options.

It is felt that wells will be an integral part of the tank systems in the future and further research is needed to identify the role of tanks in providing water supply for different needs, and to assess the required supporting management structures and investment needs. Keeping this in mind, a detailed study was undertaken in Tamil Nadu, India with the following objectives.

- Study the implications (economic and hydrologic) of using tanks as percolation ponds and increasing groundwater irrigation in the tank command areas on the performance of tanks.
- Assess the groundwater recharge patterns with tanks as percolation ponds.
- Assess the threshold at which a tank can act as a groundwater recharge structure and provide water for domestic and livestock purposes while promoting groundwater irrigation in the tank command areas.
- Assess the management strategies of tanks and investment options for tank modernization under increasing groundwater irrigation in the tank command areas.

Methodology

Three districts in Tamil Nadu, Coimbatore, Madurai and Sivagangai, were selected to obtain the sample tanks for analysis. Ten tanks in each district were selected for the sampling. In each tank 25 households were randomly selected for this study. The sample for this study consists of 30 tanks and 750 households in those selected tanks. The purpose of selecting these districts was to get the equal distribution of sample households in the three different situations which are tank-only, tank-with-wells and wells-only. The 30 tanks selected randomly for this study were categorized into three different typologies such as tank-only, tank-with-wells, and wells-only. This categorization was based on the percentages of households depending on the type of water source under each tank (Table 1).

Table 1. Sample household distribution in the study area.

Typology	Tank-only	Tank-with-wells	Wells-only	Total
Tank-only	173 (23)	27 (3.6)	0	200 (27)
Tank-with-wells	54 (7.2)	246 (33)	0	300 (40)
Wells-only	0	0	250 (33)	250 (33)
Total	227 (30.3)	273 (36.4)	250 (33.3)	750 (100)

Note: Percentages of the total are given in parentheses.

If more than 80% of the households used a tank as the only source for irrigation, then this tank was categorized as typology I (the tank-only situation). If more than 80% of the households used only the wells as the source of irrigation in the tank area then this situation was categorized as typology III (wells-only situation) and the rest were grouped into typology II (tank-with-wells situation). In this study area, eight tanks in the Madurai District were categorized under typology I (i.e., the tank-only situation). It consists of 173 households which used tanks as the only source of water for irrigation. There were 27 households under those particular tanks that used tanks with wells as the sources of water for irrigation. Likewise, 12 tanks in Sivagangai and Madurai districts were categorized under typology II (i.e., the tank-with-wells situation). It consists of 246 households that used tanks-with-wells as the sources of water for irrigation. There were 54 households in typology II that used only the tank as the source of water for irrigation. Finally, 27 households in typology I and 54 households in typology II were excluded from the analysis except for partial budgeting because these households used the water source for irrigation that was different from the typological situation. This exclusion was made to draw the conclusions and recommendations based on the results obtained from each typological situation.

In the tank-only situation most of the households are marginal, accounting for 73% of the total number of households while the large farmers account for only 2% of the total number of households. In the tank-with-wells situation, nearly 45% are small farmers and around 18% large farmers. In the wells-only situation nearly 50% of the households are small households and around 28% large households (Table 2).

Table 2. Distribution of households (HH) and farm size in the three different situations.

Farm size	Distribution of HH					
	Tank-only		Tank-with-wells		Wells-only	
	No. of HH	% of total	No. of HH	% of total	No. of HH	% of total
No. of marginal households (< 1ha)	126	73	90	37	57	23
No. of small households (1-2 ha)	43	25	112	45	124	50
No. of large households (>2 ha)	4	2	44	18	69	28
Total no. of households	173	100	246	100	250	100

General Characteristics of the Sample Households

General characteristics of the sample households like age, education and landholdings of respondents, etc., were hypothesized to have significant influence on the adoption of new and improved technology and income of the respondents. The participation of the farmers in the tank and water management activities also depends on the socioeconomic characteristics.

Age of the Sample Respondents

Age is an important factor that affects various farm and tank management decisions. Hence, the age-wise distribution of the sample respondents is discussed below.

In the tank-only situation, nearly 32% are in the age group of 31-40 years followed by 29% of households in the age group of 41-50 years and 21% of households in the age group of 51-60 years. In the tank-with-wells situation around 38% belonged to the age group of 41-50 years, nearly 23% to the age group of 31-40 years, and approximately 21% to the age group of 51-60 years. In the wells-only situation, around 80% belonged to the age group of 31-50 years (Table 3).

In the tank-only situation, the majority are marginal farmers and a very few of them are large farmers. Around 94% of the marginal farmers and nearly 91% of the small farmers are in the age group of more than 30 years. In the tank-with-wells situation nearly 38% of the total households are in the age group of 41-50 years and many of them are marginal and small farmers. In the wells-only situation, nearly 40% belonged to the age group of 31-40 years followed by 39% belonging to the age group of 41-50 years. It can be concluded that most of the household heads are more than 31 years of age. This implies that these households might have enough experience in farming. In the tank-only and the tank-with-wells situations, less than 10% of the households are in the age group of 21-30 years and engaged in farming, and in the wells-only situation nearly 15% of the households are engaged in farming. This might be due to the migration of youngsters from villages to urban areas in search of alternative jobs and nonfarm activities.

Educational Status of the Sample Respondents

Education is an important variable that determines the access and adoption of technologies. Hence, data on the educational status of the respondents were collected and discussed concurrently.

Among the subgroups of households, the tank-only situation has the highest illiteracy rate compared to the other two groups of households. In the tank-only situation, around 28% of the sample households are illiterate. In the tank-with-wells and the wells-only situations, around 17% of the households in each group are illiterate. Among marginal households in the tank-only situation, the illiteracy rate is nearly 31%. In the tank-with-wells situation it is around 21%. In all three situations, more than 40% of the marginal farmers had 6-10 years of education. In the tank-with-wells and the wells-only situations more than 45% of the small farmers had 6-10 years of education. Among large farmers nearly 66% had 6-10 years of education (Table 3).

Table 3. Distribution of age and education in the study area.

	Tank-only				Tank-with-wells				Wells-only			
	Marginal farmers	Small farmers	Large farmers	Total	Marginal farmers	Small farmers	Large farmers	Total	Marginal farmers	Small farmers	Large farmers	Total
Age group (years)												
21-30	8	4	0	12	8	2	4	14	7	18	8	33
	(6.35)	(9.30)	(0.0)	(6.94)	(8.89)	(1.79)	(9.09)	(5.95)	(12.28)	(14.51)	(11.59)	(14.96)
31-40	43	13	0	55	22	25	9	56	22	47	32	101
	(34.13)	(30.23)	(0.0)	(31.79)	(24.44)	(22.32)	(20.45)	(22.70)	(38.60)	(37.9)	(46.38)	(40.16)
41-50	37	12	2	50	30	44	19	93	24	50	25	99
	(29.37)	(27.91)	(50.00)	(28.90)	(33.33)	(39.29)	(43.18)	(38.38)	(42.10)	(40.32)	(36.23)	(38.58)
51-60	25	10	1	37	18	24	11	53	4	9	4	17
	(19.84)	(23.26)	(25.00)	(21.39)	(20.00)	(21.43)	(25.00)	(21.08)	(7.02)	(7.26)	(5.80)	(6.30)
61-70	11	4	1	17	11	15	1	27	0	0	0	0
	(8.73)	(9.30)	(25.00)	(9.83)	(12.22)	(13.39)	(2.27)	(10.81)	(0.0)	(0.0)	(0.0)	(0.00)
71-80	2	0	0	2	1	2	0	3	0	0	0	0
	(1.59)	(0.0)	(0.0)	(1.16)	(1.11)	(1.79)	0.00	(1.08)	(0.0)	(0.0)	(0.0)	(0.00)
Total	126	43	4	173	90	112	44	236	57	124	69	250
Educational status												
Illiterate	39	8	0	88	19	18	4	31	13	21	9	43
	(30.95)	(18.60)	(0.00)	(28.30)	(21.116)	(16.07)	(9.09)	(16.76)	(24.14)	(16.67)	(2.86)	(17.32)
Primary	25	13	2	70	25	40	11	56	12	32	17	61
	(19.84)	(30.23)	(50.00)	(22.51)	(27.78)	(35.71)	(25.00)	(30.27)	(20.69)	(25.4)	(24.29)	(24.02)
Secondary	57	18	1	137	38	50	29	89	26	65	33	124
	(45.24)	(41.86)	(25.00)	(44.05)	(42.22)	(44.64)	(65.90)	(48.11)	(44.83)	(53.17)	(48.57)	(50.00)
Plus 1	5	3	1	15	7	4	0	8	4	5	8	17
	(3.97)	(6.98)	(25.00)	(4.82)	(7.78)	(3.57)	(0.0)	(4.32)	(6.90)	(3.97)	(11.43)	(6.69)
College	0	1	0	1	1	0	0	1	2	1	2	5
Total	126	43	4	173	90	112	44	246	57	124	69	250

