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State of Irrigation in Tamil Nadu: Investments and Returns

Upali A. Amarasinghe,[1] K. Palanisami,[1] O.P. Singh[2] and R. Sakthivadivel[3]
[1]International Water Management Institute, India Office.
[2]Banaras Hindu University, Varanasi, India.
[3]Consultant, Tamil Nadu (Former Fellow, International Water Management Institute).

Introduction

Development of land infrastructure for agriculture in monsoonal Asia had three major phases of growth (Kikuchi et al. 2002). Bringing new land under cultivation for increasing agricultural output dominated the first phase. However, the cost of opening up new land increased gradually due to limitations of suitable arable land and constraints for developing them for agricultural activities. The response to this cost increase was development of irrigation on existing lands, which dominated the investments in the second phase. With increasing unit cost of new irrigation development, water management for agriculture became dominant in the third phase. At present, investments in the agriculture sector in Tamil Nadu are in the third phase, where improving the performance of existing irrigation facilities is the primary concern.

Trends in irrigation development show that the State of Tamil Nadu as a whole has already reached its irrigated potential. Most of the utilizable surface water resources for canal irrigation are stored in 64 large and medium, and 11 small reservoirs (GoTN 2007). Conventional potential developed with the available surface water resources in major and medium systems has reached a peak of about 1.5 million ha (Mha) in the 1970s (GoI 2006). More than 39,202 tanks support tank irrigation whose potential was reached long before 1970. The potential utilization of groundwater is more than 85% of the available resources (CGWB 2006). In fact, many regions in Tamil Nadu are experiencing severe groundwater depletion at present. Thus, maintaining the existing infrastructure and managing the distribution of surface water and abstraction of groundwater constitute the major focus in recent policy interventions and investment patterns (GoTN 2003).

However, in spite of significant investments in operation, maintenance and water management, especially in major, medium and tank irrigation sectors, the area under surface water irrigation has been decreasing in recent years. Moreover, in spite of vastly overexploited groundwater resources, private investments in groundwater development are increasing, albeit at a reduced pace (Amarasinghe et al. 2009).

This paper assesses recent trends in public and private investments, and their returns to agricultural production in Tamil Nadu. Such knowledge, with increasing water scarcities and demand, would be important to aid future investment decisions. First, we show the trends of public and private investments in the irrigation sector of Tamil Nadu since 1970. Next, we assess the contribution from different growth and investment patterns in irrigation to the state crop output. Third, we assess irrigation demand at present and potential water management improvements for meeting future demand. Finally, we conclude the paper with recommendations for investments in the irrigation sector to improve agricultural productivity and production.

Trends of Investments in Irrigation

Public investments, mainly on major, medium and minor irrigation schemes, meet the cost of new construction and rehabilitation, recurrent expenditure on operation and maintenance (O&M) and staff salaries and benefits. Major and medium irrigation reservoirs include schemes with commands over 10,000 ha and between 2,000 and 10,000 ha, respectively. Minor irrigation involves tanks; surface flow irrigation, which involves diversion from a stream or storage in a community-owned small tank or pond; and surface lift irrigation schemes, in which water is lifted from a stream or river into irrigation channels due to topographic constraints for direct surface flow irrigation.

Private investments are mainly in dug wells and in shallow and deep tube wells. Dug wells are open wells with a depth up to the water-bearing stratum. Shallow tube wells tap groundwater from the porous zones with a depth not exceeding 6-70 meters (m) and would, generally, operate about 6-8 hours and yield 100-300 m^3 per day during the irrigation season. Deep tube wells in general have a depth more than 100 m, discharge 100-200 m^3/hour, and can have 15 times more annual output than shallow wells. But the output is not sustainable (CGWB 2006; Palanisami et al. 2008).

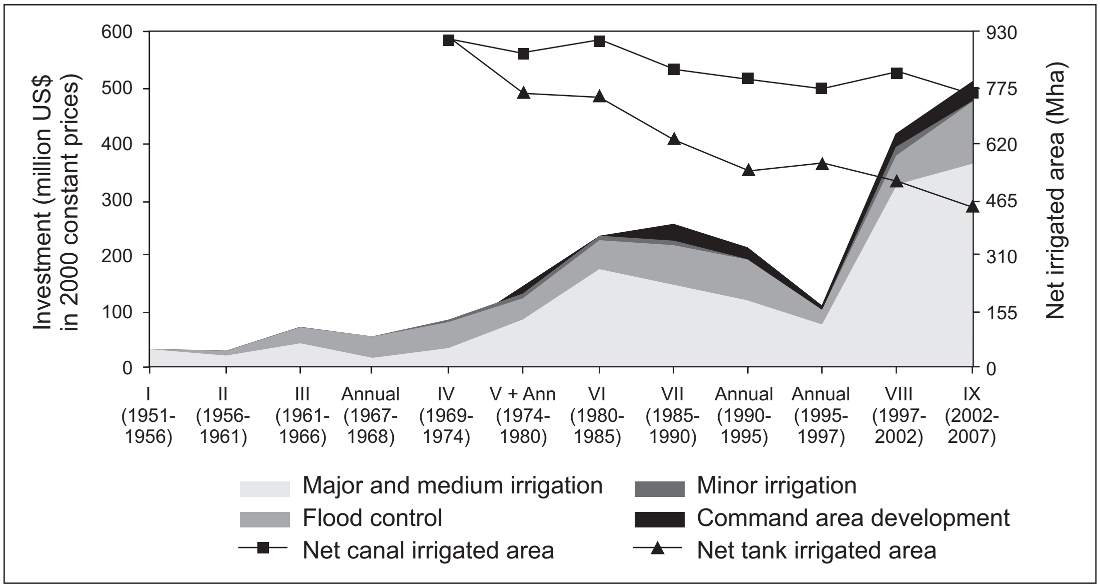
Data on plan-wise investments in Tamil Nadu on major, medium and minor irrigation schemes were collected from various government publications for the study (GoTN 2007)

Public Investments in Major and Medium Irrigation Schemes

Public investments in major, medium and minor irrigation schemes from the first Five-Year Plan (1951-1956) to the tenth Five-Year Plan (2002-2007) are shown in Figure 1.[1] The investments in major and medium irrigation schemes show three different periods. First, the investments gradually increased to a peak in mid-1980, up to the sixth Plan. Almost all new constructions ended by that time. Since then, the investments have declined, along with net irrigated area, until the late 1990s. A major investment again in the eighth Plan has reversed and perhaps stabilized the declining trend in major/medium irrigation scheme areas.

[1]This includes annual plans between 1967/68 and 1968/69, 1978/79 and 1980/81, and 1990/91 to 1996/97.

Figure 1. Public investments in major/medium and minor irrigation schemes.



Source: GoTN 2007.

The total expenditure in major/medium irrigation schemes was US$1,327 million (Rs 5,961 crores in 2000 constant prices) during 1970-2007. Indeed, a part of this public expenditure meets the salaries and benefits of the staff, amounting to 70-80% of the total annual recurrent expenditure. The annual expenditure on staff salaries and benefits in this sector is estimated to be around $16-18 million.[2] Thus, investments for rehabilitating and new construction of major/medium irrigation schemes in five-year plan periods since the mid-1970s could be well over $730 million. Yet, over this period, the net irrigated area under canals has declined by about 85,000 ha, or 10% from the level of the mid-1970s. This conforms to the all-India level marginal increase of 0.11 Mha per year during the 1990s compared to 0.22 Mha in the 1970s.

Regionally, the deltaic and central regions account for 53% and 32%, respectively, of the net irrigated area under major and medium irrigation schemes. Thus, it is assumed that these two regions benefited vastly from investments in major/medium irrigation schemes in the past few decades. However, the net canal irrigated area in deltaic and central regions has decreased by 50,000 and 10,000 ha, or 10% and 6%, between 1980 and 2000 (Amarasinghe et al. 2009). With increasing population and urbanization, the water demand in both domestic and industrial sectors will increase in the future. And, with higher income and affordability, the share of surface water supply for both sectors would likely be increased (Shah et al. 2008; Sundarajan et al. 2009). Thus, sustaining canal irrigation at the present level, especially in both the regions and generally in the state, will be a major challenge.

Public Investment in Minor Irrigation

***Tank irrigation*:** Minor irrigation has the next highest share of public investments, and a major part of it is spent on tanks. Tamil Nadu accounts for 17% of all tanks in India. As per official records, there are 39,202 tanks in the state. Most of these tanks are small and are linked to one another under cascading systems (Palanisami and Easter 2000; Gomathinayagam 2005). These tanks have inextricable links to the lives of the rural communities and are indispensable in sustaining village habitats and the socioecological balance. About 1.0 million rural households depend on the tank for their livelihoods and more than 75% of them are small and marginal farmers. Thus, O&M of tanks are important for the overall investment portfolio of the state water resources.

Tamil Nadu has initiated many tank rehabilitation programs in the past few decades, with several of them under the aegis of various external donors. They include the European Economic Community (EEC), Japan International Corporation Agency (JICA), National Bank for Agriculture and Rural Development (NABARD) and the World Bank. Since 1970, under the above programs, the state government has invested $430 million (Rs 1,940 crores in 2000 prices) in minor irrigation schemes, and a major part of this was on tanks. Of this, as much as $125 million[2] would have been spent on rehabilitation and new constructions of minor irrigation schemes. In tanks, these investments are mainly for physical rehabilitation and institutional interventions.

