Irrigation Investments and Groundwater Depletion in Indian Semi-Arid Villages: The Effect of Alternative Water Pricing Regimes

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Introduction

Agriculture is the dominant economic sector in many South Asian countries, including India. It provides livelihoods to nearly 70% of the population and employment for about 60% of the labor force. Several studies have documented the vital roles played by irrigation and the Green Revolution in transforming traditional agriculture in Asia, and particularly, in India. Irrigation investments along with high-yielding varieties and other improved inputs have contributed to faster growth in agricultural productivity. In India, Hazell and Fan (2001) estimate a total factor productivity growth of 2.21%, 3.1% and 1.58% per year (1970-94) for irrigated (>25% of cropped area irrigated), and high and low potential rainfed districts (<25% of cropped area irrigated) respectively. Coupled with favorable input-output pricing and marketing policy, and investment in infrastructure, this has contributed significantly to accelerating the transition from deficiency to national surplus in the major food staples, rice and wheat. Increased productivity has also been associated with reduction in levels of rural poverty during this period. This is especially so in areas that benefited from the Green Revolution: the levels have dropped from 39 to 28% in irrigated areas and from 52 to 39% in rainfed areas (Hazell and Fan, 2001).

Irrigation accounts for over 90% of water consumption in India, as in many South Asian countries (Rosegrant et al. 2002; FAO 2003). Projections indicate declining trends in irrigation investments and growth rates for areas under irrigated agriculture. The high costs of new water development, inter-sectoral competition for water and environmental degradation contribute to the slowdown in irrigation development. In India, the withdrawal of water for non-agricultural, ie, domestic and industrial purposes, accounted for 8% in mid-1990s and is expected to increase to 14% by 2025 (Rosegrant et al. 2002). Moreover, the impressive productivity gains in cereal production achieved in certain areas during the Green Revolution are now showing signs of decline or stagnation. Emerging empirical evidence shows that under intensive rice-wheat monocultures systems, it is difficult to sustain productivity over a long term. Intensive agriculture under the Green Revolution has been associated with the build up of salinity in dry areas and water logging in wet areas, depletion of groundwater reserves, formation of hardpan (sub-soil compaction), soil-nutrient imbalance and increased incidence of pests (Pingali and Rosegrant 2001).[1]

As growth opportunities in more favorable zones are exhausted, the need to improve the productivity of less-favored regions is becoming more compelling, on the grounds of equity, efficiency and sustainability. Hence, development planners and policy makers in India are increasingly focusing on these less-favored rainfed regions. Integrated rural development based on watershed management has been promoted as a viable strategy for improving productivity in drought-prone and water-scarce rainfed areas (Farrington et al. 1999). Although substantial public and external funds are being spent on watershed management ($500 million per year), the economic and environmental impacts of the program have, so far, been limited. The role of the community in cost-sharing and collective action too has been limited (Kerr et al. 2002). Watershed management requires active cooperation of local communities to handle the complex externalities involved in soil, surface and groundwater and biodiversity management. New policies and institutional arrangements are required to stimulate collective action and private investments in sustainable land and water management practices.

Furthermore, addressing future water constraints would require strategies for supply augmentation and demand management (Rosegrant 1997; World Bank 1993). This calls for further

[1] Although these external environmental impacts were associated with the Green Revolution, intensification of land use and productivity growth has perhaps reduced the expansion of agriculture into forests and marginal and ecologically vulnerable areas.

improvements in economic efficiency of water use in agriculture (defined as higher economic net returns per unit of applied water) both in irrigated and non-irrigated areas. Innovative demand management would require adoption of water-saving technologies, localized management and policy and institutional reforms that create incentives for an *in situ* conservation of water and its management. In India, irrigation water and energy prices are highly subsidized by the government. Groundwater for smallscale irrigation is also free to all farmers who can privately invest in tube and open wells. These kinds of policies often lead to overuse and depletion of groundwater reserves (World Bank 1993).[2] With increasing investment in smallscale irrigation, depletion of groundwater in many dryland villages is occurring at alarming rates.

This paper reviews some of the externalities involved in the management of groundwater resources in watershed communities and provides some empirical results on potentially useful policy approaches to counter groundwater depletion. We use empirical data collected through ICRISAT household and community surveys in 12 dryland villages to track the changes in smallholder irrigation investments, and its effects on cropping patterns and depletion of groundwater aquifers. Plot level data from six villages is used to estimate an econometric model with endogenous input equations. The model is used to evaluate alternative policies for water pricing and to assess the resulting impacts on the returns to smallholder irrigation. The following section presents the watershed management approach and externalities that lead to groundwater depletion. Further, we discuss the data and production systems in the study villages; present the empirical model used in the analysis and discuss the empirical results. We conclude by highlighting the policy implications.

Groundwater depletion, externalities and water charges

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 like the USA, China, India and Mexico, where increasing population pressure and expected economic gains have created strong incentives to deplete the resource (Rosegrant et al. 2002). The magnitude of the problem is poorly documented, particularly in developing countries. In India, along with supportive policies, factors such as the increase in the productivity of agriculture due to the Green Revolution technologies, declining farm sizes due to rural population growth, and the frequent drought risk in the drier areas, have induced a dramatic increase in groundwater utilization. Marginal farmers owning less than one ha constitute about 60% of the operational holdings (FAO 2003). The number of operational holdings with less than two ha has increased from 70% in the early 1970s to 81% in 2001 (Jha 2001). Between 1970 and 1994, the area under groundwater irrigation increased by 105%, while the area under surface water irrigation grew by only 28% (Shah 2002). This has reversed the roles of ground and surface water irrigation; today groundwater irrigation accounts for about 60% of the 50 million ha of irrigated land in the country. The availability of institutional credit for setting up tube wells and highly subsidized electricity for pumping water have induced a remarkable increase in the number of wells (<1 million in 1960 to 19 million in 2000) (Ibid.), particularly in drier areas where surface water is scarce. While this has made a substantial contribution in terms of raising agricultural

[2] In medium and large irrigation schemes, lower water prices may also encourage farmers to over-irrigate their fields, which leads to a gradual rise in the water table and problems of water-logging and soil salinity. Appropriate water price policies can therefore be expected to address both the problems of rising and declining water tables.

productivity and farm incomes for the poor and marginal farmers, excessive extraction without reinvesting in recharging facilities has led to depletion of scarce groundwater resources in many parts of the country. Even when the level of recharging has increased, the groundwater level in many watersheds is declining due to unregulated over-exploitation by large number of irrigators. This is expressed in terms of 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 (especially open wells) once in use in many parts of India have completely dried up. The situation is already critical in northern Gujarat, southern Rajasthan, coastal Tamil Nadu, parts of Haryana and Punjab (Shah 2002). Agricultural economies built on the basis of groundwater irrigation will eventually collapse as non-sustainable water use leads to depletion of the resource. In drier areas of the country, watershed management is being promoted and encouraged to counter this problem and provide sustainable livelihood security to the rural poor.