In the sample as a whole, the number of farmers with 6-10 years of education was greater in the tank-with-wells and the wells-only situations accounting for nearly 48% and 50%, respectively, whereas in the tank-only situation, the illiteracy rate and the proportion of households were 1-5 years of education and around 50%, respectively.

The educational status showed that nearly 22% of the households were illiterate. Further, most of the literates had less than 10 years of schooling. Hence, necessary effort should be taken to educate the farmers on the new technology developed in the agriculture sector.

Cropping Pattern

In the sample, in the tank-only situation, around 84% of the households cultivated only one crop per year and about 16% two crops per year. The source of water supply is the tank for the first crop and rain for the second crop. Among the households cultivating two crops per year, nearly 43% are large farmers. In the tank-with-wells situation, around 67% of the households cultivated two crops a year, 32% only one crop a year and 1% three crops a year. In the wells-only situation, around 84% of the households cultivated two crops a year, 16% only one crop a year and 2% three crops a year. Clearly, this shows the availability of water in different situations. The analysis shows that in all three situations most of the small and large farmers cultivated two crops a year and the level of supplemental irrigation influenced the cropping pattern.

In the tank-only situation, 99% of the farmers cultivated only paddy. In the tank-with-wells situation, nearly 75% were involved in paddy cultivation and around 53% in sugarcane cultivation. The percentage of households involved in coconut, cotton and banana were 15, 11 and 4, respectively. In the wells-only situation 45% of the households were involved in cultivating banana, 41% in sugarcane, 43% in coconut, 32% in sorghum (rain-fed) and 8% in maize while a very few of them (less than 4% of the households) were involved in cultivating Bengal gram, turmeric, curry leaves and onion. This indicates that in the wells-only situation most of the households cultivated high-value crops as there is less risk in the supply of water through well irrigation, and in the tank-with-wells situation a considerable number of farmers diverted their cultivation pattern towards high-value crops.

Productivity

Productivity refers to the yield per unit area of land. Table 4 indicates that the productivity of the same crop varies with different typologies. The source of water supply is an important factor that decides crop productivity. Productivity of paddy is higher in the tank-with-wells situation than in the tank-only situation. Likewise, the productivity of sugarcane is nearly 8.6 tons/ha higher in the wells-only situation than in the tank-with-wells situation.

Income of the Sample Respondents

The average income per ha of the tank-only farmers from crop cultivation was Rs 17,599 whereas it was Rs 46,993 in the tank-with-wells situation and Rs 117,365 in the wells-only situation (Table 5). The income from agricultural crops alone contributed nearly 24%, 50% and 80% of the total income of the farmers in the tank-only, the tank-with-wells, and the wells-only situations, respectively. The contribution of income from nonagriculture was 27% in the tank-only situation whereas it was 26% in the tank-with-wells situation and 9% in the wells-only situation. The income from off-farm work contributed 16% in the tank-only, 11% in the tank-with-wells and 6% in the wells-only situations. The income from livestock contributed 17% of the total income in the tank-only situation. In the tank-with-wells and the wells-only situations the corresponding proportions were only 7% and 1.5%, respectively. The contribution of tree resources to the total income of farmers was less than 8% in all three situations.

In the tank-with-wells situation, all three categories of farmers (marginal, small and large) received more than double the income of what they received in the tank-only situation from agricultural crops alone. Similarly, the farmers in the wells-only situation earned more than double the income of what they earned in the tank-with-wells situation from crop cultivation. Table 4 shows that the income is increasing with assured water supply.

In the wells-only situation, farmers cultivated high-value crops as there was minimal risk in water supply. This is the reason for getting a higher income. But in the tank-with-wells situation, the majority of the farmers cultivated rice as the first crop and high-value crops as their second choice. This is the reason for getting a considerably lower income in the tank-with-wells situation compared to the wells-only situation.

From the above discussion, it could be concluded that agricultural crops were the main source of income among the selected farmers in all the situations. Further, a significant portion of the income was also from the nonfarm and off-farm activities. But in the tank-only situation, contribution of income from nonfarm activities was slightly higher than that from crop cultivation. It is necessary to strengthen the source of water supply to promote their major income source of crop cultivation.

Tank Performance and Management

The characteristics of the farmers have an influence on the overall performance of the tanks through farmers' involvement in tank management. Table 6 summarizes the participation of farmers in tank-management activities. It shows that the farmers in the tank-with-wells situation had participated comparatively less in tank management than in the tank-only situation. Farmers normally contributed labor, gunny bags and money for tank management. The average period of participation was only 1 to 2 days. In the wells-only situation, participation in tank management was very poor (Table 6).

For the sample as a whole, the number of farmers who contributed their labor for tank management was comparatively higher in the tank-only situation (69.9%) than in the tank-with-wells situation (22.3%). In contrast, the money contributed by the farmers for tank management activities was higher in the tank-with-wells situation (43.0%) than in the tank-only situation (27.2%), indicating that farmers felt the importance of tanks in crop production.

Water Management

Next to tank management activities, farmers' participation in water management was considered important, since in most of the years the tanks used to get below-normal supplies. Hence, an analysis of water management among the tanks in different typologies was done (Table 7).

Table 4. Productivity of different crops in different typologies.

Crop	Tank				Tank-with-wells				Wells-only			
	Marginal	Small	Large	Total	Marginal	Small	Large	Total	Marginal	Small	Large	Total
Paddy (kg/ha)	4,832	4,910	4,999	4,856	4,897	5,616	5,850	5,063	-	-	-	-
Sugarcane (kg/ha)	-	-	-	-	91,425	95,300	97,525	96,635	104,525	106,375	102,500	105,315
Banana (bunches/ha)	-	-	-	-	-	1,800	1,875	1,812	2,004	1,895	2,500	1,970
Coconut (nuts/ha)	-	-	-	-	15,370	16,135	16,417	15,694	16,594	17,511	17,317	16,931
Cotton (quintal/ha)	11.47	12	10	12.24	-	17.07	18.42	17.62	-	-	-	-

Source: Based on the primary survey.

