Energy Policy 33 (2005) 39–51

ENERGY POLICY

www.elsevier.com/locate/enpol

Impact of electricity prices and volumetric water allocation on energy and groundwater demand management: analysis from Western India

M. Dinesh Kumar*

International Water Management Institute, India Project Office, Elecon Building, Anand-Sojitra Road, VV Nagar 388120, India

Abstract

In recent years, power tariff policy has been increasingly advocated as a mean to influence groundwater use and withdrawal decisions of farmers in view of the failure of existing direct and indirect regulations on groundwater withdrawal in India. Many researchers argue that pro rata electricity tariff, with built in positive marginal cost of pumping could bring about efficient use of the resource, though some argue that the levels of tariff in which demand becomes elastic to pricing are too high to be viable from political and socio-economic points of view.

The paper presents a theoretical model to analyze farmers' response to changes in power tariff and water allocation regimes vis à vis energy and groundwater use. It validates the model by analyzing water productivity in groundwater irrigation under different electricity pricing structures and water allocation regimes. Water productivity was estimated using primary data of gross crop inputs, cost of all inputs, and volumetric water inputs. The analysis shows that unit pricing of electricity influences groundwater use efficiency and productivity positively. It also shows that the levels of pricing at which demand for electricity and groundwater becomes elastic to tariff are socio-economically viable. Further, water productivity impacts of pricing would be highest when water is volumetrically allocated with rationing. Therefore, an effective power tariff policy followed by enforcement of volumetric water allocation could address the issue of efficiency, sustainability and equity in groundwater use in India.

Keywords: Overall gross water productivity; Overall net water productivity; Overall net water productivity exclusive of irrigation cost

1. Introduction

Several regions of India face groundwater crisis. In many parts of peninsular India, which is underlain by hard rocks, excessive withdrawal of groundwater for irrigation made possible through proliferation and energisation of wells has led to depletion of the resource base, frequent failure of wells and sharp reduction in irrigation potential of wells. In alluvial areas of western India, uncontrolled abstraction through tube wells energised by high capacity pumps led to permanent depletion of shallow aquifers and alarming drops in water levels. Today, agricultural pumping accounts for 31.4 per cent of the total power consumption in India (CMIE, 2002), which observed a steady increase during the past decade mainly owing to the rising cost of abstraction of groundwater.

The poor financial working of many State Electricity Boards is attributed to highly subsidised power made available to the farm sector, which accounts for a major chunk of the electricity consumption in the respective states, and power thefts. While some states provide 100 per cent subsidised electricity in the farm sector, some states do not meter agricultural power consumption and charge electricity on the basis of connected load. Deteriorating financial condition severely limit the ability of State Electricity Boards to supply good quality power to the farm sector. In contrast to this, groundwater resources are abundant in eastern India; but its development for irrigation is precariously low. Many researchers have argued that groundwater irrigation could trigger agricultural growth and help alleviate poverty in this resource abundant region (for instance see Shah, 2000). However, this region faces major shortcomings in catering to the rural energy demands.

Great deal of consensus exists among researchers over the fact that rural-electrification and power-subsidies in

*Tel./fax: +91-2692-229311/229312.
E-mail address: d.kumar@cgiar.org (M.D. Kumar).

0301-4215/$ - see front matter
doi:10.1016/S0301-4215(03)00196-4

the farm sector have triggered exponential growth in groundwater irrigation in India (Moench, 1995; Shah, 1993; Palmer-Jones, 1995). Many have argued that the current mode of pricing power consumption in the farm sector, which does not reflect the actual unit consumption, creates incentive for wasteful use of both power and groundwater (Kumar and Singh, 2001; Palmer-Jones, 1995; Saleth, 1997). Sustainable approaches to manage groundwater resources that are grounded on a sound footing of good hydro and social sciences are, however, not forthcoming.

The groundwater management debate in India has so far focused on many direct and indirect management options: artificial recharge of groundwater in areas facing problems of overdraft; direct regulation of groundwater abstraction through state legislation; indirect regulations through well financing and other leverages; local management of groundwater by user groups; establishment of private/cooperative property rights in groundwater. Some of them have already been tried in different parts of the country. Legal interventions to check and control overdraft were never successful due to their social and political ramifications.[1]

The National Bank for Agriculture and Rural Development (NABARD) has been using "control of institutional financing for well development" in over-exploited areas; but was by and large ineffective in checking overdraft due to large-scale private financing of well development. In Gujarat, the State Electricity Board deny new agricultural power connections in over-exploited areas, and in critically developed areas when well spacing regulations are violated; but this measure has been ineffective due to the use of old power connections for newly drilled wells (Gass et al., 1996). There have not been many attempts to foster local, community-based initiatives to manage groundwater. So far as water rights reform is concerned, there have been no breakthroughs in the discussions on the institutional processes to institute them.

Artificial recharge of groundwater has been tried in many parts of India to arrest depletion, some of which are also community based; but met with very little success. The reasons are many: First, the areas facing depletion problems are falling in arid and semi arid regions where availability of endogenous surface water is extremely limited. Second, unfavourable physical conditions for recharging like poor groundwater storage potential exist in some areas. An important example is the groundwater recharge movement in Saurashtra peninsula of Gujarat, which was primarily driven by religious and spiritual organizations and voluntary movements. Though this decentralized movement of water harvesting claims to have made significant achievements in terms of number of wells and ponds recharged (Shah, 1997; Kumar, 2000b), analysis and available evidences suggest that their impact on depletion and overall water situation could be negligible (Kumar, 2000b). Third: the cost of recharging through artificial recharge structures in terms of the cost per unit volume of water is often prohibitively high.

In sum, the existing direct and indirect regulations and direct management interventions have been ineffective in arresting depletion. In the recent years, power tariff policy has been increasingly advocated as an instrument to influence groundwater use and withdrawal decisions of farmers (Shah, 1993; Saleth, 1997).

The past decade has seen wide debates on the potential linkage between electricity pricing and groundwater use for irrigation; especially the implication of electricity prices for access equity, efficiency and sustainability in groundwater use (see for instance Moench, 1995). These debates are characterized by differing and often diametrically opposite views on the potential impact of power tariff changes on access equity, efficiency of groundwater use and sustainability of the resource (based on Shah, 1993; Palmer-Jones, 1995; Saleth, 1997; Kumar and Singh, 2001; IRMA/UNICEF, 2001; de Fraiture and Perry, 2002).

Many researchers argue that pro rata electricity tariff, with built in positive marginal cost of pumping could bring about efficient use of the resource (Shah, 1993; Moench, 1995; Saleth, 1997; Kumar and Singh, 2001), though some argue that the levels of tariff in which demand becomes elastic to pricing are too high to be viable from political and socio-economic points of view (de Fraiture and Perry, 2002). Narayanamoorthy (1997) argues that influence of power tariff on the consumption of electricity and water would be too less on the ground that it constitutes a meagre portion of the total cost of cultivation.