A micro-watershed is a catchment area from which all water drains into a common point, making it an attractive unit for technical efforts to manage water and soil resources. As a geographical unit, watersheds often encompass diverse biophysical conditions – different land types with varying soils, slopes, tree cover, drainage, biodiversity, etc. – and differing potentials for agricultural development, suitability for cropping, and surface and ground water management. Watersheds are also typically inhabited by a number of smallholder farmers (belonging to differing social, political and administrative units) with fragmented landholding patterns and resource use rights. In India, except for some common grazing lands, much of the farmland that has high potential for agriculture is already privately owned. With increasing population and privatization of land, land held under common property rights has declined drastically in the last few years. Groundwater has emerged as the most important common property resource utilized by small farmers in dryland areas.

Investments in land and water management practices (including cropping systems, cereal-legume rotations, agro-forestry, soil conservation, water harvesting, etc.) by a single landholder in watersheds often generate valuable economic and ecological goods and services that influence the flow of benefits and costs both on-site (for the resource owner) and off-site (for other members of the community). The unintended spillovers from private resource use decisions affect the production and investment decisions of other farmers. These are not mediated through the market mechanism, and are commonly referred to as externalities. Some externalities could be positive and others negative. The distribution of investment costs, benefits and externalities, determine farmers' technology choices and their investment strategies. The type of policies and institutional arrangements needed to internalize externalities depends on the public good characteristics[3] of the economic and ecological goods and services generated from watershed investments. For example, groundwater is a congestible resource with high costs for excluding non-investors.

Watershed management often entails activities that generate costs and benefits to many resource users within the watershed and beyond. The unequal distribution of costs and benefits from soil and water conservation investments on sloping lands is a classic example of the upstream-downstream tradeoffs. Activities that generate local public goods that come with high costs of exclusion require cooperation by all resource users; for example, investments in controlling gully erosion and floods, and water harvesting for recharging groundwater. Tree planting on communal lands and integrated pest management are other activities that require collective action. Watershed management spans

[3] Unlike private goods sold and bought in markets, public goods (eg, multiple ecosystem services provided by improved watershed management) are mainly non-consumptive (non-congestible) and require high costs to exclude others who may want to use them without paying for the services/resources.

many such activities that necessitate local cooperation. However, the social and biophysical diversity in the watersheds has serious implications for collective action. Stratified social structures across caste and social classes increase organizational costs and impede cooperation. Private incentives for collective action are also determined by the stock of resource use rights and entitlements of individual holders and the ability to exclude others from benefiting from such investments. Excludability depends on biophysical conditions, property rights and the prevailing legal and institutional framework, including customary laws.

Topographic and landownership conditions in watersheds also imply that negative externalities could flow in several directions (reciprocal externalities), in such a way that land use and water management decisions of one farmer affect the well-being of all farmers. This is the case for groundwater use from a common aquifer where accelerated use by a single user increases the pumping costs to all well owners. When the rate of exploitation exceeds the rate of renewability of the aquifer, the groundwater will be depleted in a finite time. The basic incentive structures that induce over-exploitation of groundwater in this context are related to a lack of clearly defined and secure property rights that encourage cooperation. Lack of assurance about the actions of others, and lack of adequate legal and institutional arrangements to regulate users leads to an open access solution. This may eventually lead to over-pumping and exhaustion of the aquifer.

In the Indian watersheds, the public and watershed communities pay the investment costs needed to recharge groundwater. A number of check dams are built in each watershed at selected locations along the watercourse to retain the stream flow and increase infiltration into the ground. Interestingly, the irrigation benefits from these communal investments are captured without payment by landowners who can invest in tube and open wells. Farmers who own wells near these recharging facilities are most likely to benefit from the increased availability of groundwater.[4] We have also observed in our field studies that farmers tend to set up new tube wells closer to recharging facilities. Nevertheless, individual farmers are not willing to invest their own resources in groundwater recharging facilities because there are no legal and institutional mechanisms to regulate use and to penalize the free-riders. The inability to exclude others perpetuates free-riding behavior whereby every water user has the incentive to tap the groundwater without investing in recharging systems.

Subsidized energy prices also encourage over-pumping. In India, irrigation water is charged (partly) only for public sources, ie, canal and tank irrigation systems. There is considerable diversity in the system of levying irrigation charges across states. The rates are often levied on the basis of the acreage irrigated, differentiated by crop and season, but may be uniform throughout the state (FAO 2003).[5] Generally, in the presence of subsidies for pumping, the rates are small and smallscale private tube and open well irrigation systems are exempt from payment. Users therefore lack the economic incentive to factor in the full social cost of water used in their production activities. Regardless of its scarcity, water is a free resource to all smallholder farmers who are able to invest in infrastructure to tap existing aquifers. With increasing scarcity, local informal markets have developed in some areas where water-deficient farmers rent water seasonally from water-surplus farmers (Shah 1993; Meinzen-Dick 1998; Saleth 1998). The water rates may vary by season and the type of crop grown. As

[4] Studies on 62 open wells monitored from 1999-2002 in Adarsha watershed at the study site have shown a significant increase in the water table for all the wells, and particularly those located closer to the recharging facilities (check dams) (Wani et al. 2003).

[5] The water charges for storage systems and canal lift irrigation are higher than flow diversion and irrigation schemes. The 10th Finance Commission has adopted a norm of Rs 300/ha (about $8.5 in 1997) as the operation and maintenance charge for major and medium irrigation works and Rs 150/ha (about $4.2 in 1997) for minor irrigation schemes. This norm is to be increased by 30% in hilly areas to cover the increased conveyance and lifting costs (FAO 2003).

much as 25% of the output is paid for irrigation water. In some cases, payments may occur based on the hours of irrigation. We use variations of both these indigenous systems to assess the potential for introducing water user charges to enhance sustainability of groundwater utilization in semi-arid Indian villages.

Data and methods

The study is based on community, household and plot level data collected by ICRISAT during the year 2002 and 2003 covering 12 villages in four districts of Andhra Pradesh, India. The community surveys in the 12 villages were carried out as a prelude to the household baseline data being collected from villages where ICRISAT is conducting participatory on-farm watershed management research in selected communities. The community survey data was collected from a diverse group of key informants from each community using a semi-structured survey instrument. Among other things, it provided useful historical quantitative and qualitative data on soil and water management practices; changes in cropping patterns and land use; access to irrigation and new technologies; vulnerabilities to drought and groundwater depletion; degradation of common property resources; and socio-cultural diversity (eg, wealth, caste and religion) indicators in the communities. The data from the community surveys provided useful information on the expansion of smallholder irrigation and the associated changes in cropping patterns.