Table 5. Income details of the farmers with different farm sizes in different typologies.

Income source	Tank				Tank-with-wells				Wells-only			
	Marginal	Small	Large	Total	Marginal	Small	Large	Total	Marginal	Small	Large	Total
From crops (Rs/ha)	17,373		20,625	17,599	36,210	54,733	53,055	46,933	98,264	119,648	132,642	117,366
Off-farm income	12,079		10,000	11,825	9,208	15,333	-	10,433	4,000	15,000	-	8,500
Nonfarm income	18,403		40,500	19,266	21,214	16,231	86,667	24,069	13,693	12,063	18,444	12,997
Livestock	12,750		-	12,020	6,136	5,820	7,500	6,117	-	-	-	-
Poultry	5,000	-	-	5,000	-	-	-	-	-	2,500	-	2,333
Tree	-	-	6,500	6,500	-	4,000	9,000	5,666	4,000	6,091	64,839	6,317

Source: Based on the primary survey.

Table 6. Participation in tank management in different irrigation typologies.

Particulars	Tank-only				Tank-with-wells				Wells-only			Total
	Marginal	Small	Large	Total	Marginal	Small	Large	Total	Marginal	Small	Large	
No of farmers who participated	121	43	4	168	18	100	43	161	0	11	15	26
	(98.4)	(97.7)	(66.7)	(97.1)	(20.0)	(89.3)	(97.7)	(65.4)	(0.0)	(8.9)	(21.7)	(10.4)
Labor contribution												
No. of farmers	90	30	1	121	4	43	8	55	0	11	15	26
	(73.2)	(68.2)	(16.7)	(69.9)	(4.4)	(38.4)	(18.2)	(22.4)	0	(8.9)	(12.1)	(21.0)
Average no. of days	2.5	2.3	1.9	1.75	2.1	1.69	1.66	1.68	-	3.86	3.77	3.8
Money contribution												
No. of farmers	31	13	3	47	14	57	35	106	-	-	-	-
	(25.2)	(29.6)	(50.0)	(27.2)	(15.6)	(50.9)	(79.6)	(43.1)	-	-	-	-
Average contribution (Rs/ha)	50	50	50	50	50	50	50	50	-	-	-	
Total no. of farmers	123	44	6	173	90	112	44	246	57	124	69	250

Notes: Numbers within parentheses are percentages of the total number of farmers.
Source: Based on the primary survey.

Table 7. Participation in water management in different irrigation typologies.

Particulars	Tank-only				Tank-with-wells				Wells-only			
	Marginal	Small	Large	Total	Marginal	Small	Large	Total	Marginal	Small	Large	Total
No of farmers who participated	97	36	5	138	24	97	38	159	-	6	13	19
	(78.9)	(81.8)	(83.3)	(79.8)	(26.7)	(86.6)	(86.4)	(64.6)	-	(4.8)	(18.8)	(7.6)
Labor contribution												
No. of farmers	64	23	3	90	6	41	6	53	-	6	13	19
	(52.0)	(52.3)	(50.0)	(52.0)	(6.7)	(36.6)	(13.6)	(21.5)	-	(4.8)	(18.8)	(7.6)
Average no. of days	1.21	1.43	1.72	1.26	1.27	1.22	1.19	1.22				
Money contribution												
No. of farmers	33	13	2	48	18	56	32	106	-	-	-	-
	(26.8)	(29.5)	(33.3)	(27.7)	(20.0)	(50.0)	(72.7)	(43.1)	-	-	-	-
Average contribution (Rs/ha)	342.5	360	375	347.5	247	306.6.	343.7	311.6	-	-	-	-
Total no. of farmers	123	44	6	173	90	112	44	246	57	124	69	250

Notes: Numbers within parentheses are percentages of the total number of farmers.

Source: Based on the primary survey.

Scope of Converting Tanks into Percolation Tanks

Over the years, tanks have been converted into percolation tanks for the following reasons:

1. Conflicts in the distribution of tank water between the head- and tail-end farmers
2. Inadequate tank supplies due to poor tank storage.
3. A larger number of wells in the tank command area compared to the threshold level.
4. Interest of the farmers in growing annual crops which require water supplies throughout the year.

In the case of the three typologies, total production was comparatively high in the wells-only situation followed by the tank-and-wells situation, where the additional gross income and the net income were comparatively higher (Table 8). Water productivity was also higher in the wells-only situation followed by the tank-and-wells situation. Hence, conversion of tanks into percolation ponds was justified, even though farmers who did not have wells had to depend on the well owners for their irrigation needs. The additional cost of pumping with electricity was also higher in the wells-only situation. However, it was financially justifiable to invest in wells where possibilities for conversion of tanks existed due to the above-mentioned reasons.

Table 8. Total value of production with different typologies.

Typology	Total value of production	Total income	Additional income	Cost of cultivation	Net income	Additional net income
	Rs	Rs/ha	Rs/ha	Rs/ha	Rs/ha	Rs/ha
Tank-only	2,344,490	28,343	0	17,589	10,754	0
Tank-with-wells	13,049,154	71,406	43,063	38,719	32,687	21,933
Wells-only	2,656,928	106,582	78,238	57,505	49,076	38,322

The total income and cost of cultivation are computed using the weighted average of income and cost, respectively. The cost of irrigation was also included in the cost of cultivation. The average area per well was 2 ha in the wells-only situation, 10 ha in the tank-only situation, and 4 ha in the tank-and-wells situation (Tables 9, 10 and 11).

Table 9. Threshold level of wells in the wells-only situation.

Tank no.	Total no. of wells in ayacut	Ayacut area (ha)	No. of wells per ha	Area per well (ha)	Threshold level
1	25	60.00	0.42	1.6	Above optimum
2	21	51.77	0.41	1.52	Above optimum
3	24	43.60	0.55	0.89	Above optimum
4	22	23.20	0.95	0.56	Above optimum
5	200	208.80	0.96	0.5	Above optimum
6	22	48.40	0.45	0.91	Above optimum
7	26	46.80	0.56	0.97	Above optimum
8	32	59.15	0.54	1	Above optimum
9	2	8.00	0.25	4	Below optimum
10	4	10.00	0.40	2.5	Below optimum
Average			0.55		One well in 2 ha

Table 10. Threshold number of wells in the tank-only situation.

Tank no.	Total number of wells in ayacut	Ayacut area (ha)	Number of wells per ha	Area per well (ha)	Threshold level
1	8	46.18	0.17	6	Above optimum
2	4	146.65	0.03	42	Below optimum
3	6	47.05	0.13	8	Above optimum
4	4	29.86	0.13	7	Above optimum
5	4	42.00	0.10	11	Below optimum
6	4	24.00	0.17	6	Above optimum
7	6	66.00	0.09	11	Below optimum
8	7	518.32	0.01	74	Below optimum
Average			0.10		One well in 10 ha

Table 11. Threshold level of wells in the tank-and-wells situation.

Tank no.	Total no. of wells in ayacut	Ayacut area (ha)	No. of wells per ha	Area per well (ha)	Threshold level
1	15	131.23	0.11	9	Below optimum
2	15	36.13	0.42	2	Above optimum
3	45	115.33	0.39	3	Above optimum
4	38	414.5	0.09	11	Below optimum
5	70	744.48	0.09	11	Below optimum
6	45	343.22	0.13	8	Below optimum
7	52	260.44	0.20	5	Below optimum
8	32	447.56	0.07	14	Below optimum
9	20	26.4	0.76	1	Above optimum
10	15	48.58	0.31	3	Above optimum
11	35	222.51	0.16	6	Below optimum
12	20	43.29	0.46	2	Above optimum
Average	33.5		0.27		One well in 4 ha

Groundwater Use in Tank Irrigation

Water purchase, sales and its price show the scarcity and the details could explain the nature of water sales and the extent of water scarcity in the study region (Table 13). Out of the total number of farmers selected for the study, 26 and 27 farmers were water buyers in the tank-with-wells and the wells-only situations, respectively. Among the water buyers, marginal, small and large farmers and the price paid per pumping hour are shown in Table 12.