Not much of consensus exist at the fundamental level about appropriate tariff structures, which generate efficiency in resource use, equity in access to groundwater and sustainability of resource use. After Saleth (1997), power tariff policy alone cannot be an effective tool for achieving efficiency, equity and sustainability in groundwater use (Saleth, 1997). Unfortunately, these debates are based on theoretical reasoning and some practical considerations.

Saleth (1997) argues that even an imperfect system of groundwater rights will have more sustainable benefits than a most perfectly designed power tariff structure. Many researchers in the recent past have suggested

[1] Though groundwater legislation had been passed by Gujarat way back in 1992, it could never be enforced. Maharashtra groundwater legislation applies to only protection of public drinking water sources and has been only partially effective. The Central Ground Water Authority had enacted groundwater legislation in Delhi and neighbouring areas, but has been only successful in regulating industrial pumping. Many other Indian states, including Tamil Nadu and Madhya Pradesh are in various staging of formulating legislations to regulate groundwater.

establishment of property rights as a means to build institutional capability to ensure equity in allocation and efficiency in use of water across sectors (Saleth, 1993, 1996; Singh, 1995; Kumar, 2000c; Narain, 1998). But, again if the rights are allocated only to use water, it can create incentives to use it even when there is no good use of it (Frederick, 1993). Therefore, water rights have to be tradable. The argument is that when tradable property rights are enforced, efficient water markets would develop.[2] The price at which water would be traded will reflect the opportunity cost for using water.[3] Such transfers can promote access equity and efficiency in use (Kumar et al., 1999; Kumar, 2000c). After Frederick (1993), enforcing privately-owned, property rights that are tradable is critical to establishing conditions under which individuals will have opportunities and incentives to develop and use the resource efficiently, or transfer it to more efficient uses.

In the context of Gujarat, several scholars and institutions have argued for establishing tradable property rights in groundwater (IRMA/UNICEF, 2001; Kumar et al., 1999; Kumar and Singh, 2001). There is an absolute paucity of sufficient empirical data to compare and analyse the differential impacts of different levels of pricing of electricity, and groundwater rights allocations on water and energy productivity.

2. Review of farm sector power pricing theories

The debate on the linkage between power pricing and electricity and groundwater use in the farm sector in India is quite rich, at the same time rather complex (see Moench, 1995).

Saleth (1997) argues that the nature and magnitude of efficiency, equity and sustainability impacts of power tariff policy depends on the nature and shape of power demand curve, both at the individual and aggregate level that links power tariff and power consumption on the one hand and power consumption and groundwater use on the other.

The basis for proposing power tariff as a tool for influencing groundwater withdrawal and use is that the power demand curve is continuous, and its shape is convex, throughout its range. Saleth (1997), however, argued that the power demand curve is not continuous throughout its range, but actually has a discontinuity, the position of which is determined by a combination of economic, agronomic and hydrological and even technological factors. He further argued that if at all the farmers are responsive to tariff changes, there is a point in which they will switch to diesel pump sets provided the groundwater table and diesel availability make such energy switching technically and economically feasible. This "discontinuity", according to Saleth (1997) has important policy implication as it implies that within certain range of power tariff, power consumption will not be sensitive to variations in power tariff.

The emergence of the "discontinuity", according to him, is mainly due to two factors: (1) energy supply in terms of hours of power availability is fixed at the farm level; and (2) farmers would continue to use power unless the difference between energy cost and net value of output per unit of power becomes low. If the theory floated by Saleth (1997) holds true, for a farmer growing a high valued crop, the level at which power tariff has to be pitched to cause any reduction in demand rates for power or water will be very high. Saleth (1997) argues that farmers might respond to increased power tariff by switching over to high valued crops, by which they could keep the "marginal value productivity" of power and water high.

He proposed mainly three criteria for fixing power tariff based on: (1) the cost of generation and distribution of power; (2) the cost of diesel needed to generate the same amount of water output which a unit of electricity could produce; and (3) determination of power tariff in such a way to completely expropriate the net marginal value product due to a unit of power. According to him, so long as the marginal productivity of power in the reckoning of farmers remains higher than the full cost price of power, full cost tariff could not effectively control power consumption, and hence groundwater withdrawal.[4,5] Under the second option, he argued that, farmers could as well shift to diesel pumps, which could have positive efficiency effects. However, he argued that tariff fixation based on the price of diesel would certainly have some adverse impacts on small and marginal farmers, vis-à-vis income from irrigated crops, and access equity in groundwater.

Saleth (1997) argued that the third criteria for fixing power tariff required electricity prices to be kept very high in order to completely appropriate the difference between the marginal productivity and marginal cost of power. He argued that while such a rate would be in the

[2] Water markets are important institutional mechanisms for transfer/allocation of water to alternative uses which are more economically efficient (Frederick, 1993; Howe et al., 1986).

[3] The markets and market determined prices could work in two ways: (1) farmers can shift to alternative uses that provide higher economic returns than the price of water; or (2) they continue the existing uses with more efficient practices or resort to selling (Frederick, 1993).

[4] He, however, added that higher power cost might induce efficiency improvements in energy more through marginal improvements in watering practices leading to a higher output per unit of energy than at present. Also, to some extent, higher power cost could lead to cropping pattern shifts as the farmers will go for high valued crops so as to raise the level of discontinuity in the power demand curve.

[5] Though difference in levels of input cost is significant due to differences in unit cost of irrigation water it is negated by not considering irrigation costs.

responsive region of power demand curve that can alter power demand and groundwater use, there are high chances of poor social viability and political acceptability. Poor social viability is owing to reduced net returns. Whereas political risk is owing to the fact that the tariff regimes that run into the responsive region of power demand curve would be different for different geo-hydrological environments.

One setback in the theory floated by Saleth (1997) is his argument that fixing power tariff based on the third criteria would take electricity prices to much higher levels. His argument is based on the assumption that net marginal productivity (exclusive of electricity cost) due to a unit of electricity is always significant that the difference between net marginal productivity and the cost of electricity is positive unless and until unit price of electricity becomes very high. But, this assumption is not correct, as the net marginal productivity (exclusive of electricity cost) can become zero (or the curve of net productivity could flatten) and due to which the difference between net marginal productivity (exclusive of irrigation cost) and electricity cost, which is the real "net marginal productivity", can become negative.

Further, the argument that high tariff would lead to reduced returns from irrigated crops may not be true, as returns from well irrigation are more elastic to quality of irrigation and in turn power supply, than its cost (Kumar and Patel, 1995; Kumar and Singh, 2001). Furthermore, though in shallow groundwater/groundwater abundant regions, the level of unit rate to affect reduction in power demand has to be much higher than in areas facing over-exploitation (both alluvial areas facing secular decline in water levels or hard rock areas showing water level decline and poor well yields), such regions are outside our area of concern, and therefore the political risks become a non-issue.

