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Impact of Groundwater Over-draft on Farm Income and Efficiency in Crop Production[§]

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Abstract

In this study, the cost of groundwater extraction, impact of groundwater depletion on farm income, water-use efficiency, technical efficiency in crop production and costs of groundwater depletion among different categories of farmers have been reported. The study has been conducted in the Chamarajanagar district of the Karnataka state, where groundwater is the major source of irrigation. Data have been collected from over-exploited, semi-critical and safe villages. The study has shown a wide difference between large and small farms in their access to groundwater resource in terms of cost. The functional analysis has revealed that farm income is lower in over-exploited and semi-critical villages compared to safe villages. The mean technical efficiency in crop production has been found highest among farmers in over-exploited villages. The total cost of groundwater depletion has been reported more in over-exploited villages and the cost increases with increase in the size of holding. The impact of this cost would be maximum on small and marginal farmers because of their low resource base and limited means of income. The study has emphasized on the need for incentivising for efficient use of groundwater by adopting efficient irrigation technologies like drip, sprinkler, etc. to ensure livelihood security.

Key words: Groundwater, Over-draft, Farm income, Water-use efficiency, Technical efficiency

JEL Classification: Q12, Q15, Q25

Introduction

Groundwater irrigation has been a major component in agricultural development since 1960s. It enhanced agricultural productivity, ensured food security and induced commercialization of agriculture. Intensive use of groundwater for irrigation rapidly expanded with the adoption of tube-well and mechanical pump technology. Consequently, groundwater withdrawals in India have surged from less than 20 km^3 in 1950s to more than 150 km^3 now, making India by far the largest user of groundwater in the world. About 55-60 per cent of India's agricultural lands rely on groundwater for irrigation. The property right of groundwater is not well defined and those who have the access to resources such as land, capital and efficient pumping technology, have higher incentive to extract as much water as possible and incentives to conserve groundwater voluntarily are absent, since water not pumped is available to competing users and will not necessarily be conserved for future periods. Thus, competitive pumping often ignores the user-cost (it is a measure of the economic consequences of pumping now thereby

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lowering the water table and increasing cost of extraction for all future periods) because they believe that self-discipline will not necessarily conserve supplies for the future and because the impact of their own pumping on the water table will be small. This behaviour of farmers tends to consider groundwater as an open access resource and exploits competitively.

Over-exploitation of groundwater in many pockets of the country has caused adverse environmental, economic and social consequences. There is a perverse link between energy subsidies and groundwater over-draft (Shah *et al.,* 2008). Frequent droughts and groundwater over-exploitation have been the critical constraints to improve agricultural productivity in the semi-arid tropics (Shiferaw *et al.,* 2008). Premature failures of irrigation wells are a predicament to farmers in hard rock areas due to cumulative well interference induced by drought situation (Chandrakanth, *et al.,* 1997). The cost of groundwater over-draft is disproportionately borne by medium and small farmers (Reddy, 2003). In the state of Karnataka, tube-wells and open-wells accounted for nearly 48 per cent of irrigation.

The present study was conducted in Chamarajanagar district of Karnataka, where groundwater is the major source of irrigation. Even though the district does not have any major surface irrigation project, the farmers cultivate high water-intensive crops like sugarcane, banana and turmeric, which in turn lead to over-draft of groundwater. Declining water table coupled with deepening of existing wells and digging of new wells aggravate over-exploitation of groundwater and threaten the livelihood security of small and marginal farmers who cannot afford large investments for water abstraction. This paper has looked into the cost of groundwater extraction, impact of groundwater over-draft on farm income, water-use efficiency and technical efficiency in crop production, and costs of groundwater over-draft among different categories of farmers.

Methodology and Data Analysis

Data Collection

Ground Water Resources Estimation Committee (GWREC 2004) had divided all the taluks of Karnataka into over-exploited, critical, semi-critical, and safe categories. In an over-exploited area, the ratio of extraction to recharge exceeds 100 per cent; this ratio is between 90 and 100 per cent in critical areas, between 70 and 90 per cent in semi-critical and less than 70 per cent in the safe areas. Chamarajanagar district has four taluks, viz. Chamarajanagar, Kollegala, Yelandur, and Gundalpet. Based on the state of groundwater development, Yelandur taluk is categorized as safe, Chamarajanagar taluk as semi-critical, Kollegal taluk as critical and Gundalpet taluk as over-exploited. GWREC also categorized the villages in Karnataka state as over-exploited, critical, semi-critical and safe villages using the same criteria as used to classify the taluks.

