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PERFORMANCE OF COMMUNITY-BASED TANK IRRIGATION SYSTEM AND ITS DETERMINANTS: EVIDENCE FROM TAMIL NADU, INDIA

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Irrigation tanks are classic examples of common pool resources that have been traditionally managed by local communities. However, the tank performance under community management in Tamil Nadu has declined over the last few decades and threatened the local livelihoods. This study investigates the effect of community management on irrigation tank performance using village-level two-period data collected across 100 tank-intensive villages in Tamil Nadu. To address the problems encountered in the subjective measures, this study adopts an objective assessment method using the satellite imageries of Landsat-7 to derive tank performance measures. Satellite-derived data are then incorporated with the field survey data and used in the analysis. The results show that community participation in tank management has a significant positive impact on tank performance, suggesting that strengthening traditional institutions in irrigation tank management can be a viable strategy for reviving tank irrigation systems.

Keywords: Community participation; Tamil Nadu; Tank performance
JEL classification: Q15, Q25

1. INTRODUCTION

COMMON pool resources (CPRs) are non-excludable and rivals in nature. CPRs include a wide range of natural resources such as forests, irrigation systems, grasslands, and fisheries, but their management remains challenging due to free-rider problems and a lack of law enforcement. A decentralized approach is becoming popular in the management of CPRs (Agarwal and

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Ostrom 2001). Community institutions play an important role in CPR management because the local resource use patterns are closely related to traditional norms (Quinn et al. 2007).

However, the effectiveness of community-based management considerably varies between the different types of CPRs and resource use patterns. Irrigation tanks are a classic example of CPRs in the Indian subcontinent as they have a high potential due to the geographical and climatic conditions in this region. These tanks provide a wide range of benefits not only to the farmers but also to the entire rural community. The highest concentration of irrigation tanks is found in south Indian states. Tamil Nadu is the southernmost state of India with approximately 39,202 irrigation tanks (Palanisami et al. 2008). Until recently, these tanks had contributed around one-third of the total irrigated area in Tamil Nadu. Most small-scale farmers in Tamil Nadu choose tanks as their main irrigation source because the tank irrigation systems are highly accessible and the least expensive compared to the other irrigation sources. Moreover, Tamil Nadu is heavily subjected to prolonged dry spells and a lack of monsoonal rains. Therefore, precipitation and river flows cannot guarantee that the farmers get an adequate water supply throughout the year. In this situation, tanks act as a buffer source for irrigation against severe drought (Deivalatha, Senthilkumaran, and Ambujam 2014).

In terms of the management of irrigation tanks, the participation of community members in tank management activities (*Kudimaramathu*) has been a regular practice in the villages of Tamil Nadu since ancient times. This norm was legalized after the Kudimaramathu Act was passed by the British rulers in 1858 (Palanisami 2006). Farmers in the tank command area are supposed to engage in the routine activities of tank maintenance to ensure effective tank performance. Tank management activities include tank bed cleaning, silt removal, cleaning of the supply channel and main canal, minor repairs in tank irrigation structures, and water distribution. Water users' associations in each village facilitate tank management activities (Palanisami et al. 2008). Tank-using farmers prefer to craft the water rules by themselves rather than state intervention (Bardhan 2000). Most irrigation tanks (78%) in Tamil Nadu are under the control of village authorities (Palanisami and Meinzen-Dick 2001). These tanks are smaller in size (less than 40 ha of command area) compared to the tanks managed by the state government (public works department), which makes it easier for the village authorities to manage the tanks with the support of community members. Effective implementation of governance rules or traditional institutions is necessary to ensure the proper management of such tank irrigation systems at the village level.

However, Tamil Nadu has been witnessing the disappearance of traditional irrigation institutions over the last few decades, which has resulted in poor performance of tank irrigation systems across the state. The disintegration of traditional institutions in tank management can be attributed to several reasons. The large-scale development of groundwater resources in tank command areas, the takeover of larger tanks by the state, state intervention in tank management activities, abolition of the Zamindari system, recent changes in landownership rules, changes in farmers' perception toward tank management activities, and illegal encroachments in the catchment and tank water spread areas are often cited as the major reasons for the disintegration of traditional irrigation institutions (Balasubramanian and Selvaraj 2003; Janakarajan 1993; Kajisa 2012; Palanisami et al. 2008; Sakurai and Palanisami 2001).

The rural economy in the south Indian states, especially Tamil Nadu, heavily relies on irrigation tanks. Therefore, analyzing the impact of community participation in tank management on tank performance is crucial for making essential policy decisions to strengthen traditional irrigation institutions and ensure better tank performance. The main objective of this study is to investigate the impact of community participation in tank management on tank performance in Tamil Nadu.