Kumar and Patel (1995), based on empirical evidences collected for diesel engine and electric motor operated well commands in shallow alluvial aquifer areas, argued that the net returns from well irrigated commands will be more elastic to adequacy and reliability of irrigation water rather than the cost of energy (Kumar and Patel, 1995). Moench and Dinesh Kumar (1994) argued on the basis of analyses of empirical evidences on irrigation water use, irrigated area and cropping pattern data for diesel and electric well commands that rise in tariff could result in efficiency improvements in power and water consumption in irrigated agriculture.

Mohanty and Ebrahim (1995) argued on the basis of empirical data collected on the selling price of groundwater from Mehsana district of north Gujarat, where water markets are widespread, that given the price at which groundwater was traded, electricity tariff changes would not be effective in regulating groundwater use. Kumar and Singh (2001) argued that electricity tariff changes would induce efficiency improvements in groundwater and electricity use. At the same time, farmers would continue to grow crops that are water-intensive, but having high land use productivity as energy and water would be limiting factors.

Shah (1993) argued that though flat rate system of pricing electricity would produce low level of efficiency of use of energy, would produce high levels of social welfare as compared to pro rate system of pricing due to the incentive farmers have to resort to pump more water. At the same time pro rate system of pricing might induce higher efficiency of use of energy and water, but produce lower level of social welfare including farmers' economic surplus as compared to flat rate system of pricing due to reduction in demand for groundwater, and the increasing marginal cost of supplying energy.

Shah's model provides a macro economic view and an important dimension to the debate on energy pricing and groundwater use. However, the model has a limitation, when it comes to simulating field conditions. It does not take into account the potential differences in the reliability of power supply between the flat rate and unit pricing. Under the flat rate system of pricing, rationing is critical to achieve maximum social efficiency, whereas, it is not necessary under unit pricing. As a consequence, the quality of power supply would be better under unit pricing with positive differential impact on farm economy. More importantly, increased reliability in power supply can result in a rise in both demand rates and aggregate demand. This is contrary to with what the model suggested.

The past attempts by Gujarat Electricity Board to introduce tariff reform in agriculture sector have been fairly unsuccessful. There were widespread protests by farmers from north Gujarat who spend a significant amount as power bill for lifting water, against proposals to hike power tariff (without any proposals to improve quality of power supply) and also introduce power metering in the farm sector. They to a great extent enjoyed political patronage as free electricity for farm sector was one of the main agenda in the election manifestos of major political parties. However, with deteriorating financial condition of the Gujarat Electricity Board and with deepening crisis of the state exchequer, the government is increasingly brought under pressure from international financial institutions like Asian Development Bank to introduce meter electricity use and start charge for it on the basis of actual consumption with realistic rates. As a matter of fact, the chief minister recently announced a scheme for farmers wherein if accept metering, they could get free kits of drips systems.

3. The context

The context is north Gujarat alluvial plains where intensive use of groundwater in irrigated agriculture has led to serious problems of depletion. Pumping depths are very large and the energy use for pumping per unit of groundwater is enormously high. It has been estimated that in one of the deep tube well areas, the energy requirement to pump unit volume of groundwater is nearly 0.40 kW hr. Farmers of this region are able to sustain irrigated farming by virtue of the heavily subsidised electricity. Though there is no fixed subsidy for electricity in the farm sector, because of the flat rate system of pricing, opportunities available for selling water for irrigation and zero marginal cost of pumping, well owning farmers manipulate the implicit cost of their own irrigation to such low levels and increase their returns by over-pumping, and selling surplus water to needy farmers.

This is no way an argument that if prices for electricity are charged on actual consumption basis, the agricultural economy would collapse. It only means that given the present situation of high cost of construction of tube wells and variable cost of pumping, it will be impossible for farmers to continue with the conventional cropping systems. They will have to go for alternative cropping systems to enhance the returns from every unit of electricity/water consumed to make irrigated agriculture viable.

4. Objectives of the study

The study was carried out primarily to analyse the potential impact of different modes of electricity pricing on productivity of groundwater use. The modes of pricing for which the impact analyses are carried out are as follows: (1) Pump horsepower based pricing of electricity in which the marginal cost of abstraction of groundwater is almost nil. (2) Pro rata pricing of electricity in which the marginal cost of pumping is positive and becomes closer to the cost of electricity required to pump out unit volume of water. (3) The marginal cost of electricity is positive, but the amount of water and electricity, which the farmers are entitled, is fixed.

Since there are not many examples wherein the farmers pay for electricity on unit consumption basis, farmers who buy water from well owners on hourly charges are used as the proxy samples. The hourly water charge can be converted into the equivalent variable cost (here hourly electricity charges) using the assumption that the water charge which farmers pay is the sum total of the share of the fixed investment required for installing tube wells and the variable cost of pumping.

The cases of tube well partnerships where water allocation to different shareholders is fixed in volumetric terms and based on the land holding of the farmer are taken as the proxy cases for rationed water and electricity supply. The assumption is that the current allocations are much less than the amount of water required by the farmers to grow water intensive crops, given the fact that there are many farmers under the command.

5. A model for analyzing farmer behaviour in response to different pricing and allocation regimes

Fig. 1 provides the model for analyzing farmer behaviour in response to different pricing regimes. The model essentially provides a framework for analysing the differential impact of market-based instruments such as the unit pricing of electricity and volumetric water use rights on energy use efficiencies and physical and economic efficiencies of water use in agriculture, as against that of the flat rate system of pricing and absence of property rights regimes in water. The model suggests that the lowest water use efficiency—both physical and economic—is obtained under the flat rate system of pricing, wherein farmers continue to apply irrigation until the net marginal productivity (equal to gross marginal productivity in this case due to zero marginal cost of electricity and irrigation) becomes zero. The net marginal productivity curve will be AX_2. The selling price of water is expected to be lowest in such a situation, due to the presence of competitive markets.

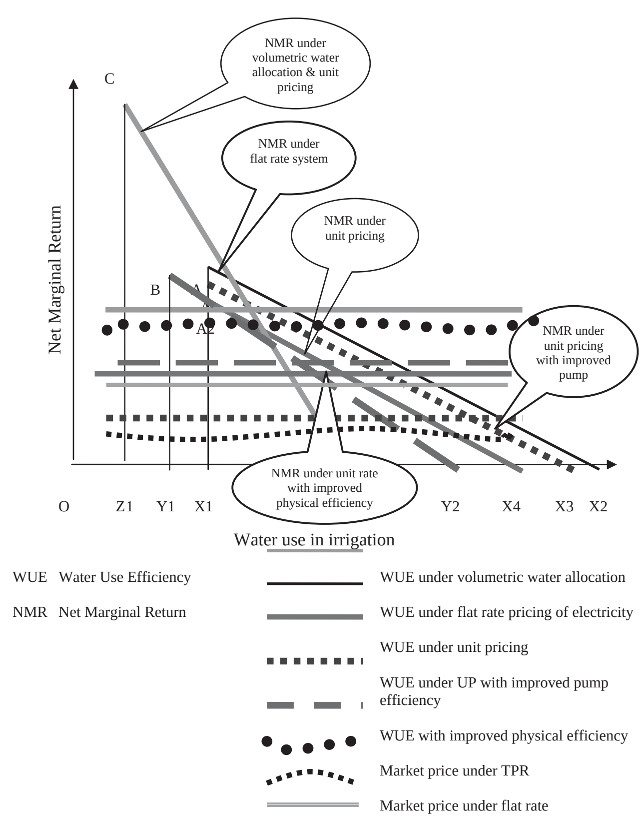

Fig. 1. Farmers response to changing price structure and water allocation regimes.