In spite of these regular investments, the net tank irrigated area has declined by more than 460,000 ha, or roughly 50% of the tank area of the 1970s (Figure 1). Many factors have contributed to the declining tank command area, including increasing variability of monsoonal rains, encroachment of supply channels and tank beds, sand mining of supply channels, rural infrastructural development such as roads and housing, and reduced tank inflows due to unplanned watershed development, etc. (Raj 2005). In several cases, the tanks have become defunct due to internal conflicts or due to no water inflows resulting from construction activities in the upstream of the tank catchment. The collection of water charge from the tanks has also declined due to nonfunctioning of the tanks, which are considered nonfunctional. In several cases, such tanks act as percolation ponds. However, not all of the area declined under net tank irrigation category has gone out of production.

In fact, groundwater irrigation is increasing in command areas in many small tanks. In the past, surface water from many small tanks was the source of irrigation in the respective command areas, and hence these areas were considered to be under the net tank irrigated command area. However, many small tanks are now primarily a catalyst for groundwater recharge (Palanisami 2008). This recharge is a reliable source for groundwater irrigation within the command area, and for the drinking water supply for the neighboring communities and livestock. Therefore, although many small tanks cease to support surface water irrigation, they still support irrigation indirectly through groundwater in command areas. These areas are now accounted for under the category of net groundwater irrigation.

Thus, although tank irrigated area is declining, maintenance of tanks in Tamil Nadu is still important. Some of them still directly support surface water irrigation, while many others, mainly small tanks, support groundwater irrigation. It is important to understand the threshold of the size of tanks, below which tanks mainly support groundwater recharge.

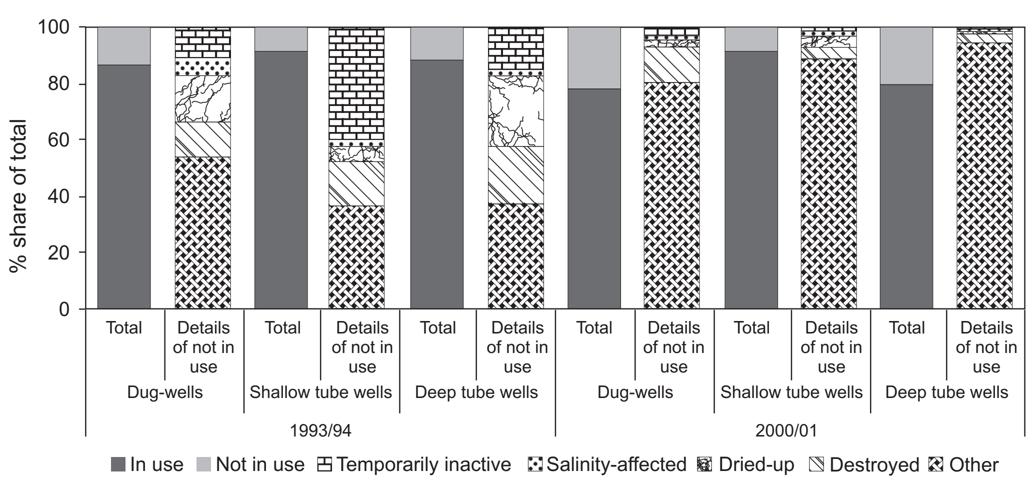
[2]The annual plans between 1990/01 and 1996/97 spent on average $14 $\pm$ 3 million (2000 constant prices) for minor irrigation. Salaries and benefits of this component, assuming 70-80% of the recurrent expenditure, are estimated to be about $10-11 million. So, overall investments in rehabilitating and construction of new minor irrigation since 1970 could be around $127 million.

Surface lift irrigation systems: Besides tanks, surface lift systems also create irrigation potential under minor irrigation. Surface lift systems mainly overcome topographic constraints by pumping water directly from streams or rivers to irrigation channels. These schemes, which are mainly public, are similar to river diversions, but often require large pumps, installed in the pump houses, to lift water from rivers. Some of them are government-authorized schemes and many operate under cooperative societies. Some of the schemes in the rivers are unauthorized and still pump water using diesel engines. The transaction cost of delivering the water is very high. Surface lift schemes provide irrigation to only 1% of the total irrigated area, and to less than 3% of the minor irrigation area in Tamil Nadu.

Private Investment

Private investments in irrigation are mainly on dug wells and tube wells. The second census of minor irrigation (MOWR 2001) shows that Tamil Nadu had more than 1.5 million dug wells, 107,661 shallow tube wells, and 36,462 deep tube wells by 1993/1994 (Annex Table 1). Of these, 13%, 8% and 11%, respectively, were not used in 1993/94 (Figure 2), and a substantial part of them were only temporarily inactive (57% of dug wells, and 37% each of shallow and deep tube wells). The permanent well failures, due to salinity, dried-up water supply, destruction or other reasons, were only 6% of dug wells and 5% and 7% of shallow and deep tube wells, respectively.

Figure 2. Wells (%) in use and the reasons for wells not in use.



Source: MOWR 2001, 2005.

The third census of minor irrigation conducted in 2000/01 shows that more than 150,000 dug wells, and 68,000 and 37,000 shallow and deep tube wells, respectively, were constructed over the 7 years since 1994 (MOWR 2005). In fact, construction of shallow wells and deep tube wells has increased substantially over this period, by 98% and 154%, respectively. However, annual growth rate of construction of tube wells is slowing down due to falling water tables. Although the number of inactive wells has increased between 1994 and 2001, the share of that in the total had decreased by 2001. In 2001, only 4%, 8% and 1% of dug wells, shallow wells and deep tube wells, respectively, were inactive. And more than 80% of them are only temporarily inactive.

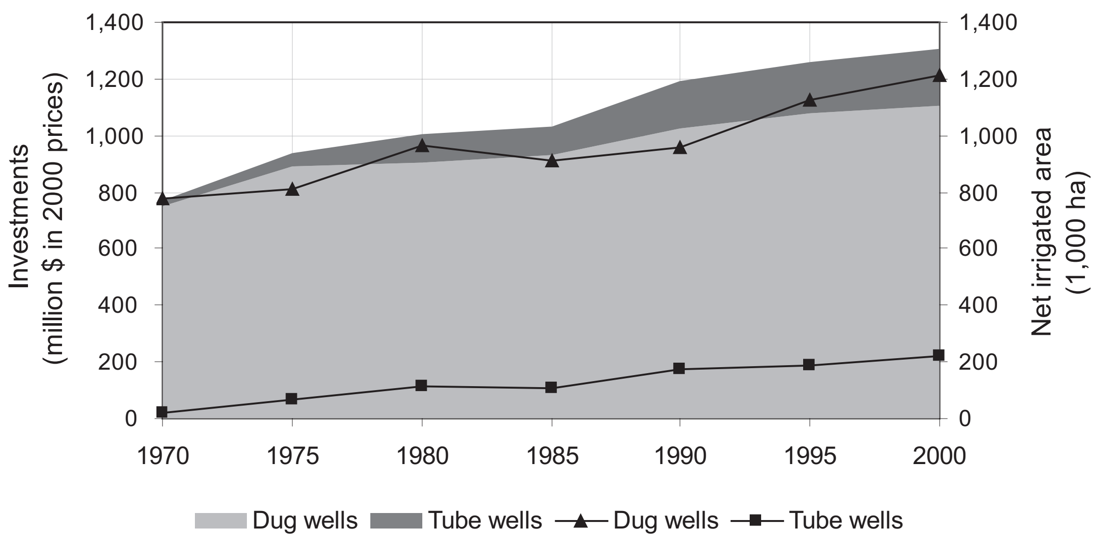
Due to extensive groundwater abstraction, the growth of dug-well construction has slowed down considerably in all regions. The central and southeast coastal regions have two-thirds of the dug wells, which had been constructed by 2000, followed by the north region with 17% (Table 1).

The growth rate of the construction of shallow tube wells has decreased in all regions except the north. But, the north region only accounts for a small share (less than 1%) of shallow tube wells. More than 85% of shallow tube wells are concentrated in the southeast coastal and deltaic regions, while the central region accounts for another 10%.

The construction of deep tube wells, however, has continued in most regions. The central region accounts for 46% of deep tube wells, followed by deltaic, north and southeast coastal regions with 18%, 14% and 10%, respectively. The growth rate of the construction of tube wells has decreased in the central and deltaic regions, while there are annual fluctuations in the growth rate in other regions.

No estimates of private investments, except the data on the number of wells, are available in official records. We estimate private investments in groundwater development[3] using the following assumptions. The construction of each dug well, shallow tube well and deep tube well costs[4] Rs 30,000, 50,000 and 100,000 (in 2000 prices; $1.00=Rs 44.94 in 2000), respectively. We also use the number of dug wells and tube wells per ha of net irrigated area (Table 1) in 1993 to estimate the total number of tube wells prior to 1993. Figure 2 shows these cost estimates along with data on the growth of net irrigated area.

Figure 2. Private investments in dug wells and tube wells.



Sources: Investments are authors' estimates. Area is from GoTN 2007.

[3]Investment in electricity was a major driver of groundwater expansion in the state. By 1970, the peak demand of the state was 1,000 Mw. The demand has increased by 10 times to about 6,290 MW by 2000. Ideally, the part of the electricity consumption in the agriculture sector needs to be considered in the total investments in this sector.

[4]Indeed, the cost of construction varies between regions and also with other parameters such as depth, type of bore, etc. As these items of information for different regions are not available for this analysis; we use the same average cost per well in all regions for estimating the total construction cost.