The factors associated with community participation and tank performance have been extensively explored (Balasubramanian and Govindaswamy 1991; Palanisami et al. 2008; Palanisami and Balasubramanian 1998; Palanisami and Meinzen-Dick 2001). However, most of the previous studies used cross-sectional survey data. In contrast, we used data from two periods (1998/99 and 2004/5), which may take into account the inconsistencies of time-invariant factors to some extent. In addition, almost all the previous studies have used subjective assessments by farmers to measure tank performance. However, there are chances to overestimate or underestimate the tank's performance under the subjective assessments unless enough attention is paid to control such errors. To fill this gap, at least to some extent, this study attempts to use an objective assessment method using satellite images to analyze the tank performance. For this purpose, satellite imagery data of the study region are obtained and incorporated with field survey data in our analysis.

2. DATA COLLECTION

Out of the seven agroecological zones of Tamil Nadu, the southern region and northern regions are considered tank intensive (Palanisami and Balasubramanian 1998). Four districts from the southern agroecological zone of Tamil Nadu were selected: Sivagangai, Ramanathapuram, Madurai, and Virudhunagar. Of these four districts, 100 villages were randomly selected for the field survey.

A village survey of the selected 100 villages was carried out in two time periods: 1998/99 (wave 1) and 2004/5 (wave 2). While interviewing the village leaders during the survey, a major irrigation tank was identified in each village. If the selected village had access to several tanks, the most important tank, usually the one with the largest extent and command area, was selected for gathering information. In total, 90 tanks were identified from the 100 villages since 10 villages did not have any irrigation tanks.

Although this study takes advantage of using two-period data, the gap between the first and the second wave was considerably large. Therefore, there is a possibility that any adverse shocks or policy changes due to state interventions that occurred during this period might not have been captured in our empirical models, and thus, led to inconsistent estimates. However, this issue can be addressed to some extent through the inclusion of control variables in our models—that is, tank modernization (a proxy for state intervention), the market price of paddy, and climatic factors. These control variables are measured as the arithmetic average of the last five-year observations so that they can capture the effects of adverse shocks or policy changes that might have occurred between wave 1 and wave 2.

2.1. *Key Variable of Interest*

Community participation in tank management is used as the key explanatory variable in this study. This variable was measured as the total number of man-days spent on tank management activities (i.e., tank bund cleaning, silt removal [tank bed cleaning], water distribution, and supply channel cleaning). The total man-days from each village were converted into 1,000-man days for easy interpretation of the results. The man-day composition of major tank management activities across the survey periods is presented in Table 1. As we can see from Table 1, there was a sharp decline in community participation activities between the two survey periods. This phenomenon could be the result of the rapid expansion of well-irrigation structures due to state-sponsored rural electrification

Table 1. Man-Days Composition of the Major Tank Management Activities

	Participation in Tank Management Activities (man-days)		
Tank management activities	Wave 1	Wave 2	Combined
Supply channel cleaning	488.25 (45.08%)	212.54 (62.38%)	312.16 (43.84%)
Tank bund cleaning	215.66 (19.91%)	54.69 (16.05%)	103.85 (14.58%)
Silt removal (tank bed cleaning)	379.15 (35.00%)	73.47 (21.56%)	296.03 (41.57%)
Total	1,083.06	340.7	712.04
No. of observations	90	90	180

programs and credit sanctions for well installations in the rural areas of Tamil Nadu in the late 1990s. Subsequently, access to an alternate source of water might have reduced the incentives for community participation in tank management activities.

2.2. *Community Participation as an Indicator of Social Norm in Tank Irrigation Management*

Social norms are the customary rules or shared cultural understandings that have been traditionally formed and practiced by a particular group of people or a community. Social norms lead to behavioral changes among community members based on what others do (descriptive norms) or what others can think of their actions (injunctive norms) (Minato, Curtis, and Allan 2010). Social norms are the main drivers of collective behavior or community action in common pool resource management (Sethi and Somanathan 1996). The strength of social norms is highly reflected in the success of community-based common pool resource management activities worldwide (Delaney and Jacobson 2016; Minato, Curtis, and Allan 2010; Oniki, Berhe, and Negash 2020). Social norms have a positive effect on collective action through the fair distribution of resources (Platteau 2000) and by reducing transaction costs (Gabre-Madhin 2001). According to Oniki, Berhe, and Negash (2020), social norms related to communal land conservation increase the community's participation rate in communal land management activities in Ethiopia. Delaney and Jacobson (2016) suggest that social norm–based approaches are more successful in community-driven common pool resource management when compared to other monetary-based incentives. Chen et al. (2009) argue that a social norm (cooperative behavior) exists among the rural farm communities in China, which encourages community enrollment in the forest conservation program and guarantees the sustainability of forest benefits to the user communities. According to the existing literature, the relationship between social norms and community engagement in common pool resource management is well established. It suggests that the variable *community participation* is a potential candidate to capture the strength of existing social norms associated with common pool resource management.