The Chamarajanagar district comes under the southern dry agro-ecological zone and is mainly composed of hard rock which limits groundwater recharge. Preliminary survey and discussion with the technical staff of the department of agriculture and department of mines and geology revealed that the groundwater problem is relatively more in Chamarajanagar taluk. In this taluk 91.3 per cent of net area is irrigated by groundwater and 80 per cent of the total electricity is consumed by irrigation pumpsets, which is substantially higher compared to the other taluks in the district. Three categories of villages, viz. over-exploited, semi-critical and safe were present in the Chamarajanagar taluk. Six villages were selected from each category in such a way that a particular category falls under a single administrative unit (Hobli in Karnataka) and geographically adjoining or closely located. Ten farmers were selected at random from each village and a total of 180 farmers were contacted for data collection during February 2009.

Data Analysis

Estimation of Cost of Groundwater Extraction

Annual cost of irrigation was estimated as the sum of amortized and maintenance costs of well, pump sets, and over ground storage structure and annual electricity cost divided by the gross irrigated area. The formulae used for different calculations are given below.

Well Life: It was calculated as per Equation (1):

$$\text{Average life of a well (AL)} = \frac{\sum_i^n \left(f_i x_i\right)}{\sum_i^n f_i} \qquad \ldots(1)$$

where, f = Frequency of wells yielding irrigation water in each age group, x = Age of well (i=1,2,3,......,n) in years.

Amortized Cost of a Well: Investment in a well at current prices was amortized considering the drilling cost and investment for water lifting (pump sets).

$$\text{Amortized drilling cost} = \frac{\left[BW_{Cost} * (1+i)^{AL} * i\right]}{(1+i)^{AL} - 1} \quad \ldots(2)$$

where, BW_{Cost} = Investment on bore-well in current prices, AL = Average life of bore-well, and i = interest rate.

Amortized Cost of Pump Sets: It was calculated by Equation (3):

$$\text{Amortized Cost of Pump Sets} = \frac{\left[WL_{Cost} * (1+i)^{AL} * i\right]}{(1+i)^{AL} - 1} \quad \ldots(3)$$

where, WL_{Cost} = Investment on pump sets in current prices and AL = Average life of pump sets.

Amortized Cost of Over Ground Storage (OGS) Structure: Due to vagaries in supply of electricity, lower yield of well and non-availability of labour for irrigation in time, farmers have built over-ground storage tanks. The amortized cost of over-ground storage tank was estimated by Equation (4):

$$AC_{OGS} = \frac{OGS_{cost} * (1+i)^5 * i}{(1+i) - 1} \quad \ldots(4)$$

where, AC_{OGS} = Amortized cost of OGS and OGS_{Cost} = Cost incurred to construct a OGS.

Water-use Efficiency: Water-use efficiency of groundwater was measured in terms of net income per ha-cm of groundwater.

Net income per ha-cm of groundwater (Rs) = [Gross returns — cost of cultivation] ÷ [Quantity of groundwater-used] …(5)

Technical Efficiency: Aigner *et al*. (1977) have proposed the stochastic frontier production function with two independent error-components. The one accounts for the presence of technical inefficiencies in production and other accounts for measurement errors in output, weather, etc. and the combined effects of unobserved inputs in production. In this study the general production function (Battese and Colli, 1995) is defined as per Equation (6):

$$Y_i = f(x_i;\beta)\exp(v_i - u_i), \quad i = 1,2,3,.........,n \quad \ldots(6)$$

where Y_i denotes the output quantity of the i[th] farm, x_i is a (1 × J) vector of input quantities and β is a (J × 1) vector of unknown parameters to be estimated. The v_is are two-sided random variables associated with measurement errors in output and other noise in the data which are beyond the control of firms; v_is are assumed to be independently and identically distributed N $(0,\sigma_{v_2})$and independent of u_i. In the absence of stochastic term u_i, the model in Equation (6) reduces to purely deterministic (mean) production function. The u_is are defined as non-negative random variables which account for technical inefficiency effects in production. Maximum likelihood estimation methods were used to estimate the stochastic frontier. For the likelihood function the variance-term is parameterized as (Battese and Coelli, 1995):

