Agricultural Economics Research Review 2018, 31 (2), 251-258
DOI: 10.5958/0974-0279.2018.00042.3

Groundwater markets in east coast of Puducherry Union Territorry: analysis of pricing and irrigation efficiency[§]

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Abstract This paper examines structure, determinants and efficiency of groundwater markets and suggest policy measures to contain over-extraction of groundwater in the Union territory of Puducherry on east coast of India. The analysis of structure of groundwater market shows a large proportion (82%) of the farmers entering into one or the other activities related to water market. The number of water buyers decreases with increase in farm size, while the number of sellers increases with the increase in farm size. The analysis of conduct of groundwater markets reveals a seller- buyer concentration ratio of 1:2.39. The farmers having less operational landholdings, higher fragmented landholdings and low capacity water lifting device have a higher probability of buying groundwater. Further, selling of groundwater is more concentrated among farmers with large operational holdings, less fragmentation and joint ownership of a modern water extraction mechanism (WEM). Resource use efficiency analysis indicates a close association between increased productivity and better irrigation management due to ownership of the modern WEMs. The Nash equilibrium framework used to study the bargaining power brings out that the level of irrigation of buyers and sellers as key factors in price determination in groundwater market. The selling price of groundwater is found markedly higher than the total cost of water extraction, implying exploitative nature of groundwater markets.

JEL classification Q15, Q25

Keywords Groundwater market, Sellers, Buyers, Pricing, Efficiency

1 Introduction

The monsoon dependent countries are facing acute water scarcity, and are looking for alternative reliable sources of water for irrigation. The groundwater resources through traditional means of water extraction could accelerate water supply, but these cannot meet the growing demand for water in modern agriculture. Nonetheless, there has been a sharp increase in the ownership of private water extracting machines (WEMs), leading to a continuous decline in water-table, drying up of the tubewells and increasing failures of tubewells and consequently higher costs of installing new tubewells, deepening of existing tubewells and pumping and other maintenance activities (Moench 1992; Shah 1985). Such indiscriminate drilling and deepening of tube wells make the distribution of groundwater use increasingly skewed in favour of resource rich farmers (Bhatia 1992; Janakarajan 1993; Shah 1993; Saleth 1996).

For resource poor farmers who cannot afford investment in groundwater irrigation, market is an alternative to access water for irrigation. It benefits both the sellers and the buyers of water as it generates efficiency, equity and sustainability benefits. The evidence show that water markets have developed on

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§ The earlier version of this paper was presented in 11th Annual Meeting of the International Water Resource Economics Consortium (IWREC) which was hosted by the World Bank in Washington D.C. from September 8 to 9, 2014.

a very large scale in South Asia, although in a localized manner (Lowdermilk et al. 1978; Meinzen-Dick 1995; Singh 1998; Singh and Singh 2002).

So far the studies on groundwater markets in India have concentrated on examining the market structure in a static manner, neglecting their dynamic transformation. Considering that the structure of groundwater market has undergone a substantial change with growing density of tube-wells, this paper looks groundwater markets from a dynamic rather than a static point of view.

2 Data

The study was undertaken in the Union Territory of Puducherry. It consists of four regions, *viz.* Puducherry, Karaikal, Mahe and Yanam. This study is confined to the Puducherry region, which has the highest area under irrigation (89%). Groundwater accounts for 60% of the total irrigated area. Apparently, the tube-wells are the major source of irrigation— there are more than 5600 tube-wells in this region. A considerable proportion of these are privately owned, and are engaged in selling water for irrigation.

The region has seven communes, and for this study Mannadipet was purposively selected because of the high density of wells per unit area there. A two-stage random sampling procedure was followed to select four villages from the list of villages of the selected commune at the first stage. In the second stage, 30 farmers from each village were randomly selected, making a total sample of 120 farmers.

The selected farmers were post classified as buyers, self-users + buyers, self-users + buyers + sellers, self-users + sellers and self-users. Further, based on the landholding size, the selected farmers were classified into three farm-size groups, *viz.,* marginal (<2.5 acres), small (2.5-5 acres) and large (>5 acres).