In Tamil Nadu, traditional institutions governing tank irrigation systems have been in practice since time immemorial. Under the traditional management of irrigation tanks, there is a social norm among the village members (mainly the local farmers) to engage in tank management activities before the rainy season starts. This social norm brings collective action among the local farmers to discuss their tank condition, plan for maintenance and minor repairs, and execute the tank management activities. This social norm is not specific to a particular village or a region but has been a common practice among all village communities that mainly depend on tanks for irrigation purposes. In addition, community mobilization for tank management activities is mainly driven by the existing social norm or traditional institutional arrangement irrespective of how the tank ownership rights are defined between the state and the local communities. Under traditional management, the active participation of the local community members (mainly the farmers) in tank management activities is the only and most critical factor for the sustainability of tank irrigation systems. Therefore, community participation is a good indicator to capture the social norm involved in traditional tank irrigation management in Tamil Nadu.

2.3. Calculation of the Dependent Variable Using Satellite Imagery Data

In addition to the data collected from the village survey, remote sensing data of the surveyed regions are also obtained in this study. For this purpose, high-resolution satellite images of Landsat-7 ETM+ C1-Level 1 were acquired using the United States Geological Survey (USGS) database. The details of the satellite images are provided in Table 2. In addition, the satellite images used in this study (path/row: 142/53, 142/54, 143/53, and 143/54) correspond to the major rice-growing seasons of the study region.

After controlling for the atmospheric disturbances, the satellite images with different spectral bands were combined using QGIS 3.12[1] to produce a virtual raster image. This image was used to derive the tank performance measures. Following Toomanian, Gieske, and Akbari (2004), the irrigated area in each tank command was estimated from the satellite image using a satellite-derived index—that is, the Normalized Difference Vegetation Index (NDVI). Ratio of the irrigated area (in percentage) by the tank under each tank command was used as a dependent variable to measure the tank performance.

Following the formula method proposed by Toomanian, Gieske, and Akbari (2004), we estimated the irrigated area from the satellite image. This method

Table 2. List of the Landsat-7 ETM+ Satellite Images Used in This Study

Serial. No	Path/Row	Date of Acquisition	Image ID
1	143/53	2005.08.30	LE07-L1TP-143,053-20050830_20170113_01_T1
2	143/54	2005.08.30	LE07-L1TP-143,054-20050830_20170113_01_T1
3	142/53	1999.11.11	LE07-L1TP-142,053-19991111_20170216_01_T1
4	142/54	1999.09.15	LE07-L1TP-143,054-19990915_20170217_01_T1

Source: Satellite images are obtained from the United States Geological Survey (USGS) database. https://earthexplorer.usgs.gov/ (accessed August 15, 2020).

[1] Open source Geographic Information System (GIS).

does not estimate the irrigated area directly but assumes that the higher the weighted average of the vegetation, the greater the chance of being irrigated.

$$I_g = Af_g n_{g,} \tag{1}$$

where I_g is the irrigated area in each village, A is the size of one pixel on the satellite image (900 m^2), n_g is the number of pixels within the tank command with the average green fraction value of f_g, which is the average green fraction of a pixel obtained in each tank command, and g denotes the observation unit (tank command area in each village).

$$f_g = \frac{NDVI\_mean_g - NDVI\_min_g}{NDVI\_max_g - NDVI\_min_g}, \tag{2}$$

where $NDVI\_mean_g$, $NDVI\_min_g$, *and* $NDVI\_max_g$ are the mean, minimum, and maximum NDVI values calculated from the tank command area pertaining to each target village.

The irrigated area is estimated as follows. First, we define the village boundaries as a square area of 3 × 3 km (10,000 pixels) around the village location obtained using the GPS data. The approximate extent of the tank command areas is defined on the satellite image using the GPS data and field-level data. Then, we calculate the average, minimum, and maximum NDVI values within the boundaries of each village (restricted to the tank command area within each village) using the image-processing software QGIS version 3.12 and obtain the average green fraction of each pixel within the tank command following equation (2). In addition, the number of pixels under each tank command is obtained from the raster layer unique values report. After that, we estimated equation (1), which estimates the irrigated area in each village as the weighted average of the vegetation cover. Finally, the estimated area calculated from equation (1) is converted to our response variable (P_{it}). Here, P_{it} implies the ratio of the irrigated area in the tank command in a village i at time t (either wave 1 or wave 2).

The observation of vegetation is restricted to the tank command area in each village to exclude the vegetation from the unirrigated or upland area. In addition, we account for the problem of bushes found in the abandoned/fallow lands in the tank command area by incorporating satellite images taken in the dry season of the same year. Bushes in the fallow lands are distinguished from those in the irrigated area by comparing NDVI raster images of both seasons based on the fact that bushes can be seen in both the rainy season and dry seasons. However, it is challenging to separate the irrigated area by wells on the satellite image. Therefore, we include the control variables (i.e., well density in the tank command and change in the number of private wells) in our regression models to control for the effect of well irrigation on tank performance.

