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ANALYSIS

Watershed externalities, shifting cropping patterns and groundwater depletion in Indian semi-arid villages: The effect of alternative water pricing policies

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ABSTRACT

Frequent droughts and groundwater depletion are critical constraints to improving agricultural productivity in the semi-arid tropics. India has been promoting integrated watershed management in drought-prone areas to address these constraints. Watershed communities are being assisted to invest in groundwater re-charging facilities. While communities and the public bear such costs, individual farmers capture irrigation benefits. Groundwater is a free common property resource and land users hold de-facto use rights. This has accelerated private irrigation investments and depletion of aquifers resulting in iniquitous distribution of irrigation water. Power subsidies and negligible pumping costs aggravate the problem. These policy failures and low irrigation costs to farmers are displacing water-efficient crops in favor of water-intensive crops in water-scare areas. The paper reviews the village-level externalities that aggravate groundwater depletion and evaluates potential policy options to enhance local collective action in water management. Using 3SLS, an econometric crop-water productivity model is used to evaluate alternative water policy instruments. The results indicate that different types of water user charges can be introduced with modest consequences on profitability and farm incomes. If properly implemented and managed by the local communities, pro-poor policies could bring considerable sustainability benefits and also ensure enhanced equity in access to the resource.

1. Introduction

In the last few decades, there has been a phenomenal increase in groundwater extraction for irrigation, municipal and industrial use worldwide. Higher rates of depletion are observed in many countries where increasing population pressure and expected economic gains have created strong incentives to deplete the resource (World Bank, 1999). In India, along with population growth, declining farm sizes, the inherent risk of recurrent droughts in the drier areas, and supportive policies for smallholder irrigation development have induced land-use intensification and dramatic increases in groundwater utilization. Between 1970 and 1994, the area under groundwater irrigation more than doubled (Shah, 2002). By 2002, this has increased to 3.5 times while area under canal irrigation increased by 1.5 times (Reddy, 2006). Currently, groundwater is the single largest source of irrigation accounting for about 60% of the 50 million ha of irrigated land in the

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country. This increase in groundwater irrigation is partly fueled by the green revolution and increased adoption of high-yielding varieties (Foster and Rosenzweig, 2005).

The availability of institutional credit for setting up bore (tube) wells and power subsidies for pumping groundwater have induced remarkable increases in the number of wells (about 1 million in 1960 to 19 million in 2000) (Shah, 2002), particularly in drier areas where surface water is scarce. While this has made substantial contributions in reducing rural poverty through raising agricultural productivity and farm incomes, excessive extraction without sufficient investment in re-charging facilities has led to faster depletion of groundwater resources, especially in semi-arid regions (Reddy, 2005). Even when the level of re-charging has increased, the groundwater level is declining in many watersheds due to unregulated use and over-exploitation. This is reflected in the increasing drilling and extraction costs for farmers as well as complete drying and abandonment of some wells. Some studies indicate that up to 50% of wells once in use have completely dried-up (Shah, 2002; Reddy, 2005).

Accelerated depletion of groundwater resources can have adverse effects on the livelihoods of the rural poor that rely on agriculture, especially in semi-arid areas where supplemental irrigation is critical for crop growth (Reddy, 2005). Moreover, water scarcity is projected to increase in the future as water withdrawal for domestic, industrial and other uses increases further. As growth opportunities in more favorable areas are exhausted, there is a growing interest to improve productivity in rainfed areas on the grounds of equity, efficiency and sustainability. Thus, India has adopted integrated watershed management as a viable strategy for improving productivity in drought-prone and water-scarce areas (Farrington et al., 1999; Kerr, 2001). Although substantial public and external funds are being spent on watershed management, the economic and environmental impacts of the program and the sustainability of the interventions have been questioned (Joshi et al., 2004,b; Reddy et al., 2007). Whereas supply-side interventions have enhanced re-charging of groundwater, open-access externalities and adverse policies are threatening to offset these gains as groundwater resources are depleted.

While competitive groundwater markets may help redistribute the resource (Shah, 1993), such markets often evolve in regions where groundwater supplies are not limiting trade, and hence much less developed in semi-arid areas. In the presence of open-access externalities, distorting subsidies, and physical barriers that limit wider water transfers, informal water markets may not also effectively mitigate depletion of groundwater resources. Addressing current and future water constraints would require new policies and institutional arrangements for supply augmentation and demand management (World Bank, 1999). When supply is constrained, innovative demand management would entail adoption of water-saving technologies, localized management and policy and institutional reforms that create incentives for an *in-situ* water conservation.

This paper focuses on groundwater depletion and the market and policy failures that discourage adoption of water-saving agricultural practices and evaluates two promising policy approaches that may motivate behavioral changes to counter water depletion in semi-arid areas. We use primary data collected through ICRISAT household and community surveys in 12 semi-arid villages to track changes in irrigation, and its effects on cropping patterns and depletion of aquifers. The plot-level data is used to estimate the shadow price of water which enters a jointly estimated econometric model of net returns and irrigation intensity with endogenous input use equations. The model is used to evaluate alternative water policies and their impacts on the returns to smallholder irrigation.

The paper is organized as follows. The following section outlines the watershed externalities and policy failures that accelerate groundwater depletion. Section 3 presents the theoretical framework for analysis of household decisions under water and other family resource constraints. The empirical model and econometric specification issues are presented in Section 4. The following section presents data and water use patterns in the study villages. The empirical results are discussed in Section 6, before we conclude in Section 7, highlighting the key findings and policy implications.

2. Groundwater depletion, externalities and water charges

Groundwater resources may include closed and open aquifers. Closed aquifers are often isolated from other surface or groundwater systems and may be considered non-renewable and exhaustible — the time to depletion would depend on the size of the aquifer and the level of annual withdrawal. Open aquifers are connected to surface or other groundwater systems and hence may be considered as renewable. However, these resources can also be exhausted when the level of withdrawal exceeds the level of recharge. The natural process of groundwater recharge can be enhanced artificially through water harvesting and percolation systems that capture and channel surface water into the ground. This implies that under proper management systems that enhance the level of renewability, some aquifers can be managed in a sustainable manner (Howe, 2002). New approaches and technical interventions that increase re-charging of groundwater and provide income and livelihood opportunities for poor people are being tested in many semi-arid areas (Joshi et al., 2004a). However, groundwater resources are fast disappearing in many areas of India as private irrigation investment and land-use intensification have increased dramatically with increasing population pressure. Foster and Rosenzweig (2005) find that for a given distribution of landholdings growth in crop productivity on irrigated land leads to both greater number and deeper tube wells with likely consequence of declining water tables. This is aggravated by recurrent droughts, inappropriate policies that subsidize excessive use (e.g., free power for irrigation) and lack of policy options that encourage collective action and internalize open-access externalities.

The impacts of watershed interventions in India are directly linked to increased groundwater availability for irrigation (Rao, 2000; Joshi et al., 2004b), making groundwater management one of the key issues for the success and sustainability of watershed programs. However, watersheds are typically inhabited by a diverse group of farmers with fragmented landholding patterns and resource use rights

(Kerr, 2001; Joshi et al., 2004a). While social and biophysical diversity within watersheds undermine the capacity for collective action, unregulated access and use of groundwater accelerates its depletion. As land is increasingly privatized, groundwater has emerged as the most important common property resource in several parts of India. Water rights are never clearly defined and depend on land-use rights. Groundwater use is unregulated and de facto open-access to all land users in a given watershed. This generates significant open-access externalities that lead to depletion of the resource. Topographic and landownership conditions in watersheds imply that externalities could flow in several directions (reciprocal externalities) in such a way that resource use decisions are highly interdependent among farmers and the choices made by one affect several others. Increased groundwater use from a common aquifer by a single user increases the drilling and extraction costs to all well owners. If such behavior persists, it can lead to complete drying up or abandonment of some wells. While re-charging facilities within watersheds are communal, unregulated private extraction of water as observed through increased drilling of new wells could lead to open-access solutions that accelerate over-pumping and depletion of aquifers.