$\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2/(\sigma_u^2 + \sigma_v^2)$, with $0 \leq \gamma \leq 1$

The technical inefficiency for the i[th] firm is estimated as the expectation of u_i conditional on the observed value $(v_i - u_i)$ as per Equation (7):

$$TE_i = E\left[\exp(-u_i)/(v_i - u_i)\right]$$
$$= E\left[\exp\left(-\delta_0 - \sum_{k-1}^{k} \delta_k z_{ik} - \omega_i / v_i\right)\right] \quad \ldots(7)$$

Empirical Model

In the present study, Cobb-Douglas production function was employed to study the technical efficiency of sugarcane production, the major crop in the study area. Even though sugarcane is a highly water-intensive crop, it is the most preferred crop in all categories of villages, viz. safe, semi-critical and critical due to high economic returns, experience in cultivation and easy access to market.

$$\ln Y = \beta_0 + \sum_{i=1}^{5} \beta_i \ln X_i + v_i - u_i, \text{ where, } i = 1,..,5 \quad \ldots(8)$$

where, Y= Yield of sugarcane (t/ha), $\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5$= Parameters to be estimated; X_1 = Labour in human days per hectare, X_2 = Tractor in hours per hectare, X_3 = Animal labour hour per hectare, X_4 = Fertilizer-use (₹/ha), X_5 = Quantity of water in ha-cm.

Impact of Groundwater Over-draft on Farm Income

Groundwater over-draft results in higher cost of extraction, reduced availability of irrigation water and lack of irrigation during critical periods of crop growth which affects the farm income. The impact of groundwater over-draft on farm income was captured through the following model:

$$FI = \beta_0 + \beta_1 LH + \beta_2 AUI + \beta_3 EDU + \beta_4 HHS + \beta_5 SC + \beta_6 OE + \beta_7 DPT + \beta_8 DPTSR + e \quad \ldots(9)$$

where,

FI = Farm income in rupees,
LH = Land owned by household in ha
AUI = Area under irrigation,
EDU = Education of household-head in years,
HHS = Size of the household in numbers,
SC = Dummy 1 for semi-critical villages, 0 otherwise,
OE = Dummy 1 for over-exploited villages, 0 otherwise,
DPT = Depth of well in feet,
DPTSR = Square of depth of well in feet, and
e = Error-term.

Cost of Groundwater Over-draft

The negative externalities of groundwater over-draft may be broadly classified into private costs and social costs. The social costs are borne by community like cost incurred by state to recharging aquifer, loss in welfare due to more travelling for drinking water, poor groundwater quality, drying of wells due to neighbours action (miss-management of resource, digging more wells, abstracting water from deeper aquifer, etc.), etc. are some of the social costs.

Private costs are simple and easy to estimate, social costs are more complex and dynamic in nature and are difficult to estimate accurately. The social and private costs of groundwater over-draft co-exist in the social system and are complimentarily related. In this study, direct and indirect costs associated with groundwater over-draft have been estimated. Direct costs included the investments made on new bore-wells and loss of capital due to drying up of wells. These costs are termed as 'sunk costs' in the case of drying up of wells and 'replacement costs' in the case of new bore-wells that have replaced the old wells. Direct costs are onetime costs and are likely to increase over time along with the drying up of open wells and increase in the number of bore-wells. Indirect costs include loss in net returns per acre due to the decline in net sown area under irrigation and loss due to the changes in cropping pattern from the more remunerative water-intensive crops to less remunerative dry crops. Indirect costs were estimated by taking differential net return between sugarcane and other crops that replaced sugarcane and the decline in area under sugarcane.