Tank irrigated area is calculated as the ratio between the actual irrigated area estimated from equation (1) and the tank command area in each village. *Ratio of the irrigated area in the tank command* (P_{it}) can be a better indicator to explain the tank performance as it controls for the effect of tank size on tank performance. In addition, *paddy yield in the tank command* (kg/acre) in each village is used as another response variable to explain tank performance. The paddy yield data in each tank command are obtained directly from the field survey. The descriptive statistics of both dependent and independent variables used in this study are presented in Table 3.

3. ANALYTICAL FRAMEWORK

In the first step of our analysis, a Tobit regression model with correlated random effects (CRE) is used to identify the factors affecting *community participation in tank management*. Tobit models are considered more convenient than linear models when the dependent variable includes both continuous positive values and zero values (Wooldridge 2012). Tobit regression models are widely applied in the literature to examine the collective effort in irrigation governance due to the truncated or limited nature of explained variables (Akuriba et al. 2020; Balasubramanian 2006; Balasubramanian and Selvaraj 2003; Nanthakumaran and Palanisami 2010). The CRE approach is widely used to control for the unobserved heterogeneity in nonlinear models (Wooldridge 2019). It has many advantages over typical panel regression models (i.e., the random effects [RE] model and fixed effects [FE] model). In the CRE approach, the key assumption of exogeneity in the RE model is relaxed, meaning that the correlation between the unobserved heterogeneity and time-varying covariates is allowed. In addition, the CRE method accounts for the incidental parameter problem in the FE model.

The following empirical framework of the Tobit model with the CRE approach is used in this study due to the truncated nature of explained variables.

$$y_{it} = \max\left(0, \pi Z_{it} + X_{it}\mu + \overline{W}_i\gamma + C_i + v_{it}\right), \qquad (3)$$

$$\mathrm{D}\left(v_{it}|X_{it}, C_i\right) = \mathrm{Normal}\left(0, \sigma_u{}^2\right),$$

where y_{it} is the response variable capturing the *community participation in tank management* activities (1,000 man-days) in the village i at time t, X_{it} is the vector of covariates in the village i at time t, $\overline{W}_i$ is the average of the covariates over

Table 3. Descriptive Statistics

	Wave 1		Wave 2		Combined	
	Mean	SD	Mean	SD	Mean	SD
Dependent variables						
Ratio of the irrigated area in the tank command (%)	55.742	20.733	31.991	17.344	43.866	22.474
Paddy yield in the tank command (kg/ac)	1,724.2	480.69	1,626.2	707.96	1,675.22	605.39
Independent variables						
Tank characteristics						
Community participation in tank management (1,000 man-days)	1.0833	1.440	0.3407	0.4073	0.712	1.1192
Water spread area of the tank (acres)	1,042.4	1,295.4	1,005.5	1,348.1	1,023.9	1,318.4
Tank command area (acres)	629.484	349.070	629.484	349.070	629.484	348.093
Participation per command area	13.609	28.366	3.638	4.716	8.623	20.883
Availability of water users' association (dummy)	0.955	0.207	0.344	0.477	0.65	0.478
Length of the main canal available (m)	1,797.8	1,352.3	2,568.3	2,283.1	2,183.1	1,910.5
Length of canal lined by concrete (km)	0.8694	3.479	0.6146	526.65	31.168	372.60
Average length of channel cleaned (km)	0.3189	0.274	0.272	0.230	0.295	0.253
Tank modernization (last 5 years)	0.355	0.481	0.2	0.402	0.277	0.449
Encroachment (dummy)	0.266	0.444	0.5	0.502	0.383	0.487
No. of tanks the village has access to	4.488	7.902	2.222	3.859	3.355	6.304
Change in private wells (tank command)	3.266	8.255	3.7	6.197	3.483	7.282
Change in private wells (non-tank command)	3.911	6.976	5.233	9.980	4.572	8.612
Availability of water man (dummy)	0.611	0.490	0.177	0.384	0.394	0.490
Well density in the tank command (per acre)	0.028	0.050	0.0225	0.034	0.025	0.043
No. of sluice available for the village	1.922	1.247	1.922	1.247	1.922	1.243
No. of fillings	1.355	0.939	1.366	0.929	1.360	0.932
Tank water source dummy (reservoir)	0.022	0.148	0.022	0.148	0.022	0.147
Tank water source dummy (canal)	0.255	0.438	0.255	0.438	0.255	0.437
Tank location dummy (head)	0.377	0.487	0.377	0.487	0.377	0.486
Tank location dummy (tail)	0.055	0.230	0.055	0.230	0.055	0.229
Village characteristics						
No. of households in the village	221.455	203.790	271.77	259.06	246.616	233.784
Conflicts between village members	0.022	0.148	0.088	0.286	0.055	0.229