When changed to unit pricing, farmers might make some improvements in pump efficiency and physical efficiency of water use in irrigation. With price shifts, the selling price of water is also expected to rise slightly. Even though water markets exist, farmers may not be confronted with real opportunity cost of using water due to couple of reasons: (1) mismatch between demand for water and the ability of farmers to supply water; and (2) the average net economic return from irrigated crops might be still higher than the price at which water is sold (Kumar and Singh, 2001).

Hence, farmers would continue to grow water intensive crops as water and energy are not limiting factors. Without any efficiency improvements, the net marginal productivity curve would take a dip to A_2X_4 as net marginal return would become zero at much lower level of irrigation itself (X_4 instead of X_2) due to the induced marginal cost of electricity and water. The attempt, therefore, would be to either reduce electricity use per unit of water pumped through improvements in pump efficiency, and maximize the level of irrigation (in which case the curve would be pushed to A_1X_3 from A_2X_4) or to use water for efficiently in which case the curve would be tilted to a new position BY_2. In these two cases, the water productivity would be slightly higher than in the first case.

But, if water is allocated on volumetric basis with rationing, farmers' preference would shift to crops that give higher returns per unit of water consumed, reason being that the price at which water would be traded would be highest as water becomes a limiting factor for generating wealth out of agriculture. Since price would represent the opportunity cost of using water, theoretically it should induce farmers to take those crops which give same or higher return per unit volume of water. The net marginal productivity curve would take a new position of CZ_2, with the average net productivity being higher than the price of water. Economic efficiency of water use will eventually rise. This model however needs hard empirical data to quantify the impact of market-based mechanisms on demand rates for water and electricity. Purpose of the present study is to validate the model through analysis of empirical data on irrigation water application and water productivity.

6. The study design and methodology

Thirty well owners who are engaged in selling water apart from irrigating their own fields are selected as samples for zero marginal cost of pumping. Though it is the opportunity cost of water rather than the marginal cost, which would determine the farmers' behaviour, the well owner is not always confronted with such opportunity costs. One reason is the absence of demand at all times when water supply is available in plenty due to regulated power supply. The other reason is due to the zero marginal cost of irrigation water, the net marginal return could continue to be positive even at very high water application rates.

The energy and water use figures for their own farms were used for the analysis. The samples are from Banaskantha district of north Gujarat. Thirty farmers were selected as samples for unit pricing. Only 10 out of these 30 farmers pay for purchased water on hourly basis. The rest 20 farmers are engaged in sharecropping with well owners. They pay a percentage of the crop yield as water charge to the well owners and are not confronted with marginal cost of using water. But, the well owners who provide water are confronted with opportunity cost of providing excessive irrigation to the sharecroppers, either due to the need to irrigate their own fields or due to the opportunity available for selling water to the neighbouring farmers.

Opportunity cost in this case is equal to the price at which water is sold by the farmers in the area or the net return from every unit of water used for irrigating his/her own field. This is their marginal cost of supplying every additional watering. At the same time, they are like other irrigators when it comes to ensuring maximum crop yield as their returns depend on that. Hence, they would make sure that the sharecroppers get optimum number and quantum of irrigation in their field with adequate reliability. Hence, the sharecroppers can be considered very much analogous to those irrigators who get reliable power supplies for irrigation and pay for electricity on hourly basis. Volumetric water charges (per unit) were found to be varying significantly in case of water buyers from a lowest of Rs $0.36/m^3$ to Rs $2.29/m^3$.

Twenty-one farmers who are members of tube well cooperatives were selected as samples for a combination of volumetric water allocation and unit pricing. These cooperatives have membership size varying from 25 to 70 and the command area of the tube well systems they share for irrigation varies from 47.4 to 102.85 acres. These shareholders have water entitlements proportional to the size of their share in the irrigation enterprise (Kumar, 2000a). The entitlement for a share is often fixed in hourly terms. It was found to be 3–5 h per *bigha*. If the command of a tube well system is 150 *bigha*, then one share is equivalent to 1.5 *bigha* in the command. If a farmer has 2 shares in a tube well command with 100 shares, s/he will be entitled for two times the hourly allocation for one share. More importantly, size of a farmers' share in the enterprise is restricted to the total holding s/he owns in the command. Irrespective of the volumetric or hourly water entitlements, these farmers need to pay for irrigation services they obtain from the cooperative on hourly basis. The volumetric water charge varied from

Table 1
Relation between irrigation and gross returns per unit irrigated area of wheat for various categories of farmers

Sr. no.	Type/no. of sample	Min. to max./mean depth of irrigation	Regression equation
1	Water seller (22)	0.34–1.44/0.78	$-730.3\mathrm{Ln}(x) + 9708$
2	Water buyer (12)	0.39–1.59/0.73	$1079.7\mathrm{Ln}(x) + 10114$
3	Shareholder (12)	0.38–0.73/0.60	$1316.3\mathrm{Ln}(x) + 13736$

Source: authors' own estimates based on primary data.

Rs 0.75/m^3 to Rs 1.47/m^3. In most cases, it was close to Rs 1/m^3.

The variables such as irrigation rates and gross returns were estimated for different categories of farmers, namely, water buyers, water sellers and shareholders of tube well partnerships for wheat crop. Based on these variables, linkages between irrigation rate and gross return for these three categories were established. This was followed by analyses of water productivity in wheat crop and overall water productivity, taking into account all crops in the command area. Water productivity was estimated by using the formula:

$$\text{Gross Water Productivity} = \text{Gross Return}/\text{Volume of Water Used for Irrigation}.$$

The overall gross water productivity (OGWP) for each farmer was estimated by summing up the gross returns from all the irrigated crops grown by the farmer and dividing it by the total volume of water used for irrigating all the crops. Overall net water productivity (ONWP) was estimated by taking the ratio of the sum of net returns (gross return − total input costs) and the total volume of water used. Volumetric water use figures for various crops were estimated using the formula given below:

$$\text{Volumetric Water Use} = \text{No. of Irrigations} * \text{Hours of Watering per Irrigation} * \text{Well Discharge}.$$

The ONWP and "overall net water productivity exclusive of irrigation costs" were also estimated. In estimating overall net water productivity, costs of all inputs, namely, irrigation, fertilizers and pesticides, imputed and actual labour costs and cost of seeds, were considered.

