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Why should farmers invest in wells when irrigation tanks underperform? the evidence from South Indian tank commands

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Abstract Irrigation tanks are perceived to contribute significantly to irrigation, agricultural production, and environmental sustainability. Realizing the significance of this perception, this paper analyses why farmers should invest in wells when irrigation tanks underperform. If the availability of water in tanks is poor, tanks perform poorly, and water becomes scarce. Farmers respond by increasing the number of private wells. If farmers do not invest, they stand to forgo an income of INR 12,430–12,775 per hectare per year. Therefore, farmers should be helped to construct wells.

Keywords Rainfall variability, tank irrigation, adaptation strategies, well investment

JEL codes Q1, Q2, Q5

Seasonality and variability in rainfall have motivated many countries in Asia to build small, medium, and large water harvesting and storage structures for irrigation and other purposes. India has an extensive network of small water harvesting structures, called tanks, some dating back several centuries. In addition to medium and major irrigation projects, these tanks play a crucial role in irrigation. Tanks are concentrated mostly in three states in southern India—Andhra Pradesh, Karnataka, and Tamil Nadu—and these account for about 60% of the 2.0 million hectares of tank-irrigated area in the country (Palanisami, Meinzen-Dick, and Giordano 2010).

The area under tank irrigation in Tamil Nadu declined from 898,000 hectares (ha) in 1970–71 (34.64% of the total net irrigated area (NIA)) to 358,000 ha in 2017–18 (13.6% of the NIA). Tank water supplies fluctuate randomly from year to year and within a year. Using the rainfall data of 44 years from 1950 to 1993, Palanisami, Balasubramanian, and Ali (1997) estimate that tanks will have full supply in two out of ten years, experience deficient supply in five years, and fail in three years. In the years that rainfall is meagre, the tanks can store only a small volume of water, and the chain of tanks (except the first tank) receive little supply (Palanisami 2000). These phenomena are more pronounced in non-system tanks (rain-fed tanks, where rainfall is the only source of water) than in system tanks (tanks connected to perennial sources of water, such as canals, reservoirs, or rivers), and the area irrigated falls as a result. About 90% of the tanks in Tamil Nadu are non-system tanks, and the reduction in irrigated area is significant and a major issue. Tamil Nadu had 41,127 tanks in 2017–18 (Government of Tamil Nadu 2017–18).

The state governments of Tamil Nadu and Karnataka invested heavily in programmes to improve the irrigation potential by repairing existing tanks and constructing new ones. Financial assistance was provided by nongovernmental organizations (ADB 2006), the European Economic Community (now the European Union (EU)), National Bank for Agriculture and Rural Development (NABARD), and World Bank. Recently, the government of Tamil Nadu introduced the "Kudimaramathu" programme to renovate tanks and improve their performance. Despite these efforts, however, the tanks continue to perform poorly, water is not available in the tail regions, the yield of crops and the area under rice cultivation have fallen, the cropping patterns have changed, crops experience water stress at the critical stages of growth, and crops fail (Muruganantham and Krishnaveni 2015; Suresh Kumar, Balasubramanian, and Chinnadurai 2015). Farmers depend heavily on groundwater because the wells are recharged by both tanks and irrigated rice fields and the availability of groundwater is relatively stable (Palanisami and Easter 2000). At the tank level, groundwater supplementation reduces the variability associated with tank water, since tank storage is below normal in most years. Earlier studies (Palanisami, Balasubramanian, and Ali 1997; Palanisami and Easter 2000) report the returns to groundwater in tank systems and estimate the groundwater stabilization value (Ranganathan and Palanisami 2004; Palanisami et al. 2008).

Farmers have adapted by altering the cropping pattern, diversifying crops and livelihoods, migrating and taking up non-agricultural employment, increasing water storage and the height of tank bunds, constructing farm ponds, investing in wells, drilling borewells, and desilting tanks (Balasubramanian and Selvaraj 2003; Palanisami and Suresh Kumar 2004; Palanisami, Gemma, and Ranganathan 2008; IWMI 2009; Suresh Kumar, Balasubramanian, and Chinnadurai 2015; Venkat 2017). Farmers have resorted to supplemental well irrigation to avoid crop loss (Palanisami and Easter 1987; Palanisami and Easter 1991). Given the failure of the monsoons and the erratic tank-filling behaviour, groundwater supplementation is warranted, but most of the farmers in the command area are small and marginal, and they cannot afford to invest in wells. Unless the value of the groundwater supplementation is attractive, any subsequent investment in new wells—whether by farmers or government agencies—will be difficult to justify. Hence, it is important to study the viability of well investment in the command areas (Palanisami, Gemma, and Ranganathan 2008). This paper aims to study the farmers' response to the underperformance of irrigation tanks; examine the strategy of investing in wells to overcome the problem of underperforming irrigation tanks; and assess the cost of uncertainty associated with well investment when tanks underperform.