In addition, irrigation water is charged only for public sources, i.e., canal and tank irrigation systems. The rates are often levied on the basis of the acreage irrigated, differentiated by crop and season, but may remain uniform in a given state. In most of the cases irrigation charges cover less than a quarter of the operation and maintenance costs of providing irrigation (Reddy, 2003). On the other hand, private sources are not only left out from pricing but also supported through generous power subsidies for pumping. The typical practice in India is fixed electricity charges slightly differentiated on the basis of the horsepower of groundwater pumps (World Bank, 1999). Neither groundwater nor irrigation power use in rural areas are metered, making volumetric pricing a difficult policy option. In fact the recent trend has been to provide free power for irrigation. There is a tendency to sanction such subsidies across states as initiated in Andhra Pradesh during the 2004 elections.

Users therefore lack economic incentives to factor in the full social cost of groundwater extraction. The under-pricing of groundwater use is inefficient and provides fewer incentives for adoption of water conserving technologies or replenishing mechanisms (Hellegers et al., 2001). With increasing scarcity, local informal markets have emerged in some areas where water-deficient farmers rent water seasonally from water-surplus farmers (Shah, 1993; Meinzen-Dick, 1998; Saleth, 1998). However, groundwater markets remain underdeveloped in many semi-arid areas where lack of sufficient surplus stifles opportunities for expanded trade. Where informal markets exist, water charges often vary by season and the type of crop grown. Proper water pricing can improve the efficiency of water use and stimulate water-saving behavior by encouraging adoption of alternative water-efficient strategies that generate higher incomes (Shah, 1993; Easter et al., 1999). On the other hand, there has been substantial reluctance against water markets and adopting incentive-based instruments in South Asia for addressing adverse externalities in agriculture (Saleth, 1998; Easter et al., 1999). One argument is the potential negative impact of such policies on the welfare of small farmers. This appears to be a misconception as the existing distorted policies seem to be more detrimental to equity and to the livelihoods of the poor than incentive-based policies that enhance equity and sustainability of groundwater use (Prahladachar, 1994; Easter et al., 1999; Reddy, 2005). The long-term benefits from sustainable use of groundwater are likely to be much higher than unregulated depletion that will foreclose future possibilities and increase vulnerability of rural livelihoods to drought and other shocks.

3. Theoretical framework

Several previous studies (e.g., De Janvry et al., 1991; Holden et al., 2001; Shiferaw and Holden, 2000) have shown that when rural markets do not function well, production and investment decisions will be non-separable from consumption choices. When credit, labor, land and other factor markets are imperfect, production and investment decisions will not be separable from consumption and labor demand decisions of the farm household (Singh et al., 1986). For example, when labor, irrigation water and land markets are imperfect or missing, the household's decision price for allocation of these factors will be endogenous. In this case, non-separability implies that the endowment of labor, land, irrigation water and other fixed farm and household characteristics will determine the level of production, conservation and household welfare. Assuming that some of these markets are imperfect, we develop a generalizable non-separable model whereby the farm household maximizes utility subject to income, labor supply and irrigation water constraints:

$$\text{Max } u = u(C_q, C_m, C_l; H) \tag{1}$$

subject to

$$\sum_{z \varepsilon (q,m)} p_z C_z = \sum_j \sum_t A_{jt} p_j q(L_{jt}, W_{jt}, X_{jt}; S_{jt}, Z_{jt}) - \sum_i \sum_j \sum_t A_{jt} e_i X_{ijt} \tag{2}$$

$$\sum_j \sum_t A_{jt} L_{jt} + C_l = \overline{L} \tag{3}$$

$$\sum_j A_{jt} W_{jt} = \overline{W}_t \tag{4}$$

where, C_q is consumption of own crop produce, C_m is purchased consumer goods, C_l is leisure time, $q(.)$ is the yield function for the production of crop j on plot t, and H represents fixed household characteristics, p is the net price of output q, and e is a vector of prices of other inputs including irrigation water (e_w). L_{jt} and W_{jt} are labor and irrigation water used in the production of crop j on land area A_{jt}. Crop yield is a function of inherent quality of the soil (S), other farm characteristics (Z), and the use of variable inputs — labor (L), water (W) and other inputs (X). Eq. (2) states that household consumption expenditures should not exceed net farm income (for simplicity other income is considered exogenous and not included). Eqs. (3) and (4) define the fixed factor constraints such that the use of labor (L) and water (W) cannot exceed household endowments $\overline{L}$ and $\overline{W}_t$. Unlike labor and other inputs, we assume that groundwater availability is constrained at the plot level mainly because water cannot be moved across plots at low cost under the conditions of fragmented holdings of small farmers. The Lagrangian from Eqs. (1) to (4) could be given as:

$$\text{Max } u = u(C_q, C_m, C_l; H) + \lambda\left(\sum_j\sum_t A_{jt}p_j q(L_{jt}, W_{jt}, X_{jt}; S_{jt}, Z_{jt}) - \sum_i\sum_j\sum_t A_{jt}e_i X_{ijt} - \sum_{z\varepsilon(q,m)} p_z C_z\right) + \mu\left(\overline{L} - \sum_j\sum_t A_{jt}L_{jt} - c_l\right) + \left(\overline{W}_t - \sum_j A_{jt}W_{jt}\right) \quad (5)$$

The following first order conditions (FOCs) could be derived from Eq. (5):

$$C: \ \partial u/\partial c_j = \lambda p_c^*$$
$$\text{where } \left[p_c^* = \overline{p}_c \text{ for } c_z = \{c_q, c_m\} \text{ and } p_c^* = \mu/\lambda \text{ for } c_z = \{c_l\}\right] \quad (6)$$

$$L: \ \partial u/\partial L = p_j(\partial q/\partial L) = (\mu/\lambda) = p_l^* \quad (7)$$

$$W: \ \partial u/\partial W_t = p_j(\partial_q/\partial W_t) = \theta/\lambda = e_{wt}^* \quad (8)$$

$$X: \ \partial u/\partial X_i = p_j(\partial q/\partial X_i) = e_i \quad (9)$$

The first order condition (FOC) in Eq. (7) shows that optimal allocation of family labor will require the shadow price to be equal to its marginal value product. Similarly, in the absence of a water market, optimal allocation of irrigation water will require the shadow price to be equal to its marginal value product. Adding the FOCs for λ, μ, and θ, the systems (6) to (9) could be solved to provide the utility maximizing allocation of family labor, water and other inputs in production and the demand system $C^*=c(p^*, p_l^*, y^*, H)$, where $y^*=\Sigma_z p_z C_z + P_l C_l$ is the full income of the household. If factor markets function well, for a given crop grown (C_j), net returns (on plot t) to land and family labor defined as total value of production less cost of purchased inputs ($\pi_t = pq_t - eX_t$) and input demands (F_t) will be a function of input and output prices and farm fixed characteristics such that:

$$\pi_t = \pi(p_j, p_l, e_i, S_t, Z_t) \quad (10.1)$$

$$F_t = f(p_j, p_l, e_i, S_t, Z_t) \text{ for } F\varepsilon(A, L, X) \quad (10.2)$$

However, when some markets are missing or imperfect, production and investment choices will be a function of endogenous shadow prices of the output and/or input factors. In this situation, crop productivity, input demand and conservation investments will be a function of the endogenous prices (p^* and e^*), exogenous prices ($\bar{p}, \bar{e}$) and household (H), plot soil quality (S) and other farm fixed characteristics (Z). The endogenous prices are, however, determined by the exogenous prices and fixed factors such that $e^*=e^*(\bar{p}_j, \bar{e}_i, S_t, Z_t, H)$ and $p^*=p^*(\bar{p}_j, \bar{e}_i, S_t, Z_t, H)$. This shows that the reduced forms of land productivity and input demand equations will be given by:

$$\pi_t = \pi\left(\overline{p}_j, \overline{e}_i, S_t, Z_t, H\right) \quad (11.1)$$

$$F_t = f\left(\overline{p}_j, \overline{e}_i, S_t, Z_t, H\right) \text{ for } F\varepsilon(A, L, X) \quad (11.2)$$