Primary data were collected from the randomly selected farmers through personal interview with the aid of a pre-tested schedule designed especially for the purpose. Secondary data on geographic location, demographic features, occupational pattern, cropping pattern, rainfall, different sources of irrigation, distribution of tube-wells, available groundwater resources and other related details were obtained from the Directorate of Economics and Statistics, Department of Agriculture, Directorate of Census Operations, Puducherry State Groundwater Authority and State Groundwater Unit in Puducherry.

3 Analytical tools

3.1 Participation in groundwater market

Probability of participation in groundwater market depends on a number of factors including land owned (in acres) (AREA OWN), number of fragments per farm (FRAGMENT), gross cropped area under sugarcane cultivation in percent (PGCASC), years of schooling (EDUCATION), number of workers in the family in percent (PFWORK), adequacy of rain (ARAIN), fertilizer use in kilograms/acre (QFERT), joint ownership of modern water extraction mechanism (PJOINTWL) and installed horse power of the water lifting device (HPPERWL).

To understand the role of these variables in farmers' decision to participation in groundwater market we run a logistic regression as below:

$$Zi = \theta_0 + \theta_1 \text{ (AREA OWN)} + \theta_2 \text{ (FRAGMENT)} + \theta_3 \text{ (PGCASC)} + \theta_4 \text{ (EDUCATION)} + \theta_5 \text{ (PFWORK} + \theta_6 \text{ (ARAIN)} + \theta_7 \text{ (QFERT)} + \theta_8 \text{ (PJOINTWL)} + \theta_9 \text{ (HPPERWL)} + U_i \quad \ldots(1)$$

Where, Z_i is binary variable taking a value of 1 if a farmer buys water or zero otherwise. U_i is the disturbance term. Except ARAIN and PJOINTWL all other variables are continuous. ARAIN takes a value of 1 if farmer reported adequate rainfall, zero otherwise. Likewise PJOINTWL takes value 1 if the farmer has joint ownership of modern WEM, zero otherwise.

3.2 Efficiency of water markets

3.2.1 Production function

Cobb-Douglas production function was fitted to examine resource productivity of water.

$$Y = aX_1^{b_1}X_2^{b_2}X_3^{b_3}\mu_i \quad \ldots(2)$$

Where, Y is the output per acre of crop in kilograms, X_1 is the human labour use per acre in mandays, X_2 is the number of irrigations per acre and X_3 is the fertilizer (NPK) use per acre in kilograms. μ_i is the error term; and b_1, b_2, b_3 are the parameters to be estimated.

3.2.2 Decomposition

We follow Bisaliah (1977, 1978) to decompose productivity differences between buyers and self-users. We specify the production function for self-users as:

$$\ln Y_1 = \ln A_1 + A_1 \ln L_1 + B_1 \ln F_1 + C_1 \ln I_1 + e_1 \quad \ldots(3)$$

and for buyers as:

$$\ln Y_2 = \ln A_2 + A_2 \ln L_2 + B_2 \ln F_2 + C_2 \ln I_2 + e_2 \quad \ldots(4)$$

Where, Y is the output (Rs/acre), L is the labour cost (Rs/acre), F is the fertilizer cost (Rs/acre), I is the Irrigation charges (Rs/acre), and A is the scale parameter. e is the random disturbance term, and A, B & C are the regression parameters or factor elasticities.

The difference is the outputs of self-users and buyers can be decomposed as:

$$\ln Y_2 - \ln Y_1 = (\ln A_2 - \ln A_0) + (A_3 \ln L_2 - A_1 \ln L_1 + (B_2 \ln F_2 - B_1 \ln F_1) + (C_2 \ln I_2 - C_1 \ln I_1) + (e_2 - e_1) \quad \ldots(5)$$

Further rearrangement yields:

$$\ln\left(\frac{Y_2}{Y_1}\right) = \ln\left(\frac{A_2}{A_0}\right) + \left[(A_3 - A_1)\ln L_1 + (B_2 - B_1)\ln F_1 + (C_2 - C_1)\ln I_1\right] + \left[A_3 \ln\left(\frac{L_2}{L_1}\right) + B_2 \ln\left(\frac{F_2}{F_1}\right) + C_2 \ln\left(\frac{I_2}{I_1}\right)\right] + \left(\frac{e_2}{e_1}\right) \quad \ldots(6)$$

The dependent variable in equation represents the difference in the log of yields between self-users and buyers. The first expression in] is interpreted as change in yield due to changes in factor elasticities. The second expression in [ ] represents change in yield due to changes in the quantities of labor, fertilizer and irrigation used.