Investments in dug wells:

- A large part of the construction of dug wells occurred prior to 1970. The aggregate investment in dug wells between 1970 and 2000 was about $357 million, which was only half of the total investment in dug-well construction before 1970 and 40% of the combined public investments (minus salaries and benefits) in major/medium and minor irrigation schemes since 1970.

- There has been a sharp decline in investments in dug wells in the last decade, accounting for only $66 million between 1994 and 1996, and only $16 million in the next 4 years.

- Regionally, central and northeast coastal regions account for 35% and 31%, respectively, of the dug wells constructed between 1970 and 200 while the north and southeastern coastal regions accounted for 17% and 12%, respectively.

Investments in tube wells:

- Most of the constructions in tube wells started after 1970. The total investment in tube wells between 1970 and 2000 was about $202 million, which was about ten times the investments before 1970, and only about 11% of the public investments in major, medium and minor irrigation schemes after 1980.

- About half the investments were on deep tube wells, and more than 60% of that were in the 1990s.

- Although, the investments in tube wells are increasing, the rate of growth is slowing down. This is especially true in the northeast coastal and deltaic regions, where more than 80% of groundwater resources are already utilized. Investments on tube wells in the north region show no signs of abating, although this region, as a whole, has overexploited its available resources.

- About 39% of shallow tube wells and 17% of deep tube wells were in the deltaic region, although this region only accounts for 8% of the net irrigated area under tube wells in Tamil Nadu. In fact, filter point wells account for about 69% of the wells in the deltaic region. This indicates that many of these wells in the deltaic region provide the necessary reliability of irrigation water deliveries in canal command areas. However, there is potential to increase the number of wells in the region.[5]

Next, we assess how these investment patterns have contributed to crop production in Tamil Nadu. We use gross value of output (GVOP) of crop production for this purpose.

Determinants of Growth of Gross Value of Output of Crops

The gross value of output (GVOP) consists of the value of production of 18 crops.[6] We use the average of unit export prices in 1999, 2000 and 2001 to estimate[7] the GVOP. It shows the change in gross production over time with respect to the changes in cropping patterns and productivity. The average export prices are used here only as a means for aggregating the crop production.

The GVOP of crops in Tamil Nadu increased steadily between 1970 and 1995 (Figure 3). The total crop output decreased slightly between 1995 and 2000, but decreased significantly after 2000, due primarily to severe droughts between 2002 and 2004. However, crop production seems to be picking up with good rainfall in recent years.

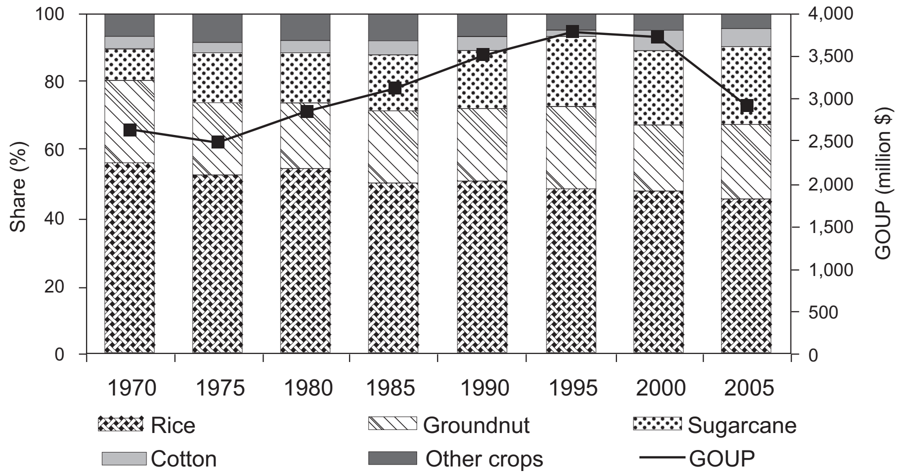
[5]Groundwater potential of the deltaic region

	Groundwater potential of the deltaic region					Distribution of wells in the deltaic region			
Districts	Ground-water recharge	Utilizable ground-water recharge	Net ground-water	Balance	Develop-ment (%)	No. of wells possible	No. of bore wells	Number of filter points	Area covered (ha)
Tanjore	163,162	138,688	58,087	80,601	45	43,659	5,342	830	12,344
Nagapattinam	59,058	50,199	50,031	168	103	91	1,006	19,420	40,852
Trichy	222,305	189,384	98,461	90,923	55	49,253	6,405	8,758	30,326
Pudukottai	118,105	100,389	23,506	76,883	26	41,644	12,753	29,008	83,522

[6]These crops includes, rice (287), sorghum (97), pearl millet and finger millet (170), maize (108), wheat (123), chickpea (455), pigeon pea (231), groundnut (567), sesamum (691), rapseed/mustard (205), safflower (204), castor (384), linseed (329), sunflower (204), soybean (189), sugarcane (219) and cotton (1,150). The values within parentheses are the average of the unit export prices ($) in 1999, 2000 and 2001. Cotton prices are for cotton lint.

[7] $GVOP_t = \sum_{i=1}^{18} P_{it} \times average\,(p_i^{1999}, p_i^{2000}, p_i^{2001})$, where P_{it} is the production of i^{th} crop in t^{th} year, and $p_i^{1999}, p_i^{2000}, p_i^{2001}$ are the world export prices of i^{th} crop in 1999, 2000 and 2001, respectively.

Figure 3. Share of gross value of output (GVOP) by major crops.



Source: Authors' estimates.

Four crops, rice, sugarcane, groundnut and cotton, contribute to 95% of the crop output. The share of rice in gross crop production has decreased from 56% to 46% from 1970 to 2005 , while that of sugarcane has increased from 9% to 23%, and that of cotton has increased slightly from 3% to 6%. Among the other crops, maize had a major increase in crop production, accounting for only 1% in 1971 to 26% by 2005 of the gross output of other crops. In fact, maize production has increased by 16 times over this period to cater to the growing feed demand for livestock, especially for poultry.

Contribution from Irrigation to Crop Output in Tamil Nadu

The contribution from irrigation to crop productivity growth in India is well recognized. Irrigation is the key input that explains the vast differences of crop yields in neighboring irrigated and rain-fed areas (Huzzain 2005). With its ability to control water application, groundwater irrigation can have significantly higher crop yields than in other irrigated fields (Dhawan 1998; Kumar et al. 2008).

We estimate the contributions of different sources of water inputs, in terms of net irrigated and rain-fed areas, to crop output growth in Tamil Nadu between 1970 and 2000. The contribution from irrigation is further subdivided into different sources of irrigation, such as net irrigated area under canals, tanks, tube wells and dug wells. Along with irrigation, application of many other agronomic inputs, which has increased over time, has contributed to the growth of crop productivity. The information on total fertilizer use and area under high-yielding varieties (HYVs) of rice area is available for this analysis. Cropping intensity and crop diversification affect gross value of output. We estimate these effects in irrigated and rain-fed areas through aggregate indices (see Amarasinghe et al. 2009 for a detailed discussion). The use of many nonagronomic inputs, such as machines, transport, etc., also contributes to productivity growth. Increase in road infrastructure, which acts as a trigger for increasing many nonagronomic inputs, is available for this analysis. We estimate the contributions of different factors to gross value of output growth using a series of recursive panel regressions. The panels, consist of data in 10 districts over 31 years (1970-2000) and include

$$\begin{aligned} GVOP_{it} = \beta_0 + \sum_{i \in districts} \beta_{1i} D_{it} + \beta_2 NIA\_Canal_{it} + \beta_3 NIA\_Tank_{it} + \beta_4 NIA\_TW_{it} + \\ \beta_5 NIA\_DW_{it} + \beta_6 NRFA_{it} + \beta_7 CI\_IR_{it} + \beta_8 CI\_RF_{it} + \beta_9 CDIVI\_IR_{it} + \\ \beta_{10} CDIVI\_RF_{it} + \beta_{11} FERTT_{it} + \beta_{12} HYVRA_{it} + \beta_{13} ROADL_{it} + \\ \beta_{14} GOUP_{it-1} + \beta_{15} RF\_SWM_{it} + \beta_{16} RF\_NEM_{it} + e_{it} \end{aligned}$$

$$\begin{aligned} CI\_IR_{it} = \alpha_0 + \sum_{i \in districts} \alpha_{1i} D_{it} + \alpha_2 NIA\_Canal_{it} + \alpha_3 NIA\_Tank_{it} + \alpha_4 NIA\_TW_{it} + \\ \alpha_5 NIA\_DW_{it} + \alpha_6 CDIVI\_IR_{it} + \alpha_7 ROADL_{it} + \alpha_8 RF\_SWM_{it} + \\ \alpha_9 RF\_NEM_{it} + \alpha_{10} CI\_IR_{it-1} + \varepsilon_{it} \end{aligned}$$

$$\begin{aligned} CI\_RF_{it} = \gamma_0 + \sum_{i \in districts} \gamma_{1i} D_{it} + \gamma_2 NIA\_RF_{it} + \gamma_3 CDIVI\_RF_{it} + \gamma_4 ROADL_{it} + \\ \gamma_5 RF\_SWM_{it} + \gamma_6 RF\_NEM_{it} + \gamma_7 CI\_IR_{it-1} + \varepsilon_{it} \end{aligned}$$

$$\begin{aligned} FERTT_{it} = \eta_0 + \sum_{i \in districts} \eta_{1i} D_{it} + \eta_2 NIA\_Canal_{it} + \eta_3 NIA\_Tank_{it} + \eta_4 NIA\_TW_{it} + \\ \eta_5 NIA\_DW_{it} + \eta_6 NRFA_{it} + \eta_7 CI\_IR_{it} + \eta_8 CI\_RF_{it} + \eta_9 CDIVI\_IR_{it} + \\ \eta_{10} CDIVI\_RF_{it} + \eta_{11} ROADL_{it} + \eta_{12} RF\_SWM_{it} + \eta_{13} RF\_NEM_{it} + \\ \eta_{14} FERTT_{it-1} + \varepsilon_{it} \end{aligned}$$

where,

- Subscripts *i* and *t* vary over districts (10 in this analysis) and time (31 years from 1970,..,2000), respectively.
- $GVOP_{it}$ is the gross output of crops (in million $).
- D_{0i} are dummy variables taking value 1 for the i^{th} district and 0 otherwise. We assume different intercept coefficients for districts in the panel regressions.
- NIA_Canal_{it}, NIA_Tank_{it}, NIA_TW_{it}, NIA_DW_{it}, are net irrigated area under canals. tanks, tube wells and dug wells; and $NRFA_{it}$ is the net rain-fed area (in 1,000 ha).
- CI_IR_{it} and CI_RF_{it} are cropping intensities[8] in irrigated and rain-fed areas.