Study area

The state faces many challenges in the water sector. Water scarcity and droughts are severe in many regions. The demand for water from the agriculture, domestic, and industrial sectors is ever-increasing, and allocating water is difficult. The groundwater table has fallen dramatically. The storage capacity of the tank system in states like Tamil Nadu has fallen 30%. Conflicts between water-using groups are growing. In Tamil Nadu, Andhra Pradesh, and Karnataka, the traditional irrigation management institutions have failed, and the tanks and canals are poorly maintained and managed. Industrial pollution threatens the already scarce water supplies (Bhatia et al. 2006). The long-term analysis reveals that, over four decades, the irrigated area in Tamil Nadu increased slightly—from 2.59 million ha in 1970–71 to 2.63 million ha in 2017–18—but the sources of irrigation changed dramatically. In the 1970s, canals accounted for 34.09% of the total NIA, and tanks accounted for 34.64%, together contributing nearly 69%. In the 1980s, canals accounted for 34.59% of the NIA, and tanks 22.95%, together contributing nearly 59%. Well irrigation accounted for 29.89% of the NIA in 1970–71, and 41.52% in 1980–81, but after the 1980s wells became the dominant source of irrigation, accounting for 52.46% of the NIA in 2000–01 and 63.8% in 2017–18. In 2017–18, canals and tanks accounted for, respectively, 22.4% and 13.6% of the total NIA.

The study was conducted on two tanks: Pramanur, in the Sivagangai district of southern Tamil Nadu, and Thiruvampattu, in the Villupuram district of northern Tamil Nadu (Figure 1). Both tanks are managed and maintained by the Water Resources Department of the state government. Agriculture in these tank commands is dominated by marginal and small farmers. The major crops in the Pramanur tank are rice, cotton, sugarcane, and maize. Rice is grown using, mainly, tank water, supplemented by well water, and sugarcane is grown mainly with well water. Crops like cotton and maize are grown as rain-fed crops. In Thiruvampattu tank, the major crops are rice, sugarcane, and groundnut. Rice and sugarcane are grown under irrigated conditions. Groundnut is cultivated both under irrigated and unirrigated conditions. The two tanks differ in well density (the number of wells per hectare of command area) and inthe source of water supply. Pramanur is a

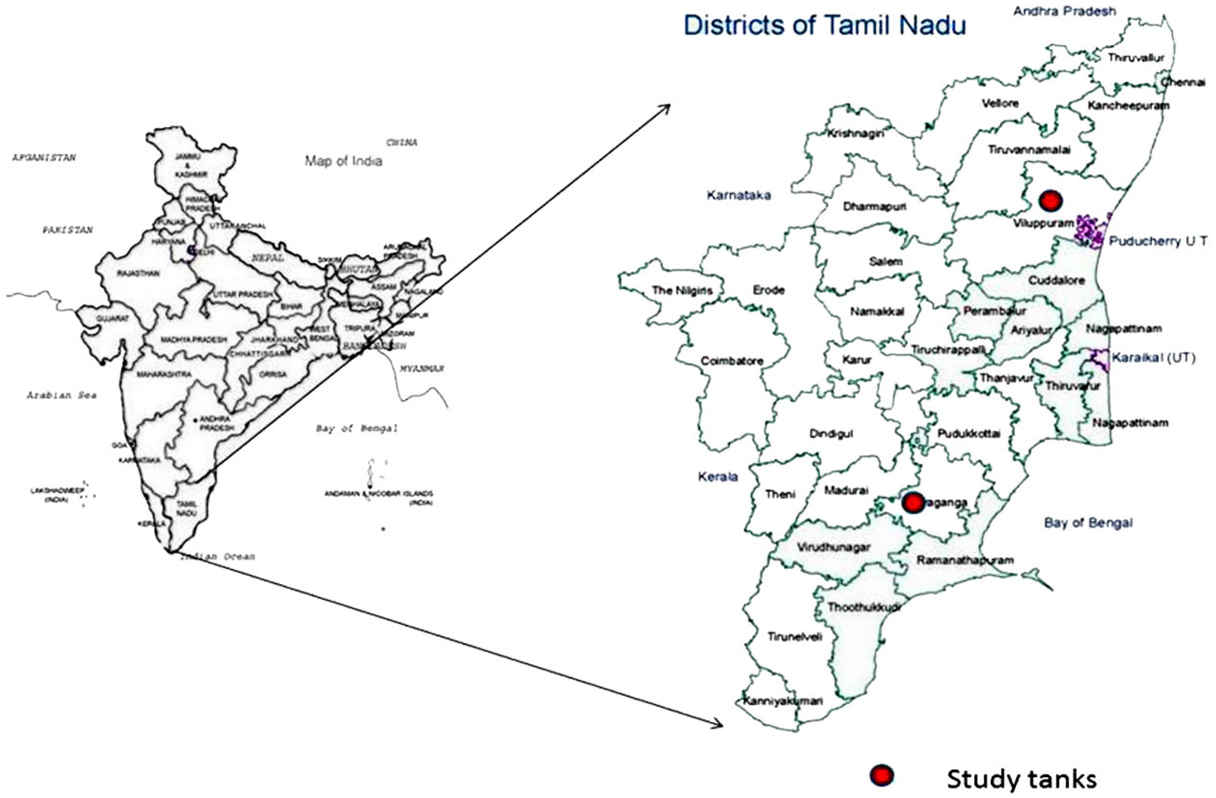

Figure 1. Map showing the location of study tanks

system tank connected to the Vaigai river; Thiruvampattu is a rain-fed tank. The well density is very low in Pramanur tank (0.13) and very high (0.38) in Thiruvampattu tank (Table 1).