The econometric estimation of the productivity effects of irrigation comes from the detailed household survey and plot level input-output data collected in 2002 from six of the villages in Ranga Reddy district. In one of the villages (Kothapally) a participatory community watershed management program was initiated in collaboration with the Drought Prone Area Programme (DPAP) of the Government of India during the year 1999. Along with ICRISAT, a consortium of NGOs and national research institutes is testing and developing technological, policy and institutional options for integrated watershed management in the village (Wani et al. 2002; Shiferaw et al. 2002). A package of integrated genetic and natural resource management practices are being evaluated on farmers' fields (including IPM and new varieties) through participatory approaches. A census of all households (N = 825) in the six villages was carried out before the detailed household survey. As is typical for many rural villages in India, the social structure is characterized by a multi-caste and heterogeneous social system. As per the Indian classification system, 53% of the households belong to backward castes, 23% to scheduled castes, 13% to minorities, and 11% to forward castes. Because of a recent land reform, landlessness is not a major problem in these villages. About 5% of the households were landless. About the same proportion of households were headed by women. Analysis of this data provided useful information about the general profile of the rural economy and local institutions. This formed the basis for random selection of 60 households from each group (within and outside the catchment) for a detailed survey.

Along with other standard farm household information, a detailed plot and crop-wise input and output data was collected soon after harvest from the operational holdings of all the sample households for the 2001/02 production year. Farmers considered production conditions during the year good and favorable. This is unlike the widespread drought conditions that prevailed in the following year (2002/03). The associated biophysical data on major plots was collected using locally accepted soil classification systems. Trained enumerators lived in the villages during the course of the survey. Because of their geographical proximity, the six household survey villages were held to be generally similar in biophysical conditions, including rainfall. The plot-level data contained information on differences in soil quality (soil depth, soil type and soil fertility), risk of soil degradation, slope gradients and soil and water conservation investments. Access to markets was also fairly similar. The major difference lay in terms of access to new production and resource management technologies. Households within the catchment benefit from new varieties and land and water management options, which are being evaluated in close participation with the community. Households outside the project area do not yet have such access.

The majority of the households use farmyard manure, fertilizer and pesticides. Fertilizer use intensity ranges between 100 and 200 kg/ha, averaging 125 kg/ha. However, farmers indicate that the incidence and degree of soil degradation has increased over time. Drought risk is a serious problem in the areas. Although the supply of drinking water has improved in recent years, farmers consider shortage of irrigation water to be a major constraint in improving their incomes and securing their livelihoods. The major cropping period is during the monsoon rains (*kharif* season), but some crops (eg, chickpea, paddy, flowers and some vegetables) are also grown during the postrainy (*rabi*) season. Crop production is highly diversified and farmers practice intercropping. With increasing access to markets and irrigation, the cropping pattern is gradually shifting towards commercial crops like cotton, vegetables and flowers. However, paddy is a low risk crop that provides good returns to family labor, and is highly preferred by small farmers in irrigated conditions.

Empirical model

Several previous studies (eg, de Janvry et al. 1991; Delforce 1994; Pender and Kerr 1998; Holden et al. 2001) 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; Sadoulet and de Janvry 1995). 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, ie, the local market prices (if observed) will differ from the subjective shadow prices. 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 investments and household welfare. Since we cannot rule out the possibility that some of the input markets in the study villages are imperfect, we employ the theory of farm household economics under imperfect markets and include a number of household and farm fixed factors in the estimation of production and investment equations.

In this way, land productivity is likely to depend on a host of exogenous (pre-determined) and endogenous variables. The latter includes all variable input factors used on the plot. The choice of crops and the level of use of different inputs in a given plot is an endogenous decision by the household, which will be determined based on exogenous variables like access to markets and credit, soil types and household assets. This means that estimating land productivity using these endogenous variables would cause a simultaneity bias. Hence, the standard assumption of the independence of the regressors from the disturbance term will not hold. Because of the simultaneity problem, ordinary least squares (OLS) estimates will be biased and inconsistent. Hence, we estimate a system of simultaneous equations using three-stage least squares (3SLS), which provides consistent and asymptotically efficient estimates (Green 1998).

The empirical structural model contained a system of six structural equations:

$$\pi_k = \pi\left(c_j, L_k, X_{fk}, X_{bk}, I_k, S_k, z^q, h^q, R_1\right) \quad (1)$$

$$L_k = L\left(c_j, K, S_k, z^q, h^q, R_2\right) \quad (2)$$

$$X_{fk} = X_f\left(c_j, K, S_k, z^q, h^q, R_3\right) \quad (3)$$

$$X_{bk} = X_b\left(c_j, K, S_k, z^q, h^q, R_4\right) \quad (4)$$

$$I_k = I\left(K, S_k, U_k, V_k, z^q, h^q, R_5\right) \quad (5)$$

$$V_k = V\left(I_k, S_k, z^q, h^q, R_6\right) \quad (6)$$

where the system of equations (1-6), respectively, represents: net returns to owned land and family labor (1); expenditure on labor (hired and family) (2); expenditure on fertilizer, seeds and pesticides (3); expenditure on other variable capital inputs (bullocks, tractors, etc.) (4); cumulative investments in soil and water conservation (SWC) practices (5); and the market value of farmland as perceived by the owner (6). The productivity of land on plot k is modeled as a function of the crop grown (c_j), expenditure on labor (L_k), expenditure on inputs like fertilizer, seeds, pesticides and farmyard manure (X_{fk}), expenditure on capital inputs (bullock, tractors, etc) (X_{bk}), SWC investments (I_k), soil and plot characteristics (S_k), household assets and farm characteristics (z^q), household characteristics and social capital (h^q) and other exogenous variables (R). Among the other variables, the level of use of inputs depends on the amount of credit received (K) during the year. Investments on SWC may also depend on access to credit. Further, SWC investments depend on land quality characteristics (S_k), farm characteristics (z^q), exogenous public investments (U_k), and perceived market value of the farmland by the owner (V_k). The latter depends on the level of private and public SWC investments on the plot as well as land quality and farm characteristics. The exogenous variables (R_1 to R_6) capture a set of specific pre-determined variables with a special influence on a given equation.

The system was estimated using input-output data from 509 plots from 120 sample households in the six survey villages. The structural equation system was estimated using 3SLS in the SAS package. Equation (1) was specified as a semi-log model (net returns may have zero or negative values). Other equations (2-6) were specified in a double-log form. The results from the complete system are reported elsewhere (and can be made available on request). In this paper, we will report only the results from the land productivity model (1). In order to evaluate the productivity effects of alternative water policy instruments, the equation system was estimated with differing levels of water charges.

Results

Smallscale irrigation and groundwater depletion

Results from the community surveys in the 12 villages show that, consistent with the pattern observed at the national level, the number of pump-operated open and tube wells has shown a tremendous increase in the last twenty years (Table 1). Open wells are indigenous practices, which have been historically used in the dryland areas of India for supplementary irrigation. However, with the advent of electricity and diesel pumps, there is an increasing trend towards tube well irrigation. Since the mid-1990s, the number of tube wells has increased much faster than open wells. In many villages, tube

Table 1. Expansion of smallscale irrigation in selected districts of Andhra Pradesh, India.