Nevertheless, in a cross-section of households in a given location, the exogenous prices will not be expected to vary significantly across households, i.e., all households face the same prices. Hence, under market imperfections for some factors, the estimable land productivity and input demand functions for a given crop can be given as a function of non-price exogenous factors:

$$\pi_t = \pi(S_t, Z_t, H) \quad (12.1)$$

$$F_t = F(S_t, Z_t, H) \text{ for } F\varepsilon(A, L, X) \quad (12.2)$$

An imperfect or missing water market is particularly true in much of Andhra Pradesh (AP) where power for irrigation water is free and informal markets are very thin. Unlike in northern India and other states where informal water markets are more vibrant, water markets are very limited in many semi-arid regions of AP partly because of shortage of surplus water and traditional shared ownership of tube wells (e.g., Shah, 1993; Somanathan and Ravindranath, 2006).[1] When water is free and the number of transactions in informal markets is very limited, the water market is largely imperfect and water prices are endogenous to the resource user. As we show below, we use a crop-water production function to estimate the plot and crop-specific shadow price of water which is then used to estimate the net returns from cropping and the intensity of irrigation.

4. Empirical model

The level of use of different inputs in a given plot is an endogenous decision by the household, determined based on exogenous and pre-determined variables like crops grown, access to markets, soil types and household assets. The returns to land and input demand equations in Eqs. (12.1) and (12.2) are therefore interdependent and need to be estimated jointly. With plot-level data, the empirical model is formulated as a system of the following six structural equations:

$$\pi_t = \pi(e_{wt}, C_j, I_t, S_t, Z_t, H, R_1) \quad (13.1)$$

$$X_{wt} = x(e_{wt}, C_j, L_t, X_{ft}, K, S_t, Z_t, H, R_2) \quad (13.2)$$

$$L_t = L(C_j, K, S_t, Z_t, H, R_3) \quad (13.3)$$

$$X_{ft} = X_f(C_j, K, S_t, Z_t, H, R_4) \quad (13.4)$$

$$X_{bt} = X_b(C_j, K, S_t, Z_t, H, R_5) \quad (13.5)$$

$$I_t = I(K, S_t, U_t, V_t, Z_t, H, R_6) \quad (13.6)$$

$$V_t = V(I_t, S_t, Z_t, H, R_7) \quad (13.7)$$

where the system of Eqs. (13.1)–(13.7), respectively, represents: net returns to owned land and family labor, intensity of irrigation (hours of irrigation), expenditure on labor (hired and family), expenditure on fertilizer and pesticides, expenditure on other capital inputs (bullocks, tractors, etc), cumulative (over 5 years) expenditure on soil and water conservation (SWC), and market

[1] About 45% of the households surveyed in the 12 villages of this study own an irrigation pump. Of this, about 46% have reported a pump jointly owned with other farmers.

value of the land as stated by the owner. Net returns were calculated as total value of production less all variable costs except family labor and owned land. For simplicity, continuous variables were standardized into Rs 1000/ha. Eq. (13.1) is modeled as a function of crop grown (C_j), shadow price of water (e_w), conservation expenditures (I_t), soil and plot characteristics (S_t), household assets and farm characteristics (Z_t), household characteristics (H) and other exogenous variables (R).[2] The intensity of irrigation (13.2) on a given plot depends on the price of water, crop grown, other inputs used and soil and farm characteristics. Among the other variables, input use intensification (13.3 to 13.5) and conservation (13.6) depends on the amount of credit received (K). Private conservation (13.6) is specified as a function of land quality (S_t), farm attributes Z_t), public conservation investments (U_t), and the market value of the land as perceived by the owner (V_t). The value of land (13.7) depends on the level of private conservation effort (I_t), public conservation investments (U_t) and land quality and farm characteristics.

We estimate the equation system using three-stage least squares (3SLS), which provides consistent and asymptotically efficient estimates (Greene, 1997). In order to ensure identification for the parameters of the structural equation system, certain identifying restrictions were imposed in such a way that there are enough exogenous variables excluded from each equation to serve as instruments for endogenous variables included as regressors. The *order condition* criteria for identification requires that the number of excluded exogenous variables must be greater than or equal to the number of included endogenous variables less 1 (Greene, 1997). This was achieved by using in each equation a selected subset (based on hypothesized relationships) of the variables S_t, Z_t and H along with other exogenous variables (R) as identifying restrictions (instruments). The latter set included variables such as household endowment of various assets, cropping season, cropping pattern, crop rotations, land tenure, caste category and village characteristics. All the dependent variables in the model are continuous allowing us to estimate the structural equation system using 3SLS. As net returns may have zero or negative values, Eq. (13.1) was specified as a semi-log model. The same is true for the intensity of irrigation (13.2) where rainfed plots have zero levels of irrigation. All other equations were specified in a double-log form. Because of space limitations, we report only the results from Eqs. ((13.1) and (13.2)), which are most relevant for this paper (results from the remaining equations are available on request).

5. Data and trends in groundwater use

In this section we present the primary data used in estimating the empirical model and emerging trends in the intensity of irrigation, cropping patterns and groundwater depletion in the studied villages.

[2] The variable capturing the farmer conservation effort (I_t) is endogenous in this equation. Similarly, farmer conservation expenditures depend on the perceived value of land and vice versa (Eqs. (13.6) and (13.7)). As decisions are made by others, public conservation investments on private plots are considered exogenous.

Table 1 – Descriptive statistics for important variables used in the analysis

Variables	Mean	SD	Min.	Max.
Household assets (Rs 1000/ha)				
Total physical asset value	57.34	43.42	8.67	304.43
Livestock wealth	6.91	9.44	0.00	69.19
Total non-farm income	13.93	17.07	0.00	86.73
Household characteristics				
Age of household head (in years)	44.73	11.17	25.00	76.00
Sex of household head (1=Male, 2=Female)	1.05	0.21	1.00	2.00
Education of household head (in years)	2.92	4.30	0.00	18.00
Family size (in number of members)	5.90	2.68	2.00	18.00
Belongs to backward caste	0.53	0.50	0.00	1.00
Belongs to scheduled caste	0.17	0.38	0.00	1.00
Belongs to minorities (Muslims)	0.08	0.27	0.00	1.00
Plot and farm characteristics				
Farm size in hectares (owned area)	2.22	2.46	0.10	16.19
Total operated area irrigated (ha)	0.65	0.83	0.00	2.83
Stated value of the plot (Rs 1000/ha)	139.68	58.91	49.42	345.95
Land tenure (1=owned; 0=otherwise)	0.98	0.14	0.00	1.00
Irrigation plot (1=irrigated, 0=rainfed)	0.29	0.45	0.00	1.00
Plot located within the watershed (1 if yes)	0.49	0.50	0.00	1.00
Soil type on plot (1=vertisol; 0=others)	0.72	0.45	0.0	1.00
Soil depth class: 1=shallow (<0.5 m); 2=medium (0.5 to 1 m); 3=deep (1 to 1.5 m); 4=very deep (>1.5 m)	1.98	0.81	1.00	4.00
Fertility of soil on the plot; 0= very poor; to 3=very good	1.94	0.62	1.00	3.00
Plot-level input use (Rs 1000/ha)				
Expenditure on labor (male and female)	3.42	3.60	0.13	33.61
Expenditure on fertilizer, FYM, seed and pesticides	3.54	3.69	0.03	27.83
Expenditure on other variable inputs	1.24	1.27	0.00	12.36
Credit used for 2 years	5.34	11.38	0.00	88.96
Plot-level returns (Rs 1000/ha)				
Production value of the crop (grain and by-product)	13.58	14.67	0.00	112.02
Returns to owned land and family labor	7.43	11.15	−19.12	95.53
Plot-level conservation investments (Rs 1000/ha)				
Private (soil and water conservation) investments	0.65	1.61	0.00	20.11
Public investment	0.70	1.55	0.00	11.86
Cropping patterns and crop choice				
Cropping system: 1=sole cropping; 0=intercropping	0.64	0.48	0.00	1.00
Crop variety grown: 1=improved, 0=local	0.64	0.48	0.00	1.00
Vegetable crop (1 if yes)	0.17	0.37	0.00	1.00
Cotton crop (1 if yes)	0.06	0.24	0.00	1.00
Dryland cereal crop (1 if yes)	0.18	0.38	0.00	1.00
Legume crop (1 if yes)	0.28	0.45	0.00	1.00
Paddy and sugarcane (1 if yes)	0.06	0.23	0.00	1.00