Table 12. Details of water buyers in the tank-with-wells and the wells-only typologies.

Particulars	Tank-with-wells		Wells-only	
	No. of farmers purchasing water	Price Rs/hr	No. of farmers purchasing water	Price Rs/hr
Marginal farmers	3	10	0	-
Small farmers	20	16.81	13	23.26
Large farmers	3	35	14	29.7
Total	26		27	

Price per pumping hour differs with locations of the wells, their depths and the monopolistic behavior of the well owner. It ranged from Rs 10 per pumping hour to Rs 50 in the study area. The majority of the large farmers owned wells. A few of them did not own wells. As they were large farmers, the well owners would fix a higher rate for them and also due to the location of lands, the farmers paid a higher rate for a pumping hour in the study area.

Yield and Input Use

Paddy was the main crop in the tank-only and the tank-with-wells situations but paddy was not cultivated in the wells-only situation. Paddy performs better in the tank-with-wells situation compared to the tank-only situation (Table 13). Input use is also less when compared to the tank-only situation except in the case of farmyard manure.

Farmers cultivated sugarcane in the tank-with-wells and the wells-only situations. The yield of sugarcane was nearly 8.6 tons/ha higher in the wells-only situation compared to the tank-with-wells situation (Table 14). Except for human and machine labor other inputs were used more in the tank-with-wells situation compared to the wells-only situation. The higher yield in the wells-only situation may be due to more frequent usage of human and machine labor besides better water control.

Table 13. Yield and input use in different typologies – paddy crop.

Typology	Yield	Input use						
		Seed	NPK	Human labor	Machine labor	*Water	Chemicals	Farm manure
	kg/ha	kg/ha	kg/ha	man-days /ha	hours/ha	m^3/ha	No. of sprays	(tons/ha)
Tank-only	4,899	94.90	293.35	71.00	11.35	9,469	2.00	3.00
Tank-with-wells	5,063	85.38	289.13	65.69	9.94	7,956	1.39	3.50
Wells-only	-	-	-	-	-	-	-	-

*Water used excluding rainfall is given. The average rainfall received during the crop season was about 645 mm.

Table 14. Yield and input use in different typologies – sugarcane crop.

Typology	Yield	Input use					
		Seed	NPK	Human labor	Machine labor	Water	Farm manure
	kg/ha	kg/ha	kg/ha	man-days/ha	hours/ha	m^3/ha	tons/ha
Tank-only	96,635	74,868	370	120.1	6.0	9,294	8.2
Tank-with-wells	105,475	71,775	337	196.4	9.9	7,613	6
Wells-only	96,635	74,868	370	120.1	6.0	9,294	8.2

In the tank-with-wells situation, 27 households depended only on tanks as the sole source of water supply. The supplemental irrigation along with other inputs contributed to the yield (Table 15). Farmers in the study area used up to eight supplemental irrigations. The yield was continuously increasing with the number of irrigations with increased use of human labor and NPK fertilizer. As the other inputs did not change much with the increase in the number of supplemental irrigations, the other input quantities are not displayed in Table 15. Further, the increase in yield was more when the number of supplemental irrigations was two. It reveals that at least two supplemental well-irrigations appear to be important for the rice crop since irrigation generally occurs during the reproductive stage of the rice crop. Water stress at this stage has a tremendous adverse effect on yield. The yield increase was more than 956 kg/ha for the second supplemental irrigation. The application of NPK fertilizer moved up to four supplemental irrigations and then it declined. Use of human labor was increasing or was stable with the use of supplemental irrigation.

Table 15. Change in yield and input use with change in supplemental irrigation – paddy crop.

Number of supplemental irrigations	Yield (kg/ha)	NPK fertilizer (kg/ha)	Human labor (man-days/ha)
0	4,970	234	59
1	5,277	271	62
2	5,926	286	68
3	5,674	299	72
4	5,383	300	73
5	5,294	274	75
6	5,087	264	74
8	5,056	258	76

Cost of Pumping

The annualized cost of wells was computed to find out the average cost of irrigation in the tank-with-wells and the wells-only situations. The cost of irrigation depended on the type of well (dug well, dug-cum-bore well, tube well), current status of the well, year of construction, average age or life of the well and the discount rate. The cost of the electric motor and the annual repair charges were also included for the computation of annualized cost of irrigation.

Cost Calculation

Capital cost = Rs C

$Capital\ recovery\ factor\ (CRF) = \frac{i(1+i)^n}{(1+i)^n - 1}$, where, *n* is the life of the well in years and i is the bank interest rate.

Annualized cost (A)= Rs C * CRF

Other costs (Repair + labor cost) = Rs OC

Total cost = Rs. A+OC

This calculation was done separately for tank-with-wells and wells-only situations. The average annualized cost of wells was higher in the wells-only situation than in the tank-with-wells situation (Table 16). Though the annual pumping hours was higher in the wells-only situation the average cost of pumping was also higher than in the tank-with-wells situation. This may be due to the greater depth of the water table in the wells-only situation, where most of the farmers have bore wells, dug-cum-bore wells and tube wells. The water table is very deep and the cost of construction is also high.

Table 16. Annualized cost and average cost of pumping hours in different typologies.

Typology	Average annualized cost	Average annual pumping hours[1]	Average cost/ pumping hour	Average price/ irrigation/ha[2]
Tank-with-wells	14,117	1,116	12.65	215.05
Wells-only	23,261	1,378	16.88	320.72

[1] The number of pumping hours was calculated from the survey data. During the survey, data on the pumping hours per day, hours of pumping per irrigation, and frequency of irrigation in a week were collected from the farmers. Based on these items of information the number of month-wise pumping hours was calculated from January to December, 2006/07 cropping year.

[2] For the sugarcane crop it takes about 17 hours to irrigate 1 ha in the tank-with-wells situation and 19 hours in the wells-only situation in the study area. The average cost per pumping was multiplied by the time taken to irrigate per ha of crop thus arriving at the average price per irrigation per ha.

Partial Budget

The partial budget is used to work out costs and returns of making relatively small changes in the existing farm practices. It is aimed at answering the question relating to financial losses and gains due to the proposed changes in the agricultural enterprise. The partial budget was worked out with the aim of comparing the financial gains and losses by cultivating paddy and sugarcane crops in the place of paddy only. In normal practice, a farmer in the tank-with-wells situation having 2 ha land preferred to cultivate 1 ha of paddy and 1 ha of sugarcane. The same farmer in the tank-only situation cultivated only paddy for 2 ha (Table 17).

Net change in income due to the cultivation of paddy and sugarcane in 1 ha each was Rs 11,624, over the cultivation of paddy in 2 ha in the tank-only situation. This is why farmers prefer to have sugarcane whenever they have access to well irrigation in the tank system. The rate of return for this change will be about 27%.