	Tube wells			Open wells		
Villages	1980	1990	2003	1980	1990	2003
Ranga Reddy district						
Kothapally	0	3	34	35	50	64
Hussainpura	0	2	3	3	3	13
Masaniguda	2	7	40	20	40	80
Yenkepally	0	5	27	15	30	50
Yervaguda	12	15	18	2	3	5
Oorella	0	3	30	70	110	150
Sub total	14	35	152	145	236	362
Mahboobnagar district						
Malleboinpally	15	40	62	25	35	35
Mentapally	6	32	74	12	45	110
Sub total	21	72	136	37	80	145
Nalgonda district						
Tirumalapuram	4	40	70	8	35	35
Kacharam	10	25	54	22	72	85
Sub total	14	65	124	30	107	120
Kurnool district						
Nandavaram	8	15	24	30	54	60
Devanakonda	5	70	110	12	30	53
Sub total	13	85	134	42	84	113

Source: ICRISAT Community Watershed Surveys (2003).

wells are already overtaking open wells. The average depth of open and tube wells is 12.5 m and 61.2 m. The density of the wells is correlated with the number of households, the expected vulnerability to drought and availability of groundwater in each village. The density of wells is higher in the drier districts of Nalgonda and Mahabubnagar (about 0.3 wells/household). It is lower in villages in Kurnool district partly due to better growing conditions and rocky terrain that increases the cost of drilling and groundwater abstraction. Along with the expansion of smallscale irrigation, the area under irrigation has also shown three to five-fold increase during the last 20 years. The discussions with community leaders have indicated that population growth, declining farm sizes and perceived household vulnerabilities to drought are the basic drivers of this change.

When we look at groundwater depletion, the accelerated exploitation of aquifers without sufficient investment in recharging facilities already shows the unsustainable nature of water use in these villages. As the water table declines, farmers also invest in well deepening which contributes to faster depletion of shallower wells. One good indicator of the extent of water depletion is the number of wells that have gone out of service due to depletion of the water table. We asked key informants about the number of tube and open wells that have dried up and have not been in use for at least three years. The village-wise picture is presented in Table 2. We note that except in the Kothapally village where the watershed project has been in operation since 1999, in all other villages where the watershed project is yet to take effect, a large proportion of the wells have dried up completely. More than 65% of the open wells in each village have dried up, while the corresponding rate for tube wells is slightly lower (28-45%). This is partly because the tube wells are relatively new and deeper than the open wells. In many of the villages, more than 90% of the open wells have completely dried up. Coupled

Table 2. Smallscale irrigation and groundwater depletion in selected districts, Andhra Pradesh, India.

Villages	Households (No.) (2003)	Total tube wells (No.)	Tube wells dried-up (%)	Total open wells (No.)	Open wells dried-up (%)
Ranga Reddy district					
Kothapally	308	34	26.4	64	31.2
Hussainpura	40	3	0	13	76.9
Masaniguda	160	40	40.0	80	62.5
Yenkepally	175	27	51.8	50	64.0
Yervaguda	206	18	38.8	5	100
Oorella	460	30	73.3	150	80.0
Sub total	1349	152	44.7	362	65.4
Mahboobnagar district					
Malleboinpally	230	62	56.4	35	77.14
Mentapally	235	74	32.4	110	98.1
Sub total	465	136	43.3	145	93.1
Nalgonda district					
Tirumalapuram	70	70	24.2	35	65.7
Kacharam	324	54	33.3	85	100
Sub total	394	124	28.2	120	90.0
Kurnool district					
Nandavaram	1234	24	58.3	60	100
Devanakonda	1798	110	36.3	53	79.2
Sub total	3032	134	40.2	113	90.2

Source: ICRISAT Community Watershed Surveys (2003).

with lack of sufficient recharging systems, farmers indicate that this process is accelerated by droughts and below normal rainfall during the last ten years. These results show that unless households and communities invest in systems that recharge the groundwater and encourage conjunctive use of surface and groundwater resources, many of the aquifers are likely to be depleted in the near future. The lifetime of the resource will depend on the size of the aquifer, the rate of extraction and the recharging efforts. If the external recharging efforts are minimal, as in the case of many of the villages surveyed, the time taken to extinguish the resource will depend on the available stock and the volume of withdrawal. Along with watershed management, economic and institutional mechanisms for regulating the use of the common property resource are the key to enhancing the renewability of groundwater resources.

Changes in cropping patterns and water productivity

In response to improved access to irrigation, changing consumption patterns and 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 Kelly (1999) find falling shares in gross cropped area in the Indian SAT for sorghum, pearl millet, cotton and groundnut in marginal areas and rising shares for tradables like sunflower, soybean, mustard and chickpea. In more favorable, irrigated areas of the SAT, 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

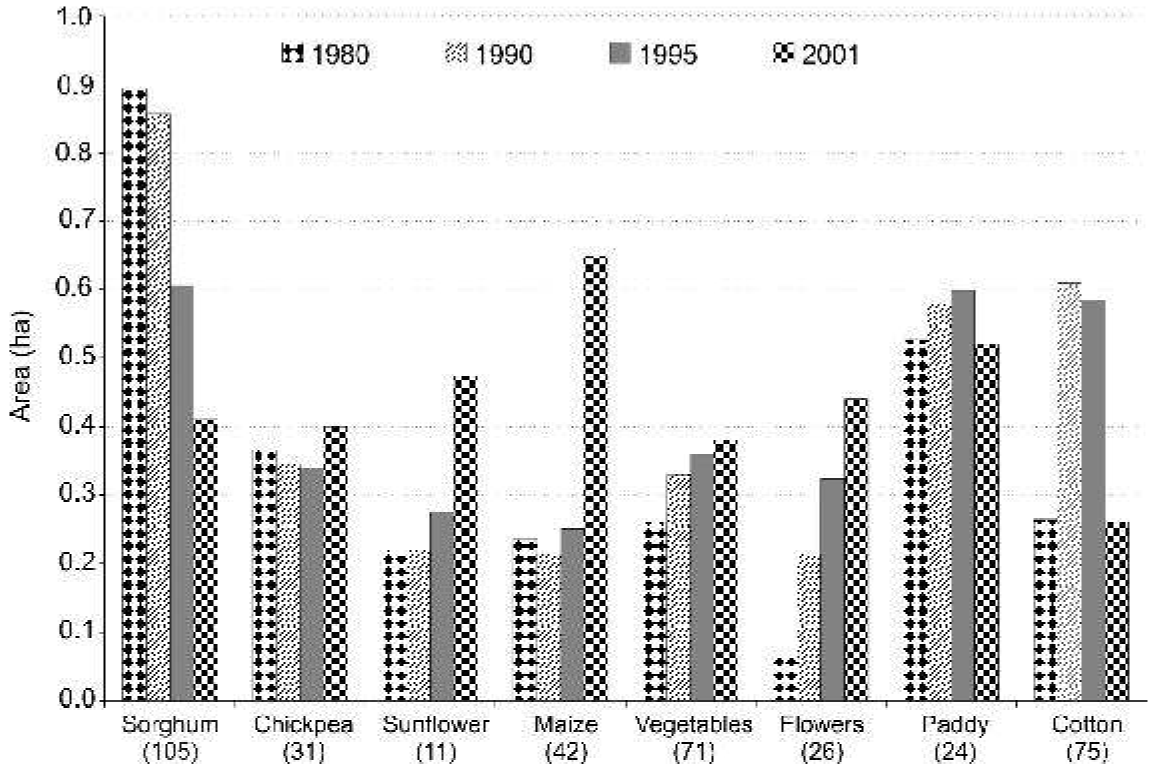

Figure 1. Changes in area allocated to different crops in six villages.
(Values in parenthesis are the number of sample households who grew the crops since 1980. The values for the pre-2001 period are approximate three-year averages centered on that year.)