Cost of groundwater over-draft = Direct cost + Indirect cost …(10)

where,

Direct cost = Sunk cost + Replacement cost;

and

Indirect cost = Net losses due to change in cropping pattern + Decline in net sown area under irrigation

Results and Discussion

Cost of Water extraction

The higher digging and extraction investment in over-exploited villages were due to secular lowering of water table in the area. In the process of competitive race for groundwater development, farmers' access and average productive age of the bore-wells has declined with time. This has led to a situation in which overhead nature of investments on wells has been turned into short-term investments. The conveyance structures are the permanent earthen channels and/or underground pipes which are buried all along the borders of land to convey the irrigation water from source to sink. The investment on over ground storage structure and conveyance structure was substantially higher in the over-exploited villages. Even though farmers in the three village categories were facing similar electricity problems, the farmers in over-exploited villages were facing an additional problem of lower well yield.

The annual cost of irrigation included the amortized cost of well investment plus the operation and

Table 1. Annual cost of groundwater irrigation

(₹/ha)

Particulars	Safe villages	Semi-critical	Over-exploited
Amortized cost of well (₹)	10775	11817	15135
Amortized cost of OGS + conveyance structure (₹)	883	854	1210
Annual electricity charges (₹)	1680	1680	2400
Annual average repair cost (₹)	350	500	435
Total cost (₹)	13687	14851	19180
Gross area irrigated (ha)	154	148	87
Gross area irrigated per well (ha)	3.00	2.60	2.50
Annual cost of irrigation (₹/ha)	4563	5712	7672
Water extracted per annum per well (ha-cm)	139.5	124.5	102.5
Cost of water extracted (₹/ha-cm)	33	46	75

Source: Survey data,
Note: OGS= Over ground storage structure.

maintenance cost and the flat rate electricity charges, based on the horsepower of the pump. Electricity charges are subsidized in the rural areas for pumping groundwater and the state electricity board is not charging for agricultural pump sets up to 10HP capacity. Therefore, the marginal cost of groundwater irrigation was zero. The cost of groundwater irrigation in the over-exploited villages was highest (₹ 7672/ha), as against semi-critical (₹ 5712/ha) and safe (₹ 4563/ha) villages (Table 1). The water extracted per hectare per annum was highest in safe villages (139.5 ha-cm), followed by semi-critical (124.5 ha-cm) and over-exploited (102.5 ha-cm) villages. One of the critical factors that influence the cost of bore-well irrigation is its depth. In the over-exploited villages, the water table has been falling, resulting in increased drilling depths. Hence, there was appreciable difference in the irrigation cost between over-exploited and safe villages. The highest cost of water was in over-exploited villages (₹ 75/ha-cm), followed by semi-critical (₹ 46/ha-cm) and safe villages (₹ 33/ha-cm). The important factor which affects the groundwater irrigation is the water yield of wells, a lower yield of well increases cost per volume of water extraction. In over-exploited villages the lower yield of well accompanied with higher annual cost of irrigation, increased the cost per unit volume of water extracted.

Cost of Groundwater Irrigation for Small and Marginal Farmers

Cost of groundwater irrigation decreased with increase in the size of holding, particularly in the over-exploited villages; it was highest for marginal farmers (₹ 8636/ha), followed by small (₹ 8573/ha), semi-medium (₹ 8256/ha), medium (₹ 7800/ha) and large (₹ 7130/ha) farmers. Cost per hectare-cm of water extracted was highest for marginal farmers (₹ 87/ha-cm), followed by small (₹ 86/ha-cm), medium (₹ 76/ha-cm) and large (₹ 79/ ha-cm) farmers. While, in the safe and semi-critical villages this variability was not much distinct and all the categories of farmers in these villages incurred more or less the same cost in water extraction. This inequality in cost of groundwater irrigation across different categories of the farmers was mainly due to the lower irrigable area with higher investment. Small farmers have to incur the same amount of investment on borewell as that of a large farmer but a large farmer can irrigate more area by virtue of his large size of holding and enjoy the fruits of scale economies. In addition to this, large farmers in over-exploited villages having the option to choose best water yielding diving point to drill a well which certainly yield more water at a lower cost.

