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Crop Water Planning and Irrigation Efficiency in Rainfed Agriculture

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Abstract: More than 70 % of irrigation needs in India are currently met from groundwater resources. Hard rock areas (HRA) in India occupy more than 65% of the geographical area where groundwater resource is in increasing demand, but fraught with poor recharge. Indian farmers pump twice the groundwater used in USA and six times that used in EU. India's green revolution was significantly supported by increased groundwater irrigation, and can be termed as 'groundwater revolution' leading to overexploitation in many regions. A fall out of overexploitation is farmers increasingly facing risk of initial and premature well failure which exacerbates the cost of groundwater. Water policies focus on the demand side of water (Million wells scheme, Subsidy for micro irrigation, conveyance pipes, energy subsidy) neglecting the supply side of water (or lack of efforts towards recharging well) affecting its sustainable use. Even considering the energy subsidy, farmers are bearing more than 50 to 75 % of cost of groundwater, treating groundwater expenditure as implicit rather than as explicit cost. The costing methodology of cultivation by DES (Directorate of Economics and Statistics) / CACP (Commission for agricultural costs and benefits) ignores the cost of groundwater by treating depreciation on all items of expenditure on irrigation well and irrigation pump (IP) set as fixed cost (for an unspecified number of years). Even the yield of the well and number of hours of operation of IP set for different crops are not properly accounted in the record type forms, where cost of cultivation is assessed on daily basis from thousands of sample farmers all over India. Thus, the DES/CACP is yet to take adequate steps in properly accounting for the cost of groundwater irrigation in the Cost Concepts (of Cost A1, A2, B1, B2, C1, C2, C3). In fact DES/CACP computes average cost of cultivation clubbing both irrigated and rainfed crop conditions. This paper suggests how DES can modify its methodology in costing of groundwater irrigation, highlighting the extent of overestimation of profits due to underestimation of cost of irrigation. By appropriately accounting for the costs of groundwater irrigation incurred by farmers, this article offers solutions for facilitating in the appropriate costing methodology for Minimum Support Prices (MSP), Statutory Minimum Price and Market Intervention Scheme for crops for the benefit of farmers.

Keywords: Cost of groundwater, Groundwater irrigation, Irrigation efficiency

INTRODUCTION

Due to factors *inter alia*, lack of awareness among farmers regarding groundwater extraction and utilization, rural electrification policies, institutionally weak policy on groundwater, poor implementation and governance, and reciprocal negative externality, the probability of initial and premature well failure in HRA, has surpassed 0.5 reducing the life and age of irrigation wells. This has even resulted in dynamic transition in the type of irrigation wells (from dug wells to dug-cum-bore wells to shallow borewells on to deep borewells), the type of water extraction structures (from Yetha, Kapile, Persian wheel to centrifugal pump on to submersible pump sets), the depth of wells (from 300 feet to beyond 2000 feet), the magnitude of Horse Power of irrigation pumpset (from 5 HP to 20 HP or beyond). Even on a conservative basis, research studies reported by the Department of Agricultural Economics, UAS Bangalore (http://www.toenre.com/) estimated that groundwater irrigation costs around Rs. 500 per ha cm on volumetric basis. On area basis, groundwater irrigation cost varied from Rs. 10,000 per acre for vegetables/ flowers, to Rs. 20,000 per acre for water intensive crops like banana / paddy. However, in the CACP / Farm management Surveys, irrigation cost often does not include cost of water in general and cost of groundwater irrigation in particular. The water rate charged for canal irrigation is also a poor reflector of the true cost of canal water (Nagaraj et al. 2003) as the Government of Karnataka has fixed Rs. 100 per acre as water rate for paddy, Rs. 400 per acre for sugarcane, Rs. 35 per acre for semi dry crops. Thus, even though there is physical / economic scarcity of groundwater signaled through costs /

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prices, they are not reflected in MSP or even the market price. Hence, output / input prices are distorted which correspondingly result in lopsided crop pattern and net returns for farmers sometimes resulting in over production or under production including welfare losses.