Table 3 (Continued)

	Wave 1		Wave 2		Combined	
	Mean	SD	Mean	SD	Mean	SD
No. of households out-migrated	10.033	16.567	8.833	14.769	9.433	15.661
Landholding distribution (Gini)	0.583	0.226	0.583	0.226	0.583	0.226
No. of farm households	257.466	383.91	257.433	383.925	257.45	382.844
Distance to market (km)	53.116	89.549	53.116	89.549	53.116	89.299
Male education (%)	42.5	17.560	69.999	16.862	56.249	22.018
Female education (%)	27.433	16.185	60.519	18.956	43.976	24.168
Labor wage male outside the village (Rs/day)	63.666	14.177	95.333	26.614	79.5	26.537
Labor wage female outside the village (Rs/day)	33.5	9.039	95.333	26.614	64.416	36.796
No. of households cultivate (tank command)	107.688	113.676	111.202	93.654	109.435	103.926
Land ownership (%)	0.700	0.153	0.695	0.327	0.698	0.254
Availability of agriculture market (dummy)	0.055	0.230	0.055	0.230	0.055	0.229
Price of irrigated land (Rs/ac)	53,094.4	27,889.1	47,666.6	33,509.3	50,380.5	30,861.5
Market price of paddy (Rs/kg)	5.028	0.783	6.598	3.095	5.813	2.385
Total fertilizer use (kg/ac)	1,569.489	1,139.601	3,878.889	3597.174	2,724.189	2,901.756
Average fertilizer cost (Rs/ac)	1,237.814	833.922	1,290.878	194.207	1,264.346	604.344
Yield improved (dummy)	0.622	0.487	0.055	0.230	0.338	0.474
Average annual rainfall (mm/year) (last 5 years)	830.792	127.675	789.968	111.395	810.380	121.217
Coefficient of variation of rainfall (last 5 years)	3.464	0.792	5.016	2.242	4.227	1.838
No. of drought years (last 10 years)	3.411	2.693	3.988	1.240	3.7	2.111
No. of observations	90		90		180	

Note: Wave 1 = 1998/99, wave 2 = 2004/5. SD = standard deviation.

the time period, C_i is the individual unobserved heterogeneity, Z_{it} indicates exogenous instruments, and v_{it} denotes the idiosyncratic error term. The terms D and *Normal* indicate the expected value of the error terms and the normal distribution of error terms, respectively.

In the second step, we examine the impact of community participation in tank management activities on tank performance. *Paddy yield in the tank command* and the *ratio of irrigated area in the tank command* are our indicators of tank performance and are used as dependent variables. The explanatory variable of our interest is *community participation in tank management* (y_{it} in equation 3). However, community participation is endogenous. There is a possibility of reverse causality between community participation and tank performance; well-performing tanks may attract community members to engage in tank management activities and remain in good condition (positive feedback), while poorly performing tanks may discourage community participation in tank management and further decline tank performance. The opposite is also true: poorly performing tanks may increase farmers' awareness to take part in tank maintenance activities. This may result in either an upward or downward bias of the estimation.

Standard panel regression models (i.e., CRE or FE) alone cannot solve the problem of endogeneity caused by reverse causality in our analytical framework. The instrumental variable (IV) approach is considered a better way to account for the concerns about such endogeneity (Wooldridge 2012). IV regressions will provide unbiased estimates by addressing the endogeneity issues (i.e., reverse causation in the panel data models) (Milner et al. 2018). However, finding a good IV is always a challenge. In our models, we use the *average annual rainfall* of the last five years, *coefficient of variation of rainfall*, *number of drought years* in the last 10 years, and *labor wage outside the village* as the IVs. Farmers' decision to participate in tank management should be influenced by the rainfall pattern in the past, but it cannot depend on the rainfall in the current year because tank management activities are performed before the rainy season of the current year. In contrast, tank performance in the current year is affected by tank management before the rain as well as the rainfall in the current year. Therefore, our IVs (the mean and variability of the past rainfalls) do not directly affect tank performance in the current year but indirectly only through the influence on community participation in the current year. Thus, the IVs will satisfy the condition of exclusion restriction and relevance. In addition, male and female wage rates outside the village are used as IVs together with the three rainfall variables. The wage rate should affect the participation in tank management but will not directly influence the tank's performance. Using equation (3) as the first stage equation, equation (4) is estimated by adopting an instrumental variable approach with correlated random effects (CRE IV) to control for the endogeneity issues.

$$P_{it} = \beta_0 + \beta y_{it} + \gamma X_{it} + \delta \overline{W}_i + C_i + U_{it}, \tag{4}$$

$$y_{it} = \max\left(0,\ \pi Z_{it} + X_{it}\mu + \overline{W}_i \gamma + C_i + v_{it}\right),$$

where P_{it} is tank performance in the village i at time t, y_{it} is community participation in tank management, X_{it} is the vector of time-variant regressors, $\overline{W}_i$ is the average of the covariates over the time period, C_i is unobserved heterogeneity (random effect), U_{it} is the error term, and Z_{it} denotes the instrumental variables. The parameter of our interest is β.