our micro-level evidence in the selected villages (Figure 1). In the last twenty years, farmers who have been growing sorghum (mainly intercropped with pigeonpea) have, on average, significantly reduced the area under this crop. But the area under oil crops, maize, vegetables and flowers has grown significantly over the period. The area under rice and chickpea seems to be stable. Cotton has become an important cash crop for many dryland farmers, but owing to the increasing pest and disease pressure, recent trends indicate declining areas for this crop. In order to see the economic incentives that drive this process of change, we plot results from the plot level data in Figure 2, which shows the net returns to irrigation for the different crops. When irrigation water becomes available and it is free, it makes economic sense to the farmer to shift towards flowers, sugarcane, vegetables, rice and turmeric. This is largely consistent with the shift in cropping patterns that has occurred in the six villages studied in Ranga Reddy district (Figure 1). These results show that with increasing irrigation investments, farmers have adjusted their cropping patterns and diversified into new crops to exploit the emerging economic opportunities. Unfortunately, as long as groundwater remains a free common property resource, the emerging cropping pattern is likely to hasten the depletion of this scarce resource. The 'boom and bust' in the groundwater-based agricultural economies has been widely observed in India (Shah 2002; Rao et al. 2003). Table 3 shows how the current cropping system relates to the net productivity of water. Farmers irrigate about 4% of the cultivated area. Vegetables and paddy represent 30% and 22% of the total irrigated area. Water requirements (hrs/ha) are highest for "blue water" crops like sugarcane, paddy and wheat, grown only under irrigated conditions. For other crops

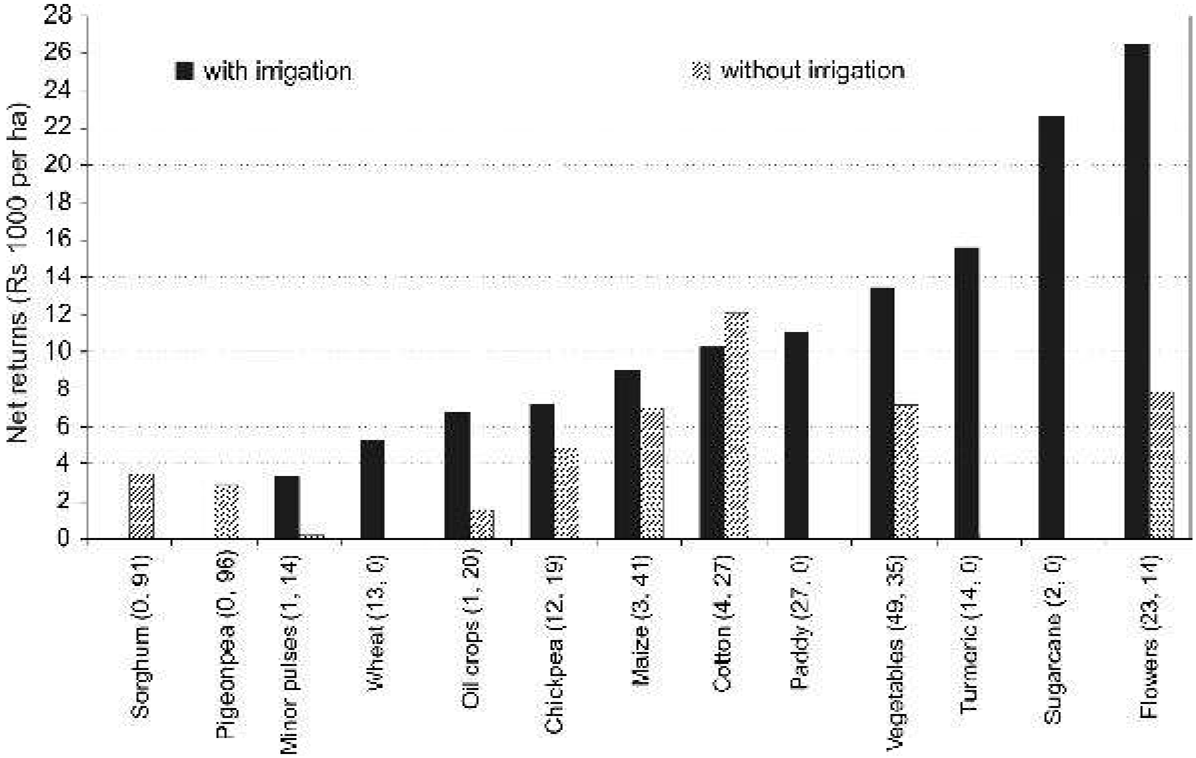

Figure 2. Farm-level profitability of different crops with and without irrigation.
(Values in parenthesis are number of plots with and without irrigation, respectively)

Table 3. Farmers' irrigation decisions and water productivity relationships.

Crops	Area Cultivated (ha)	Area irrigated (ha)	Percentage of total area irrigated	Intensity of water use (hrs/ha)	Net Returns (Rs 1000/ ha)[a]	Net water productivity (Rs/hr)	Actual irrigation (hrs)	Percentage of 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**

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

such as flowers, chickpea, cotton and vegetables, water is applied only in the form of supplemental irrigation. Hence, water requirements are lesser. Water productivity is highest for high-value crops with low water demand and lowest for low-return, high water demand crops like paddy and sugarcane. Since water is a free resource, farmers' water use and allocation patterns do not reflect the marginal productivity of scarce water resources. Paddy accounts for less than a quarter of the irrigated area, but consumes over 60% of the applied water. Crops with high water productivity like flowers, vegetables, chickpea and cotton receive less than 20% of the available irrigation water. Economic incentives and water charges would be needed to regulate groundwater abstraction and to shift cropping patterns towards water-saving options and crops with high net water productivity.