(continued on next page)

Table 1 (*continued*)

Variables	Mean	SD	Min.	Max.
Cropping patterns and crop choice				
Maize and wheat (1 if yes)	0.11	0.31	0.00	1.00
Oil seeds and spices (1 if yes)	0.07	0.26	0.00	1.00
Previous legume crop (1 if yes)	0.32	0.47	0.00	1.00
Season dummy: 1=Kharif, 0=Rabi	0.84	0.37	0.00	1.00

5.1. *Data*

The empirical model presented above was estimated based on primary community, household and plot-level data collected during the years 2002 and 2003 covering 12 randomly selected villages in four semi-arid districts of Andhra Pradesh, India. The survey was conducted by the authors as part of a larger watershed study by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Data from community surveys provided useful information on investment trends in irrigation, condition of irrigation wells, and changes in cropping patterns. The household and plot-level data was collected from six of the 12 villages studied where a stratified random sample of 120 households was selected for a detailed survey. Half of the sample came from a watershed project village (Kothapally) where a community watershed project has been operational since 1999. The other half came from adjoining villages where such watershed management interventions have not been operational, representing typical conditions in many semi-arid areas.

Along with other standard farm household data, a detailed plot and crop-wise input and output data was collected from the 509 operational plots of all sample households for the 2001/02 production year, which farmers characterized as an average year. The unusually rich plot-level dataset contained information on plot-specific soil quality, risk of soil degradation, slope gradients and soil and water conservation investments. Trained enumerators lived in the villages during the course of the survey and administered in-person interviews in all villages.

The majority of households use farmyard manure, fertilizer and pesticides. Fertilizer and pesticide use on some irrigated crops is high. Households ranked shortage of irrigation water (in all villages) as the most pressing constraint in improving their incomes and securing their livelihoods. Some low level informal markets for irrigation water that allow seasonal water transfers through various contracts have emerged in the villages. The major cropping period is during the monsoon rains (June–September), but some crops are also grown during the post-rainy season. Crop production is highly diversified and farmers practice intercropping. The descriptive statistics for some of the relevant household and plot-level variables used in this study are given in Table 1.

5.2. *Changes in irrigation intensity and groundwater depletion*

Data from the community surveys in the 12 villages show that, consistent with observed broader trends in India, the number of pump-operated open and tube wells has shown a tremendous increase in the last 20 years (Table 2). While farmers in semi-arid regions have historically relied on open wells for supplementary irrigation, the availability of subsidized power has increasingly shifted farmers towards tube wells operated using electrical pumps. Since the early 1980s, the number of tube wells has increased by four to ten fold, while open wells have increased by up to three fold. Hence, tube wells are gradually overtaking open wells in many semi-arid villages. The average depth of open and tube wells, estimated at 12.5 m and 61.2 m in 2003, is increasing further as farmers desperately try to drill deeper as water tables fall. The area under irrigation in these villages has also increased three to five-fold during the last 20 to 25 years.

The accelerated exploitation of aquifers without sufficient investment in re-charging facilities already shows the unsustainable nature of water use in these villages. More than 65% of open wells and 28–45% of the tube wells in the 12 semi-arid villages studied have been depleted and gone out of service (Table 3). This is based on the well being dry for over three consecutive years. The rate of depletion is lower for tube wells mainly because tube wells are relatively new and deeper. In many of the villages, more than 90% of the open wells have been depleted. This process is accelerated by recurrent droughts and lack of sufficient re-charging of aquifers. These results show that unless households and communities make sufficient investments in groundwater re-charging systems and adopt regulating mechanisms, the remaining aquifers are likely to be depleted in the near future.

5.3. *Changes in cropping patterns*

In response to improved access to irrigation and changing market opportunities, the composition and mix of crop-livestock production activities in the semi-arid areas of India has changed significantly over the years. Comparing 1968–70 to 1992–94, Gulati and Kelley (1999) found falling shares in

Table 2 – The average increase in number of wells per village in semi-arid districts of Andhra Pradesh, India

District	Tube or bore wells				Open wells			
	1980	1990	2003	Change (%)	1980	1990	2003	Change (%)
Ranga Reddy (6 villages)	2.3	5.8	25.3	1000	24.2	39.3	60.3	149
Mahboobnagar (2 villages)	12.0	37.3	66.0	450	20.7	38.3	60.0	190
Nalgonda (2 villages)	6.0	35.0	64.7	978	12.7	47.3	51.7	300
Kurnool (2 villages)	7.0	33.3	52.7	652	24.0	46.0	57.7	140

Source: ICRISAT Community Watershed Surveys (2003).

Table 3 – Small-scale irrigation and groundwater depletion in selected districts, AP, India.

Districts	Tube or bore wells dried-up (%)	Open wells dried-up (%)
Ranga Reddy (6 villages)	44.7	65.4
Mahboobnagar (2 villages)	43.3	93.1
Nalgonda (2 villages)	28.2	90.0
Kurnool (2 villages)	40.2	90.2

Source: ICRISAT Community Watershed Surveys (2003).

gross cropped area in the Indian semi-arid areas for sorghum, pearl millet, cotton and groundnut in marginal areas and rising shares for high-value crops like sunflower, soybean, mustard and chickpea. In more favorable and irrigated semi-arid areas, they found rising shares for wheat, paddy, cotton and oilseeds and declining shares for chickpea, millets, sorghum and barley. We find a similar pattern from our micro-level evidence in the selected villages (Fig. 1). In the last 25 years, farmers have significantly reduced the area under sorghum. But the area under oil crops, maize, vegetables and flowers has grown significantly. The area under rice and chickpea seems to be relatively more stable.

The increasing shift towards irrigated crops (e.g. vegetables and flowers) is motivated by the higher returns from increased market access. When irrigation water is heavily subsidized or available at low cost, farmers find it profitable to shift towards flowers, sugarcane, vegetables, rice and turmeric (Table 4). Unfortunately, the emerging cropping pattern is likely to hasten groundwater depletion. Table 4 shows how the current cropping systems and water allocation relate to the net productivity of water. About 40% of the cultivated area receives some irrigation. Vegetables and paddy represent over half of the total irrigated area. Water requirements (h/ha) are highest for water-intensive crops like sugarcane, paddy and wheat, grown only under irrigation. For other crops such as flowers, chickpea, cotton and vegetables, water is applied only in the form of supplemental irrigation. Water productivity is highest for high-value crops with low water demand and lowest for water-intensive crops like paddy and sugarcane. Since irrigation water is free, water allocation patterns do not reflect its marginal value. Paddy accounts for less than a quarter of the irrigated area, but consumes over 60% of the applied water. Crops with high water productivity (e.g., flowers, vegetables, chickpea and cotton) receive less than 20% of the available water. This provides stronger evidence to change the structure of incentives that stimulate water-intensive and unsustainable cropping patterns in semi-arid areas.