Water-use Efficiency and Technical Efficiency in Crop Production

Water-use Efficiency

The water is increasingly becoming a scarce commodity due to competing demand from domestic, industrial and agricultural sectors. About 70 per cent of the groundwater is abstracted for agricultural production and therefore it has to be used judiciously

Table 2. Cost of groundwater irrigation among different categories of farmers

Particulars	Annual irrigation cost/well (₹)	Area irrigated per well (ha)	Water extracted per well (ha-cm)	Annual irrigation cost per ha (₹)	Cost per ha-cm of water (₹)
Safe villages					
Marginal farmers	27374	3.90	134.89	4670	33.11
Small farmers	15208	2.03	130.75	5011	39.24
Semi-medium farmers	13687	2.35	141.16	4531	32.01
Medium farmers	11406	2.45	150.00	4481	29.15
Large farmers	8555	4.00	147.32	4531	30.56
Semi-critical villages					
Marginal farmers	2122	1.96	129.12	6125	49.26
Small farmers	2122	2.02	124.33	5725	47.32
Semi-medium farmers	1485	2.34	139.16	5432	42.15
Medium farmers	1238	2.96	132.22	5412	45.00
Large farmers	743	3.05	135.61	5380	45.32
Over-exploited villages					
Marginal farmers	2397	1.93	103.45	8636	87.22
Small farmers	2131	1.52	99.36	8573	86.21
Semi-medium farmers	3197	2.60	117.24	8256	80.14
Medium farmers	6393	5.86	123.12	7800	75.65
Large farmers	2397	3.15	132.21	7130	79.12

for attaining maximum output. The new paradigm for efficient water-use is to produce more crop per drop of water. In the present study, the water-use efficiency of groundwater was measured in terms of net income per ha-cm of groundwater (Table 3).

The net return received per ha-cm of water-used from sugarcane was highest in the safe villages (₹ 188), followed by semi-critical (₹ 151) and over-exploited (₹140) villages. But, water-use efficiency of sugarcane in terms of output was highest in over-exploited villages

Table 3. Efficiency of water-use in sugarcane production across different categories of villages

Sl. No.	Particulars	Safe villages	Semi-critical villages	Over-exploited villages
1	Cost of cultivation (₹/ha)[Excluding groundwater cost]	94389	92111	89116
2	Gross return (₹/ha)	134794	125260	118725
3	Groundwater-used (ha-cm/ha)[1]	183	168	138
4	Unit groundwater cost (₹/ha-cm)[2]	32.71	45.89	74.87
5	Total groundwater cost (₹/ha)	5986	7710	10332
6	Cost of cultivation + groundwater extraction cost (₹/ha)	100375	99821	99448
7	Net returns (₹/ha) [2-6]	34418	25439	19277
8	Net income per ha-cm of groundwater (₹)[7/3]	188	151	139
9	Total output (t/ha)	98.82	92.40	88.32
10	Output per unit of groundwater(t/ha-cm) [9/3]	0.54	0.55	0.64

Notes: [1]Groundwater-used (ha-cm/ha) = Water extracted (ha-cm)/Total area irrigated (ha); Water extracted (ha-cm) = [(Average number of days pumped /year*Average number of hours pumped /day*yield of bore wells in liters/ hour) ÷ 101171.26];
[2]Unit groundwater cost (₹/ha-cm) = Annual cost of irrigation ÷Water extracted/ annum/ well

(0.64 t/ha-cm), followed by semi-critical (0.55 t/ha-cm) and safe (0.54 t/ha-cm) villages. The higher output per ha-cm of water in the over-exploited villages reflected better water-use efficiency. It was mainly due to scarcity of groundwater that motivated the farmers to use water more efficiently.

Technical Efficiency in Crop Production

The maximum likelihood estimates of the stochastic frontier production function of sugarcane production are given in Table 4. Output elasticity of water was highest in the over-exploited villages, followed by semi-critical and safe villages. For increase in every ha-cm of water-use, sugarcane output increased by 0.298 tonnes.