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[8]In general, cropping intensity is defined as the ratio of gross cropped area to net sown area. However, this approach ignores the fact that some crops occupy the land in more than one season, and thus underestimates the cropping intensity. For instance, although sugarcane occupies the land throughout the year, its contribution to cropping intensity using the normal method is 100%, as both gross and net areas are the same. However, if rice occupies the same area and cropped twice a year, then cropping intensity is 200%. We eliminate this anomaly by taking the contribution of sugarcane, cotton and other non-food-grain crops, excluding oilseeds by multiplying the cropped area by a factor of 2, 1.6 and 1.5, respectively. That is, the cropping intensity in irrigated area is defined as s

$$CI\_IR = \frac{(IA\_grains + IA\_oilcrops + 2 * IA\_sugar + 1.6 * IA\_cotton + 1.5 * IA\_nongraincrops)}{NIA} * 100$$

where, IA_grains, IA_oilcrops, IA_sugarcane, IA_cotton, and IA_non-graincrops are annual irrigated areas under food grains, oilseeds, sugarcane, cotton, and other non-grain crops (mainly vegetables and fruits) respectively. Cropping intensity in rain-fed areas is defined using a similar method.

- $CDIVI\_IR_{it}$, and $CDIVI\_RF_{it}$ are crop diversification indices[9] of irrigated and rain-fed areas.
- $FERTT_{it}$ is the total fertilizer used (1,000 tons).
- $HYVRA_{it}$ is the total (HYV) rice area (1,000 ha).
- $ROADL_{it}$ is the total road length (1,000 km).
- RF_SWM_{it} is the actual southwest monsoonal rainfall (June-October).
- RF_NEM_{it} is the actual northeast monsoonal rainfall (November-April).
- e_{it} is the error term.

We estimate the coefficients using weighted least square regression with net sown area as weights. This eliminates the effects of heteroscedasticity. The estimated coefficients are given in Table 2. The contributions from different sources to the changes in GVOP over different time-periods are given in Table 3. We use the regression coefficients, which indicate the average growth in GOUP, to estimate the changes in contribution over different periods. The first regression results clearly indicate that irrigation had an enormous contribution to the increase in gross output of crops in Tamil Nadu. The contribution from irrigation alone to GOUP is about $600/ha ($894/ha of net irrigated area to $292/ha of net rain-fed area).

[9]Crop diversification in general expects to boost gross value of crop output. We capture the crop diversification using the following index, which is similar to the Theils index of inequality. Let the irrigated crop area of rice, maize, other cereals, pulses, oilseeds, sugar, cotton, and other non-food-grain crops as a percent of gross cropped area be defined as %IA_rice, %IA_maize, %IA_other, %IA_pulses, %IA_oilseed, %IA_sugar, %IA_cotton, and %IA_nongraincrops. Then the crop diversification index in irrigated areas is defined as

$$CDIV\_IR = (\%IA\_rice^2 + \%IA\_maize^2 + \%IA\_otcer^2 + \%IA\_pulses^2 + \%IA\_oilseed^2 + \%IA\_sugar^2 + \%IA\_\cot ton^2 + \%IA\_ongrcr^2)*100$$

Crop diversification in rain-fed areas is defined similarly using the area under rain-fed crops. The index value of 100% shows the least crop diversification, indicating only one crop occupies the gross cropped area. The highest crop diversification occurs when gross crop area is equally divided among eight crop categories and indicated by the index value 12.5%.

Table 2. Estimated regression coefficients of gross output (GVOP in million $), cropping intensities in irrigated and rain-fed areas (CI_IR, Is this CI minus CI_RF in %), and total fertilizer use (FERT in 1,000 tonnes).

Variables	Estimated Coefficients (Coeff) and Standard error (SE) of estimates*									
	Gross output (GVOP) Regression 1		Gross output (GVOP) Regression 2		Cropping intensity in irrigated areas (CI_IR)		Cropping intensity in rain-fed areas (CI_RF)		Fertilizer use (FERT)	
	Coef	SE	Coef	SE	Coef	SE	Coef	SE	Coef	SE
Net irrigated area (1,000 ha)	0.864	0.10*	-	-	-	-	-	-	-	-
▪ Net canal irrigated area (1,000 ha)	-	-	1.052	0.23*	0.117	0.05*	-	-	0.114	0.05*
▪ Net tank irrigated area (1,000 ha)	-	-	0.761	0.17*	0.012	0.05	-	-	0.048	0.04
▪ Net tube-well irrigated area (1,000 ha)	-	-	1.232	0.25*	-0.127	0.06*	-	-	0.189	0.06*
▪ Net dug-well irrigated area (1,000 ha)	-	-	0.954	0.16*	-0.184	0.04*	-	-	-0.001	0.03
Net rain-fed area (1,000 ha)	0.262	0.07*	0.275	0.07*	-	-	0.154	0.04*	-0.005	0.02
Cropping intensity in irrigation (%)	0.569	0.21*	0.587	0.21*	-	-	-	-	0.060	0.05
Cropping intensity in rain-fed (%)	-0.090	0.09	-0.147	0.09	-	-	-	-	-0.022	0.02
Crop diversification in irrigated areas (%)	-1.504	0.49*	-1.171	0.53*	-0.238	0.14**	-	-	-0.181	0.12
Crop diversification in rain-fed areas (%)	-0.019	0.62	0.256	0.64	-	-	1.045	0.44*	0.309	0.15
Total fertilizer application (1,000 tonnes)	1.127	0.17*	1.025	0.19*	-	-	-	-	-	-
High-yielding rice area (1,000 ha)	0.247	0.09*	0.197	0.09*	-	-	-	-	-	-
Total road length (1,000 km)	2.586	0.81*	2.698	0.87*	0.400	0.19*	0.216	0.43*	0.864	0.20*
Southwest monsoonal rainfall	-0.024	0.03	-0.017	0.03	-0.009	0.01	0.003	0.02	0.008	0.01
Northeast monsoonal rainfall	0.005	0.01	0.006	0.01	0.004	0.00	0.004	0.01	0.010	0.00
Lag dependent variable of order 1 (Y_{t-1})	0.194	0.04*	0.172	0.05*	0.383	0.05*	0.206	0.06*	0.728	0.05*
R^2	89%		90%		63%		78%		92%	
Durbin Watson statistic	1.65		1.61		1.95		1.96		2.0	

Source: Authors' estimates.

Note: For brevity, coefficients of district dummies are not presented here. * and ** indicate that coefficients are statistically significant at 0.05 and 0.1 level.

Table 3. Contribution of different factors to the change in GVOUP in Tamil Nadu.

Factor	Units	Value (3-year averages)				Decadal change				Contribution from different factors to the change in GVOUP as a % of total estimated change			
		1970	1980	1990	2000	1970-1980	1980-1990	1990-2000	1970-2000	1970-1980	1980-1990	1990-2000	1970-2000
NIA-canals	1,000 ha	907	907	801	822	0	-106	20	-86	0	-48	6	-9
NIA-tanks	1,000 ha	911	752	544	518	-159	-208	-26	-392	-27	-62	-5	-27
NIA-tube wells	1,000 ha	20	114	173	218	94	59	45	198	27	29	14	23
NIA-dug wells	1,000 ha	778	963	959	1214	185	-4	255	436	33	-1	50	31
Net rain-fed area	1,000 ha	3,642	3,042	3,179	2,382	-600	137	-797	-1260	-37	15	-54	-31
CI_IR	%	142	144	144	138	2	0	-6	-4	0	0	-1	0
CI_RF	%	127	130	133	142	3	3	9	15	0	0	0	0
CDIVI_IR	%	51	46	39	39	-6	-7	-1	-13	1	3	0	1
CDIVI_RF	%	22	22	19	20	0	-3	1	-2	0	0	0	0
FERT_total	1,000 tonnes	296	519	807	975	222	289	167	678	48	107	40	59
HYVRA	1,000 ha	1,973	2,162	1,798	1,927	190	-364	129	-46	8	-26	6	-1
ROAD_length	1,000 km	61	118	175	207	56	58	31	145	32	57	20	33
Lag (GOUP)	Million $	2,510	2,922	3,351	3,958	412	429	606	1,448	15	27	24	21
GOUP	Million $	2,640	2,853	3,520	3,722	213	667	202	1,082	100	100	100	100

Notes: NIA denotes net irrigated area; CI_IR, CI_RF are cropping intensities in irrigated and rain-fed areas. CDIVI_IR, CDIV_RF are crop diversification indices in irrigated and rain-fed areas; HYVRA denotes high-yielding rice area; FERT is fertilizer use.