6. Results and discussion

6.1. *Estimated shadow price of water*

One of the key questions that need to be answered in agricultural water pricing is the marginal value of water in growing different crops. The marginal value of water establishes the farmer's maximum willingness to pay for an additional unit of irrigation water (Tsur, 2005). This can also be used to determine the inverse demand curve for water. If data on average and marginal costs of water supply is available, then the marginal value of water can be used in

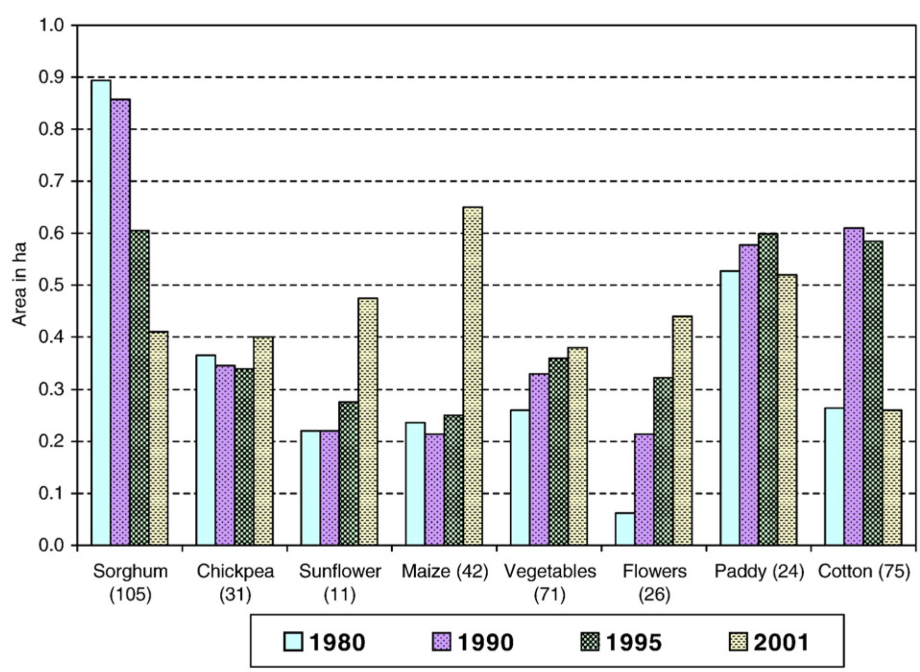

Fig. 1 – Changes in area allocated to different crops in six villages. (Values in parenthesis are the number of sample households who grew the crops since 1980. The values for the pre-2001 period are approximate three-year averages centered on that year).

Table 4 – Farmers' irrigation decisions and water productivity relationships

Crops	Area cultivated (ha)	Area irrigated (ha)	Area irrigated (%)	Intensity of water use (h/ha)	Net returns (Rs 1000/ha) [a]	Net water productivity (Rs/h)	Actual irrigation (h)	Total water applied (%)
Cotton	0.17	0.02	3.66	26.19	10.23	391	0.473	0.49
Flowers	0.15	0.07	13.74	71.96	26.45	368	4.875	5.01
Chickpea	0.11	0.04	8.61	21.24	7.20	339	0.902	0.93
Vegetables	0.24	0.15	30.49	76.92	13.41	174	11.562	11.88
Turmeric	0.05	0.05	10.15	94.38	15.59	165	4.723	4.85
Maize	0.26	0.01	2.02	56.61	9.03	160	0.563	0.58
Wheat	0.03	0.03	6.41	109.01	5.36	49	3.446	3.54
Paddy	0.11	0.11	22.72	530.96	11.07	21	59.473	61.13
Sugarcane	0.01	0.01	1.47	1541.94	22.58	15	11.143	11.45
Sum	1.24	0.49	100	–	–	–	97.29	100

Source: Estimated based on average cropping and irrigation decisions of sample farmers (n=120). h=hours.
[a] Rs 46=US$1 (2002/03).

determining water prices, which occurs at the point when inverse demand curve equals the average or marginal cost of water supply. The shadow value of water can be derived in different ways (Tsur, 2005). The most common method is based on constrained profit maximization where water availability is constrained at a certain level. This can be specified using linear or non-linear programming methods. The dual multiplier for the water constraint determines the shadow value of water. This is a measure of the gain in income from relaxing the water constraint by one unit. The inverse water demand curve can be derived by solving the model for different levels of the water constraint. The second method which is also liked to profit maximization is the use of the crop-water value function where the value of output is regressed against the volume of water use and other factors. This assumes that water availability is constrained at a level (x); hence, the marginal value product $pf'(x)$ will be the maximal price the farmer is willing to pay to relax the water constraint. Using plot-level data, we employ the second approach to derive the shadow price of water. This is estimated using a non-linear crop-water production function where the value of production on a given plot depends on the hours of irrigation, use of farm inputs, soil quality and other plot characteristics and exogenous factors. In order to capture any indirect and differential effects of irrigation, we included interaction terms with selected input use and crop types. The estimated model (Table 5) is highly significant. The direct effect of irrigation hours is significant ($P<0.05$) while the second term is negative suggesting diminishing marginal returns as water use increases. Significant interaction terms also show that the marginal effects vary according to the level of use of other inputs (fertilizer, labor, manure, etc), plot size, soil quality and the crop grown.

The net marginal value of irrigation was then computed for irrigated plots using the derivatives with respect to irrigation hours and significant interaction terms. The average marginal value of water is about Rs 50 per hour of irrigation. The marginal values across crops are Rs 114 for pulses, 98 for flowers, 95 for oil seeds and spices, 40 for vegetables and 4.5 for paddy. This clearly indicates that the scarcity value of water is lowest on water-intensive crops. If one uses average cost pricing, which suggests a price level that equates the inverse

Table 5 – The crop-water production function and shadow value of irrigation water

Dept variable=production value (Rs 1000)	Estimated coefficient	Robust T-values
Labor costs (1000 Rs)	1.820	4.15***
Fertilizer and pesticide costs	1.347	4.4***
Other variable costs	−0.430	−0.48
Total hours of irrigation	0.065	2.07**
Irrigation h squared	−3.33E−5	−0.28
Labor costs squared	−0.092	−2.06***
Fert and pesticide cost squared	−0.016	−0.69
Other costs squared	1.110	3.71***
Education of head (years)	0.039	1.12
Crop variety (Improved=1)	0.625	1.75*
Season (Kharif=1)	0.312	0.6
Incidence of stress (yes=1)	−3.444	−7.8***
Local soil (Regadi=1)	1.338	1.74*
Local soil (Baraka=1)	1.112	1.38
Plot size (acres)	1.482	6.29***
Cotton crop dummy	−0.253	−0.29
Vegetable crop dummy	−0.977	−1.6
Pulses crop dummy	−0.725	−1.28
Dryland cereals crop dummy	−1.593	−2.83***
Oil seeds and spices dummy	−2.283	−2.93***
Paddy crop dummy	−0.890	−0.52
Labor costs × irrigation h	−0.011	−4.47***
Other costs × irrigation h	−0.010	−2.29**
Fertilizer costs × irrigation h	0.025	3.66***
Pesticide costs × irrigation h	−0.009	−0.95
Farmyard manure × irrigation h	−0.029	−3.68***
Plot size × irrigation h	0.031	4.78***
Maize and wheat × irrigation h	−0.131	−3.31***
Vegetable dummy × irrigation h	−0.069	−2.36**
Paddy dummy × irrigation h	−0.105	−4.00***
Pulses dummy × irrigation h	0.056	0.53
Oils and spices dummy × irrigation h	0.031	0.84
Season dummy × irrigation h	0.001	0.04
Soil depth × irrigation h	0.012	2.73***
Dist to check-dam (km) × irrigation h	−0.101	−2.18**
Location of plot in catchment	−0.226	−1.3
Constant	−0.387	−0.34
Adjusted R^2	0.7512	
Sample size (plots)	509	

*, **, *** represent significance at 10%, 5% and 1% level respectively.

demand curve for water and the average cost of irrigation (Tsur, 2005), the real price of water may be around Rs 5–10/h.[3] The average cost is estimated from cost of irrigation labor and average pump repair and running costs using 2003 prices. In the next section we discuss how this kind of pricing would affect the farm-level profitability of irrigation.