However, the assumption for exclusion restriction may hold only if the tanks completely dry up every year before the monsoon. This may not always be true. According to the results presented in Table 4, the instruments that we have used are considered to be weak. Therefore, to confirm our results, we use a much simpler estimation with pooled OLS and RE regressions without considering the endogeneity. The estimated results of these regressions are given in Table 6, which shows that the estimates are quite consistent with the main results.

4. RESULTS

The estimation result of equation (3) is presented in Table 4. First, rainfall in the past influences community participation in tank management. The variability of annual rainfall (*coefficient of variation of rainfall*) significantly increases participation. In contrast, lower rainfall level (i.e., low *average annual rainfall* and *the number of drought years*) tends to decrease participation, although the estimation is not statistically significant.

In addition, *the water spread area of the tank* has a significant and positive impact on community participation in tank management. A higher water spread area may attract more participation since the farmers or other community members have the incentive to take part in tank management as long as they receive enough water supply from the tank. In addition, variable *tank modernization* has a strong and positive impact on community participation in tank management. This implies the positive feedback effect of better-performing tanks on community participation. Generally, tank modernization or tank restoration programs are assisted by state/local governments. Due to tank modernization, tank storage capacity could be improved by removing the silt deposits from the tank bed. An increase in the water capacity or water storability of the tank may attract more farmers to engage in tank management activities. When we look at the variable *tank water source*, the tanks connected with canals have a significant and positive impact on community participation compared to those that are rainfed. In general, canals are connected to large streams or rivers. Therefore, the tanks connected with canals may have a higher chance to receive a continuous supply of

Table 4. Factors Influencing Community Participation in Tank Management (CRE Tobit estimates)

	Marginal Effect
Average annual rainfall (last 5 years)	0.0001 (0.0003)
Coefficient of variation of rainfall	0.0729 (0.0268)***
No. of drought years (last 10 years)	−0.0243 (0.0186)
Tank properties	
Water spread area of the tank	0.0011 (0.0001)***
Tank modernization (last 5 years)	0.3627 (0.1464)**
Tank command area	−0.00016 (0.00015)
Length of the main canal available	0.0000128 (0.00002)
Tank water source dummy (reservoir)	−0.6122 (0.3905)
Tank water source dummy (canal)	0.3991 (0.1352)***
Tank location dummy (head)	0.1167 (0.1302)
Tank location dummy (tail)	0.1419 (0.2324)
Well density in the tank command	1.4134 (5.1366)
Well density squared ($\times 10^2$)	−10.6183 (22.4479)
Change in private wells (tank command)	−0.0058 (0.0064)
Village characteristics	
No. of households in the village	−0.0003 (0.0003)
No. of farm households	−0.1741 (0.1015)
No. of households out-migrated	0.0049 (0.0028)*
Landholding distribution (Gini)	1.5707 (1.0707)
Landholding (Gini squared)	−1.3388 (0.9560)
Labor wage male outside the village	0.0023 (0.053)
Labor wage females outside the village	−0.0039 (0.0056)
Distance to market	0.0001 (0.0005)
Male education	0.0014 (0.0038)
Female education	−0.0024 (0.0039)
Market price of paddy	−0.0183 (0.0180)
Total fertilizer use	0.0000276 (0.0001)**
Average fertilizer cost	0.0000055 (0.000064)
Means of time-variant variables	Yes
Year dummy	Yes
District dummies	Yes
No. of observations	180

Note: Dependent variable = participation in tank management (1,000 man-days). CRE Tobit = correlated random effects Tobit model. Standard errors are in parentheses.
***$p < 0.01$; **$p < 0.05$; *$p < 0.10$.

water throughout the year. This may encourage the farmers and other community members to participate in tank management activities. In contrast, rainfed tanks are more likely to be subjected to erratic rainfall patterns and remain dry most of the time. Another interesting finding is that the *number of households out-migrated* has a positive correlation with community participation. This phenomenon explains that the existing social norm of community participation in tank management does not always provide positive implications for the local community. Sometimes, it may lead to the migration of certain households, especially when the tanks are in poor condition.