Source: Authors' estimates

Irrigation has also contributed to increased cropping intensity, crop diversification and input use. Thus, overall contribution of irrigation, directly or indirectly, to GVOP growth is more than the estimated direct contribution of $600/ha. The second regression, which estimates the contributions under different sources of irrigation, shows that:

- Canal and groundwater irrigation gives significantly higher outputs. The difference between canal irrigated and rain-fed areas is $777/ha, and the differences between tube well plus dug-well areas and rain-fed area are $957 and $679 /ha, respectively.
- Higher cropping intensities in irrigated areas also contribute to higher GVOP, with every 100% increase in cropping intensity in irrigated areas adding a further $587/ha to GVOP. With higher cropping intensities, the contributions to GVOP in canal irrigated areas are significantly higher.
- Crop diversification also had a significant positive impact on irrigated lands, where every 1% reduction in index, or increase in crop diversification, increases GVOP by $1.504 million. However, the contribution from diversification in rain-fed areas is not significant. The main reason for this difference is that irrigation assures the all-important reliable water supply for diversifying to high-value crops, while in rain-fed areas crop diversification is only a risk aversion for a total crop failure.
- Fertilizer application also has a significant impact, where every additional ton of fertilizer applied on gross cropped area increased GVOP by $1,205.
- Area under HYVs of rice also has a significant impact, adding $197 for every additional hectare.
- Infrastructural development also had a significanct effect in increasing crop output, with every kilometer addition to the road network having effected an increase of $2,698 in GVOP.

There are decadal changes in different factors and their contribution to GVOP increase in Tamil Nadu (Table 3). Between 1970 and 1980:

- Net canal irrigated area in Tamil Nadu had no significant change. Over this period, net area under tank irrigation and rain-fed area decreased by 17% and 16%, respectively. But, net groundwater irrigated area increased by 279,000 ha. A part of this groundwater irrigation expanded in areas previously considered under tank irrigation commands; also in several rain-fed farms farmers made new groundwater investments through drilling bore wells to avoid further uncertainty in rainfall.
- Total fertilizer application has increased by 75%, with an increase in their rate of application from 39 to 73 kg/ha.
- Total area under HYVs of rice has increased by 10%, while the coverage has increased from 75 to 85% of the total area.
- The length of the road network has expanded by 91%, with the road density increased from 4.7 to 9.0 km/ha.

The contributions from increased a) tube well and dug-well irrigated areas (27% and 33%, respectively), b) fertilizer and HYV use (48% and 8%, respectively) and c) road network (32%) have offset the production loss due to the reduction in tank irrigated and rain-fed areas

(27% and 37%, respectively). As far as irrigation is concerned, groundwater expansion has contributed significantly to increase crop production between 1970 and 1980.

Between 1980 and 1990:

- Net irrigated area under canals declined by 12%, while under tanks it further declined by 28%, which decreases are equivalent to a loss of 314,000 ha of net irrigated area from these two sources since 1980. However, over this period, net irrigated area under tube wells and rain-fed agriculture has increased by 52% (about 69,000 ha) and 15% (about 137,000 ha), respectively.
- With a 56% increase in total fertilizer application, the rate of fertilizer application has further increased from 73 to 113 kg/ha of gross cropped area.
- Total area under HYV rice has decreased by 17%, but high-yielding rice varieties covered 95% of the total area in 1990.
- The length of road network increased by 49%, resulting in an increase in the road density from 9.0 to 13.5 km/ha.

Contributions from increased area under tube wells, fertilizer application and expanded road infrastructure have offset the production losses in canal and tank irrigated areas. Increased fertilizer application had the largest contribution to GOUP increase. Once again, groundwater irrigation expansion offset the losses due to decreased tank and canal irrigated areas.

Between 1990 and 2000:

- Net irrigated area increased by 12%, from 2.492 to 2.787 Mha. Dug wells, (255,000 ha), tube wells (45,000 ha) and canals (20,000) have contributed to this increase. And, they offset the area declined under tank irrigation (25,000 ha) and rain-fed conditions (797,000 ha). Obviously, a part of the command area that declined under tank and rain-fed conditions is now irrigated under dug wells and tube wells.
- Total fertilizer use increased by 20%, with an increase in the rate of application from 117 to 157 kg/ha.
- Rice area under HYV increased by 7%, and almost all rice areas (97%) had been covered with HYV by 2000.
- Total road length increased by 17%, with increased road density from 13.5 to 15.9 km/ha.

Additional irrigation from groundwater and fertilizer application has contributed significantly to the increase in GVOP in this period. Although expanded road infrastructure contributed to GVOP increase, the magnitude is significantly lower than in the two previous decades.

Irrigation Investments and GVOP Increase

Clearly, a major part of the increases in GVOP in Tamil Nadu between 1970 and 2000 was due to private investments in dug wells and tube wells. The contribution from irrigation investments to the change in GVOP in Tamil Nadu between 1970 and 2000 is given in Table 4.

- A major portion of investments in major and medium irrigation schemes after 1970 was for rehabilitation and O&M of existing systems. In spite of close to $1 billion investments, net irrigated area under major and medium irrigation schemes decreased by 9%. And, that contributed to a 9% decrease in GVOP.
- In spite of continued investments in minor irrigation, tank irrigated area almost halved during this period. As a result, the contribution to GVOP decreased by 27%.
- However, investments in groundwater irrigation had a major positive contribution in increasing GVOP. Every dollar invested in tube well and dug-well irrigated areas added more than one dollar to GVOP over this period.

This analysis clearly shows the disproportionate returns to investments between surface water and groundwater irrigation in Tamil Nadu. The investments in surface-water irrigation in the 1980s and 1990s had twofold and threefold increases, respectively, compared to investments in the 1970s. Yet, there were no comparable gains in crop output over this period. In comparison, the investments in groundwater irrigation, although only 40% of the total investments in surface water irrigation, had a large impact in increasing crop output in Tamil Nadu between 1970 and 2000. This does not, however, mean that investments in O&M of canal irrigation and tanks were not useful. What is clearly required is a major overhaul in the pattern of public irrigation investments in Tamil Nadu. Some pertinent questions here are:

Table 4. Investments in irrigation, changes in net irrigated area and contributions to GVOP change between 1970 and 2000.

Scheme	Investments	Absolute and relative change in net cropped area (1,000 ha)		Contribution to change in GVOP and as a % of total change	
	(Million $ 2000 prices)	Million ha	%	(Million $ 2000 prices)	%
Major/medium irrigation	962	-86	9	-106	-9
Minor irrigation	368	-392	43	-321	-27
Tube-well irrigation	181	198	1,016	268	23
Dug well irrigation	357	436	56	368	31
Rain-fed agriculture	-	-1,260	35	-369	-31

Note: Although not included in the table, there were substantial investments for the watershed development program to assist rain-fed agriculture. (Please complete).

Source: Authors' estimates.

1. What investments in major/medium irrigation sector are required to maintain the schemes to irrigate crop area at the present level? It is a fact that major and medium reservoirs will end up in meeting the increasing demand in domestic and industrial sectors. It is unlikely that net irrigated area under major/medium irrigation schemes will increase in the future with the present level of water development. Therefore, crop production needs to be concentrated in high-productivity and high-potential canal irrigation schemes. Some important aspects that should be investigated here are:

   - Which major/medium irrigation schemes in different regions, or regions as a whole, will have a major competition for domestic and industrial water in the future?
   - Which major/medium irrigated areas have the highest productivity and income per every unit of water consumed?
   - What potential exists and what interventions are required to increase the productivity through crop or agricultural diversification?
   - What physical, institutional and policy interventions are required to spread water saving irrigation techniques such as sprinklers, drip system of rice intensification, aerobic rice, etc.?

These items of information will be necessary for identifying high productivity and high potential zones in major/medium irrigation command areas for crop production.

2. What minimum investments in minor irrigated areas are required to maintain surface-water irrigation in tank commands? It is obvious that in spite of large investments, tank irrigated area has been gradually decreasing. But the data indicate that groundwater irrigation may have replaced irrigation in many small tank command areas in recent times. Therefore, it is important to identify:

   - The tank irrigated commands with high crop productivity for sustaining crop production under surface water irrigation.
   - The small tanks that can be used for groundwater recharging to support groundwater irrigation in tank command areas (such as converting them into percolation tanks).
   - The institutional and policy arrangements required for maintaining tanks for groundwater irrigation in command areas, etc.

3. Where will investments in tube wells/dug wells generate high returns in the future? It is clear that, due to overexploitation of the available resources, new investments in tube wells and dug wells are gradually decreasing. The total investments in the 1980s were only 75% of the investments in the 1970s, and have since decreased to 49% in the 1990s. Because of overexploitation, further investments in tube wells and dug wells will only spread the water into a large area, but may not provide the adequate irrigation supply that the investment is required to provide. Thus, it is important to know:

   - What part of the total groundwater withdrawals is, in fact, depleted as consumptive water use and what investments are required to reduce overabstraction and improve the efficiency of groundwater use?
   - Which areas have high potential for further development? And what are the consequences of additional depletion in the downstream water use?

In the next section, we explore some of the questions that we posed above. There we estimate the total water withdrawals and consumptive water use in different regions, and develop scenarios to understand the implications of increased efficiency of water use.