6.2. *Effect of water pricing on farm income*

We use the empirical model (Eq. (13.1)) jointly estimated with other equations to assess the effect of water pricing on farm-level net returns and incomes. The estimated plot-wise shadow prices (Rs/h of irrigation) were included in the system of equations to assess how water pricing will affect the farm-level profitability of different crops and the intensity of use of irrigation water. The plot-wise net returns (after accounting for cost of water) were specified as a function of estimated plot-wise shadow price of water, private conservation investments, non-farm income, credit acquired during the previous 2 years, soil and plot characteristics, crop variety, incidence of stress (drought, pest and/or disease), farm size, irrigation, household education and identifiers for the type of crop grown on the plot.[4] Since non-farm income was considered endogenous in the model, it was instrumented using its predicted values. The results for Eq. (13.1) are presented in Table 6. As expected the net returns from crop production are negatively correlated to water prices and incidence of stress factors on the plot. Credit, non-farm income and conservation investments seem to have a negative effect, but the estimated parameters were not significantly different from zero. Similarly net returns increase with improved soil conditions, adoption of new varieties, and investment in irrigation. On average, returns per ha are Rs 2200 higher on plots where new high-yielding cultivars and improved varieties are grown. However, controlling for other factors, net returns on average decline by more than Rs 8700/ha when drought or pest and/or diseases affects the plot.

Farm-level net returns for several crop groups are lower compared to high-value crops (flowers) used as a reference group. The dryland cereals (sorghum and millets) and other cereals (maize and wheat) followed by paddy and dryland pulses seem to be the least profitable compared to the high-value flower crops. The most important result for the purpose of this paper is the effect of water prices and irrigation on plot-level net returns from crop production. After controlling for soil quality, input use, crop type and other variables that affect crop yields, net returns on irrigated plots are significantly higher (Rs 5800/ha) than non-irrigated plots. On average, a 10% increase in irrigated area increases net returns by about 9%. This shows why farmers are willing to invest in groundwater exploration, extraction and deepening of existing wells, leading to a dramatic increase in the area irrigated and the number of wells.

As expected, plot-level profits decrease with an increase in the price of irrigation water. On average, net returns decline by Rs 41/ha per unit increase in the hourly shadow price of irrigation water. The relative decline in net returns varies by crop type and the amount of irrigation hours required. This is consistent with our earlier estimate of Rs 50 as the average shadow value of an hour of irrigation in agriculture in the studied semi-arid villages. How would such pricing affect smallholder irrigation and crop-wise net returns? We turn to this analysis in the next section.

Table 6 – The effect of irrigation water pricing on net returns to land and family labor for different crops

Variables (dependent variable = net returns Rs 1000/ha)	Parameter estimate	*T*-values	Elasticities[a]
Intercept	10.54	2.60***	
Price of water (Rs/h of irrigation)	−0.041	−2.11**	−0.311
Ln (private SWC investment per ha)	−0.030	−0.32	−0.005
Ln (predicted non-farm income per ha)	−0.118	−1.57	−0.02
Ln (cumulative 2 years credit per ha)	−0.078	−1.40	−0.01
Soil type dummy (vertisols = 1)	0.436	0.36	0.07
Soil depth	1.547	2.37**	0.461
Soil fertility level	−0.596	−0.78	−0.175
Season (Kharif = 1)	1.362	1.09	0.205
Land tenure (owned = 1)	−1.151	−0.39	−0.173
Crop variety (improved = 1)	2.204	2.24**	0.332
Incidence of stress (Yes = 1)	−8.797	−7.23***	−1.323
Cotton dummy	−6.214	−2.56**	−0.93
Vegetable dummy	−8.305	−4.19***	−1.25
Pulse crop dummy	−9.731	−4.93***	−1.46
Dryland cereals dummy	−11.880	−5.81***	−1.79
Maize and wheat dummy	−9.777	−4.36***	−1.47
Oils and spices dummy	−11.221	−5.00***	−1.69
Paddy and sugarcane dummy	−9.816	−3.54***	−1.48
Previous legume crop dummy	0.536	0.58	0.08
Log (farm size–plot size)	0.035	0.26	0.01
Irrigation dummy	5.822	3.31***	0.88
Watershed dummy	0.760	0.72	0.11
Ln (years of education for head)	0.018	0.37	0.003
Model fitness	System weighted R^2 = 0.84, degrees of freedom = 2909		

*, **, *** represent statistical significance at 10%, 5% and 1% levels, respectively.

[a] Elasticities at the means for the logarithmic variables are computed as $\beta_i / \bar{Y}$, where β_i is the estimated parameter, and $\bar{Y}$ is the mean of the dependent variable. For the dummy variables, the values are for positive value of the indicator.

[3] An hour of irrigation may be roughly equivalent to 12.3 m^3 of water, giving an estimated price of Rs 1.22 to 2.45 per m^3 of irrigation water using average cost pricing of Rs 5–10/hr. This is estimated using the relationship (Michael, 1989): water discharge (lt/s) = [HP of pump * 76 * efficiency of pump)/(well depth (m)]. We use an average depth of 200 ft and 5 HP pump with an efficiency of 60% for irrigators in the surveyed villages.

[4] The crop grown on the plot may be considered endogenous, but lack of good exogenous instruments to predict crop choice has made it difficult to estimate this jointly. The crop dummies are used here to capture the differential effects of water pricing on net returns for different crops.

Table 7 – The effect of water pricing on hours of irrigation

Variables (dependent variable = hours of irrigation/ha)	Parameter estimate	T-value	P-value
Intercept (no intercept)	0		
Water prices (Rs/h of irrigation)	−0.60	−2.08	0.038
Vegetable dummy	−7.35	−0.32	0.753
Pulse crop dummy	−28.04	−1.04	0.299
Maize and wheat dummy	−2.96	−0.12	0.904
Oils and spices dummy	15.01	0.54	0.587
Paddy and sugarcane dummy	578.42	15.14	<.0001
Crop variety (improved = 1)	5.69	0.36	0.717
Season (Kharif = 1)	20.67	1.05	0.293
Soil type dummy (vertisols = 1)	−13.10	−0.74	0.461
Soil depth	8.63	0.92	0.356
Ln (male workforce per ha)	0.81	0.3	0.764
Ln (female workforce per ha)	−5.45	−0.61	0.541
Ln (labor costs/ha)	−50.07	−1.48	0.139
Ln (fertilizer, seed and pesticide costs/ha)	32.50	1.8	0.073
Ln (other farm input costs/ha)	−5.26	−0.59	0.556
Watershed village (=1)	−12.37	−0.7	0.487
Ln (Plot size, ha)	−27.21	−1.45	0.148
Ln (total irrigable land, ha)	7.61	4.28	<.0001
Ln (distance to check-dam, km)	1.69	0.44	0.659
Ln (age of household head)	24.85	2.45	0.015

6.3. *Effect of water pricing on intensity of irrigation*

One of the important policy objectives in introducing irrigation water pricing is to enhance the sustainability of groundwater by reducing the level of water use. There is lack of information on how smallholder irrigators may respond in terms of reducing the intensity of water use if a water pricing policy was adopted. We use our empirical model (Eq. (13.2)) estimated jointly with net returns to estimate this effect. The results are presented in Table 7. The intensity of water use (irrigation h/ha) was modeled as a function of water prices, crop grown, season, soil quality and plot attributes, level of use of different inputs (endogenous), total irrigable area, plot size, distance to water harvesting facilities and family labor and household characteristics. We find a positive and significant effect of paddy cropping, fertilizer and pesticide use, total irrigable area and household age on the intensity of irrigation. The intensity of water use is highest on rice fields compared to other less water-intensive crops like flowers (reference group). Interestingly, elder farmers with larger irrigable land seem to apply more water per unit of land. This seems to follow from the open-access and unregulated nature of groundwater use in the villages.