The base model for land and water productivity

The simulation results from the basic econometric model are given in Table 4. The first column shows the base model results estimated with the lowest rate of Rs 1.5/hr of irrigation.[6] The upper and lower bounds for the parameters estimated using alternative pricing approaches are shown in the following columns. The complete simulation results on the impact of alternative pricing regimes on the profitability of irrigation are depicted in Figure 3 and 4. The base model results indicate that net returns per ha were positively associated with the use of labor and capital inputs. A 10% increase in labor and capital input expenditures would increase returns by about 7% and 2.5% respectively. In order to capture the differential input productivities across crops, we included seven crop dummies (flowers as reference group). Controlling for land quality and crop types, the expenditure on fertilizer and pesticides was however negatively related to net returns per ha. This is a counterintuitive result. However, this is partly because farmers are diversifying into new high-value crops (eg, flowers and oilseeds) where expenditures on inputs are much lower than other dryland crops (eg, cotton and vegetables). This was confirmed from the jointly estimated input demand function (fertilizer, pesticides and seeds), which shows that expenditures on these inputs are 204% and 69% higher for cotton and vegetables than for flowers. There is also a possibility that farmers are using these inputs to mitigate risk than to maximize yields, especially when the inputs are highly subsidized. In order to better understand these relationships, there is a need to evaluate the effects of fertilizers separately from pesticides. We also found a negative association between off-farm income (earnings from agricultural wages and off-farm sources) and land productivity. Increase in average off-farm income per capita or per ha of cultivated land was associated with lower per ha labor input, fertilizer use, and investment in SWC, which in turn translated into lower economic productivity of land as off-farm income increases. This is an interesting relationship that requires policy interventions to reduce undesirable tradeoffs between land productivity and sustainability as households diversify their incomes into non-agricultural activities.

As expected, results also show that adoption of improved varieties increase returns significantly. On average, returns per ha are Rs 3270 higher on plots with improved varieties. However, land productivity declines substantially when the plots are affected by certain stresses related to drought and pest and diseases that reduce crop yields. A 10% increase in the area affected by the incidence of pests, diseases and other stresses will reduce land productivity by about 12%, indicating the extent of losses incurred in the event of such risk. As hypothesized, crop choice will also influence returns to family land and labor in cropping. Compared to the reference group of flowers, the net returns are

[6] As expected in the presence of endogenous independent variables, the m-statistic of Hausman's specification test (Hausman 1978; Hausman and Taylor 1982) confirmed that 3SLS estimates are more consistent than OLS estimates (P<0.001). We therefore use the 3SLS land productivity model for simulating the effect of alternative water charging regimes.

Table 4. Determinants of land productivity and the effect of water pricing approaches on returns to irrigation.

Explanatory variables (dependent variables are net returns Rs 1000/ha)	Hourly water charges			Output share charges	
	Rs 1.5/hr		Rs 50/hr	2.5%	20%
	Parameter estimate	Elasticity[a]	Parameter estimate	Parameter estimate	
Intercept	12.24**		4.46	12.26***	10.76***
Ln (expenditure in labor per ha)	5.17***	0.70	4.25*	5.06***	4.13***
Ln (expenditure on fertilizer, seed and pesticides per ha)	–6.87***	–0.93	–7.71***	–6.73***	–5.88***
Ln (other capital expenditures per ha)	1.86***	0.25	2.93***	1.80***	1.58***
Ln (private SWC investment per ha)	–0.15	–0.02	–0.08	–0.15	–0.14*
Ln (off-farm income per ha)	–0.16**	–0.02	–0.17**	–0.16**	–0.13**
Ln (cumulative 2 yrs credit per ha)	–0.11*	–0.01	–0.16**	–0.11*	–0.09*
Soil type dummy (vertisols = 1)	0.45	0.06	2.11	0.42	0.61
Soil depth	2.02***	0.54	1.67*	1.98***	1.59***
Soil fertility level	–1.28	–0.33	–1.56	–1.24	–0.99
Season (*kharif* = 1)	1.74	0.23	0.89	1.61	0.55
Land tenure (owned = 1)	–3.21	–0.43	8.73**	–3.35	–1.77
Crop variety (improved = 1)	3.27***	0.44	3.12**	3.22***	2.87***
Incidence of stress (Yes = 1)	–8.94**	–1.20	–9.27***	–8.81***	–7.96***
Cotton dummy	–3.14	–0.42	–3.13	–2.95	–1.56
Vegetable dummy	–7.34***	–0.99	–7.84***	–7.16***	–5.94***
Pulse crop dummy	–9.90***	–1.33	–11.31***	–9.73***	–8.82***
Dryland cereals dummy	–17.20***	–2.32	–19.44***	–16.85***	–14.83***
Maize and wheat dummy	–12.16***	–1.64	–13.89***	–11.81***	–9.75***
Oils and spices dummy	–11.33***	–1.53	–13.42***	–11.15***	–10.28***
Paddy and sugarcane dummy	–14.75***	–1.99	–44.01***	–13.44**	–10.59***
Log (farm size - plot size)	–0.03	0.00	–0.12	–0.02	–0.02
Irrigation dummy	7.13***	0.96	3.33*	6.66***	2.54**
Watershed dummy	1.72	0.23	1.46	1.72	1.68*
Ln (years of education for head)	–0.001	0.00	–0.02	–0.002	–0.01
Model fitness	System weighted R^2 = 0.83, Degrees of freedom = 2909				

[a] Elasticities at the means for the logarithmic variables are computed as $\hat{\beta}_i / \bar{Y}$, where $\hat{\beta}_i$ 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. *, **, *** represent statistical significance at 10%, 5% and 1% levels, respectively.

significantly lower for all crops except for cotton. Among the soil quality indicators, soil depth was most important. Soil depth was measured as an ordinal variable (1 = shallow to 4 = very deep). A 10% increase in the mean soil depth will increase the economic productivity of land by about 5%. After controlling for soil quality, input use, seasonality and crop type, the returns to cropping are much higher (Rs 7130/ha) on irrigated plots than non-irrigated plots. A 10% increase in irrigated area will increase net returns by about the same proportion, indicating high economic returns to farmers' investments in water harvesting and supplementary irrigation. This is partly because groundwater used in irrigation is essentially free to farmers. This explains why farmers spend significant resources in exploring groundwater, and invest in tube wells for irrigation. Typically, three to four drilling attempts are made before making a successful hit on the aquifer.

The effect of alternative water pricing regimes

Alternative strategies ranging from supply augmentation to demand management have been advocated for sustainable management of scarce water resources (Rosegrant 1997; World Bank 1993). Consistent with these comprehensive strategies, a number of policy instruments and economic incentives can be suggested for effective water management in agriculture (World Bank 1993; Tiwari and Dinar 2002). Removal of price and energy subsidies for pumping groundwater and proper costing of the services of public irrigation are critical policy instruments for managing demand. In smallholder agriculture in many developing countries, actual levels of groundwater extraction and use are not metered and hence cannot be directly observed. Therefore, farm-level direct volumetric charges are infeasible. Several indirect approaches can however be used to create economic incentives for water saving. The challenge is in identifying the relevant instruments with high chance of success.