Irrigation Demand

We estimate irrigation demand in 1999-2001 for 10 crops or crop categories (rice, maize, other cereals (including millet and sorghum), pulses, oilseeds, roots and tubers, vegetables, fruits, sugar, cotton and other crops) (See Amarasinghe et al. 2005, 2007a for more details).

Irrigation demand is estimated for both surface water and groundwater irrigated areas. We assume average project efficiencies of 35% for surface water and 55% for groundwater irrigation in 2000 (Amarasinghe et al 2007a). Table 5 shows the consumptive water use (CWU) of all crops, CWU of crops in irrigated areas, CWU in irrigated areas by irrigation, and irrigation demand in surface water and groundwater irrigated areas.

In 2000, Tamil Nadu depleted 29.4 km^3 as CWU in crop production. Of this, irrigated croplands depleted 23.7 km^3 or 80% of the total CWU. Irrigation deliveries contributed to 16.2 km^3, or 55% of the total CWU. The share of CWU in irrigated lands varies from 62% in the hill region to 94% in the deltaic region, and the share of CWU from irrigation varies from 45% in the north to 70% in the deltaic region. Although irrigated lands contribute to a large portion of CWU, the soil moisture due to rainfall still contributes to a substantial part of crop production. Improved rainwater management can still play a major role in crop productivity growth in many regions.

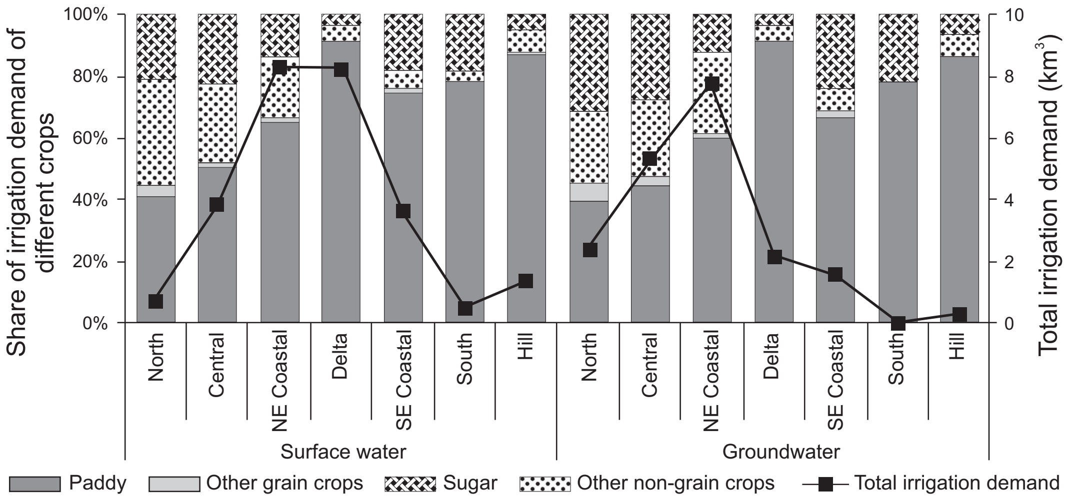
Irrigation demand, for a total irrigated area of 3.44 Mha was 46.3 km^3 in 2000. The northeast coastal, deltaic and central regions account for a large share of total irrigation demand, 35%, 23% and 20%, respectively. Of the total irrigation withdrawals, only 35% is depleted as CWU, indicating a large scope for reducing the irrigation demand by increasing irrigation efficiency. The opportunities for increasing efficiency are higher in surface water irrigation, accounting for 58% of the total irrigation withdrawals. This share in the deltaic and southeast coastal regions is much higher, accounting for 79% and 70%, respectively of the total irrigation demand. A large portion (73% withdrawals of surface water) is used for irrigating paddy (Figure 4). This share is more than 90% in the deltaic region.

Table 5. Consumptive water use and irrigation demand in 2000.

Region	CWS (in km^3)			Irrigation demand (in km^3)			CWU from irrigation as a % of	
	Total	In irrigated areas	Share from irrigation	Surface water	Ground-water	Total	Total CWU	Total irrigation demand
North	3.1	2.0	1.4	0.7	2.4	3.1	45	44
Central	7.3	5.4	3.6	3.8	5.3	9.2	49	39
NE coastal	10.4	9.0	5.9	8.3	7.9	16.2	57	37
Delta	4.4	4.1	3.1	8.3	2.1	10.4	70	29
SE coastal	2.8	2.3	1.6	3.6	1.6	5.2	58	32
South	0.3	0.2	0.1	0.5	0.0	0.5	40	25
Hill	1.1	0.7	0.5	1.4	0.3	1.7	43	28
Tamil Nadu	29.4	23.7	16.2	26.8	19.5	46.3	55	35

Source: Authors' estimates.

Figure 4. Surface water and groundwater irrigation demand for paddy, food grains, sugarcane and non-food-grain crops.



Source: Authors' estimation.

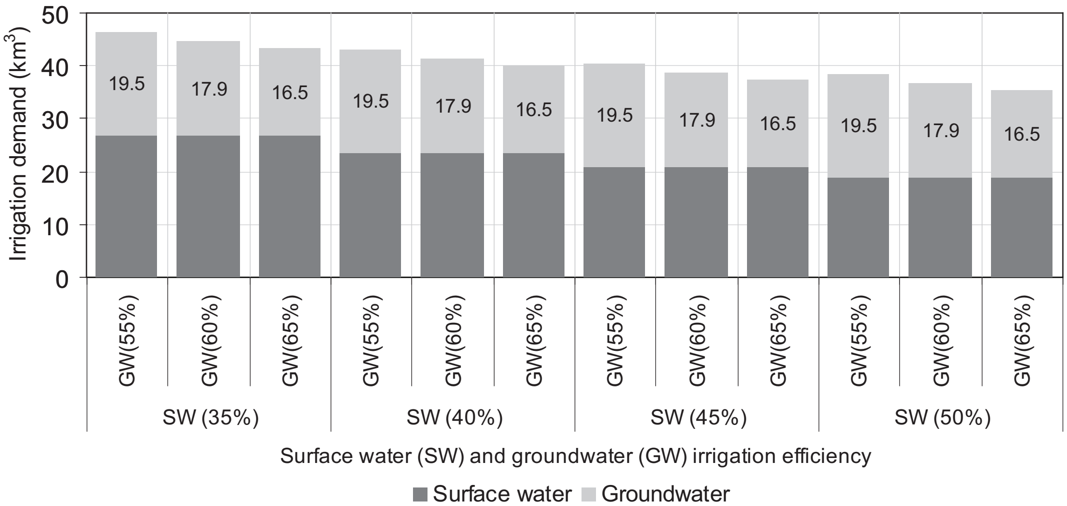
A major part of the total irrigation withdrawals in the southeast coastal, south and hill regions is also used for paddy irrigation, and these regions have very low CWU, accounting for only less than 30% of the total demand. Being located in the southern parts of the states, they have the largest scope for increasing irrigation efficiency without affecting the return flows and downstream users.

Groundwater is the source of 56% of the crop irrigated area, but it shares only 42% of the irrigation withdrawals. The north, central and northeast coastal regions account for 80% of the total groundwater withdrawals. These three regions, as well as the groundwater irrigated areas of other regions, have a significant area under non-food-grain crops, mostly dominated by sugarcane. The low ratio of consumptive water use at present, for instance 37%, 39% and 44%, respectively, in the north, central and northeast coastal regions (Table 5), shows that many groundwater irrigated areas do also have large scope for increasing efficiency, thereby reducing the pressure on scarce groundwater resources. To what extent can increasing irrigation efficiency save water in these regions? We show the benefits that can accrue using increased project efficiency scenarios in surface water and groundwater irrigation schemes.

Impact of Higher Irrigation Efficiency on Water Demand

Figure 5 shows the surface water and groundwater withdrawals under different efficiency scenarios: 35%, 40%, 45% and 50% for surface water, and 55%, 60% and 65% for groundwater irrigation.

Figure 5. Surface water and groundwater irrigation demand under different irrigation efficiency scenarios.



Source: Authors' estimation.

The current levels of surface water and groundwater irrigation efficiencies are 35% and 55%, respectively, and the total withdrawal at this level is estimated to be 46.3 km^3 (left-most bar in Figure 5). The differences between the first and the remaining bars show the reduction in irrigation withdrawals with improved irrigation efficiency scenarios.

If the groundwater irrigation efficiency is increased to 65% (third bar in Figure 5) the groundwater and total irrigation demand are 15% and 6% lower than the current level. If surface water irrigation efficiency is also increased simultaneously (say to 40%, sixth bar in Figure 5), then the surface water and groundwater irrigation demands are 15% and 12%, respectively, lesser than the current levels, and the total irrigation demand is 14% lesser than the current level.

If surface water and groundwater irrigation efficiencies can be increased to 50% and 65%, respectively, (last bar in Figure 5), then the surface water, groundwater and total irrigation demand can be decreased by 30%, 15% and 24%, respectively. Indeed, such irrigation efficiency improvements, which are not impossible to achieve under the current advances in technology, could have a large positive impact for water-scarce states like Tamil Nadu. The water saved by improving irrigation efficiency can then be used for either increasing production of the same crop, or to meet additional water demand for crop diversification, to meet increasing domestic and industrial demands, or to ecosystem water needs. We illustrate the potential benefits of the first two next.