As anticipated, water prices are negatively correlated with the intensity of water use (h/ha). We find that for a unit increase in the price of water, the intensity of irrigation will decrease by 0.6 h/ha. The estimated price elasticity of irrigation water demand at the average shadow price and water demand of all crops is about −0.15, which implies that if water prices increase by 10%, water demand will decrease by 1.5%. This indicates that although farmers are likely to reduce irrigation water use if water is priced, the price responsiveness seems to be quite low.

6.4. *Potential of alternative water pricing approaches*

Alternative strategies ranging from supply augmentation to demand management have been advocated for better management of scarce water resources (World Bank, 1999). Consistent with these comprehensive strategies, a number of policy instruments and economic incentives can be suggested for effective water management in agriculture (Tiwari and Dinar, 2002). However, actual volumes of groundwater extraction and use in small-scale irrigation in developing countries are not metered and hence cannot be directly observed. This makes farm-level direct volumetric charges an infeasible policy option (Gornish et al., 2004). An incentive-based approach that relates pricing to the volume of water is therefore more likely to perform better than regulatory approaches that specify quotas and standards on the volume of water or irrigated acreage (Schaible, 2000; Tiwari and Dinar, 2002). While several options can be used to create economic incentives for water-saving, equity issues are critical in

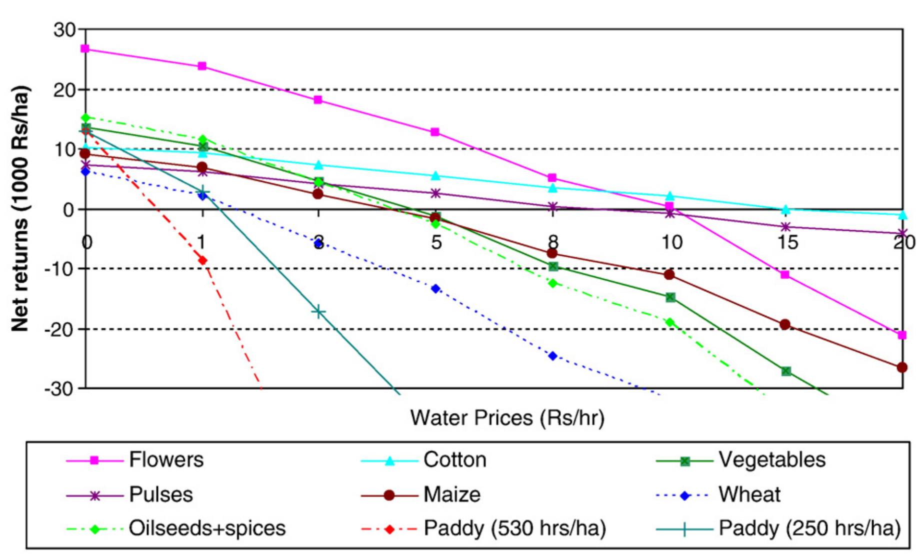

Fig. 2 – Effect of full water pricing for irrigation (charges for total hours of use) on crop incomes.

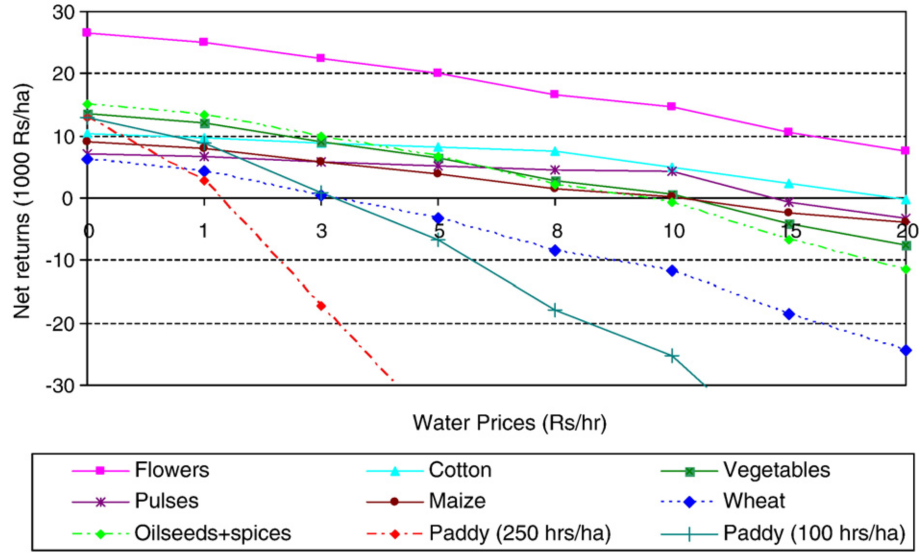

Fig. 3 – Effect of partial (block) water pricing (50% of water use) for irrigation on crop incomes.

developing effective and politically acceptable instruments. The main challenge is to understand how introduction of alternative pricing systems would affect profitability of small-scale irrigation and agricultural incomes.

Pricing approaches that build from local experiences would also have a better chance of acceptance. In the past, farmers in the semi-arid areas of Andhra Pradesh used output sharing schemes where the irrigator pays up to a quarter of the produce to the well owner. The informal water markets have however gradually declined as water availability has decreased with expansion of high-yielding varieties and irrigated crops. Output-based pricing approaches however require information on the level of output, which is difficult to observe under smallholder conditions (Gornish et al., 2004). In such situations and when the flow is predictable, the time used for irrigation could be a good proxy for volume of use and relatively easier to monitor. In some parts of south Asia (e.g. north India and Bangladesh), charges based on irrigation hours are becoming quite common in informal markets. Another widely used approach worldwide is a pricing scheme based on the area of irrigated crops. Using results from our econometric models, we therefore evaluate two alternative incentive-based instruments: (a) charges based on hours of irrigation, and (b) charges based on irrigated crop area. While the former is directly related to volume of use, the second approach may not always reflect volume. As we show below, the two approaches can also be applied jointly, making the instruments complimentary.

6.4.1. *Charges based on irrigation hours*

As discussed earlier, volumetric water charges are impractical in many developing regions where the infrastructure needed to routinely measure the volume used by individual farmers is lacking. Hence, volumetric methods are used in less than 25% of the cases worldwide, mainly in the developed countries (Tsur, 2005). The advantage of volume-based pricing is that it is incentive compatible as the marginal cost of the last unit of water used is positive. If local communities and user groups are empowered to manage and implement time-based pricing, information on the duration of irrigation (as a proxy for volume of use) can be easily gathered or inferred indirectly from the type of crop grown.

We use the econometric results to assess how charges based on irrigation hours would affect the profitability of cropping. Using the average level of irrigation needed for each crop, this is evaluated by varying water charges and examining how such pricing would affect net returns for different irrigated crops (Fig. 2). The effect of water charges on net returns includes the direct effect of water pricing on restricted farm profits (Eq. (13.1)) and the indirect effects on reduction in the intensity of irrigation (Eq. (13.2)). These values are derived from results reported in Tables 6 and 7.[5] The values for zero water charges (Fig. 2) reflect the status quo where groundwater is free for irrigators. If water prices are introduced for irrigation, the results show that farm-level net returns would remain positive for less water-intensive crops up to the level of Rs 3.5/h. The situation is different for wheat and rice which requires about 110 and 530 h/ha, respectively. Paddy and wheat production in semi-arid areas would not be profitable if water is charged more than Rs 0.5/h, but this may increase up to Rs 1/ha if charges are based on 50% of the water used. On the other hand, water charges can increase up to Rs 5–10 for less water-intensive high-value crops like pulses, flowers and cotton. This shows that if water pricing is introduced, it is likely to shift cropping patters from irrigated rice and wheat towards less water-intensive crops more suitable for water-scarce semi-arid areas.