The main results of this study are shown in Table 5. The point estimates of the CRE IV model indicate that *community participation in tank management* has a significant positive impact on tank performance outcomes (i.e., the ratio of irrigated area in the tank command and the paddy yield in the tank command). An increase of 1,000 man-days of participation in tank management is estimated to enhance the area under irrigation by approximately 5.12% points and paddy yield by approximately 196 kg/acre. This finding suggests that community participation in tank management is still effective in maintaining tank performance. Considering the factors influencing participation, as presented in Table 4, better-performing tanks attract more participation. This situation indicates that the causation goes both ways. In reality, it may be true, but our IV models identify the one-way impact: participation improves tank performance. Since we admit the weakness of our IVs used in the model, we have included simpler estimation methods (i.e., pooled OLS and RE) to confirm the estimation results' robustness. The estimated results of pooled OLS and RE regressions presented in Table 6 show the same trend as the main estimation results. For instance, under the RE estimation, an increase of 1,000 man-days of participation in tank management is estimated to enhance the area under irrigation by approximately 3.7% points and paddy yield by 160 kg/acre. Likewise, pooled OLS estimation shows an increase of 1,000 man-days of participation in tank management is estimated to enhance the area under irrigation and paddy yield by 3.3% points and 161 kg/acre, respectively.

The positive impact of *community participation in tank management* on the ratio of the irrigated area suggests that community engagement in tank management activities can improve the condition of tanks in terms of water storability and water discharge. Any defects in tank irrigation structures can be easily resolved if the community members are actively engaged in tank management. Encroachment problems on the tank foreshore or catchments that may hinder the tank's performance can be addressed with the help of local or state authorities if the traditional institutional arrangements are well performed.

Again, the positive impact of *community participation in tank management* on the paddy yield in the tank command implies that community participation in tank management can ensure the provision of continuous water supply to the farmers in the tank command area. Tank management activities (i.e., silt removal from the tank bed, cleaning of supply channels and main canal, and repair or replacement of damaged irrigation structures) may increase the amount of inflow and water-holding capacity of the tank. When the collective effort of tank management is well established, water shortages during the dry season can be shared by all tank users, which can ensure effective water use among the tank users.

Table 5. Impact of Community Participation on Tank Performance (CRE IV estimates)

	Ratio of the Irrigated Area in the Tank Command (%)		Paddy Yield in the Tank Command (kg/acre)	
Explanatory variables	CRE	CRE IV	CRE	CRE IV
Community participation in tank management (1,000 man-days)	4.617***	5.127***	158.48***	195.841***
	(0.9438)	(1.7998)	(35.278)	(73.269)
Time dummy (wave 2 = 1)	−18.206***	−16.905***	−262.39	−197.326
	(3.658)	(4.327)	(259.218)	(261.263)
Control variables	Yes	Yes	Yes	Yes
Observation	180	180	180	180
R^2	0.5764	0.5620	0.3726	0.3385

Notes: 1. Robust standard errors clustered at the village level are in parentheses. CRE IV = instrumental variable estimates with correlated random effects. Here, we use nonlinear specification for CRE IV as the CRE Tobit model was used in the first stage (as specified in equation 4).
2. Control variables include tank modernization, well density in the tank command, change in the number of private wells, number of farm households, availability of waterman, length of main canal available, length of canal lined by concrete, command area, land ownership, price of irrigated land, encroachment (dummy), tank water source dummy (reservoir), tank water source dummy (canal), tank location dummy (head), tank location dummy (tail), yield improved (dummy), availability of agricultural market in the village (dummy), number of sluices available for the village, number of fillings, distance to market, male education, female education, the market price of paddy, total fertilizer use, and average fertilizer cost.

***$p < 0.01$.

Table 6. Impact of Community Participation on Tank Performance (pooled OLS and RE estimates)

	Ratio of the Irrigated Area in the Tank Command (%)		Paddy Yield in the Tank Command (kg/acre)	
Explanatory variables	Pooled OLS	RE	Pooled OLS	RE
Community participation in tank management (1,000 man-days)	3.3067**	3.707***	160.873***	159.91***
	(1.3524)	(1.119)	(39.174)	(39.93)
Time dummy (wave 2 = 1)	−18.553*	−21.23***	131.796	114.869
	(9.9732)	(8.125)	(289.515)	(294.552)
Control variables	Yes	Yes	Yes	Yes
Observation	180	180	180	180
R^2	0.4734	0.4513	0.3547	0.3444

Notes: 1. RE = random effects. Robust standard errors clustered at the village level are in parentheses.
2. Control variables include tank modernization, well density in the tank command, change in the number of private wells, the proportion of farm households in the village, number of villages under the tank, availability of waterman, length of main canal available, length of canal lined by concrete, command area, the proportion of household having own land, price of irrigated land, encroachment (dummy), tank water source dummy (reservoir), tank water source dummy (canal), tank location dummy (head), tank location dummy (tail), yield improved (dummy), availability of agricultural market in the village (dummy), number of sluices available for the village, number of fillings, distance to market, male education, female education, the market price of paddy, total fertilizer use, and average fertilizer cost.
***$p < 0.01$; **$p < 0.05$; *$p < 0.10$.