Methodology

The farm household survey was conducted with a sample of 120 farmers selected randomly across the tank command area from each tank. Farmers were

Table 1 Profile of the study tanks

Particulars	Pramanur	Thiruvampattu
Registered command area (ha)	743.5	274
Number of wells in the command area	94	105
Well density (no of wells/ha)	0.13	0.38
Number of farmers		
Marginal (< 1 ha)	600 (59.4)	220 (44.4)
Small (1–2 ha)	200 (19.8)	150 (30.3)
Medium (2–4 ha)	120 (11.9)	75 (15.1)
Large (>4 ha)	90 (8.9)	50 (10.1)
Total	1,010 (100.0)	495 (100.0)
Average size of holding (ha)	1.02	0.68
Percentage of farmers own well	9.30	21.2
Major crops	Rice, cotton, sugarcane, and maize	Rice, sugarcane, groundnut

Source Water Resource Department (WRD), Government of Tamil Nadu, and Village Administrative Office of the concerned villages.

selected from the head, middle, and tail reaches of the tank command area. The household survey was conducted in 2015–16. Both secondary and primary information were collected from different sources. The secondary information includes time series data on rainfall, area irrigated by tanks, and the growth in the number of wells over the 43 years between 1970–71 and 2012–13. The secondary information was collected from several issues of the Season and Crop Report of Tamil Nadu, Department of Economics and Statistics, Government of Tamil Nadu. Tank-level information, such as hydrological information, area irrigated by tanks, cropping pattern, and the number of wells, was collected. The information was gathered personally by administering the interview schedule. The primary information collected from the farm households include details on well investment, groundwater use, tank water use, management, crop production (including input use and output realized), farm income, the adoption of water-saving technologies, land use particulars, the coping and adaptation strategies of farmers, and the education and other socio-economic conditions of the respondents.In addition, the key informants, like the community heads, village elders, and local leaders were also interviewed. The economic value of irrigation water was determined by employing the production function approach (Gibbons 1987). A quadratic production function was estimated, with yield (kg per ha) as the dependent variable, and the volume of irrigation water used, in ha cm (WATER), as the independent variable. The estimated production function is

$$\text{YIELD} = a_0 + b_1\text{WATER} + b_2\text{WATER}^2 \qquad \ldots(1)$$

The uncertainties over crop yield, price, and income are directly related to rainfall and the availability of water in a tank. In the years that rainfall is good, tanks have a full supply of water, production is expected to be high, and prices and incomes are stable, but input and output prices, and production, fluctuate significantly in the years that rainfall is bad. Normally, in the tank irrigation systems of Tamil Nadu, one rice crop is grown using tank water, supplemented with groundwater at the later stages of the crop cycle. Only about 10–15% of the farmers in the tank system own wells, however, and many lack access to supplementary irrigation from groundwater. The water storage of tanks depends on the rainfall during a season; the storage will be surplus or adequate if the rainfall is above normal, and deficit or low if the rainfall is below normal.

Farmers who own wells provide supplemental irrigation through groundwater. Farmers who do not own wells (non-owners) either buy water, to make irrigation optimal, or they do not practise supplemental irrigation. Non-owners' access to groundwater is limited; therefore, their yield is lower, and they forgo income. The income they forgo by not investing in wells represents the cost of the wrong decision. This paper attempts to assess the cost of not investing in wells, or the cost of the wrong decision, following earlier studies (Palanisami, Paramasivam, and Ranganathan 2002; Palanisami et al. 2014).

Rice is a major crop, and it is grown mainly using tank water with supplemental irrigation; therefore, the cost of the wrong decision is analysed by using rice as the main crop. In the years that the rainfall is in deficit, supply falls, and rice prices rise. In the years that the rainfall is in surplus, supply rises, and rice prices fall. These phenomena are common, and the price of rice is assumed at three levels: low (RP_1), normal (RP_2), and high (RP_3). Assuming that the investment in wells is independent of the price level, their joint probabilities are given by:

$$p\,(IB = IB_i;\ RP = RP_j) = p(IB = IB_i)\ p\,(RP = RP_j) \qquad \ldots(2)$$

where I =1,2 and j=1,2,3

The irrigation behaviour (IB) and the price of rice (RP) are considered random variables. The joint probability distribution of the IB and RP can be used to calculate the average net income a farmer can expect, or the expected net income:

$$E(NI) = \sum_{i}^{3} \sum_{j}^{3} N_{ij}\ p_{ij} \qquad \ldots(3)$$

The cost of not investing in wells is lower than the normal (expected) values of the random variable, because supplemental irrigation is not practised. The expected cost of uncertainty is the weighted sum of the reduction in net income, where the weights are the corresponding joint probabilities.

$$E\,(Cr) = \sum_{i}^{3} \sum_{j}^{3} Rn_{ij}\ \ p\,(X_{ij}) \qquad \ldots(4)$$

Table 2. Definition and descriptive statistics of the variables

Variable	Description	Pramanur			Thiruvampattu		
		Mean	Min.	Max.	Mean	Min.	Max.
FSIZE	Farm size (hectare)	1.54	0.5	3.0	0.63	0.3	1.0
NSA	Net sown area (hectare)	1.46	0.4	2.6	0.58	0.3	0.9
GCA	Gross cropped area (hectare)	1.46	0.4	2.6	0.60	0.3	1.0
CI	Cropping intensity defined as the ratio of gross cropped area to net sown area and expressed as percentage (%)	100.0	100.0	100.0	103.4	100.0	111.1
NIA	Net irrigated area (hectare)	1.05	0.2	1.4	0.40	0.2	0.6
GIA	Gross irrigated area (hectare)	1.05	0.2	1.4	0.42	0.2	0.7
II	Irrigation intensity is the ratio of gross irrigated area to net irrigated area (NIA) and expressed as percentage (%)	100.0	100.0	100.0	105.0	100.0	116.6
YIELD	Yield of rice (kg/ha)	3,944.7	3,253.0	5,000.0	4,972.8	4,200.0	5,780.0
WATER	Water used (m^3)	10,050.8	10,000.0	11,600.0	10,242.5	9,000.0	11,500.0

Source Farm Household survey, 2015–16

where,

E (Cr) is the expected cost of uncertainty;

P (Xij) represents the probabilities of joint events IB and RP; and

Rn_{ij} is the reduction in net income.