7. Results and discussions

7.1. Comparison of irrigation–gross return linkage

Wheat was taken as the sample crop for analysing the linkage between irrigation water application and gross return under different price and water allocation regimes. The results are presented in Table 1, which shows that shareholders represent the lowest level in the irrigation water use regime amongst the three categories of farmers. Though water buyers represent higher level in the water use regime, the mean value is lower than that of water sellers.

Fig. 2 shows the variation in return from crop production per acre across farmers with varying intensities of irrigation. In the case of water sellers, irrigation water application is within a regime where incremental irrigation leads to reduction in gross returns. Therefore, the gross marginal return with respect to irrigation is negative. Irrigation water use by water buyers and shareholders of tube wells is, by and large, within a regime where the incremental irrigation leads to increase in gross returns. Hence, gross marginal return with respect to irrigation is positive.

Regression analysis carried out to understand the linkage between irrigation water use and gross return from crop production shows that in the case of water buyers/sharecroppers and shareholders of tube well cooperatives, irrigation elasticity of gross return is positive, whereas in the case of water sellers, irrigation elasticity of gross return is negative. In the case of water sellers, those who are applying water in larger depths are getting lesser returns as compared to those who are applying in smaller depths. Needless to say that those who apply in larger depths and get lower yields end up achieving much lower water productivity—which is the ratio of yield and depth of watering—as compared to those who apply water in smaller depths and get higher returns. If we apply this to a single farmer, the gross marginal productivity will be negative, which is in contrast to the assumption made by Saleth (1997).

In case of farmers belonging to water buyer, sharecropper and share holder categories, those who are applying more water than the others are getting more return from every unit of land, whereas in the case of well owners, the general trend is downward. Regression coefficient is highest (1316.3) for shareholders, meaning that the gross marginal return from every additional unit of irrigation water is highest for them. Therefore if we assume that the level of efficiency with which the other resources are used is same across farmers, it could be inferred that shareholders and sharecroppers are using water more efficiently than water sellers.

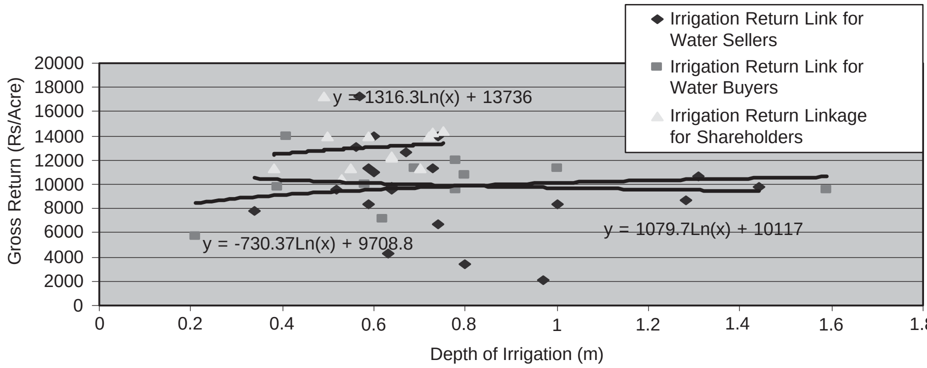

Fig. 2. Irrigation vs Gross Returns.

7.2. Comparison of water productivity in wheat

7.2.1. Gross water productivity

Water productivity of wheat for all three categories of farmers was analyzed by comparing the gross return and the irrigation water use figures. For the purpose of analysis, only those farmers engaged in sharecropping with well owners were considered as samples for water buyers' case and those buying water from well owners on hourly basis were not considered. This is in view of two important facts. First, those who buy water on hourly basis are not guaranteed about adequate and reliable supplies of water. Second, timely supply of adequate quantities of water is essential for obtaining good yield from wheat. It might be perhaps due to this reason that only one-third of the farmers purchasing water (four out of 12) took wheat crop. But, 12 out of the 18 sharecroppers were found to be growing wheat.

Table 2 shows that water productivity range for shareholders is highest amongst the three categories. Water productivity range is lowest for tube well owning water sellers. More importantly, the variation in water productivity across samples is lowest for shareholders in whose case it varies from 4.06 to 8.74. The difference between lowest and highest value is 4.68 whereas in the case of water sellers and water buyers, it is approximately 7. The mean value of water productivity was found to be highest (Rs 5.61/m^3) for shareholders, and lowest for water sellers. The difference in mean value of water productivity between water buyers and water sellers is not very remarkable (Rs 0.40/m^3). But when we consider the fact that in the case of water purchasers, a good percentage of the water pumped out of the well would be lost during conveyance, and therefore the actual quantum of water used by water buyers in their field, the actual water productivity would be significantly higher.

7.2.2. Net water productivity

We have found that gross water productivity figures for wheat are much higher for sharecroppers as compared to water sellers. But, gross water productivity only reflects the physical efficiency of water use. High physical efficiency of water use does not mean higher economic returns. The net returns farmers get from every unit of water used depend on how much he/she pays for water and other inputs. Irrigation cost is the net effect of the water use rate and unit price of irrigation water. Though higher physical efficiency of water use would mean lower water use rate, the overall irrigation cost may not be low as it can be offset by the high unit price for irrigation water. Here, there are significant differences in the cost of irrigation water across water buyers, shareholders and well owners. Water buyers are paying the highest charges in terms of cost per unit volume of water.

Analysis shows that net return per cubic metre of water is highest for shareholders, followed by water sellers and lowest for water buyers. Though physical efficiency (expressed as the ratio of gross return per cubic metre of water) is higher for water buyers as compared to water sellers, the net return becomes lower due to the high cost of irrigation water.

7.3. Comparison of overall water productivity

Selection of crops by farmers would involve several considerations, economics perhaps being the most important of them. Some of the other considerations are: subsistence needs, cash, fuel wood and fodder needs, and food and nutritional security. Potential variations in water productivity across crops (net return per unit volume of water transpired expressed as Rs/ET_0) could be significant even if the farmers use water with the level of physical efficiency. For instance, some of the oilseed crops yield much higher return for every unit of water used.

In the previous section, we analysed water productivity for wheat in order to analyse the impact of pricing and water allocation regimes on efficiency of water use. In order to get a comprehensive understanding of water use productivity, it is essential to consider water productivity figures for all the crops grown. Farmers were found to be growing castor, mustard, cumin,

Table 2
Water productivity of wheat for different categories of farmers

Sr. no.	Farmer category /(no. of samples)	Water productivity range (Rs/m^3)	Mean value of water productivity (Rs/m^3)
1	Water seller (22)	0.54–7.51	3.61
2	Sharecroppers (12)	1.48–8.29	4.01
3	Shareholder (12)	4.06–8.74	5.61

Source: authors' own estimates based on primary data.