An alternative pro-poor policy would be a variation of block-pricing that would allow farmers pay only for a certain portion of their irrigation water use. We evaluated how such a

[5] The full effect of the water price on income is estimated as $\beta_0+\phi e_w(W+\gamma e_w)$ where β_0 is the net return when water is free, ϕ (negative) measures the decline in profits per unit price of water, e_w is the assumed price of water, W is the hours of irrigation, and γ(negative) measures the reduction in irrigation hours due to price changes.

Table 8 – Effect of area-based charges on water use and irrigation incomes (Rs 1000)

Irrigated crops	Irrigation (h/ha)	Baseline (free water for irrigators)		Fixed area charges using average crop-water demand (Rs 1/h) [a]		Area charges using crop-wise water demand (Rs 1/h)	
		Area irrigated	Water use (h)	Area irrigated [b]	Water use (h)	Area irrigated [b]	Water use (h)
Flowers	71	0.33	23.43	0.120	8.52	0.30	21.30
Cotton	26	0.23	5.98	0.040	1.04	0.25	6.50
Vegetables	76	0.34	25.84	0.060	4.56	0.15	11.40
Pulses	26	0.38	9.88	0.025	0.65	0.14	3.64
Maize and wheat	124	0.29	35.96	0.020	2.48	0.03	3.47
Oil seeds and spices	90	0.40	36.00	0.070	6.30	0.14	12.60
Paddy rice	530	0.37	196.10	0.050	26.50	0.02	8.48
All crops	179	2.34	333.19	0.385	50.05	1.02	67.39
Irrigation income		30.95		6.40		16.03	

[a] Based on average crop-water demand of 179 h/ha irrigated.
[b] This is the maximum estimated area that will make crop production profitable under the water charging policy.

policy may affect profitability of irrigation using a 50% partial pricing i.e., farmers pay only for half of their water use (Fig. 3). As expected, block-pricing improves the profitability of all crops, but paddy and wheat production still remains less profitable even when farmers pay only for half of their water use. Other dryland crops remain profitable for water charges up to Rs 10/h. In some cases, farmers may also be able to grow some crops under rainfed conditions which offer net returns in the order of Rs 3000–4000/ha. In this case, the optimal water price under the block-pricing approach is likely to be around Rs 3–5/h of irrigation. This would allow farmers use irrigation to supplement rainfed cropping and reduce income variability and vulnerability of livelihoods in drought-prone areas.

6.4.2. *Area-based water charges*

A common and easy to implement approach to water pricing is an area-based water charge. Tsur (2005) cites that about 60% of irrigation water pricing cases worldwide use this approach. This can take two forms: fixed charges for all crops per acre irrigated or crop and area-based charges that take into account crop-water requirements. A fixed rate per irrigated area does not consider the volume of water used and may in fact encourage excessive application as the marginal cost of water is close to zero. Acreage-based charges for irrigation, if differentiated by crop-water demand, could however create incentives for farmers to plant less water-consuming crops (Gornish et al., 2004). We evaluated the effect of these two approaches on area irrigated, water demand and farm net incomes. The first approach uses area charges based on average water demand of 179 h/ha (excluding sugarcane). The second refines this by combining crop-water demand and irrigated areas. The results are presented in Table 8. When area charges do not take into account crop-specific water demand, the impacts on irrigated area and farm incomes are quite dramatic. This is mainly because dryland crops do not require 179 h/ha irrigated and charges based on this high rate would limit area irrigated substantially. Hence, net income from irrigation falls significantly. If area charges consider crop-specific water demand, area irrigated and water use decrease but much less than the non-targeted area pricing. The negative effect on farm incomes is not severe but remains significant. This assumes that farmers pay for area irrigated based on all hours of irrigation, indicating that cost-sharing or block-pricing approaches will also be needed to minimize the negative effects on short-term farm incomes. Targeted area-based charges that discriminate according to the crop irrigated are more effective in terms shifting production towards less water-intensive crops while also reducing the negative effects on farm incomes.

7. Conclusions

The results from this study show that the unregulated use and depletion of groundwater is likely to have serious consequences for poor farmers as their livelihoods will have to depend increasingly on drought-prone and risky rainfed agriculture. Coupled with indirect subsidies that lower the relative profitability of water-efficient dryland crops, the availability of free water for irrigation is shifting cropping patterns in favor of water-intensive crops that should not be encouraged in water-deficit areas. Unregulated extraction of groundwater resources undermines the ongoing efforts for integrated and sustainable management of watersheds being promoted widely in India. Given the open-access externalities, low pumping costs and free access to water that jointly encourage groundwater depletion, water charges may be considered a suitable policy option to mitigate depletion of aquifers in semi-arid areas where water-intensive cropping patterns are expanding.

Using plot-level data, and an econometric model developed using a farm household decision framework, we estimated the shadow price of water and evaluated alternative water pricing options and their likely impacts. The policy analyses aimed to evaluate time-based and area-based instruments for irrigation water pricing. The results indicated a good potential for using any or a mix of the two approaches. We found that the average shadow value of water in the semi-arid villages is about Rs 50/h of irrigation but this value increases up to two-folds for high-value crops or falls to one-tenth for water-intensive crops like paddy and wheat. The effectiveness of pricing instruments could be further enhanced if the hourly charges could be differentiated by the pump capacity, and when the area-based charges are varied by crop-water demand. If these options are carefully introduced, they are likely to induce adoption of water-saving technologies and shift cropping patterns towards high-value crops with low water demand. The incremental income and profitability effects analyzed here could be used to assess the likely impacts of alternative water policy approaches on farm-level water-saving and the livelihoods of poor farmers. The results showed that full water pricing will have significant negative effects on short-term farm incomes, but this can be reduced if pro-poor approaches where farmers pay a portion of the total water used for irrigation is adopted along with strategies that encourage water-saving practices.

Considering the current political reluctance to adopt such policies, there could be several mechanisms for introducing water user charges. Perhaps the best option is for the communities themselves to agree on an equitable and more sustainable policy and locally manage the funds. The watershed communities can use such scarcity rent funds to further develop water re-charging systems, enhance market linkages for water-saving crops and expand equity effects through employment opportunities for landless and low-income groups. However, improvements in water productivity may not necessarily translate into large scale (e.g., basin level) water-saving as this would depend on several factors that influence the total volume of agricultural water use. Water-saving would be possible only if farmers use less water overall in agricultural activities. Water markets alone may not also bring about improvements in water use efficiency and water-saving unless supported by changes in other distorting policies and removal of subsidies for power and water-intensive irrigated crops.

The success of these policy choices will therefore depend on whether communities are prepared to forego short-term benefits and governments are able to remove policies that encourage depletion of groundwater. The present deadlock over some of the hard policy decisions for groundwater management in India is fueled by the notion that farmers will reject policies that affect their livelihoods. This may be correct to the extent that groundwater remains an open-access resource and communities lack information about available stocks and sustainable levels of extraction. Future policy for groundwater management should aim at improving local knowledge on available groundwater stocks, consequences of unregulated use, and sustainable levels of extraction; and promoting water-saving practices and institutional arrangements to foster collective action. In the long-term, there is a need for diversification of income through development of non-farm livelihood strategies. We anticipate that the smallholder farmers would ultimately gain from such policies that improve equity and sustainability of groundwater resources that underpin their livelihoods.

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