Non-owners' access to groundwater is limited; therefore, their yield is lower, and they forgo income. The income they forgo by not investing in wells is the cost of the wrong decision. Table 2 presents the definitions of the variables studied and the descriptive statistics.

Results and discussion

Rainfall and tank irrigation

The tank-irrigated area has declined consistently since 1971–72, though the rainfall has varied. We mapped the tank-irrigated area and the deviations in rainfall for the period from 1986–87 to 2012–13 to study the effect of rainfall on the tank-irrigated area. The correlation is 0.67 and the pattern of variations uniform (Figure 2),confirming that rainfall influences tank irrigation.

The area under tank irrigation is determined by the rainfall, land under non-agricultural uses, population density, and time trend (Suresh Kumar 2016).We analysed the data on the two study tanks for 34 years (1980–2013), and our analysis shows that the variability in rainfall resulted in the reduction of tank water storage, as reflected by the actual tank-irrigated area (Table 3).

The actual tank-irrigated area, a proxy for tank water storage, is directly influenced by the rainfall; as the rainfall fluctuates, the tank-irrigated area fluctuates correspondingly. The reduced tank water storage motivated the farmers in the tank commands to adopt various short- and long-term measures.

We assume that the tank-irrigated area is influenced not only by the rainfall but also by management factors (poorly maintained, or silted, tanks) and human-induced factors (encroachment of tank beds, blockage of supply channels). To study the effect of rainfall on the tank-irrigated area, we employed the detrending of the tank-irrigated area.

The analysis makes clear that the tank-irrigated area is determined not only by the rainfall but also by other factors (encroachment, urbanization, the growth in the number of wells, the demand of land for non-agricultural uses). To examine whether these factors really matter, we tried to map the relationship between the growth in tank irrigation in the state and human-

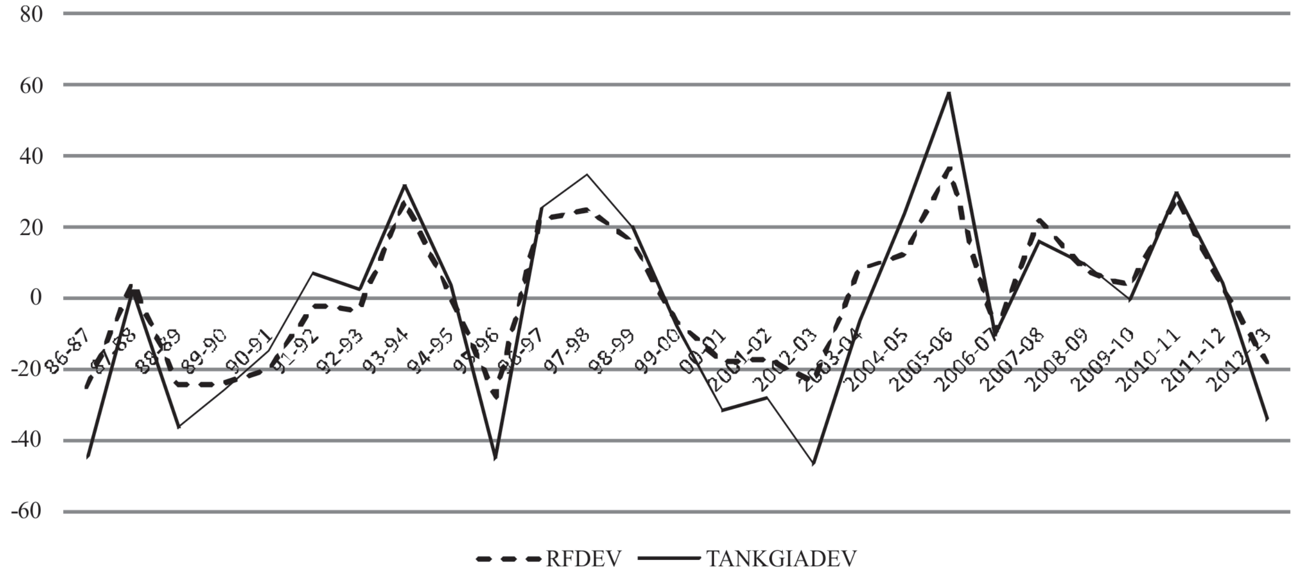

Figure 2. Trend in deviations in Rainfall and gross irrigated area by tanks

Table 3. Details of rainfall, tank-irrigated area, and tank performance

Period	Pramanur tank				Thiruvampattu tank			
	Rainfall (mm)	Command area (Ha)	Actual area irrigated by tank (ha)	Tank performance (%)	Rainfall (mm)	Command area (Ha)	Actual area irrigated by tank (ha)	Tank performance (%)
1980s	801	744	734	99	848	274	261	95
1990s	851	744	526	71	849	274	266	97
2000s	774	744	487	66	790	274	231	84

Source Water Resource Department (WRD), Government of Tamil Nadu, and Village Administrative Office of the concerned villages.

induced factors. Thus, there is a need to study the determinants of tank irrigation in the state.