Increasing Crop Production from Water Savings

In this, we illustrate the benefits only under the last scenario, where surface water and groundwater irrigation efficiencies are increased to 50% and 65%, respectively. Under this scenario, the total irrigation demand for maintaining the current level of crop production decreases by 24%. Paddy and sugarcane account for 84% of the total irrigation demand. Under the improved efficiency scenario, irrigation demand for paddy and sugarcane decreases by

25% and 22%, respectively. This increases water productivity--which is defined here as the ratio of irrigation production to irrigation withdrawals--of paddy and sugarcane by 33% and 29%, respectively (Table 6).

If all water savings in paddy are again used for paddy cultivation, the total production under the improved irrigation water productivity scenario could be 33% higher. Since almost all (97%) paddy production at present is under irrigation, the additional production with improved efficiencies would basically increase the overall rice production. Such increases would be more than enough to meet the rice demand of Tamil Nadu's increasing population in the short term. In fact, the total population in Tamil Nadu is projected to increase by 13% between 2001 and 2025, and then decrease by about 8% by 2050.

Table 6. Water productivity and savings in the cultivation of rice, maize, sugarcane and fruit crops under the improved efficiency scenario.

Region	Water productivity (kg/m^3 of irrigation water delivered)								Water savings under increased efficiency (km^3)			
	Under current level of efficiency[1]				Under increased efficiency[2]							
	Paddy	Maize	Sugar-cane	Fruits	Paddy	Maize	Sugar-cane	Fruits	Paddy	Maize	Sugar-cane	Fruits
North	0.32	0.41	0.36	1.13	0.39	0.49	0.46	1.37	0.23	0.00	0.16	0.04
Central	0.31	0.41	0.53	1.28	0.40	0.50	0.68	1.60	0.95	0.02	0.49	0.12
NE coastal	0.24	0.29	0.42	1.01	0.31	0.37	0.54	1.33	2.36	0.00	0.82	0.12
Delta	0.17	0.39	0.34	0.95	0.24	0.53	0.47	1.30	2.59	0.00	0.14	0.02
SE coastal	0.20	0.32	0.42	1.03	0.27	0.41	0.56	1.37	0.97	0.01	0.09	0.11
South	0.32			1.00	0.45			1.41	0.13	0.00	0.00	0.01
Hill	0.20	0.31	0.36	1.10	0.27	0.42	0.49	1.49	0.40	0.00	0.04	0.01
Tamil Nadu	0.23	0.39	0.44	1.12	0.30	0.48	0.57	1.43	7.64	0.03	1.74	0.43

[1]Current level of surface water and groundwater irrigation efficiencies are 35% and 55%, respectively.
[2]Improved level of surface water and groundwater irrigation efficiencies are 50% and 65%, respectively.
Source: Authors' estimation.

If the water savings in paddy are used for maize production, total maize production under the improved irrigation water productivity scenario could have a 28-fold increase. Although the current level of maize production is very small compared to paddy, it is the only food-grain crop that has recorded a significant growth of demand in recent times. Between 1995 and 2005, commensurate with increasing livestock feed demand, maize irrigated area and production had a fourfold increase. At the present rate of demand growth, maize production requires at least an 8-12-fold increase in the next two to three decades. Thus, most water savings through efficiency increase in paddy can be diverted to meet increasing demand for maize.

If water savings in sugarcane are again used for more of its cultivation, irrigated sugarcane production can be increased by 29%. As in paddy, all crop production at present is under irrigation. Thus, any additional production under irrigation will increase the total production with a similar rate of growth. Tamil Nadu produces significantly more sugar than it consumes now. And the present level of surplus is more than adequate to cater to the increasing population in the foreseeable future. Thus, the better option here is to divert the water savings in sugarcane irrigation to other non-food-grain crops.

If all water savings in sugarcane irrigation are used for fruit cultivation, additional fruit production could be 62% more than the total production at present, and the additional vegetable and cotton production could be, 126% and 269%, respectively, higher than the present production. Thus, as in the case of paddy, most water savings in sugarcane can be diverted to increase the production of fruits, vegetables and cotton. In fact, per capita demand of these crops has increased significantly over recent years and is likely to further increase with increasing income in the coming decades.

The above discussion primarily focused on the implications of crop production due to improvements in irrigation efficiency and water productivity. Increases in water productivity here are only due to a decrease in irrigation water use. But water productivity can also be increased by increasing crop yield. We discuss the implications of crop-yield growth on crop production and irrigation demand next.

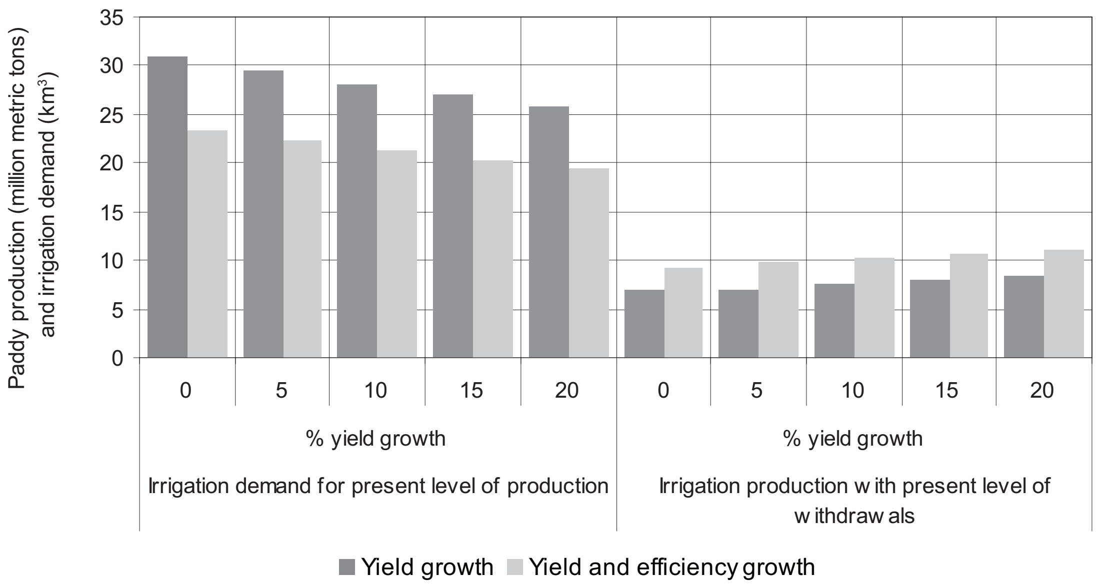
Impact of Higher Crop Yield on Irrigation Water Demand

Thanks to irrigation, yields of major crops in Tamil Nadu are comparatively better than those in most other major states. For instance, only Punjab (Indian part) has a slightly better rice yield (4.0 tonnes/ha) than Tamil Nadu (3.56 tonnes/ha). Sugarcane yield in Tamil Nadu is the highest, 12% higher than in Karnataka and 21% higher than in Maharashtra.

However, these yields in comparison to other major rice- and sugarcane-producing countries in Asia are still low. The average rice yields in China, the Republic of Korea and Turkey are more than 15% higher than those in Tamil Nadu. Yet, there could be an opportunity for increasing rice yield with better input management. In fact, Amarasinghe et al. (2009) show that the increase in paddy yield is significantly related to better fertilizer application, reliable irrigation input, and other technological advancements. We assess the implications of irrigated paddy production and irrigation demand, if irrigated yields are increased simultaneously with efficiency increase (Figure 6).

At present, the estimated irrigation demand for paddy is 31 km^3. If paddy yields can be increased by 10-20%, the irrigation withdrawals required to achieve the present level of paddy production will decrease by 9-17%. If irrigation efficiencies are also increased simultaneously, from 35% to 50% in surface water irrigation and from 55% to 65% in groundwater irrigation, then the irrigation demand for paddy would decrease by 31-37% from the present level.

Figure 6. Irrigated paddy production and irrigation demand under different scenarios of yield growth (0-20%) and irrigation efficiency growth (surface water efficiency is 35-50% and groundwater efficiency is 55-65%).



Source: Authors' estimation.

If paddy yield increases, then, barring any decline in area, production also increases at the same rate. But if the water savings through efficiency growth are again used for expanding paddy cultivation, then with a 10-20% yield growth, irrigated production can be increased by 39-53%.

This shows that a slight increase in crop yields and a moderate growth in irrigation efficiency can, in fact, decrease the irrigation demand for producing food for the increasing population. The total population of Tamil Nadu is projected to peak to about 71 million by the early 2030s, which is about 14% more than the 2001 level. So, essentially a similar increase in yield can meet the increasing demand for rice at the present level of per capita consumption.

But, in Tamil Nadu, per capita rice consumption is also decreasing at 0.69% and 0.39% annually in urban and rural areas, respectively; and a substantial difference exists in per capita rice consumption between urban and rural areas, 8.58-10.13 kg/month. Moreover, the urban population is increasing rapidly, 2.2% annually in the 1990s. So, with the present level of changing consumption and demographic patterns, the total rice demand could increase by only 6%, which is 8% points lesser than the population growth, by 2035. Thus, a yield increase of 6% is adequate to meet increasing demand for rice, and any simultaneous growth in efficiency can reduce the irrigation demand. In addition, interstate rice arrivals can also meet the local demand whenever the rice production decreases in the state due to failure of rains.

The above analysis clearly shows that a simultaneous increase in yield and irrigation efficiency can be a solution to the increasing water scarcities in Tamil Nadu.