Table 18. Partial budget for cultivating 1 ha paddy and 1 ha sugarcane instead of cultivating 2 ha paddy

		Debit (A)		Credit (B)
I	*Added cost*		*Added return*	
i)	Seed	9,907	Gross income	54,252
ii)	Human labor	3,010		
iii)	Machine labor	10,640		
iv)	Manures and fertilizers	11,605		
v)	Irrigation	3,962		
vi)	Interest on working capital	3,503		
II	*Reduced return*	0	*Reduced cost*	0
		42,628		54,252

. Rate of return = (B-A)/A = 27.27%

Water Market

Optimum Use of Wells

When the source of irrigation is the tank-with-wells, it is important to find out the possibilities of digging more wells in the study area. Farmers with more than 2 ha of land, who are about 15% of the total number of farmers in the tank command area, have wells in the study area. As there are only a few well owners, they act like monopolists. Each well owner may be the only supplier of groundwater, at least for the group of farmers located around the well. Since the number of wells is limited in most tanks, monopolistic behavior is quite common. Well interference during pumping and recharge rates are reflected in water availability and price. Well owners maximize their profits with respect to the water supplies available and the likely demands. They cannot set the price and quantity independently since the price is determined by the supply and demand for water. Reduction in pumping (up to a certain level) can increase the water price resulting in a higher profit. However, the marginal cost of pumping is very low (as electricity is free of charge) and it only pays to reduce pumping in the range where demand is inelastic.

For different levels of water prices and varying pumping hours in the study area, it is important to know at what level of pumping and water price (Pp) well owners maximize their profit. Using the fitted inverse demand, and output and average cost (AC) functions, and solving the equations for well yield (WY).[1]

[1]Gives the profit equation,

$$\Pi = (Pp * Qp) - (AC * Qp) - FC$$
$$= g(Qp) . Qp - h(Qp).Qp - FC$$

$d\Pi/dQp = g'.Qp + g - h'.Qp - h = 0$, and by substituting Qp in the equation, the value of WY can be obtained, where Π = profit, Pp = price of pump water, Qp = quantity available for pumping, AC = average cost of pump water, and FC = fixed cost.

Inverse demand function: Pp = 36.47 – 2.77 Qp**
(1.622) (0.27)

Output function: Qp = - 0.237 +1.19 WY**
(.784) (.177)

Cost function: AC = 11.001* – 0.491 Qp**
(0.49) (0.063)

**, * significant at 1% and 5% levels, respectively. Values in brackets are standard errors; the profit maximizing levels of WY and Qp are 5 meters and 5.59 hours, respectively.

Well owners maximize profits from water sales when the water level is about 5 meters and this corresponds to about 5.6 hours of pumping per day from the well. Under these conditions, output of well water can best be increased by having farmers install more wells and with increased competition. With more wells, the demand for water from each individual well will fall, resulting in a lower price for well water. According to a detailed survey, the number of wells can be increased in many tank command areas by 25% over the existing number (Palanisami and Flinn 1988).

Considering the following assumptions the number of wells that can be dug in the study area was assessed using the block-level data. Sample tanks with source of well-water supply for irrigation fall under three blocks in Sivagangai and Madurai districts. Block-level data from Thirupuvanam and Sivagangai blocks in the Sivagangai District were used to explore the possibilities of digging more wells in that particular block where tanks-with-wells are the major source of irrigation.

The assumptions for the above estimation of groundwater recharge are:

1. 10% of the annual rainfall in the total geographical area contributes to groundwater recharge.
2. 50% of the total command area was considered as the water-spread area (Palanisami and Easter 2000).
3. About 550 mm of water percolate from the total command area and the water-spread area.
4. About 30% of the recharge is considered as losses.

The number of wells that can be dug in these two blocks is given in Table 18.

Table 18. Groundwater recharge and additional wells.

Blocks	Thirupuvanam	Sivagangai
Total geographical area (ha)	32,073	44,660
Average annual rainfall (mm)	905	905
10% goes for recharge (ha. cm)	290,164	404,039
Total command area (ha)	13,600	4,562
Water-spread area (ha)	6,800	2,281
Total (ha)	20,400	6,843
Infiltration (ha.cm)	1,122,005	376,391
Total recharge (ha.cm)	1,412,170	780,430
Net recharge (ha.cm)	988,519	546,301
Current extraction (ha.cm)	640,093	304,166
Balance available (ha.cm)	348,426	242,135
Average annual pumping hours	1,116	1,016
Number of wells to be installed	312	238

Stabilization Value of Groundwater in Tank Irrigation Systems

Tanks serve the purposes of irrigation and enriching the water table through percolation. The function of tanks is extremely useful in maintaining the water table to ensure sustained growth of flora and fauna in the region. In recent years, due to poorly maintained structures (bunds, surplus weirs), siltation of tank beds and disintegrated channels and weirs most of the tanks are in a bad state (Palanisami and Easter 2000).

Supplies of tank water fluctuate randomly from year to year and within a year. Using 40 years' rainfall data, it was estimated that out of 10 years tanks will be experiencing deficient supply in 5 years; will fail in 3 years; and in will have full supply in 2 years (Palanisami et al. 1997). The poor performance of the tanks has resulted in heavy dependence on groundwater supplementation. Groundwater stocks, on the other hand, are relatively stable because the wells get recharged from both tanks and irrigated rice fields (Palanisami and Easter 2000).

Normally the number of supplemental irrigations required by the farmers could not be met as only about 15% of the farmers owned wells in the tanks (Palanisami and Flinn 1989). Most of the farmers in the tank irrigated areas are marginal farmers each having less than a hectare and it is expensive for them to invest in wells to meet the supplemental water requirements. It is argued that the government can invest in community wells or encourage the farmers to invest in their private wells so that all the farmers in the tank systems can share the tank and well water. This is possible only when the value attributed to the groundwater, i.e., stabilization value of groundwater, is attractive. The justification for increasing the number of wells in the tank systems is based on the stabilization value of groundwater supplementation.

Stabilization Value of Groundwater

The concept of "stabilization value of groundwater' was introduced by Tsur (1997). Unless the value of groundwater supplementation is attractive at the system level, subsequent investment in new wells by the farmers or the government agencies cannot be justified. Hence, it is important to study the value of groundwater at the tank level. As such, groundwater supplementation reduces the variability associated with tank water, since in most of the years tank storage is below normal. In the periods with below-normal tank supply, if groundwater is not supplemented the crop yield will be drastically reduced or the crop will fail completely. The variable reducing value of the groundwater carries an economic value, which is designated as the stabilization value of groundwater. The stabilization value is largely relative to the overall value of groundwater (Ranganathan and Palanisami 2004). Given the erratic tank-filling behavior over the years, groundwater supplementation is highly warranted. However, at the individual farm level, it is easy to appreciate the value of groundwater through additional increases in the rice yield, which also varies between farms and tanks depending on the level of groundwater supplementation.

Cross-sectional data related to the selected tanks with the source of irrigation of tank-with-wells in Sivagangai and Madurai districts of Tamil Nadu state were used to estimate the stabilization value of groundwater in the tanks. These tanks are located in a homogenous region, and inter-tank differences in terms of rainfall, storage pattern, filling pattern and irrigation pattern were observed to be the same.

In the tank-with-wells situation, farmers grow more than one crop. The choice of crop is also not restricted to paddy alone. Field-level data regarding the water usage relating to various crops were used to estimate the total water usage of each crop in the particular region. For each crop, various levels of water and corresponding yields were used in the analysis of the production function. The cost of surface water was calculated, based on the prevailing water charges fixed by the government for different crops in the region. With respect to the cost of groundwater, annualized cost of wells was arrived at using an 8% discount rate and 20 years' life of the well, and using the total hours of pumping, the unit cost of groundwater pumped was worked out. Finally, the total water use at the tank level was arrived at by summing up the water use by different crops. The water losses were also accounted in the computation. Normally, under the tank system, 38% of water is lost in seepage and percolation from both the canals and the fields (Government of Tamil Nadu 1996).