Determinants of tank irrigation

Rainfall directly affects tank water storage and the irrigation potential, and it is expected to positively influence tank performance, which is influenced also by urbanization and the demand for land for non-agricultural uses. In the process of urbanization, the use purpose of agricultural land is converted into non-agricultural purposes at a faster rate, reducing the tank water spread, catchment area, and the tank-irrigated area. The non-agricultural use of land can negatively influence tank performance. Population density is included in the model to capture the effect of encroachment on the catchment area, tank bed and tank water spread area, supply channels, etc., all of which can reduce the performance of tanks.

With the help of the central government and international donors, the state government has made huge investments over the years in tank management and maintenance activities, overseen also by water users' associations. These management and maintenance activities help improve the conditions of the tanks and ensure good storage of water, and the performance of tanks is expected to improve as a result. The variable TREND, thus, is expected to influence the tank performance positively, and it is included mainly to examine the effects of the management and maintenance activities undertaken continually. The estimated results indicate that, as expected, the performance of tanks is significantly influenced by rainfall (RAINFALL), land under non-agricultural uses (NAGLAND), population density (POPDENSITY), and TREND (Table 4).

Table 4. Factors influencing tank performance

Variables	Coefficients	Std Error	t ratio
CONSTANT	400.86	65.034	6.16
NWELLS	-0.0000006	0.000009	-0.06
RAINFALL	0.056743***	0.0068	8.31
NAGLAND	-0.00013***	0.00004	-3.77
POPDENSITY	-0.4712***	0.1645	-2.86
TREND	3.7415***	0.9973	3.75
Adjusted r-squared	0.82		
F-statistics	38.71***		

Note *** = P<0.01 indicates significance at 1% level

Features of tank-based agriculture

Marginal and small farmers dominate the tank command areas in Thiruvampattu (NSA 0.58 ha) and Pramanur (1.46 ha). The cropping intensity, or the intensity of the land under use, is 103% in Thiruvampattu and 100% in Pramanur. The NIA, the maximum area that can be irrigated in any of the three seasons, varies from 0.40 ha in Thiruvampattu tank to 1.05 ha in Pramanur tank.

When tank water is supplemented by well water, the cropping intensity and irrigation intensity are higher than in tank commands where the level of supplementary irrigation is low. Thiruvampattu has many wells, and its cropping intensity and irrigation intensity exceeds 100%, but the irrigation intensity is only 100% and 105%, implying that the water availability is inadequate for more than one crop. Most tanks can supply water for one crop only, and the irrigation intensity is around 100%. Farmers who have access to supplemental irrigation by wells can raise crops more than once a year, and the irrigation intensity may be higher.

In any region, the proportion of the area cultivated with a crop indicates the cropping pattern, which is determined by the resource availability, output price, and product markets. The proportion of the rice-irrigated area to total cropped area varies from 37.39% in Thiruvampattu to 67.87% in Pramanur. The availability of water is low in both tanks, and a reduction is observed in the rice area. The reduction in the tank water supply and the consequent water scarcity compels the farmers to diversify their crop complex by including irrigated crops and crops that consume less water.

Farmers in both the study tanks perceive that the major issues relating to rainfall variability are the reduction in tank water availability (100.0%), frequent tank failure (94.0%), crop failure due to water stress (92.0%), and the reduction in the rice area (92.0%).[1] This confirms that farmers experience variation in climatic factors such as rainfall and resulting negative effects on tank-based agriculture.

Adaptation strategies by farmers

When irrigation tanks perform poorly and water is scarce, farmers respond by adopting short- and long-term measures.

Short-term interventions

The performance of tanks has declined over the years and, in turn, tank irrigation has declined dramatically. Rice is the major crop grown by tank irrigation; when the water supply in tanks is inadequate and water scarce, farmers supplement it with well irrigation. Even then, farmers are compelled to grow short- or medium-duration varieties. Depending on the water available in the tank and on the onset of the monsoon, farmers alter the sowing dates of the rice crop or delay sowing. They reduce the number of irrigations, and adopt direct seeding, the system of rice intensification (SRI), partially or fully, and alternate wetting and drying. Farmers also diversify their crops, by including crops that are less water-intensive, such as maize, sorghum, and pulses, under rain-fed conditions, and crops like vegetables, sugarcane, and banana under irrigated conditions. The other important coping strategies are altering the cropping pattern, inclusion of livestock, migration, and mobility of labour.

[1] Respondents were asked to rank responses from 'strongly agree' to 'strongly disagree' for a number of questions relating to their perception about impact of rainfall variability. The percentage of respondents stating 'strongly agree' responses is invariably above 90% for almost all the reasons identified.

Farmers who own wells are assured of their supply of water and they practise micro irrigation, which has become important in the cultivation of sugarcane, coconut, and vegetables. Farmers who have access to well water provide three or four supplemental irrigations to save their crop. Farmers who do not own wells buy water from well owners to avoid crop loss. At the farm level, the sale of water is affected by the desire to help resource-poor farmers, the availability of water in the wells, and cheap power tariffs. Farmers purchase water because the water supply is inadequate and they need to save their crop from drought; they do not own a well and cannot afford to invest in one. If rainfall is adequate, however, and the supply of water assured, these measures would be redundant.