The higher technical efficiency in crop production was confirmed further by the distribution of technical efficiency (Table 5). The higher technical efficiency range of 81-90 per cent was achieved by the majority of the farmers in the over-exploited villages (81.8%) while it was 48.3 per cent in semi-critical villages and 35.0 per cent in safe villages. It is noteworthy that mean

Table 4. ML Estimates of stochastic production frontier of sugarcane

Variables	Over-exploited villages	Semi-critical villages	Safe villages
Constant	0.280	0.441	0.554
	(0.788)	(0.788)	(0.777)
Human labour (humandays/ha)	0.176**	0.288***	0.306***
	(2.278)	(6.656)	(4.823)
Tractor labour (hours/ha)	0.162**	0.118***	0.133***
	(2.053)	(3.209)	(3.351)
Animal labour (hours/ha)	0.183***	0.075	0.084
	(3.397)	(1.336)	(1.257)
Fertilizers (₹/ha)	0.142**	0.131**	0.126**
	(2.173)	(2.37)	(2.007)
Water (ha-cm)	0.298***	0.170**	0.124**
	(2.173)	(2.299)	(2.002)
Sigma-square	0.203	0.958	0.171
Gamma	0.174	0.726	0.870

Note: Figures within the parentheses indicate estimated 't' ratio;
*** and ** denote significance at 1 per cent and 5 per cent levels, respectively.

Table 5. Distribution of technical efficiency across different village categories

Efficiency range (%)	Over-exploited villages	Semi-critical villages	Safe villages
< 50	0	0	3
	(0.0)	(0.0)	(5.0)
51-60	0	2	5
	(0.0)	(3.3)	(8.3)
61-70	0	4	9
	(0.0)	(6.7)	(15.0)
71-80	5	16	15
	(8.3)	(26.7)	(25.0)
81-90	49	29	21
	(81.8)	(48.3)	(35.0)
>90	6	9	7
	(10.0)	(15.0)	(11.7)
Number of farmers	60	60	60
Mean technical efficiency (%)	86.7	81.7	76.0

Note: Figures within the parentheses are percentage to total

Table 6. Influence of groundwater over-draft on farm income

Variables	Co-efficient	p-value
Constant	372.64 (0.06)	0.9520
Total land holding of house hold (ha)	9369.31*** (12.62)	0.0000
Depth of well (ft)	40.530 (0.72)	0.4717
Square of depth (ft)	-0.112 (-0.77)	0.4395
Per cent area under irrigation	10368.17*** (9.88)	0.0000
Education of household head (years)	646.50*** (2.10)	0.0039
Household size (No.)	-412.36** (-1.66)	0.0989
Dummy for over-exploited villages	-10000.42*** (-2.91)	0.0040
Dummy for semi-critical villages	-6694.42*** (-2.76)	0.0064
R^2	0.97	-
Adjusted R^2	0.97	-
No. of observations	180	-

Notes: Number within the parentheses indicate t-values;
***, ** and * indicate significance at 1 per cent, 5 per cent and 10 per cent levels, respectively

technical efficiency was highest among farmers of over-exploited villages (86.7%), followed by semi-critical (81.7%) and safe (76.0%) villages.

Groundwater Over-draft and Farm Income

The impact of groundwater over-draft on farm income was estimated and is presented in Table 6. The significant negative coefficients of dummy variable for over-exploited and semi-critical villages indicate lower farm income in these category villages compared to safe villages. The negative and significant sign of the coefficient for holding size implies that small households are more efficient in managing and utilization of groundwater resources than the large households. Irrigation and education had a positive significant influence on farm income.

Cost of Groundwater Over-draft

Cost of groundwater over-draft includes both direct and indirect costs. Direct costs were the investments made on new bore-wells and loss of capital due to drying up of wells. Indirect costs included loss in net returns per acre due to the decline in net sown area under irrigation and loss due to the changes in cropping pattern from the more remunerative water-intensive crops to less remunerative dry crops. Indirect costs were estimated by taking differential net return between sugarcane and other crops that replaced sugarcane and the decline in area under sugarcane.

The cost of groundwater over-draft was maximum in over-exploited villages (₹ 51485/ha) followed by in semi-critical (₹ 32984/ha) and safe (₹ 21762/ha) villages. The total cost of groundwater over-draft increased with increase in the size of holding. The impact of this cost would be maximum on small and marginal farmers because of their low resource base and limited means of income. The total cost per household due to groundwater over-draft is given in Table 7.