Many of the farmers surveyed consider free and unrestricted access to groundwater a fundamental and ancestral right. Despite the efforts of community watershed management projects to regulate water use, this entrenched perception of private rights has contributed to lack of cooperation and to the dramatic increase in unregulated smallscale irrigation. Because of high transaction costs, the regulatory approach (based on inflexible standards and quotas) will not be effective for optimizing the extraction of common property groundwater resources. For example, a quota system (on volume or acreage) requires new infrastructure and institutions for monitoring water use and enforcement of standards, which will be costly given the large number of fragmented users. The incentive-based approach is therefore likely to perform better than the regulatory approach while also providing higher and sustainable economic benefits from water conservation to small farmers (Schaible 2000; Tiwari and Dinar 2002). Water-deficit farmers in South Asia buy water seasonally from adjacent farmers through various informal arrangements (Saleth 1998; Meinzen-Dick 1998). As in land contracts, the transactions may vary from in-kind labor contracts to upfront cash payments. The common approach in the studied villages is based on an *a priori* agreed output share. The fixed share approach rather than a fixed quantity or cash rental is preferred perhaps due to its risk sharing benefits. Unlike the acreage-based approach, it also allows flexibility in crop choice and permits actual payments to vary according to the crop grown.[7]

We evaluate two incentive-based instruments, also reflected at different levels in the informal village water markets. These are: (a) charges based on hours of irrigation, and (b) charges per unit of output. The first is directly related to the volume of water used. The second is related to the productivity of water. The water charges should be large enough to shift cropping patterns to high-value and water-efficient crops and induce efficient and judicious use of groundwater. Since farmers in our surveys often do not pay (or pay a minimal flat rate) energy tariffs, the water charges can be considered to include energy prices for pumping.[8] Based on the empirical econometric model, we illustrate the profitability impacts and potentials for implementation of these two pricing instruments.

[7] Because of the fragmented nature of land holdings and high transaction costs in water conveyance, even farmers who own tube wells on some of their plots often buy water from other farmers to irrigate plots in other locations. This means that when water is available, many farmers enter into informal contracts to trade water within the village market. Shah (1993) reports situations where farmers in Gujarat have pipelines from three or four different suppliers. This makes monopoly pricing less likely (Easter et al. 1999).

[8] Currently, the typical practice in India is a flat rate electricity charging system slightly differentiated on the basis of the horsepower of groundwater pumps (World Bank 1999). Neither groundwater nor irrigation power in rural areas is metered.

The effect of 'volume-based' water charges

The results from our analysis of volume-based water charges (Figure 3) indicate that direct charges on the hours of irrigation, differentiated by the horsepower of irrigation pumps, could be an effective option for water saving and for shifting cropping patterns towards crops of high-value and low water demand.[9] The level of irrigation required varies by crop type, season and soil type, all of which are controlled in the econometric model. As water charges increase progressively, the profitability of irrigation declines. Irrigation remains economically attractive as water charges are increased up to Rs 30-35/hr of irrigation ($P<0.05$). Beyond these levels, irrigation is unlikely to be profitable to small farmers and it may trigger a complete switching towards rainfed agriculture. As upper and lower bound coefficients reported in Table 3 show, as water charges increase, the relative profitability of all crops (except cotton which has higher net water productivity) with respect to flowers declines progressively. The most visible effect is on paddy and sugarcane, which show a two-fold decline (–14.75 to –44) in their relative returns to irrigation with respect to flowers. This is likely to signal and induce reallocation of water from water-intensive crops to water-efficient and high value crops. It is difficult to select the best price that results in sustainable water use and higher incomes for farmers. The appropriate price is likely to depend on the groundwater level, the number of users, the size of the pumps and the cropping system. In situations where the aquifer is facing extinction from unregulated use, a rate closer to the upper bound may be most appropriate. The purpose should be to encourage adoption of water-saving technologies and cropping practices.

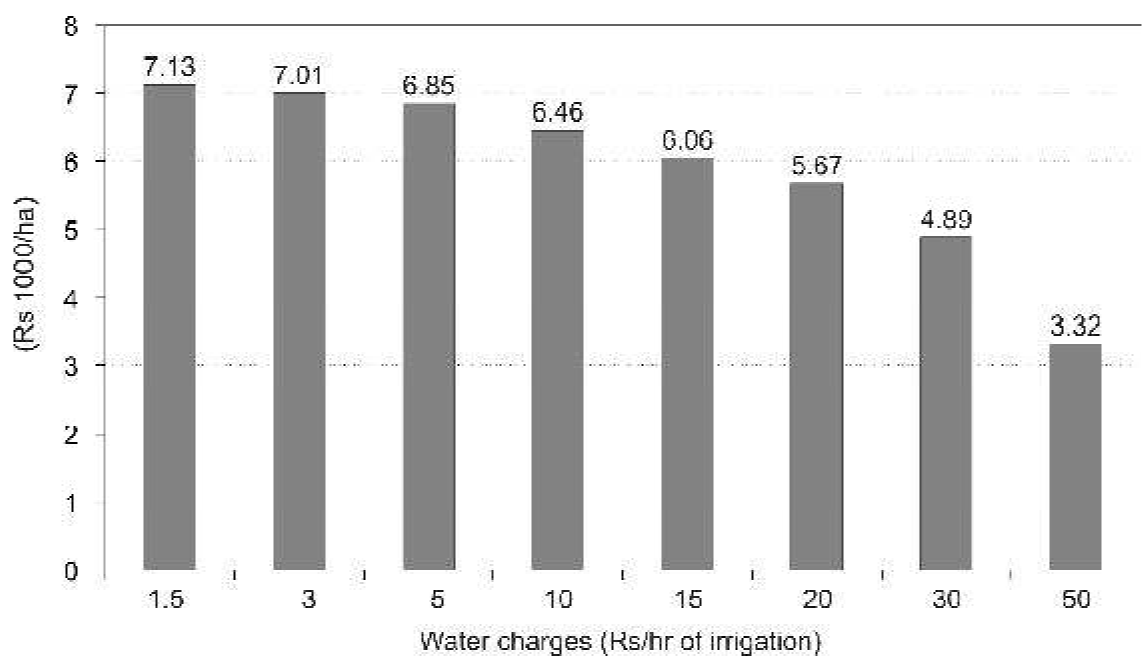

Figure 3. The effect of various 'volume-based' water charges on the profitability of irrigation.

[9] Since subsidized irrigation water charges are set according to pump capacity (eg, Rs 250/month for a 5 HP pump in Andhra Pradesh), farmers may lack the incentive to disclose the capacity of their pumps. As long as actual energy consumption is not known, hourly irrigation water charges should be differentiated by pump capacity.

The effect of output-based water charges

The likely effects of this option on the profitability of irrigation are depicted in Figure 4. Irrigation remains profitable as charges increase up to 20% ($P<0.05$). Beyond this level, irrigation loses its economic advantage. The local practice where irrigators pay up to 25% of the output for water seems to be the cutoff point and perhaps beyond the upper bound for many crops. The net gain from irrigation declines progressively from about Rs 6700/ha at 2.5% share to about Rs 2500/ha at 20% share. Further increases in water charges will simply wipe out incentives for irrigation. When groundwater charges are linked proportionally to the level of total output, the response in terms of water saving may not be as high as the hourly charges. As these output-linked charges do not always reflect the volume of use, it may even induce an increase in water application in the hope of increasing crop yields. However, when the water level is fixed, it provides the incentive to select crops that provide the highest return per volume of water used. If the water level is not fixed, it still encourages growing of crops with higher returns, but not necessarily those with low-water demand. Hence, one way to reduce the incentive problem is to fix the water level (eg, hours of irrigation) and vary the output shares depending on crop-water demand so that water-efficient crops will have lower shares than water-intensive crops. Acreage-based charges for irrigation, if differentiated by crop-water demand, will also have a similar effect. The advantage of this approach is its familiarity to many water users, which may enhance its chances of being accepted by the community.