Long-term interventions: wells as adaptation strategy

Growing water scarcity and the failure of the monsoon in the tank commands in the study area compelled the farmers to invest in groundwater abstraction structures. Constructing wells, and investing in drilling new bore wells or dug wells, is considered a vital strategy in augmenting the supply of water, and this paper focuses only on the analysis of well construction. The groundwater abstraction structures cost INR 11,121 per ha in Pramanur and INR 34,375 per ha in Thiruvampattu. The total amortized cost of the investment in irrigation is the sum of the amortized cost on wells, electric motors, and equipment:

Amortized cost of well = [(Compounded cost of well) $*(1+i)^{AL} * i]$,$[(1+i)^{AL}-1]$,

where,

AL is the average life of wells and

the compounded cost of a well = (Initial investment on well)* $(1+i)^{(2014\text{-year of construction})}$.

We used the long-term, sustainable discount rate of 5%, and we amortized the investment in conveyance, pump sets, and electrical installation. We assume that the AL is 30 years, based on the AL in the study area, and that the average life of electrical motors is 15 years.

Wells account for 77% of the cost and electric motors around 23%. The cost per hectare is high because the costs of drilling new bore wells and digging wells have increased and because labour for digging wells is not available (Table 5).

Table 5 Details of well investment in the study area

(INR/ha)

Particulars	Pramanur	Thiruvampattu
Investment on wells	8,522.4 (76.6)	26,476.9 (77.0)
Investment on Electric motor	2,598.6 (23.4)	7,898.6 (23.0)
Total amortized cost	11,121.0 (100.0)	34,375.5 (100.0)

Source Farm Household survey, 2015–16

Water use, crop yield, and water productivity

Within a tank command, water use by crop, tank, and region differs, depending on the access to well water, from 10,050.8 m^3 per ha to 10,242.5 m^3 per ha (Table 6).Well owners in Pramanur use 10,525 m^3 per ha of water, 7.6% more than non-owners; in Thiruvampattu, the difference is 15%. Rice requires 13,000 m^3 of water per ha but, in general, farmers use less, mainly because the tank water supply is inadequate. The yield varies from 3,944.7 kg per ha to 4,972.8 kg per ha. Compared to non-owners, well owners reap a higher yield (16% in Thiruvampattu tank and 38% in Pramanur, Figures 3 and 4).The yield ranges from 3,200 kg per ha to 4,100 kg per ha for most farmers in Pramanur, but for a few observations, the yield ranges between 4,400 kg per ha and 5,000 kg per ha, mainly because of the supplemental irrigation provided by wells. The distribution is concentrated around the mean in Thiruvampattu where the number of wells is larger.The value marginal product (VMP) of water is evaluated at the mean values of water use. Keeping water as the input, we estimated a production function to derive the marginal physical productivity and VMP of water:

Pramanur: Y= 1688.828 + 27.911 WATER*** – 0.033 WATERSQ (1.844) (-0.271)

Adj. R square= 0.48

Thiruvampattu: Y= 1170.129 + 47.871 WATER** – 0.058 WATERSQ (2.263) (-0.0647)

Adj. R square= 0.70[2]

[2] The figures in the parentheses indicate the estimated ‘t’ values. *** Significant at 1% level; ** significant at 5% level; * significant at 10% level.

Table 6 Irrigation water use and yield of rice in sample farms

Particulars	Unit	Pramanur	Thiruvampattu
Water used	m^3/ha		
Well owners		10,525.0	10,936.6
Non-well owners		9,776.3	9,512.8
All farms		10,050.8	10,242.5
Paddy Yield	kg/ha		
Well owners		4,753.4	5,384.6
Non-well owners		3,637.9	4,645.0
All farms		3,944.7	4,972.8
Water productivity	kg/m^3 of water		
Well owners		0.46	0.49
Non-well owners		0.45	0.48
All farms		0.46	0.48
Marginal Productivity of water			
Marginal product of water (MPP_w)	kg/ha cm	21.11	35.81
Price of Paddy	INR/kg	12.48	12.48
Value marginal product of water (VMP_w)	INR/ha cm	263.63	448.54

Source Farm Household survey during 2015–16.
MPPw: Marginal product of water; VMPw: Value Marginal Product of water