Table 3
Overall gross water productivity for different categories of farmers

Sr. no.	Farmer category/(no. of samples)	Overall water productivity range (Rs/m^3)	Mean value of water productivity (Rs/m^3)
1	Water sellers (29)	1.21–8.69	3.61
2	All water buyers (26)	1.21–15.69	5.14
3	Shareholder of tube well (21)	3.24–24.04	6.79

Source: authors' own estimates based on primary data.

alfalfa, bajra, jowar and pioneer jowar, apart from wheat. Overall water productivity was estimated using the formula:

$$\begin{aligned}&\textit{Overall Water Productivity}\\&\quad = (\textit{Total of gross return from all crops})/\\&\qquad \textit{Total Volume of Water Used by all Crops}.\end{aligned}$$

7.3.1. Overall gross water productivity

For estimation of OGWP, all samples under buyer category were considered. The estimates of overall water use efficiency for different categories of farmers are given in Table 3. The estimates of mean value of overall water productivity show that shareholders of tube well partnerships get highest water productivity, followed by water buyers and water sellers, who get least water productivity.

There are two reasons for this phenomenon. *First*, sharecroppers and shareholders use water very efficiently. *Second*, sharecroppers and shareholders choose cropping pattern in such a way that the overall returns (for cubic metre of water) are high. A comparative analysis of cropping pattern of shareholders, sharecroppers and water sellers show that water sellers' cropping pattern is skewed towards water intensive crops like summer jowar and summer bajra, while that of sharecroppers and shareholders is skewed towards cash crops like castor, mustard and cumin. This aspect is discussed separately in Section 7.5.

7.3.2. Overall net water productivity exclusive of irrigation cost

The OGWP figures were found to be higher for water buyers and shareholders when compared to well owners who are also engaged in water selling. One could argue that the differential productivity is due to greater use of inputs such as fertilizers, pesticides and labour for ploughing, weeding, etc. At the same time, expenditure, which farmers incur for a unit of irrigation water, varies across categories. In order to minimize the effect of probable differences in the level of use of fertilizers, pesticides and labour on returns, and that of the differences in unit cost of irrigation water on total input costs, net water productivity exclusive of irrigation cost were worked out for the three categories of farmers. Here one assumption being made is that the irrigation water application rates are uniform across categories of farmers.

Values of "overall net water productivity exclusive of irrigation cost" were estimated and are presented in Table 4. The table shows that net water productivity exclusive of irrigation cost is highest for shareholders of tube well cooperatives (Rs 5.20/m^3), followed by water buyers (Rs 2.93/m^3) and lowest for well owners (Rs 2.40/m^3). The figures mean that effect of improvements in the efficiency of use of water and other inputs on water productivity is quite significant. Now, even if one imputes the unit cost of irrigation water uniformly across different categories of farmers, the differences in net return would only become larger. This is because of the fact that the irrigation water application rates are lower for water buyers and shareholders as compared to well owners.

7.3.3. Overall net water productivity

The OGWP figures as estimated above do not capture the price of irrigation water. But price of irrigation water is an important variable influencing the overall economic returns from irrigated farming. The total cost of irrigation water—an important deciding factor for net return from irrigated production—is dependent on two important variables: (1) price of irrigation water; and (2) water use rate. Water use rate is determined by

Table 4
Overall net water productivity for different categories of farmers (exclusive of irrigation cost)

Sr. no.	Farmer category/(no. of samples)	Overall water productivity range (Rs/m^3)	Mean value of water productivity (Rs/m^3)
1	Water sellers (29)	0.22–6.66	2.40
2	All water buyers (26)	−1.44–10.30	2.93
3	Shareholder of tube well (21)	1.59–20.12	5.20

Source: authors' own estimates based on primary data.

Table 5
Overall net water productivity

Sr. no.	Farmer category/(number of samples)	Overall net water productivity range (Rs/m^3)	Mean value of overall net water productivity (Rs/m^3)
1	Sharecroppers (17)	−0.38–5.74	1.68
2	All water buyers (26)	−1.74–5.74	1.30
3	Water seller (29)	0.22–5.78	2.40
4	Shareholder of tube well (21)	0.63–18.65	4.18

Source: authors' own estimates based on primary data.

the level of efficiency with which farmers use water, which is again influenced by the price of irrigation water. Therefore overall net return could capture the effect of irrigation water price.

The ONWP figures are analysed separately for sharecroppers and all water buyers. In the case of sharecroppers, price of irrigation water is estimated as the cash equivalent of the crop share given by the sharecropper to the water provider. For water buyers and shareholders of tube well cooperatives, the cost of irrigation is estimated by taking the total hours of irrigation for each crop and the hourly water charge. In the case of water sellers, cost of irrigation is considered as nil.

This is essentially to capture the potential difference in reliability of irrigation between sharecroppers and water buyers, which could result in significant differences in yield levels between these two types of farmers. The ONWP figures for the four categories of farmers are presented in Table 5. It shows that the mean value of overall net productivity is highest for shareholders of tube wells cooperatives of Manund village. It is lowest for water buyers and second lowest for sharecroppers. Needless to say, ONWP is very low for water buyers owing to the fact that cost of irrigation is very high for the farmers belonging to this group, while it is much less for shareholders.

7.4. Linkage between volumetric water allocation and cropping pattern

The well owners were found to be growing crops such as wheat, bajra, fodder crops and jowar more extensively (wheat 12%; bajra 27%; jowar 6%). Farmers, who are buying water, including those who are engaged in share-cropping, grow castor (22.2%), wheat (21.6%), bajra (18.9%), mustard (13.7%), jowar (6.9%) and cumin (4.3%). Cropping system of shareholders is dominated by wheat (36.2%) and mustard (36.2%). The other crops are cluster bean (5.9%), fennel (8.1%) and cumin (7.4%).

Analysis of cropping pattern of different categories of farmers vis à vis water productivity shows that a strong linkage exists between water pricing and volumetric water allocation and the crops farmers choose to grow in terms of potential water productivity. The well owners, for whom marginal cost of water is almost zero and who enjoy comparatively much greater access to water, were found to be selecting crops without much consideration to water productivity (see Table 6). Land use productivity and food security seem to be the most important considerations for them. Their cropping pattern is heavily skewed towards bajra (29% area under the crop), which has one of the lowest water productivity (Rs 3.67/m^3). They are also growing a wide variety of other crops such as alfalfa (3.07%), *rajgaro* (8.50%), pioneer jowar (2.0%), fennel (1.5%) and barley (3.8%).

Water productivity and water requirement of crops seem to be the most important consideration for shareholders. None of them were found to be growing bajra, which has the lowest gross water productivity (Rs 2.04/m^3) amongst all the crops studied, and highly water intensive. At the same time, wheat and mustard, which dominate their cropping system, are associated with high water productivity (Rs 5.6/m^3 and Rs 5.1/m^3 respectively). They also grow crops, which have very higher water productivity such as cluster bean (Rs 18.4/m^3) and cumin (Rs 19.9/m^3), in smaller areas. Again, mustard and cumin are very low water requiring crops.