Discussion and Conclusion

This analysis shows that major, medium and minor irrigation sectors in Tamil Nadu are not contributing to crop production growth exactly as the investments in these sectors are supposed to generate. Irrigation investments in these three sectors since 1970 have been primarily for rehabilitation and O&M of existing schemes, which could be well over $1 billion. In spite of these investments, net surface-water irrigated area has declined between 1970 and 2000 by 10% in canal irrigation commands, and most notably by 50% in the tank irrigation commands. This indeed is a significant reduction, considering that 70% of the net irrigated area in the 1970s was under canals and tanks.

However, there is a strong possibility that not all the net area that declined from canal and tank irrigation has disappeared totally from crop production. A large part of the command area that was surface-water irrigated previously is now groundwater irrigated. This is more prevalent in command areas of small tanks, which are now acting as artificial groundwater recharge structures. Groundwater recharge is a source for reliable irrigation in a large part of surface water command areas, providing the much-needed domestic water supply for rural communities and livestock. Between 1970 and 2000, net groundwater irrigated area increased by 0.646 Mha compared to 1.719 Mha of area that declined under canal and tank irrigation and rain-fed agriculture. Over the same period, total investment in groundwater (dug wells and tube wells) irrigation development, which is mainly private, increased by $560 million. This is only a little over half the public investments on surface-water irrigation schemes. Indeed, our estimate of investments in groundwater does not reflect the public investments in generating power, where the agriculture sector has enjoyed free electricity in Tamil Nadu since 1989 (Palanisami 2002).

In spite of the differences in investment patterns, it is clear that groundwater irrigation had a significant contribution for crop output increase. Between 1970 and 2000, the estimated contribution of groundwater irrigation alone to crop output increase is about $636 million. In comparison, production losses due to area decline in surface-water irrigation and rain-fed sectors are estimated to be over $795 million. Groundwater irrigation, not only as a reliable irrigation input by itself but also as a catalyst for other inputs such as fertilizers, has contributed to this production growth. In fact, contribution of increased fertilizer application to crop output growth was over $695 million.

Groundwater irrigation could also have a significant impact on irrigation water use. In 2000, groundwater was the source for 56% of the 3.444 Mha gross irrigated area in Tamil Nadu. But, groundwater contributed to only 46% of the 46.3 km^3 of total irrigation withdrawals. A 10% increase in groundwater efficiency, from the present level of 50%, would reduce total groundwater demand by 15% and total irrigation demand by 6%. The Government of India has estimated that by increasing water use efficiency by 10% , it is possible to add an additional 14 Mha under irrigation (MoWR 2007). In the first place, such reductions would be a direct and enormous relief for groundwater-overexploited regions. Second, it can save the much-needed energy for other sectors, which the agriculture sector uses freely at present. If groundwater recharge from reservoirs and tanks can be effectively used for groundwater irrigation in command areas, it can improve crop productivity, increase efficiency, and save water for other sectors where demand increases with increasing population and economic activities

Increasing efficiency in surface-water irrigation is another way of meeting increasing water needs of the nonagriculture sectors. At present, surface-water irrigation is estimated to operate at 35% efficiency, and meets 58% of the total irrigation demand. A modest increase in surface-water irrigation efficiency, say by 15%, could reduce total irrigation demand by about 8.0 km^3. This saving, which is significantly more than the combined demand of 6.3 km^3 of the domestic and industrial sectors at present can meet the projected additional demand of 7.2 km^3 of these sectors by 2050 (Authors' estimates based on PODIUMSIM model; Amarasinghe et al. 2005, 2008). However, the impact of such improvements in surface-water irrigation efficiency on groundwater recharge and groundwater irrigation downstream needs better understanding

Another option is to use water savings through efficiency increases for increasing crop production. Improvements of surface water and groundwater irrigation efficiencies to 50% and 65%, respectively, from the present level of 35% and 50%, respectively, could reduce the irrigation demand by 24%. If water savings in paddy are again used for increasing paddy cultivation, additional rice production would be significantly more than the total additional demand for the increasing population. A similar production increase is possible for sugarcane, the most water-consuming crop in the state. In fact, only a part of water savings is adequate for irrigating other crops, such as fruits and vegetables for food and maize for livestock feeding. The demand for these crops is increasing with changing food consumption patterns.

Increasing crop yields on existing land can make additional irrigation demand less. For example, with the changing consumption patterns, total rice demand will increase anywhere between 6% and 14%. The latter is the growth of population of Tamil Nadu, when it reaches its maximum in the mid-2030s. Similar increases in crop yield on existing land would be sufficient to meet additional food demand without additional irrigation.

The future investments in irrigation in Tamil Nadu indeed require some rethinking. Investments in surface water irrigation would perhaps require new direction. Investments on O&M and rehabilitations of major and medium irrigation schemes are still required. More specifically, tertiary system improvements are needed for effective water control by the farmers (Palanisami et al. 2008). But investments should promote a different mode of irrigation within the command areas with a view to increase efficiency. This can include a properly managed conjunctive water use plan to utilize groundwater recharge in command areas, or intermediate storage tanks in a farm or in a group of farms for increasing on-farm water use (Amarasinghe et al. 2008). The latter can be a vehicle for spreading micro-irrigation in surface water irrigation commands.

Investments in tank irrigation require a completely new approach. Rehabilitation of tanks is still important, but the type of rehabilitation depends on whether tanks supply water for surface-water or conjunctive irrigation or whether the tanks recharge groundwater to facilitate complete groundwater irrigation in command areas. The threshold for selecting tanks only for groundwater recharge depends on its interconnectedness with other tanks in cascade systems and extents of water use in the neighboring communities, number of fillings and hydrogeology. Further research is required for selecting these thresholds. Selective tank modernization with needed interventions is recommended as against the package of modernization, which incorporates all components of tank systems (Palanisami and Easter 2000).

Groundwater irrigation is an important part of the irrigation landscape in Tamil Nadu, but overexploitation threatens its sustainability. Thus, public investment should facilitate groundwater recharge to augment water supply. Watershed development in overexploited regions for artificial recharge through dug wells needs to be taken up (Shah 2009). The state should explore policies and action plans for reducing groundwater overabstraction. As such about 19,330 micro-watersheds are delineated for interventions in the state and about 4,500 watersheds have been covered under the watershed programs. Increase in the water table due to watershed programs was ranging from 1 to 3 meters depending on the regions (Palanisami et al. 2009). Policy initiatives of pricing electricity, however, unpopular politically, can have an immediate impact, or providing separate reliable electricity supply for agriculture, such as Jothigram in Gujarat (Shah and Verma 2008) could be another option.

Irrigation investments should promote water saving techniques, such as drip and sprinklers, for reducing overabstraction. So far, Tamil Nadu has less than 20% irrigated area under drip and sprinkler irrigation. But water saving techniques can expand to a substantially more crop area (Narayanamoorthy 2009). Large-scale adoption of drip and sprinklers would not only save water but also improve irrigation efficiency and increase productivity.

Annex Table 1.

Year	Agroclimatic subregions: North	Central	Southeast coastal	Delta	Northeast coastal	Tamil Nadu	Agroclimatic subregions: North	Central	Southeast coastal	Delta	Northeast coastal	Tamil Nadu
	Number of dug wells						Number of dug well/ha of net irrigated area					
1993	265,902	548,611	466,500	28,848	182,215	1,533,839	1.19	1.41	1.28	3.5	1.52	1.39
1994	9,301	13,062	21,933	876	3,450	50161	1.12	1.30	1.31	3.6	1.48	1.34
1995	5,539	10,182	10,453	918	2,886	31528	1.14	1.52	1.32	3.0	1.77	1.44
1996	3,017	4,189	6,468	772	1,368	16549	1.62	1.48	1.27	5.6	1.91	1.53
1997	1,847	2,274	3,692	362	,804	9586	1.75	1.41	1.30	12.7	1.67	1.52
1998	992	1,648	2,403	247	483	5978	1.18	1.30	1.19	14.6	1.56	1.32
1999	620	1,075	1,053	95	412	3358	1.12	1.28	1.33	21.4	1.54	1.35
2000	766	807	1,918	33	928	5502	1.18	1.24	1.34	20.1	1.71	1.36
	Number of shallow tube wells						Number of tube wells/ha of net irrigated area[1]					
1993	718	11,083	54,314	38,920	1,555	107,661	1.36	1.19	0.43	3.25	1.72	0.78
1994	38	640	4,320	4,494	166	9,724	1.46	1.28	0.45	3.90	2.29	0.85
1995	28	921	3,789	4,466	181	9,503	1.55	1.59	0.46	4.86	2.71	0.93
1996	58	576	3,735	3,893	179	8,479	0.94	1.53	0.51	5.99	3.32	0.96
1997	125	667	2,618	3,227	191	6,944	1.25	1.67	0.49	4.99	2.46	0.98
1998	130	557	1,445	2,200	190	4,629	1.48	1.65	0.49	4.83	2.31	1.05
1999	95	470	706	1,374	128	2,809	1.41	1.67	0.50	6.13	2.66	1.06
2000	92	203	483	594	95	1,501	1.15	1.74	0.50	5.83	2.05	1.05
	Number of deep tube wells											
1993	6,136	15,218	4,827	7,441	767	36,462						
1994	907	2,359	681	1,833	148	6,532						
1995	557	4,254	467	1,600	160	8,044						
1996	782	4,686	560	1,493	165	8,518						
1997	789	3,596	386	1,034	179	7,194						
1998	658	4,319	833	890	272	8,188						
1999	1,380	2,561	409	660	247	5,978						
2000	301	1,581	229	496	99	3,094						

Source: Authors' estimates based on GoI 2009.

[1]This includes all shallow and deep tube wells per net irrigated area.

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