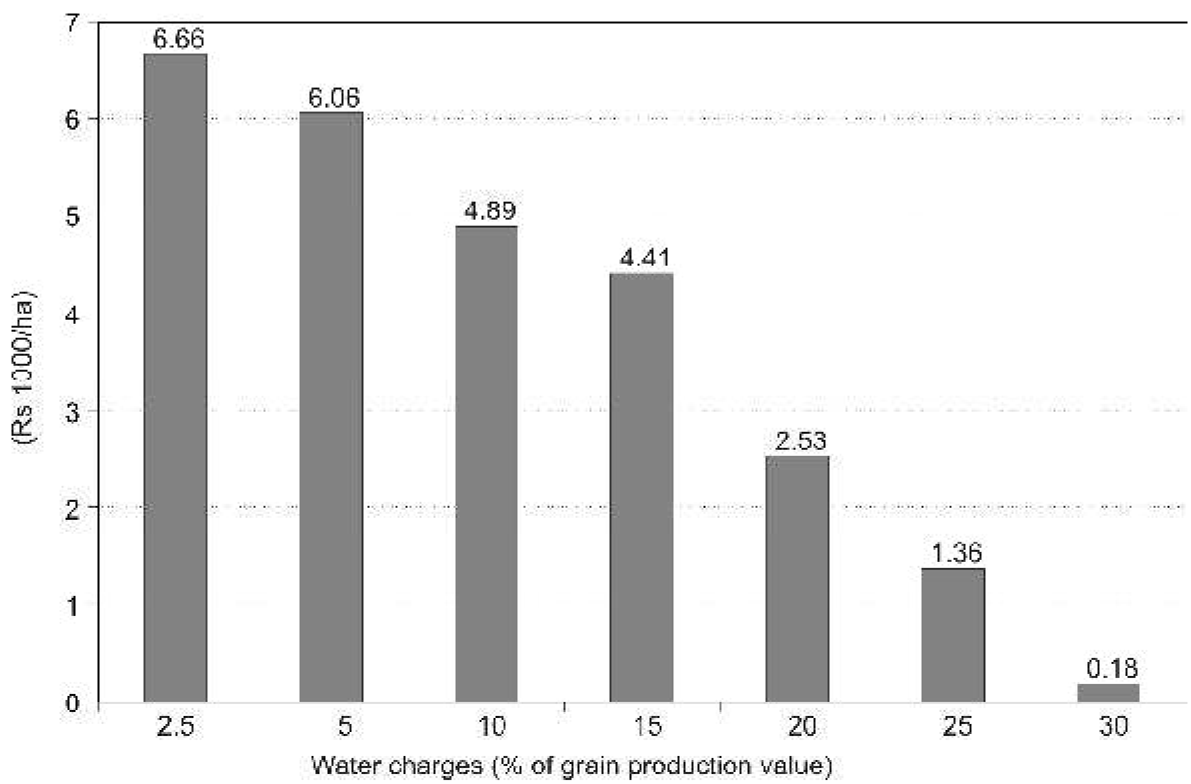

Figure 4. The effect of various output-based water charges on the profitability of irrigation.
(The irrigation dummy is significant at $p<10\%$ for all values below 25% water charges).

Conclusions

With increasing population growth and scarcity of productive lands, average farm sizes in India have declined substantially. This has prompted intensification of land use through increased use of fertilizers, pesticides, improved seeds and irrigation investments that increased the productivity of land and cropping intensities in more favored areas. In many less-favored dryland areas, which did not benefit from the new seeds, water scarcity and vulnerability to drought are driving extensive smallscale investments in groundwater abstraction. Water rights are linked to land ownership. This virtually makes many aquifers open access resources to land owners. Lack of proper legal and institutional mechanisms for regulating the use of groundwater is already leading to depletion of the resource in many rural communities. In order to address the problem of resource degradation, poverty and water scarcity in the drought-prone areas, India has been promoting community-based watershed management. Public funds and community resources have been used to build groundwater-recharging facilities in several watershed communities. However, individual farmers freely capture the irrigation benefits by installing tube wells adjacent to the recharging facilities. This creates a feeling of inequity among farmers and undermines the incentive for cooperation and collective action within the watershed communities. Moreover, very low marginal costs of pumping resulting from highly subsidized energy prices also induce farmers to use water to the point where the marginal value of production is close to zero. The empirical results from selected communities included in this study have shown that the number of wells and groundwater abstraction are increasing much faster than what could be sustained through rainwater harvesting and recharging facilities. This has led to the drying up of many wells. The unregulated use and depletion of groundwater is likely to have serious consequences for the poor farmers as their livelihoods will have to depend increasingly on the drought-prone rainfed agriculture.

When water is free to irrigating farmers, it has led to shifting of cropping patterns to more intensive crops that should not be encouraged in water-scarce areas. 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 promote water saving and to counter depletion. Using plot level data and an econometric land productivity model, we evaluated the potentials for introducing two alternative water-charging approaches: an hourly charge and output-based charge for use of irrigation water. Both approaches are prevalent in local water markets and well known to many water users. The results indicated a good potential for using any of the two approaches. The effectiveness of these instruments could be further enhanced if the hourly charges could be differentiated by the pump capacity and location, and when the share-based charges can be varied depending on crop-water demand. For semi-arid production systems investigated here, irrigation seems to be an attractive option until the water charges reach about Rs 25-30/hr ($0.55). Alternatively, the output share charges could be increased up to 20%. If these options are carefully introduced, they are likely to induce water-saving crops and technologies.

There has been substantial reluctance against adopting incentive-based instruments for addressing adverse externalities in agriculture. One argument is the potential negative impact of such policies on the welfare of small farmers. However, the long-term benefits from sustainable use of groundwater are likely to be much higher than unregulated open access utilization that will quickly deplete the resource, reduce incomes and increase vulnerabilities of small farmers to frequent droughts. If the water charges are re-invested in improving the availability of water, small farmers will directly benefit from it. There could be several mechanisms for introducing water user charges into the affected communities. Perhaps the best option is for the communities themselves to agree on an equitable and more sustainable rate and manage the funds locally, which can be used to improve water recharging facilities through conjunctive use, and support the adoption of water-saving technologies (eg, drip irrigation). Such funds can also be used to enhance marketing services for water-saving crops and to support most vulnerable household groups. Watershed communities and user groups could be legally empowered to plan, implement and enforce these kinds of policies. However, such approaches need to be complemented through provision of information on groundwater availability and the extent of depletion, and sustainable rates of extraction. This will help regulate the level of use and encourage recharging investments. In 'dark spots' where depletion levels have reached threshold levels, other approaches like licensing, quotas and a shift to diesel pumps could be introduced to save disappearing aquifers. Because of the inherent equity, the user charges policy may reduce non-cooperation (free-riding) and encourage collective action within the watershed communities. This could be a win-win option if implemented and managed properly by the local communities.

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