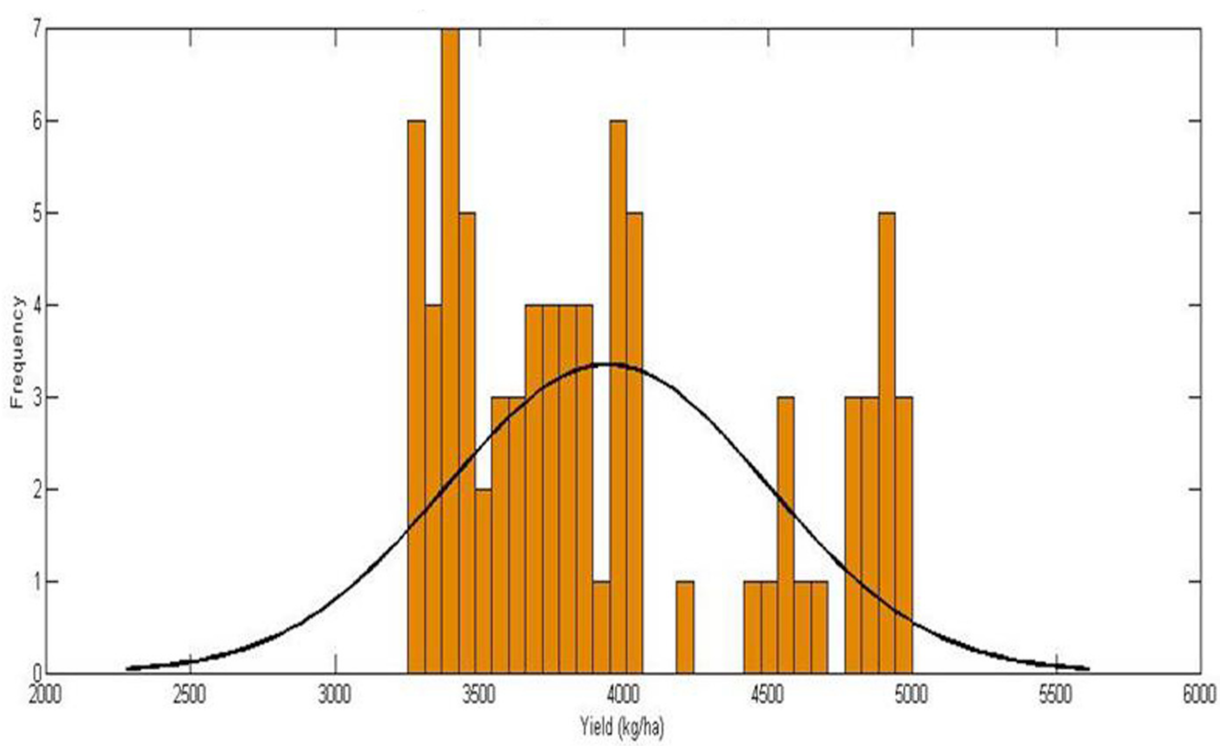

Figure 3. Histogram of rice yield in Pramanur tank

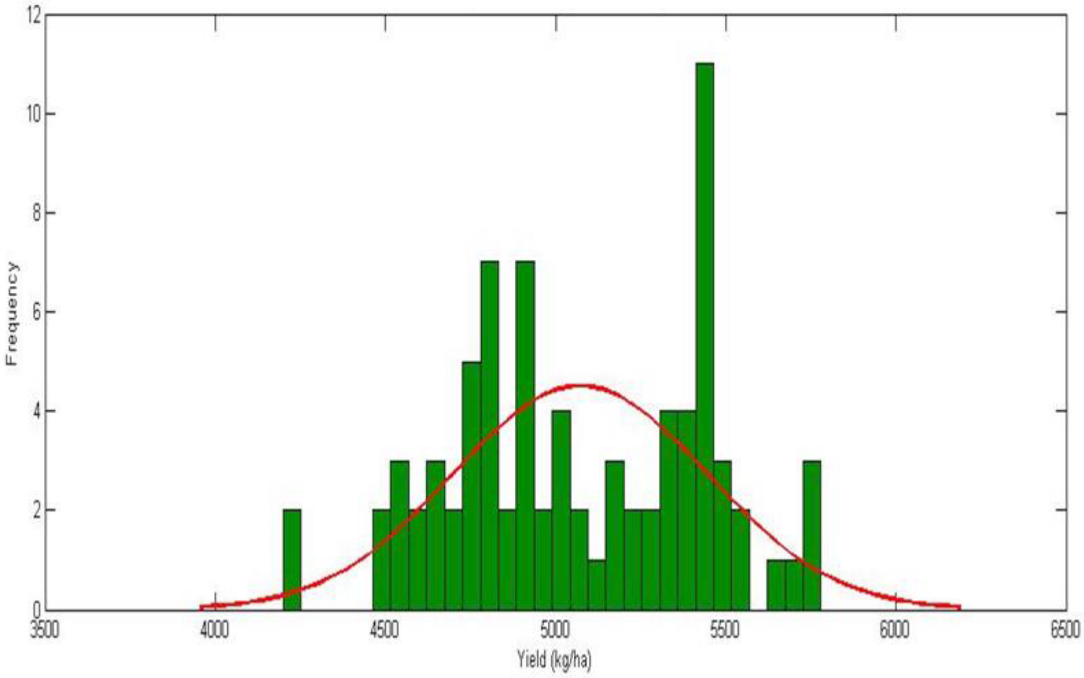

Figure 4. Histogram of rice yield in Thiruvampattu tank

Table 7 Irrigation behaviour and associated probability across tanks

Irrigation behaviour (IB)	Number of farmers	Probabilities p (IB)
Pramanur tank		
Groundwater supplementation by buying water for optimal irrigation (IB_1)	15	0.15
No supplemental irrigation (IB_2)	83	0.85
Thiruvampattu tank		
Groundwater supplementation by buying water for optimal irrigation (IB_1)	19	0.32
No supplemental irrigation (IB_2)	40	0.68

Source Farm Household survey during 2015–16

The marginal physical product is derived by taking the first order partial derivative of the estimated production function Y, with respect to the independent variable WATER. Thus,

$$MPP_{WATER} = \frac{dY}{dWATER}$$

$$VMP_{WATER} = MPP_{WATER} \cdot P_y$$

The VMP ranged from INR 263.63 per ha cm of water (Pramanur) to INR 448.54 per ha cm (Thiruvampattu) (Table 6).