3.3 Nash equilibrium model of groundwater pricing

Nash equilibrium framework is used to model bargaining power of sellers versus buyers. It assumes that the buyers and sellers are rational having equal bargaining skills, perfect knowledge of the tastes and preferences of each other and maximize their utilities. Bargaining power of the seller is assumed to be represented by their gross irrigated area and water extracted by them, and the bargaining power of the buyer is assumed to be represented by their gross irrigated area. As crop share rental arrangement between the land owner and tenants varies from one-third to one-fourth of the value of crop, the water price per acre-inch tends to remain uniform and this has been chosen as the dependent variable. This price-cost ratio is assumed as a surrogate for monopoly power.

Surrogate price of groundwater

$$W = f(V_1, V_2, V_3) \quad \ldots(7)$$

Where, W is the water price per acre-inch, V_1 is the gross irrigated area of seller, V_2 is the total water extracted by seller, and V_3 is the gross irrigated area of buyer.

The Nash bargaining model is assumed to follow the quadratic function:

$$Y = \alpha + \beta_1 V_1 + \beta_2 V_2 + \beta_3 V_3 + \gamma_1 V_1^2 + \gamma_2 V_2^2 + \gamma_3 V_3^2 \quad \ldots(8)$$

The elasticity of price-cost ratio with respect to each of the explanatory variable is estimated as $(\beta_i + 2\gamma_i V_i)\frac{V_i}{W_i}$, where i = 1, 2, 3.

4 Results and discussion

Groundwater is the only source of irrigation in the study region. The depth of tube-well ranges between 20-500 ft and the discharge is in the range of 45-120 gallons per minute (GPM). The dug well as well as the dug-cum-borewell have almost been abandoned. A large proportion (82%) of the farmers participate in water market as buyers or sellers (table 1). The number of buyers decreases as farm size increases, while the number of sellers increases with an increase in the farm size. About 23 % of the cropped area in the selected villages benefited from the operation of the groundwater markets. In other words, in the absence of groundwater markets about one-fifth of the area would have remained unirrigated (table 2). The conduct of groundwater markets shows 2.39 buyers per seller.

Rice occupies maximum share of the total cropped area, followed by sugarcane and groundnut (table 3). Cropping intensity is higher for buyers, and irrigation intensity is observed to be higher for self – users. In groundwater market, there are two types of transactions that is cash and kind. Such transactions have also been

Table 1. Farm holdings and operational size across various forms of water markets

	Buyer	Self-user+ buyer	Self-user+ buyer +seller	Self-user+ seller	Self-user	Total
Number of holdings						
Marginal (<1ha)	12(50)	4(16)	2(18)	3(13)	3(13)	24(100)
Small (1 to 2 ha)	13(28)	7(15)	11(23)	9(19)	7(15)	47(100)
Large (> 2ha)	5(10)	6(12)	15(31)	12(24)	11(23)	49(100)
Total	30(25)	17(14)	28(23)	24(20)	21(18)	120(100)

Note: Figures in parentheses show per cent to total.
Source: Based on primary survey.

Table 2. Extent of groundwater markets

S. No.	Particulars	Number
1	Sellers*	52
2	Buyers per seller	2.39
3	Average area irrigated by sellers (acre)	10.78
	a) Own fields (%)	77.32
	b) Buyers' fields (%)	22.68
4	Hours operated per WEM	911
	a) Own field (%)	66.67
	b) Buyers field (%)	33.33

Note: *Sellers include self-users + sellers and self-users + sellers + buyers

reported by Satyasai et al. (1997), Shah (1993) and Sharma et al. (2004).

4.1 Factors influencing participation in groundwater market

Table 4 presents estimates of the logit regressions for sellers. Farm size, number of fragments per farm, joint-ownership of WEM and installed horse power appear important factors in farmers' decision to sell water. A one-unit increase in farm size, the probability of selling water increases by 2.28 times. On the other hand, increase in the number of fragments reduces probability of selling water. Further, the farmers having installed large capacity water-lifting devices increases significantly the probability of selling groundwater. This is consistent with the findings in Singh et al. (2006).