Table 6
Water productivity of various crops

Sr. no.	Name of crop	Water Productivity for Well owners	Water buyers	Shareholders
1	Wheat	3.83	4.01	5.61
2	Castor	6.99	9.19	
3	Mustard	5.21	3.88	5.10
4	Cumin	16.70	22.93	19.89
5	Jowar	4.01		
6	Bajra	3.67	2.04	
7	Cluster Bean	6.46		
8	Fennel	3.36		
9	Leafy vegetable			8.11

Source: author's estimates based on primary data.

On the other hand, water buyers were found to be putting large area under bajra (18.9%), for which they got much lower water productivity as compared to mustard (Rs 2.04/m^3 against Rs 3.88/m^3), which occupies lesser area. Also, they were growing cumin in much smaller area, though it is highly water efficient. Thus, water buyers do not seem to attach as much importance to water productivity as shareholders do.

8. Findings of the study

The study offers several interesting findings that have major implications for supply and pricing of electricity for agricultural pumping.

- Water buyers (sharecropping arrangement) secure higher gross water productivity as compared to water sellers through: careful use of irrigation water—as reflected in lower water application rates; and getting higher yield rates. This means that physical and agronomic efficiencies in water use improve with positive marginal cost of irrigation water. Further, gross water productivity is further up in the case of shareholders. This means that farmers try to achieve highest physical and agronomic efficiencies when water is priced on volumetric basis and allocation is rationed.
- The overall gross and net water productivity exclusive of irrigation cost are highest for shareholders of tube well cooperatives, followed by water buyers and lowest for well owners who are also water sellers. This means that farmers try to achieve highest economic efficiencies in water use when water is priced on volumetric basis and allocation is rationed.
- Water buyers achieve high water productivity mainly through efficiency improvements in water use, and marginally through cropping pattern adjustments. Where as shareholders achieve high water productivity through crop shifts as well as efficiency improvements. Crop shift is major, owing to the fact that 90% of their irrigated area is under low water intensive and high water efficient crops. They select low water requiring crops like mustard, cumin, castor and fennel and which yield very high returns for every unit of water used. This corroborates with the model.
- The shareholders of tube well cooperatives secure higher ONWP when compared to well owners. This is in spite of the high expenditure they incur for irrigation water.
- The net water productivity exclusive of irrigation cost is higher for shareholders (Rs 5.2/m^3) when compared to water buyers (Rs 2.93/m^3). The difference between the two cases is in terms of water allocation norms and reliability of water supply[2]. In the case of shareholders, supply is rationed and known to the farmers much in advance of the season. Hence, they are able to do proper water budgeting. Whereas the farmers who purchase water on hourly basis are at the mercy of the well owners. This reinforces the fact that net return from crop production is less elastic to the cost of irrigation than the reliability of irrigation.

9. Policy implications and conclusions

Empirical analyses presented in the paper suggest positive impact of water/electricity price shift, i.e., induced marginal cost of water/electricity on physical efficiency of water use, and water and energy productivity in agriculture. Further, the study establishes positive impact of a combination of water/electricity price shifts, i.e., induced marginal cost of water/electricity, and water allocation on physical efficiency of water use, cropping patterns and overall water and energy productivity. However, physical efficiency and water and energy productivity impacts are remarkably higher when induced marginal cost coupled with water allocation in which individual entitlements are fixed. Hence, the model is validated.

These evidences build a strong case for introducing pricing changes in electricity supplied in the farm sector. One of the arguments against price change is the higher marginal cost of supplying electricity under metered system, which according to Shah (1993), could reduce the net social welfare as a result of reduction in: (1) demand for electricity and groundwater; and (2) net surpluses individual farmers could generate from cropping. Another argument against using pricing is that for power tariff levels to be in the responsive region of power demand curve, prices are often too high that it may become socially unviable.

The analyses presented in the paper, however, question the validity of these arguments. First, the argument that metering is expensive and that marginal cost of supplying electricity would increase with increased pumping is based on the assumption that with price shifts, the tendency to pilfer electricity would increase and therefore the cost of preventing that would be high. Now the aggregate demand for electricity and groundwater in irrigation is a function of the demand rates (electricity and water requirements per unit of land), and the total area under irrigation. The empirical analyses show that while the demand rates reduced due to price shift, the net surpluses from every unit of energy/water used increased. Again, owing to the improvements in quality and quantity of power supply, farmers might increase the area under irrigation, though this may work against the objective of cutting down the draft. It is important to note that under flat rate system of pricing, regulating power supply is extremely important to achieve higher social efficiency. Therefore, the net social welfare due to induced marginal cost would be more.

As regards the second argument, in spite of the higher prices, the net economic returns from farming are higher for shareholders of tube well companies, and those engaged in sharecropping with well owners, as compared to water selling well owners. They manage with less quantities of water for the same crop through efficiency improvements in irrigation; use all inputs resources efficiently to get higher yield rates; and adopt cropping patterns with combination of crops that are inherently more water productive. Though the net surplus from every unit of water and electricity used were found to be less for water buyers than for well owners, it could be mainly due to the unreliable irrigation supplies. Due to unreliable and inadequate irrigation, water buyers were not able to get differential returns sufficient to offset the effect of higher irrigation cost. This further advance the argument put forth by Kumar and Singh (2001) that net farm surplus are more elastic to the quality of irrigation than its cost.

But, as analyses suggest higher demand reduction in groundwater and electricity would be achieved if volumetric rationing of energy/water were done coupled with induced marginal cost of using energy/water. Though energy allocation through scientific power supply rationing is an effective way to cut down the demand for electricity, thereby groundwater withdrawal, this option has serious limitations. First of all, "hour of power supply" is just one factor affecting energy consumption, the other factors being capacity of machinery used (pump horsepower, etc.) and number of machinery. Second, energy requirement is not constant across farms. The larger holders would require more energy supplies as compared to small holders. Third, the energy required to pump unit volume of water varies depending on geo-hydrological environments. Fourth, with induced cuts in power supply hours, they would be motivated to adopt higher capacity pumps or install more water extraction structures. On the other hand, water allocation on socioeconomic considerations would automatically take care of the equity issues. Proper rationing of groundwater withdrawal along with unit pricing of electricity, could, therefore, be an effective tool for achieving efficiency, sustainability and equity.

When water becomes scarce, re-allocation of the resource to economically more efficient uses becomes a powerful instrument for managing its demand (Frederick, 1993; Rosegrant and Ringler, 1998). Some of the fears associated with such water transfers are that concerns such as equity, access to water for basic survival, food security etc., do not get adequately addressed (Rosegrant and Ringler, 1998). The negative equity effects of water allocation can be mitigated if water allocation is done under a congenial legal and institutional environment of properly instituted water rights (Frederick, 1993; Rosegrant and Ringler, 1998). The study showed that under volumetric water entitlements (rationing) and unit prices, farmers use lion' share of their share of water to grow crops which are economically efficient and fully abandon cereals like bajra that are low water-efficient. This could be at the cost of household nutritional security. Under allocated water rights, if opportunities for transferring water to urban areas exist, it might lead to problems of local food shortages.