Table 7. Farm-size-wise total cost of groundwater over-draft

(₹)

Particulars	Costs due to groundwater over-draft		Total cost	Total cost per ha	Total cost per house hold
	Direct cost	Indirect costs			
Safe villages	**2853103**	**204461**	**3057564**	**21762**	**50959**
Marginal farmers	285294	38279	323573	11984	11158
Small farmers	453313	69825	523138	23251	34876
Semi-medium farmers	517600	63804	581404	24225	72675
Medium farmers	634068	33463	667531	31787	166883
Large farmers	900038	0.00	900038	19566	225010
Semi-critical villages	**3693704**	**424685**	**4118389**	**32984**	**68640**
Marginal farmers	436540	83898	520438	19714	16264
Small farmers	567282	80420	647702	25950	40481
Semi-medium farmers	757150	79788	836938	46497	139490
Medium farmers	760452	79219	839671	39984	279890
Large farmers	1153136	100416	1253552	36335	417851
Over-exploited village	**5497045**	**732610**	**6229655**	**51485**	**103828**
Marginal farmers	900968	154974	1055942	31057	35198
Small farmers	1037524	142769	1180293	32786	65572
Semi-medium farmers	669882	154919	824801	51550	137467
Medium farmers	939987	136574	1076561	48935	538280
Large farmers	1916168	143358	2059526	158425	514882

Conclusions

The study has shown that there is a large difference between large and small farms in their access to groundwater resource in terms of cost. The functional analysis has revealed that farm income is lower in over-exploited and semi-critical villages compared to safe villages. The mean technical efficiency in crop production has been found highest among farmers of over-exploited village compared to farmers in safe villages.

The total cost of groundwater over-draft has been observed more in over-exploited villages and it increases with increase in the size of holding. The impact of this cost would be maximum on small and marginal farmers because of their low resource base and limited means of income. Small and marginal farmers should be incentivized to take initiatives in efficient use of groundwater by adopting efficient irrigation technologies like drip, sprinkler, etc. to ensure the livelihood security. In the over-exploited areas, in order to bridge the gap between extraction and recharge, efforts should be made through peoples' participation for construction of water harvesting structures and desilting of the existing tanks so that groundwater supply can be augmented through recharge. Spacing norms for wells have to be enforced strictly to prevent cumulative well interference problems leading to well failures. Subsidized/free electricity is one of the important reasons for over exploitation of groundwater. Appropriate pricing of electricity for groundwater reflecting its scarcity value would serve as an instrument of groundwater regulation. Creating irrigation literacy through media, trainings and demonstrations about the importance of water and its conservation is important for sustainable use of groundwater.

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References

Aigner D. J., Lovell, C.A.K. and Schmidt, P. (1977) Formulation and estimation of stochastic production function models, *Journal of Econometrics*, **6(1)**: 21-37.

Battese, G.E. and Coelli, T. J. (1995) A model for technical inefficiency effects in a stochastic frontier production function for panel data, *Empirical Economics*, **20**: 325-345.

Chandrakanth, M.G. and Arun, V. (1997) Externalities in groundwater irrigation in hard rock areas, *Indian Journal of Agricultural Economics*, **52**(4): 761-771.

Reddy, V. Ratna (2003) *Costs of Resource Degradation Externalities: A Study of Groundwater Depletion in Andhra Pradesh*, Working paper No. 49, Centre for Economic and Social Studies, Hyderabad.

Shah, Tushar, Bhatt, Sonal, Shah, R. K. and Talati, Jayesh (2008) Groundwater governance through electricity supply management: Assessing an innovative intervention in Gujarat, western India, *Agricultural Water Management*, **95**: 1233-1242.

Shiferaw, Bekele, Ratna Reddy, V. and Wani, Suhas P. (2008) Watershed externalities, shifting cropping patterns and groundwater depletion in Indian semi-arid villages: The effect of alternative water pricing policies, *Ecological Economics*, **67**: 327-340.

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