Results of the logit model for buyers of groundwater are presented in table 4. As for water sale decisions, the farm size, number of fragments per farm, and installed horse power influence water buying decision but differently. The probability of buying groundwater reduces with increase in farm size and capacity of water lifting device, while it increase with fragmentation of land holding. Kolavalli and Chicoine (1989), Saleth (1996), Meinzen-Dick (1996) and Singh (1998) have also reported similar findings.

Table 3. Net area sown and total cropped area, cropping and irrigation intensity and cropping pattern across the water markets

Particulars	B	SU+B	SU+B+S	SU+S	SU
Net area sown (acre)	39.34	35.21	80.22	57.24	53.58
Total cropped area (acre)	60.40	52.78	115.95	85.92	80.86
Cropping intensity (%)	154	150	144	150	151
Irrigation intensity (%)	144	146	140	149	150
Share of crops in gross cropped area (%)					
Paddy	40.62	46.44	47.95	47.62	46.30
Sugarcane	5.43	21.28	22.50	22.38	21.25
Groundnut	5.56	4.65	3.48	3.40	3.43
Others	48.39	27.63	26.07	26.60	29.02

Note: B: buyers; SU+B: Self-users + buyers; SU+B+S: Self-users + buyers + sellers; SU+S: Self-users + sellers; SU: Self-users.

Table 4. Coefficients of Logistic regression for factors influencing groundwater selling and buying

Variable	Selling				Buying			
	Coefficient	Exp(b)	Standard error	Level of significance	Coefficient	Exp(b)	Standard error	Level of significance
AREA OWN	0.826	2.284164	0.501	0.009	-1.123	0.325302	0.404	0.005
FRAGMENT	-1.624	0.197109	0.619	0.009	0.225	1.252323	0.301	0.046
PGCASC	-0.075	0.927743	0.055	0.171	0.212	1.236148	0.062	0.061
EDUCATION	-0.757	0.469072	0.356	0.633	0.029	1.029425	0.257	0.911
PFWORK	0.023	1.023267	0.026	0.364	0.031	1.031486	0.020	0.134
ARAIN	0.434	1.543467	0.681	0.524	-0.853	0.426135	0.538	0.113
QFERT	0.015	1.015113	0.009	0.125	0.022	1.022244	0.008	0.086
PJOINTWL	11.597	108771	3.343	0.001	-1.815	0.162838	0.976	0.063
HPPERWL	0.565	1.759448	0.148	0.000	-0.187	0.829444	0.104	0.041
Intercept	-1.458	0.232701			-3.508	0.029957		

Value of Chi-square (Significant at 1 per cent) = 97.21
Value of -2 log likelihood (Significant at 1 per cent) =65.79
Nagelkerke R square =0.75
Prediction of success = 86.70
Number of observations=120

Value of Chi-square (Significant at 1 per cent) = 64.52
Value of -2 log likelihood (Significant at 1 per cent) =94.26
Nagelkerke R square =0.57
Prediction of success = 85.80
Number of observations=120

4.2 Water use efficiency

Table 5 presents estimates of the Cobb-Douglas production function for rice and sugarcane. In the case of rice, the coefficient on fertilizer use is significant across different forms of water market, while it is insignificant on human labour. The coefficient on the number of irrigations is significant on water buyers' and self-users' farms but with opposite sign. It is negative for self-users indicating overutilization of groundwater. The summation of production coefficients on all forms of water markets is less than unity indicating decreasing returns to scale. The findings suggest a possibility of increasing productivity of rice by reducing excessive water-use by self-users, and if water saved is sold it would add to the rice productivity for buyers of water.