Well investment and cost of uncertainty

The cost of drilling new wells has increased, and the availability of water involves risks and uncertainty, and farmers prefer not to invest in wells. But farmers who do not own wells have limited access to groundwater, and they forgo income, because their yields are lower. The irrigation behaviour and associated probabilities across tanks are given in table 7. It is essential to demonstrate that the income forgone is the cost of not investing in wells, or the cost of the wrong decision. The cost of the wrong decision is analysed by using rice as the main crop. In the years that the rainfall is in

Table 8 Price of rice and associated probabilities across tanks

Price of rice (RP)	Probability
Pramanur tank	
Low (RP_1)	0.33
Normal (RP_2)	0.35
High (RP_3)	0.32
Thiruvampattu tank	
Low (RP_1)	0.42
Normal (RP_2)	0.35
High (RP_3)	0.23

Source Farm Household survey during 2014–15.

deficit, supply falls, and rice prices rise. In the years that the rainfall is in surplus, supply rises, and rice prices fall. These phenomena are common, and the price of rice is assumed at three levels: low (RP_1), normal (RP_2), and high (RP_3). The probability distribution for the price of the rice crop is given in Table 8.

Expected cost of not investing in wells

The cost of not investing in wells is lower than the normal (expected) values of the random variable because farmers do not practise supplemental irrigation (invest in wells). The expected cost of uncertainty of not investing in wells thus worked out to INR 12,775.86 per ha in Pramanur tank and in Thiruvampattu INR 12,430.37 per ha (Table 10). Groundwater supplementation and water sales help well owners maximize profits. In many tank command areas, the number of wells can be increased by 25% (Palanisami et al. 2014). Thus, farmers should be encouraged to practise supplemental irrigation.

Conclusions and recommendations

Farmers in the tank commands adapt to the variability in rainfall by practising short-term interventions (like altering the cropping pattern), long-term interventions (like investing in wells), or both short- and long-term interventions. Altering the cropping pattern requires farmers to grow crops that use less water, and it appears to be useful from the perspective of sustainability. These adaptation measures are entirely farmers' initiatives, and they vary from year to year depending on the rainfall and tank-filling patterns.

Farmers need inputs such as high-yield varieties, medium- and short-duration varieties, and drought-tolerant and other varieties. The tank water is inadequate, and farmers need to learn to manage water efficiently and diversify crops. This study recommends that extension efforts provide farmers these inputs through campaigns at the tank level. Long-term measures are critical, because investing in wells will enable the farmers to provide supplemental irrigation to the crop and increase their yield, particularly of rice, and income. If they do not invest in wells, they will forgo an income of INR 12,430 per ha per year to INR 12,775 per ha per year. That is the cost of not investing in wells. The groundwater department can support the farmers in building wells and other water harvesting structures, and conducting a survey in each tank to determine the number of wells that can be built will give farmers the confidence to invest in wells.

Table 9 Joint probabilities of farmers' irrigation behaviour and price of rice

Farmers irrigation practice	Low price	Normal price	Higher price	Total
Pramanur tank				
Groundwater supplementation by buying water for optimal irrigation (IB_1)	0.051	0.054	0.048	0.153
No supplemental irrigation (IB_2)	0.282	0.296	0.268	0.847
Total	0.333	0.350	0.317	1.000
Thiruvampattu tank				
Groundwater supplementation by buying water for optimal irrigation (IB_1)	0.134	0.113	0.075	0.322
No supplemental irrigation (IB_2)	0.282	0.237	0.158	0.678
Total	0.417	0.350	0.233	1.000

Table 10 Expected cost of not investing in wells

(INR/ha)

Irrigation practices of farmers in the tank command	Joint probability	Yield (kg/ha)	Gross income (INR/ha)	Net income (INR/ha)	Reduction in net income (INR/ha)	Expected cost of uncertainty (INR)
Pramanur tank						
Groundwater supplementation by buying water for optimal irrigation (IB_1) and low price (RP_1)	0.051	4,057.00	47,825.0	3,900.00	14,273.23	728.23
Groundwater supplementation by buying water for optimal irrigation (IB_1) and normal price (RP_2)	0.054	4,034.00	47,468.0	7,195.00	10,978.23	588.12
Groundwater supplementation by buying water for optimal irrigation (IB_1) and high price (RP_3)	0.048	4,021.00	55,133.0	13,217.00	4,956.23	240.23
No supplemental irrigation (IB_2) and low price (RP_1)	0.282	3,630.80	42,873.9	1,827.00	16,346.23	4,614.75
No supplemental irrigation (IB_2) and normal price (RP_2)	0.296	3,650.00	47,239.9	5,749.63	12,423.60	3,682.71
No supplemental irrigation (IB_2) and high price (RP_3)	0.268	3,550.17	49,129.4	7,278.92	10,894.31	2,921.82
Expected cost of uncertainty	12,775.86					
Thiruvampattu tank						
Groundwater supplementation by buying water for optimal irrigation (IB_1) and low price (RP_1)	0.134	4,826.00	56,086.0	15,338.00	10,618.98	1,424.86
Groundwater supplementation by buying water for optimal irrigation (IB_1) and normal price (RP_2)	0.113	4,765.00	60,180.0	19,984.25	5,972.73	673.20
Groundwater supplementation by buying water for optimal irrigation (IB_1) and high price (RP_3)	0.075	4,802.00	65,426.0	25,397.00	559.98	42.08
No supplemental irrigation (IB_2) and low price (RP_1)	0.282	4,150.00	48,650.0	7,396.75	18,560.23	5,243.00
No supplemental irrigation (IB_2) and normal price (RP_2)	0.237	4,190.00	53,280.0	12,309.25	13,647.73	3,238.44
No supplemental irrigation (IB_2) and high price (RP_3)	0.158	4,200.00	57,600.0	14,522.83	11,434.14	1,808.79
Expected cost of uncertainty	12,430.37					

Source: Farm Household survey 2014–15

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