5. CONCLUSIONS AND POLICY RECOMMENDATIONS

CPRs have been traditionally managed by local user communities. However, the CPRs under traditional management have been facing serious concerns due to the weakening of traditional institutional arrangements over time. This study takes an irrigation tank in Tamil Nadu as an example of CPRs under traditional management and analyzes the impact of community-based tank management on the performance of tank irrigation systems.

This study uses satellite imagery data in addition to field-level data to capture the tank performance measures with high accuracy. The ratio of the irrigated area and the paddy yield are used as the dependent variables. Community participation in tank management activities is used as the key variable of interest. Socioeconomic factors and other factors related to traditional institutional arrangements are controlled in our empirical models. However, there are many unobservable factors that may be specific to each community, or each time period may affect the consistency of our estimates. Village fixed effects and time dummies are incorporated into our empirical models to address the issues of unobserved heterogeneity at least to some extent. Moreover, the IV approach is used to address the endogeneity problems existing in our empirical model.

The key finding of this study is that *community participation in tank management* has a significant and positive impact on tank performance in terms of the ratio of irrigated areas in the tank command and the paddy yield in the tank command. This finding suggests the importance of preserving and strengthening traditional institutions to protect and maintain the irrigation tanks in a good condition. As a first step to strengthen the traditional institutions in tank governance, the government and local authorities must take necessary measures to revive the defunct Water Users' Associations (WUAs) in each tank village. WUAs are local organizations that play a major role in the governance of traditional irrigation institutions at the village level. Mobilizing community members for collective action depends on the functionality of WUAs and their network with other village- or regional-level organizations.

The state authorities must focus on the devolution of powers toward the local communities in irrigation tank management. This may provide a sense of ownership and encourage the community members to take part in the protection of their local resources. In addition, the decentralization of powers may work effectively in controlling the encroachment problems in the tank catchments as well as in the tank bunds. Another important concern regarding the functionality of local bodies is financial constraints. Therefore, relevant authorities should take necessary steps to promote community-level income generation activities (i.e., brick making, social forestry, and inland fishery) among the tank-dependent local people. The revenue collected from such activities can be used to cover the expenditures in tank management. In addition, such community-based activities create community awareness and build up social capital among the local villagers, which enhances the collective action for tank management.

The free-riding behavior of dominant group members discourages the participation of other users in tank management. Ultimately, the less-privileged group members will leave the tank irrigation systems. This occurs especially under water shortage conditions. Therefore, the state government or regional administrative bodies must ensure that the property rights or tank usufructs are clearly defined among the tank users under each tank irrigation unit. Water deficits and water surpluses must be equally shared among all tank users regardless of their situations and conditions.

This study also finds that better-functioning tanks are more likely to attract participants in tank management, which is quite natural. Thus, there seems to be a chicken-and-egg problem in tank improvement. In this regard, the significantly positive effect of tank modernization in the past on the current participation may have a good implication. Projects initiated by external agencies like the government or NGOs will be able to enhance tank performance and community participation simultaneously, solving the chicken-and-egg problem.

Although several tank rehabilitation projects have been implemented in the past by the state government of Tamil Nadu, the majority of the tanks are still facing the same issues of degeneration of tank irrigation structures and poor tank performance. These tank rehabilitation projects mainly focus on tank infrastructure development, but rarely address the issues related to user participation in tank management. Therefore, it is necessary to focus on users' perspectives, especially on community participation in tank management when devising the policies for reviving tank irrigation systems.

6. LIMITATIONS AND FUTURE SCOPE

This study has addressed an ongoing issue of declining tank performance in Tamil Nadu using two-period data along with objective assessments and rigorous estimation techniques. However, the study has several limitations, which need to be addressed in future studies. First, the data that we have used are relatively old, which sometimes may not have captured the effects of any recent policy changes. In addition, the time gap between the first and second waves is considerably larger (5–6 years). Any type of economic or natural shock that could have occurred between the two periods may affect the consistency of our estimates. Although we have addressed this issue to some extent by using our control variables, which have been generated as average values of the observations from the last five years, it is still a major limitation in this study. In addition to that, we could not control for all the community-level factors, market characteristics, and policy changes due to the data limitation that we have. Although the rigorous estimation techniques that were used might have addressed this problem to some extent, we acknowledge that there is still room for improvement. Another important concern is the validity of the IVs used in this study. Even though the IV approach is the best way to address the endogeneity issues, finding suitable IVs is always challenging. To address this issue, we performed some additional robustness checks in this study and found the estimates to be consistent with our main findings. However, the analytical part still needs improvement. In addition, this study focuses on only a specific aspect of social norms (i.e., cooperative behavior) that is related to community participation in irrigation tank management. Therefore, future studies should explore more aspects of the existing traditional institutional arrangements for tank irrigation management in Tamil Nadu using continuous panel data with the latest information.

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