Table 5. Production elasticity of factors influencing Rice and Sugarcane productivity

Variables	Rice					Sugarcane				
	B	SU +B	SU+B+S	SU+S	SU	B	SU +B	SU+B+S	SU+S	SU
Intercept	2.643	2.133	2.373	1.448	3.747	2.493	3.020	1.086	2.164	2.144
Human labour	0.111	0.104	0.050	0.368	0.041	0.769***	0.596**	0.299**	0.592***	0.821***
	(0.088)	(1.802)	(1.262)	(0.232)	(0.060)	(0.169)	(0.240)	(0.139)	(0.198)	(0.203)
Irrigation	0.636***	0.023	0.039	0.014	-0.079**	0.596**	0.031	0.097	-0.077	-0.141**
	(0.129)	(0.079)	(0.081)	(0.079)	(0.032)	(0.240)	(0.142)	(0.137)	(0.115)	(0.055)
Fertilizers	0.087***	-0.064***	0.557***	-0.113***	0.082**	-0.360	-0.080	-0.360	0.417	0.067
	(0.026)	(0.021)	(0.086)	(0.033)	(0.034)	(0.185)	(0.128)	(0.185)	(0.173)	(0.301)
R^2	0.70	0.54	0.58	0.52	0.73	0.79	0.55	0.58	0.63	0.85
Returns to scale	0.834	0.063	0.646	0.269	0.044	1.005	0.547	0.036	0.932	0.747
Number of observations	29	17	28	24	21	20	15	28	24	21

Note: 1. Figures within the parentheses are standard errors
2. *** and ** indicate significance at one and five per cent levels, respectively.
3. SU: Self-users; SU+B: Self-users + buyers; SU+S: Self-users + sellers; B: buyers; SU+S+B: Self-users + sellers + buyers.

Table 6. Production functions of self-users and buyers form of water market

Variables	Rice			
	Self-users		Buyers	
	Coefficients	Geo-mean	Coefficients	Geo-mean
Intercept	3.0745	82500	3.7828	35000
Labour(Rs/acre)	0.1531***	6125	0.3425***	2750
	(0.0507)		(0.0824)	
Fertilizers(Rs/acre)	0.2431**	4625	0.1020	2975
	(0.1152)		(0.1442)	
Irrigation (Rs/acre)	-0.0113***	5550	0.0224***	3603
	(0.0040)		(0.0050)	
Dummy variable	-		-	
R^2	0.63		0.54	
Number of observations	20		20	

Note: 1. Figures within the parentheses are standard errors
2. *** and ** indicate significance at one and five per cent levels, respectively.

For sugarcane, the coefficient on human labour is positive and significant while the fertilizer is insignificant across all forms of water market. Irrigations is positive and significant for buyers. It is negative and significant for self-users, indicating overutilization of irrigation water. The summation of production coefficients on buyers' farms exhibits constant returns to scale. For self-users + buyers, self-users + buyers + sellers, self-users + sellers and self-users, there is a decreasing returns to scale, implying possibility of increasing sugarcane productivity by reducing water use.

4.3 Decomposition of productivity change for rice

The results of the estimates of the production functions for buyers and self-users, used for decomposition of the productivity difference between the two, are shown in table 6 and table 7. Water management accounts for 18 percent of the productivity difference. The differences in labour, fertilizer and irrigation account for only 0.12 percent of the productivity difference.

4.4 Groundwater pricing

Results of the Nash equilibrium model shows gross irrigated area and water extracted by sellers, and the gross irrigated area of buyers are significant determinants of water price (Table 8). The elasticity of price of groundwater with respect to the explanatory

Table 7. Estimates of decomposition of output difference between Self users and buyers of water

S. No.	Particulars	Percentage
1	Total observed change in productivity	21.65
2	Total estimated difference in productivity	18.13
3	Changes due to irrigation management	17.89
4	Total change due to all inputs	0.12
	a) Labour	0.97
	b) Fertilizer	0.77
	c) Irrigation	-1.62

variables was calculated and it was found that for 1 percent increase in the gross irrigated area of the sellers, the price of groundwater per acre inch increases by 0.069 percent. For a 1 percent increase in the total water extracted also increases water price by 0.0006 percent. On the other hand, a 1 percent increase in the gross irrigated area of the buyers increase water price by 0.13 percent.

On an average, per hour cost of irrigation water is estimated Rs. 22.84 including Rs. 7.48 as fixed expenses (table 9). The per hour fixed as well as variable costs are almost similar across farm size groups. It is further observed that the per hour irrigation cost is slightly higher on large farms.