Estimation of Demand Curve for Water

A quadratic production function was employed to estimate the crop responses to water.

$Y_i = a + bX_i + cX_i^2$

where,

Y_i = Yield in kg per ha to crop i (i = 1 to 5) and

X_i = Water applied in cm per ha to crop i

Particulars of yield (Y) were gathered from the farmers. Quantity of water applied (X) was quantified using the formula Q = Discharge rate × hours of irrigation × number of irrigation for well irrigation; Q= Area of planting × depth of irrigation × number of irrigations The total quantity of water was calculated by adding the quantity of water from both tank and well irrigations using this value as X.

Using the results of the quadratic production function for various crops, the value of marginal products (VMP) was derived for each crop (Table 19). The VMP and water requirements of the different crops are presented in Table 20.

Table 19. Quadratic functions for different crops and the VMP.

Crop	Fitted quadratic function	Marginal product (kg)	P_y (Rs/kg)	VMP (Rs)
Paddy	Y= 2227.58 -48.49 X +.579 X^2 (R^2 = 73%)	42.75	7.44	318.00
Sugarcane	Y= -141312 + 2092.7 X +5.86 X^2 (R^2 = 94%)	444.00	1.00	444.00
Coconut	Y= - 5761.65 +133.61X + .365 X^2 (R^2 = 85%)	187.79	2.86	537.00
Banana	Y= 20788.49 -529.65 X +3.783 X^2 (R^2 = 93%)	258.50	7.22	1,866.37
Cotton	Y= 1277.668 - 88.5 X + 2.75 X^2 (R^2 = 73%)	43.45	27.60	1,199.00

Table 20. Value of marginal product (VMP) and total water used for different crops.

Crops	VMP (Rs)	Total water used (ha.cm)
Banana	1,866	1,154
Cotton	1,199	2,382
Coconut	536	23,725
Sugarcane	444	93,092
Paddy	318	214,311

The amount of total water used was arrived at in a cumulative manner taking the mid-point values in the histogram. This value of marginal product of each crop and its total water requirement were plotted in the histogram. By arranging the crops in descending order of the value of marginal value of the irrigation water, an approximate value of marginal productivity curve for irrigation water was obtained. Then using these data, an exponential form of the demand curve for water was derived (Figure 1).

$$\pi(s) = \int_{o}^{s} Y dw - p_s s$$

$$= \int_{o}^{s} a e^{-kw} dw - p_s s$$

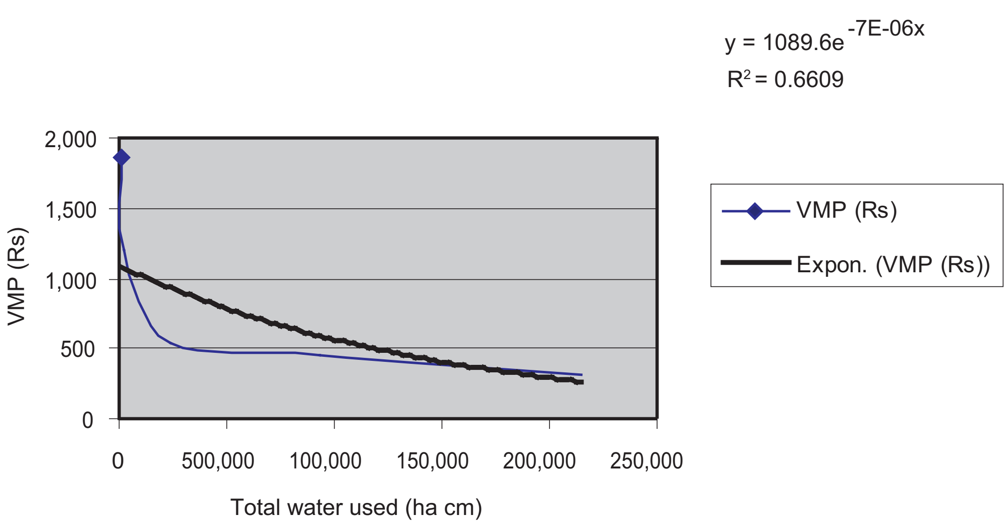
$$= \frac{a}{k}(1 - e^{-ks}) - p_s s$$

Similarly,

$$\pi(s+g) = \frac{a}{k}\left(1 - e^{-k(s+g)}\right) - p_s s - p_g g$$

where, π = profit in Rs, s=surface water quantity in ha.cm, g=groundwater quantity in ha.cm, p_s=price of surface water in Rs/ha.cm, p_g=price of groundwater in Rs/ha.cm and a, k=coefficients estimated from the model.

Figure 1. Demand curve for water.



For each tank the values of groundwater and surface water were calculated as follows. Let S_t t = 1,2 3,……..12 denote the surface water realization for 12 tanks. Let g_t be the groundwater demand in each tank associated with S_t and $\Pi\ (S_t+g_t)$ be the corresponding profit. The value of the groundwater when surface water supply was S_t equals $\Pi\ (S_t+g_t)$ - $\Pi\ S_t$. The average was calculated by the following formula (Tsur 1997).

$$(1/12)\sum_{i=1}^{i=12} [\ \Pi\ (S_t+ g_t) - \Pi\ (S_t)]$$

The profit with groundwater minus the profit without groundwater gives the value of groundwater had surface water been stable at the mean level. The difference between the groundwater value and the groundwater value at mean level gives the stabilization value. The results are presented in Table 21.

Table 21. Profit and stabilization value of groundwater.

Tanks	Surface water (S) (ha.cm)	Groundwater (G) (ha.cm)	Profit (S) (Rs)	Profit (S+G) (Rs)	Profit ([S+G[-S) (Rs)
1	24,315	10,922	24,312,839	32,884,588	8,571,748
2	14,497	11,626	14,991,739	24,821,396	9,829,656
3	12,828	3,582	13,342,897	16,508,258	3,165,361
4	7,131	7,401	7,565,185	14,301,039	6,735,854
5	8,018	9,812	8,480,203	17,267,300	8,787,096
6	14,974	10,922	15,459,675	24,684,432	9,224,756
7	4,342	4,039	4,651,560	8,456,842	3,805,282
8	1,440	774	1,557,875	2,313,442	755,567
9	799	981	866,743	1,828,132	961,389
10	1,562	836	1,689,571	2,504,242	814,672
11	1,488	1,334	1,609,667	2,907,942	1,298,275
12	1,406	386	1,521,824	1,899,369	377,546
Average	7,733	5,218	8,004,148	12,531,415	4,527,267
Profit at average S	7,733	5,218	8,186,828	12,531,415	4,344,586.762
Stabilization value of groundwater (Rs)					82,680.3
Proportion of stabilization value to total value of groundwater (%)					4.04

The average value of the groundwater equals Rs 4,527,267. The profit, assuming that the surface water supply was stable at the mean level (7,733 ha.cm), equals Rs 4,344,587. The difference between these two rows is Rs 182,680 which is the stabilization value of groundwater. This was the value of groundwater due to its role in stabilizing the supply of irrigation water (disregarding its role in increasing average supply of irrigation water). The stabilization value of groundwater accounted for 4% of the total value of groundwater assuming that surface water supplies were stable at the mean level and would bias assessments of groundwater benefits downward by 4%.