But introducing water rights reforms would require arduous institutional processes for creating participatory institutions at various levels from aquifer/basin to watersheds and villages involving groundwater users for allocating volumetric water rights, and monitoring and enforcing water use (Kumar, 2000c).

Finally, whether one should go for electricity tariff reforms or a combination of tariff reform and water rights reform would depend on several considerations, the most important of which are physical, social and legal, i.e., gravity of groundwater depletion problems, possibility of community mobilization, and pursuing legal reforms, respectively. In regions where groundwater ecology is severely threatened, electricity tariff reform alone will not be sufficient to achieve the goals of efficiency, access equity and sustainability. Water rights reforms also will have to be initiated along with tariff reforms, though it will be more arduous than tariff reforms. The water rights reforms would complement tariff reforms and hence can go hand in hand with.

The ability to introduce unit based tariff would depend heavily on the ability of the electricity departments to muster political support. On the other hand, instituting private property rights in water would require creation of water rights law and local institutional development apart from mustering political support. Though the resistance to any reform, electricity pricing or water rights, would be high in regions where communities heavily depend on groundwater for their survival like in north Gujarat region, the chances of mustering support for the same are also likely to be higher in such regions, as the section of the community which pays the price of lack of appropriate electricity pricing structure and well defined water rights—in terms of reduced benefit of electricity subsidies, prohibitively high water rates and poor access to groundwater for survival—, is much larger than those who benefit from them and their number increases as depletion continues.

References

Centre for Monitoring Indian Economy (CMIE), (2002). Energy 2002. Economic Intelligence Service, Centre for Monitoring Indian Economy.

de Fraiture, C., Perry, C., 2002. Why is irrigation water demand inelastic at low price ranges? Paper presented at Irrigation Water Policies: Micro and macro considerations. Jointly organized by World Bank and government of Morocco, 15–17 June 2002, Adigar, Morocco.

Frederick, K.D., 1993. Balancing water demand with supplies: the role of management in a world of increasing scarcity. Technical Paper 189, Washington, DC: World Bank.

Gass, G., Dinesh Kumar, M., Mc Donald, D., 1996. Groundwater degradation and its socioeconomic and health impacts: practical and policy options for mitigation. Draft Report of VIKSAT-Natural Resource Institute Collaborative Research Project.

Howe, C.W., Schurmeier, D.R., Shaw, Jr., W.D., 1986. Innovative approaches to water allocation: the potiential for water markets. Water Resources Research 22 (4), 439–445, April.

Institute of Rural Management Anand (IRMA)/UNICEF, (2001). White paper on water in Gujarat. Report submitted to the Government of Gujarat, Gandhinagar, 2001.

Kumar, M.D., 2000a. Institutions for efficient and equitable use of groundwater: irrigation management institutions and water markets in Gujarat, Western India. Asia-Pacific Journal of Rural Development X (1), 53–65.

Kumar, M.D., 2000b. Dug well recharging in Saurashtra: are the benefits and impacts over-stretched? Journal of Indian Water Resources Society 20 (3), 143–148.

Kumar, M.D., 2000c. Institutional framework for managing groundwater: a case study of community organizations in Gujarat, India. Water Policy 2, 423–432.

Kumar, M.D., Patel, P.J., 1995. Depleting buffer and farmers response: study of villages in Kheralu, Mehsana, Gujarat. In: Moench, M. (Ed.), Electricity Prices: A Tool for Groundwater Management in India? VIKSAT-Natural Heritage Institute, Ahmedabad.

Kumar, M.D., Singh, O.P., 2001. Market instruments for demand management in the face of scarcity and overuse of water in Gujarat. Water Policy 3 (5), 387–403.

Kumar, M.D., Chopde, S., Mudrakartha, S., Prakash, A., 1999. Addressing water scarcity: local strategies for water supply and conservation management in Sabarmati Basin, Gujarat. In: Moench, M., Caspari, E., Dixit, A. (Eds.), Rethinking the Mosaic: Investigations into Local Water Management. Nepal Water Conservation Foundation and Institute for Social and Environmental Transition, Kathmandu and Boulder.

Moench, M. (Ed.), 1995. Electricity pricing: A Tool for Groundwater Management in India? VIKSAT-Natural Heritage Institute, Ahmedabad.

Moench, M., Dinesh Kumar, M., 1994. Distinction between efficiency and sustainability: the role of energy prices in groundwater management. In: Agarwal, A. (Ed.), The Challenge of the Balance: Environmental Economics in India, Proceedings of a National Environment and Economics Meeting. Centre for Science and Environment, New Delhi.

Mohanty, S., Ebrahim, A., 1995. Groundwater Management Perspectives for Junagadh District of Saurashtra. In: Moench, M. (Ed.), Electricity Prices: A Tool for Groundwater Management in India? VIKSAT-Natural Heritage Institute, Ahmedabad.

Narain, V., 1998. Towards groundwater management institutions for India. Water Policy 1, 357–365.

Narayanamoorthy, A., 1997. Impact of electricity tariff policies on the use of electricity and groundwater: arguments and facts. Artha Vijnana XXXIX (3), 323–340.

Palmer-Jones, R., 1995. Ground water markets in South Asia: a discussion of theory and evidences. In: Moench, M. (Ed.), Electricity Prices: A Tool for Groundwater Management in India? VIKSAT-Natural Heritage Institute, Ahmedabad.

Rosegrant, M.W., Ringler, C., 1998. Impact on food security and rural development of transferring water out of agriculture. Water Policy 1, 567–586.

Saleth, R.M., 1993. Water rights system: is it feasible for India? Journal of Indian School of Political Economy 5 (3), 578–594.

Saleth, R.M., 1996. Water Institutions in India: Economics, Law and Policy. Sage, New Delhi.

Saleth, R.M., 1997. Power tariff policy for groundwater regulation: efficiency, equity and sustainability. Artha Vijnana XXXIX (3), 312–322.

Shah, T., 1993. Water Markets and Irrigation Development: Political Economy and Practical Policy. Oxford University Press, Bombay.

Shah, T., 1997. The deepening divide: diverse responses to the challenges of ground water depletion in Gujarat. Paper presented at the IDPAD Seminar on Managing Water Scarcity: Experiences and Future Prospects held at Amersfort, The Netherlands, October 11–17.

Shah, T., 2000. Wells and welfare in Ganga basin: public policy and private initiative in Eastern Uttar Pradesh, India. Research Report 54, International Water Management Institute, Colombo, Sri Lanka, 2000.

Singh, K., 1995. Cooperative Property Rights as Instruments for Managing Groundwater. In: Moench, M. (Ed.), Groundwater Law: The Growing Debate Monograph, VIKSAT—Natural Heritage Institute, Ahmedabad.