The total cost of water extraction of electric operated modern WEMs works out to be Rs. 22.84 per hour

Table 8. Nash bargaining model of groundwater niche market

Explanatory variables	Coefficients	t-value
Intercept	-1.726	
X_1	2.005**	2.198
	(0.912)	
X_2	0.139***	9.929
	(0.014)	
X_3	3.786**	2.469
	(1.533)	
X_1^2	-0.210**	2.561
	(0.082)	
X_2^2	-0.077	0.669
	(0.115)	
X_3^2	-0.264	1.257
	(0.210)	
R^2	0.77	
Number of observations	29	

Note: 1. Figures within the parentheses are standard errors
2. *** and ** indicate significance at one and five per cent levels respectively.

Table 10. Cost of water extraction and selling price

(Rs/hr)

S. No.	Particulars	Electric operated modern WEM
1	Cost of water extraction	
	a) Fixed cost[a]	7.48
		(32.75)
	b) Operating cost[b]	15.36
		(67.25)
	c) Total cost	22.84
		(100)
2	Selling price	25.00
3	Net income	
	a) Over fixed cost	17.52
	b) Over operating cost	9.64
	c) Over total cost	2.16

Note: 1. Figures in parentheses are percentage of total cost.
a. It includes depreciation and interest on fixed investment of tube-well installation, pump sets and water conveyance structures, etc.
b. It includes operating and maintenance charges and interest on working capital and interest on working capital.

Table 9. Cost of irrigation water on different categories of farm sizes

Categories of farm size	Average number of working hours in one year	Cost of irrigation water per hour in terms of fixed expences(Rs/hr)	Average variable expences in one year (Rs)	Cost of irrigation water per hour in terms of variable expences (Rs/hr)	Cost ofirrigation water per hour (Rs/hr)
Marginal (< 1 ha)	354.00	7.06	5500.00	15.54	22.60
Small (1-2 ha)	666.00	7.50	10000.00	15.01	22.51
Large (>2 ha)	950.00	7.89	14750.00	15.53	23.42
Average	657.00	7.48	10083.00	15.36	22.84

(Table 10). The sale price of groundwater is Rs. 25 per hour. The sellers of water earn a net profit of Rs. 2.16 per hour over the cost of extraction.

5 Conclusions and Policy implications

The study analyzed the water markets and its implications on pricing of groundwater in Puducherry. About 82 percent of the farmers participated in water markets. Water markets resulted in an increase of 23 percent in gross cropped area. The logit analysis revealed that the probability of farmers to sell water increased with farm size, fragments per farm and horse power of engine. In contrast, farmers with large farm size and higher capacity of water lifting machine were less likely to buy water while highly fragmented holdings had a higher probability to buy water.

Functional analysis across five different forms of water markets for rice and sugarcane indicated the significant role of irrigation in increasing yield for water buyers but was negative for self-users which implied overutilization of groundwater by self-users. Irrigation and inputs (fertilizer and labour) contributed to 17.89 percent and 0.12 percent respectively of the difference in rice output between buyers and self-users.

Nash equilibrium model revealed that gross irrigated area was the significant determinant of water price for both buyers and sellers. The cost of groundwater extraction worked out to Rs. 22.84 per hour and with a sale price of Rs. 25 per hour, sellers earned a net profit of Rs. 2.16 per hour.

The following policy implications emerged from the study. The consolidation of holdings would help in efficient water management and economize investment on irrigation. The increase in capacity of engine increased the probability of selling groundwater. The linkage between pumping groundwater from aquifers and electricity is rather straight forward. The regulation of electricity supply and pricing would be an effective tool for governing groundwater use. The excessive use of groundwater resulted in decline in yields of rice and sugarcane. The farmers may be encouraged to shift the cropping pattern from water intensive crops to growing less water consuming crops. Measures to promote efficient irrigation technologies like precision farming are a feasible avenue for reducing demand for groundwater and electricity. A uniform policy of groundwater exploitation in terms of spacing, intensity and depth of tube-wells would prevent overexploitation of groundwater and prevent salinity intrusion into aquifers in the ecologically fragile coastal regions.

Acknowledgement

The authors sincerely thank the anonymous referee for providing helpful suggestions.

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Received: 21 November 2017; Accepted: 31 October 2018