Production Efficiency of the Farmers in Different Typologies

Normally, when endowed with adequate resources, farmers use inputs in excess, expecting to reap higher yields. The excessive cost thereby included in the production process could not only bring down their profit but waste the scarce resources. Subsidized agricultural inputs could stimulate extensive use of other inputs. For instance, if irrigation water is available in plenty and at subsidized rates, where water charges are minimal, farmers are tempted to use the other resources like fertilizer, labor, etc., indiscriminately to get higher yields. However, not all the farmers are irrational in their input use. Hence, it is necessary to study the efficiency of the crops produced by the farmers, which will help address the issues of yield gap, etc.

Technical, Allocative and Economic Efficiencies of Farmers

Production efficiency has two components: technical and allocative. Technical efficiency (TE) is the extent to which the maximum possible output is achieved from a given combination of inputs. On the other hand, a producer is said to be allocatively efficient (AE) if production occurs in a subset of the economic region of the production possibilities that satisfy the producer's behavioral objective.

Technical efficiency is the ability to produce a given level of output with a minimum quantity of inputs under a certain technology. Allocative efficiency refers to the ability of choosing optimal input levels for given factor prices. Overall productive efficiency or economic efficiency (EE) is the product of technical and allocative efficiency. Thus, if a farm has achieved both technically efficient and allcatively efficient levels of production, then it is economically efficient and new investment streams may be critical for any new development

Average, minimum and maximum technical, allocative and economic efficiencies of the farms in the study area are presented in Table 22. As there is no single crop cultivated in all three typological situations, the farmers cultivating paddy in the tank-only and the tank-with-wells situations and the farmers cultivating sugarcane in the tank-with-wells and the wells-only situations were used for estimation purpose. The TE of all four groups of farmers such as farmers cultivating paddy in the tank-only situation and the tank-with-wells situation and farmers cultivating sugarcane in the tank-with-wells and the wells-only situations is higher than the AE and EE. The paddy farmers in the tank-with-wells situation are technically more efficient than the paddy farmers in the tank-only situation. Likewise, sugarcane farmers, in the wells-only situation are technically more efficient than those in the tank-with-wells situation.

The results indicate that the TE indices range from 40 to 95% for the paddy farms in the tank-only situation with an average of 82% (Table 22). This means that if the average farmer in the sample is to achieve the TE level of his most efficient counterpart, then the average farmer could realize 14% cost savings (i.e., 1-[82/95]). A similar calculation for the most technically inefficient farmers reveals cost savings of 58% (i.e., 1-[40/95]). The mean AE of the sample is 61%, with a low of 45% and a high of 83%. The combined effect of technical and allocative factors shows that the average EE level for this sample is 51% with a low of 21% and a high of 73%. These values indicate that if the average farmer in the sample is to reach the EE level of his most efficient counterpart, then the average farmer could experience a cost saving of 30% (i.e., 1-[51/73]). The same computation for the most economically inefficient farmer suggests a gain in EE of 71% (i.e., 1-[21/73]).

Table 22. Mean, minimum and maximum technical, allocative and economic efficiencies of paddy and sugarcane farms in different typologies.

	Paddy		Sugarcane	
	Tank-only	Tank-with-wells	Tank-with-wells	Wells-only
TE				
Mean	82	85	92	93
Minimum	40	59	72	85
Maximum	95	97	98	96
AE				
Mean	61	74	76	50
Minimum	45	66	56	32
Maximum	83	89	81	96
EE				
Mean	51	63	70	47
Minimum	21	45	52	29
Maximum	73	82	77	92

In the tank-with-wells situation, the EE ranges from 59% to 97% with the average of 85% for paddy farms. This means that if the average farmer in the sample is to achieve the TE level of its most efficient counterpart, then the average farmer could realize 12% cost savings (i.e., 1-[85/97]) and the same computation for the most technically inefficient farmer reveals cost savings of 39% (i.e., 1-[59/97]). The mean AE of the sample is 74%, with a low of 66% and a high of 89%. The mean EE is 63% with a low of 45% and a high of 82%. If the average farmer in the sample is to reach the EE level of its most efficient counterpart, then the average farmer could experience cost savings of 23% (i.e., 1-[63/82]) and the same computation for the most economically inefficient farmer suggests a gain of 45% (i.e., 1-[45/82]).

In sugarcane farms under the tank-with-wells situation the TE ranges from 72 to 98% with the average of 92%. This means that if the average farmer in the sample is to achieve the TE level of his most efficient counterpart, then the average farmer could realize 6% cost savings (i.e., 1-[92/98]) and the same computation for the most technically inefficient farmer reveals cost savings of 27% (i.e., 1-[72/98]). The mean allocative efficiency of the sample is 76%, with a low of 56% and a high of 81%. The mean EE is 70% with a low of 52% and a high of 77%. If the average farmer in the sample is to reach the EE level of his most efficient counterpart, then the average farmer could experience cost savings of 9% (i.e., 1-[70/77]) and the same computation for the most economically inefficient farmer suggests a gain of 32% (i.e., 1-[52/77]).

In sugarcane farms under the wells-only situation the TE ranges from 85% to 96% with the average of 93%. If the average farmer in the sample is to achieve the TE level of his most efficient counterpart, then the average farmer can realize 3% cost savings (i.e. 1- [93/96]) and the same computation for the most technically inefficient farmer reveals cost savings of 11% (i.e., 1-[85/96]). The mean AE of the sample is 50%, with a low of 32% and a high of 96%. The mean EE is 47% with a low of 29% and a high of 92%. If the average farmer in the sample is to reach the EE level of his most efficient counterpart, then the average farmer can experience cost savings of 49% (i.e., 1-[47/92]) and the same computation for the most economically inefficient farmer suggests a gain of 68% (i.e., 1-[29/92]).

The mean AE of farms in the wells-only situation is low compared to the tank-with-wells situation. Though the water supply is assured, the cost of inputs is very high when compared to other situations. The average wage rate of labor in the wells-only situation is Rs 175/day and the same costs Rs 85/day in the tank-with-wells situation. This affects the allocative efficiency in the wells-only situation. As the EE is the combined effect of TE and AE, the mean EE of the wells-only situation is only 47%.

Tank Management and Modernization

The critical factor in conjunctive water use will be managing the release of tank water over the season depending on rainfall and groundwater supplies. Ideally, a water user association (WUA) working with a technical advisory group from the State Government would decide on a strategy for water releases for the crop season. In some years, it may mean a continuous flow because of abundant supplies while in others it may mean keeping the sluices closed throughout the season and using the tank in the tank-only situation to recharge the groundwater.

The best way to induce changes in collective tank management may be to combine management changes with modernization activities. Such activities could include sluice modification or repair, additional wells, limited canal lining, partial tank desilting, improved maintenance or catchment management, such as providing feeder channels or contour bunds. These physical improvements alone, or in combination with management improvements, such as sluice management or the rotation of deliveries, generated substantial returns, although the B/C ratios were less than 2.0 (Table 23).

Table 23. Benefit/Cost (B/C) ratios and internal rates of return (IRR) for different tank improvement strategies, Tamil Nadu.

	Project life (years)	B/C ratio	IRR (%)
Additional wells	10	1.4	26
Canal lining + additional wells	8	1.2	21
Sluice management + additional wells + canal lining	15	1.4	25

Although, on average, tanks have lost 20% of their capacity due to accumulation of silt, removal of silt is expensive unless farmers want the silt for use on their farms.[2] The cost of partial desilting, including excavation and transport, is about Rs 15/m^3 (Table 24). Such expenditures may offer economic returns if the silt is removed in key places such as those adjacent to the sluices.

[2]Quantity of the silt is the difference between original and actual tank storage capacities using the formula C = a1+a2+(a1*a2)1/2H, where C=total storage capacity in cu.m; a1, a2=areas under contours (in m^2); H=difference between contours in m.

Table 24. Cost of partial desilting of tanks.

Type	%	Cost (Rs/m^3)
Excavation		
Manual	25	30.50
Mechanical excavator	75	17.00
Transport[1]		
Manual	5	25.00
Mechanical excavator	95	19.00

[1] Only about 15% of the silt removed needs transport around the tank water-spread area.

Strategies involving maintenance of newly rehabilitated structures may be needed. Without maintenance, these tanks will deteriorate rapidly and the rehabilitation investments will be lost. A separate maintenance provision could be included in the budget for the rehabilitated structures. Another, even better, alternative would be to require that farmer associations agree to take over the responsibility for maintenance before the structures are rehabilitated. Alternatively, the government could establish a separate budget allotment for maintenance of rehabilitated structures, which would be funded by increased water charges on the rehabilitated tanks.

However, improved water management may also require institutional changes before they become fully effective. In many cases, farmer associations will need to be formed and take over the responsibility for O&M of the tanks (government turnover of tanks to farmers). The government could establish a tank management authority to provide farmers with technical assistance for improving their tank management. It is also possible to transfer PWD tanks to the panchayat unions if the latter tanks perform better in terms of resource mobilization, water distribution, and overall tank management. Since each tank has its own management issues, the appropriate management strategies should be identified after studying each existing tank.

Selecting the Appropriate Management Strategy

It is important to identify tank management strategies in association with groundwater supplementation. In deciding on the rules for managing sluice gate operations it will be important to involve all groups served by the tank. Not all water users will be affected in the same way. In fact, some may lose while others benefit. The primary groups likely to be affected by tank management changes include: well owners, non-well owners, encroachers (legal and illegal), watermen, fisherman and local panchayats (Table 25).

Table 25. Distribution of possible benefits from tank management changes.

Actors	Level of benefits
Well owners	High
Non-well owners	Medium
Legal-encroachers	None (loss)
Illegal-encroachers	None (loss)
Watermen	Low
Fishermen	Medium
Panchayat	Medium
WUAS	High

The largest beneficiary may be the well owner in the command. Since only comparatively well-off farmers could invest in wells, the management changes may tend to benefit higher-income farmers the most. However, these well owners normally sell the well water to other farmers during the later part of the rice crop season. It is highly likely that these well owners will continue to sell well water to the non-well owners. Since electricity is free to farmers, the well owners will be encouraged to sell the water at a comparatively low price. To make sure that the management change works, it is important to have a detailed dialogue between the well owners and the non-well owners. The local panchayat or WUA could play a role in arriving at an agreeable solution. The WUA will benefit from the changes and dialogue, since there would be fewer conflicts to be resolved to improve water distribution.

There are both legal and illegal encroachers in the tank beds or foreshore areas. The legal encroachers are those who have obtained legal rights to cultivate these foreshore lands when these areas are not submerging. However, there are illegal encroachers, who cultivate the foreshore areas by paying a penalty. Since tanks will likely have standing water for a longer period under the new management strategy, the encroachers may not be able to cultivate in most years. The local panchayat and WUA will need to prevent the encroachers from illegally opening the sluice gates to lower the water level in the tank. Watermen and fishermen in the tanks have comparatively minor roles in most tanks and the new management strategy may not affect them much. Fishermen who have fishing rights may benefit since the tanks will have storage for a longer time. In the case of watermen, they could be given the responsibility to carry out the new management rules.

However, there are also cost considerations. There will be additional electricity consumption due to extra pumping by the well owners, because they will need to pump for the neighboring non-well owners. Since electricity is free to farmers, it will add an extra burden to the state electricity boards. Currently, the Village Administrative Officer (VAO) at the village level is collecting the water charges, cess, and surcharges from the tank-beneficiary farmers. The tank water charges go to the Revenue Department and the cess and surcharges are used by the panchayat for village improvements.

The most domestic management change would be to close the sluices permanently and use the tank as a percolation pond. In several locations, where well intensity is quite high and over 50% of the tank storage capacity has been lost, this might be a good strategy. In fact, this was effected in several cases in Andhra Pradesh.

Conclusions and Recommendations

Due to increasing scarcity of tank water, the demand for supplemental irrigations is increasing. However, the majority of farmers are not operating at the economic optimum level of well water use. This is due to the inadequate number of wells in the command area, as well as the limited water availability in existing wells, particularly during December and January. In many locations, groundwater levels declined by about 1-2 meters in the 1970s and by an additional 2-4 meters in the 1980s. Under constraints of poor recharge from rains, wells depend heavily on tank water supplies for recharge.

Well owners maximize profits from water sales when the water level in the well is about 4 meters. Under these conditions, output of well water can best be increased by having farmers install more wells and increase the competition where well density is less than one well per 10 ha, With more wells, the demand for water from each individual well will fall, resulting in a lower price in well water. Still priority should be given to both the tank and well management for efficient conjunctive use of tank and well water.

This can be achieved by a series of actions that will increase the availability of tank and well water. First, physical and management measures can be taken to improve the runoff from catchment areas. Second, physical and management activities can be used to improve the effective supply of water delivered from the tank. Third, in areas with less than one well per 10 ha, government incentives can be used to promote the development of wells. Fourth, WUAs should be supported and encouraged to coordinate the use of tank and well water supplies. Last, where tanks have lost more than 50% of their storage capacity, and there is a high concentration of wells, it may be best to use the tanks as percolation tanks.

Recommended Strategies for Sustaining Tank Irrigation

1. Since groundwater supplementation is an integral part of the tank system, it is important to maintain the number of wells at the threshold level (i.e, one well per 2 ha in the wells-only situation, one well per 4 ha in the tank-with-wells situation and one well per 10 ha in the tank-only situation). This means the WUA should be encouraged to maintain tank management in such a way that the digging of additional wells above the threshold level is discouraged.

2. In situations where tanks cannot have adequate supply for crop cultivation, it is possible to convert them into percolations tanks, as the productivity and income are comparatively higher even after inclusion of the additional pumping costs due to such tank conversions. Hence, government can initiate a detailed survey on the tanks and can encourage the tank conversion into percolation tanks. This will thus help maximize crop production and income at both the tank and the farm level.

3. Since only about 15% of the farmers own wells in the command area, supplemental irrigation at the end of the crop season can be done through water markets. Hence, water markets should be encouraged at the tank level through coordination of well owners using both tank management and well recharge strategies. Efforts should be taken in such a way that all the tanks could provide at least two supplemental irrigations to the paddy crop. The tank and groundwater management should be conjunctively used to provide the required number of supplemental irrigation.

4. The optimum number of pumping as evidenced from the study should be maintained in all tanks which will have a positive impact on the water market and pricing of well water when overexploitation of groundwater will be minimized.
5. Given the budget constraints, tank rehabilitation or modernization should start with management options followed by physical investments as indicated by the higher internal rate of returns. The national and international agencies should give priority for tank rehabilitation and management based on the groundwater supplementation aspects.
6. Crop diversification towards non-rice crops such as pulses and oilseeds should be encouraged, as the tanks have less than 50% storage in most of the years which is insufficient for rice cultivation. Needed agricultural extension efforts with marketing facilities should be promoted at the tank level.

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