The resulting deterioration of groundwater resource has seriously impacted the overexploited HRAs and is continuing to damage other areas too. According to The Karnataka Ground Water (Regulation And Control Of Development And Management) Act, 2011 (*http://dpal.kar.nic.in/ao2011/25of2011(E).pdf*), the GW regulation authority which has Notified Areas in Karnataka covers 70 percent of overexploited areas in Karnataka (15 taluks out of 21 taluks) as in Eastern Dry Agro-climatic Zone notably in Kolar and Chikkaballapur districts (*http://cgwb.gov.in/CGWA/Notified_areas.html*). This calls for rational water policy towards sustainable use of groundwater and land resources for shaping the economy of marginal and small farmers who bear the brunt of weak institutions, imperfect markets and distorted policies. This paper deals with resource economic costing of groundwater irrigation for different crops in HRAs of Karnataka, demonstrating the right methodology for estimation of costs of groundwater irrigation and the returns including the cost of recharge with implications on research, extension and policy.

Cost of groundwater irrigation ignored

Paradoxically, even with innumerable number of organizations on water – such as Central Water Commission, Ministry of Water Resources, Central Groundwater Board, National water development authority, State Water Resource Departments, State Departments of Mines and Geology, urban and rural water supply development boards, efforts towards volumetric measurement of water applied are crude and approximate. Cost of irrigation water is not properly accounted in any of the costing procedures including the DES/CACP, having no adequate information on water use in the RT forms[1]. There are no compelling reasons to accept that the DES costs of cultivation and the MSP are properly estimated, and in fact are grossly underestimated. For instance, the DES/CACP methodology at best computes depreciation of irrigation structure over___ number of years (?) which is subjective and left to the discretion of the field assistant who obtains data from farmers. This study provides details of costing groundwater resource for irrigation considering the hard rock areas of Karnataka.

Limitations of the DES/CACP methodology on costing irrigation water

The current methodology of CACP computes depreciation over ___ Number of years (which is subjective as it is not mentioned in the RT (…..) forms. For example, if an irrigation well is constructed / drilled in 2004 and is still yielding water, and if the data are collected in 2012, then the age at present will be 8 years. The Remaining life has to be estimated, for which there no basis is provided. For instance, in one of the RT forms, life of the well is recorded as 20 years and the remaining life is 20 – 8 years = 12 years. If the investment made on the borewell / tubewell is Rs. 35000, the salvage value is taken as 10% of the investment as = Rs.3500. Thus, the value of the tubewell is taken as Rs. 35000 – Rs 3500 = Rs. 31500.The annual depreciation is calculated as 31500/20 = Rs.1575. The value of tubewell at present (in 2012) is recorded as Rs. 1575 *12yrs of remaining life = Rs. 18900. The value of IP sets is worked out similarly. Let aside the poor basis of such a computation of depreciation, the methodology does not account for the ground reality of increasing cost of groundwater irrigation in the hard rock areas because of increasing negative externalities exacerbated due to mushrooming of irrigation wells in violation of the isolation distance.

SAMPLING

In this study, sample farmers from two horticulturally dominant districts in hard rock areas of Karnataka, viz, Chitradurga and Kolar districts representing the eastern dry zone (EDZ) and central dry zone (CDZ) were selected. Field data from 30 sample farmers each, representing supply side groundwater technology (ie. Farmers who have undertaken on-farm borewell recharge) and groundwater institution (who are sharing their irrigation borewell among siblings/relatives) were selected. Similarly, in order to represent demand side interventions such as micro irrigation, 30 sample farmers who have adopted drip irrigation for broad spaced crops and 30 sample farmers with drip irrigation who have adopted for narrow spaced crops were selected. The field data on cropping pattern, land holdings, source of irrigation, investment on irrigation borewell, investment on micro-irrigation structure, investment on recharge structure, cost and returns of various crop enterprises for the agricultural year 2012-13, considered as normal rainfall year were elicited from the sample farmers.

[1]The RT 440 of CACP, has the information pertaining to type of well, number of wells, HP of pump, command area irrigated, percentage owned, year of drilling, age at present, remaining life, amount invested, value at present, salvage value. However there is no information on expected age or life of wells which is subjective and is assumed to be 10 or 20 years as left to the discretion / imagination of Field Assistant who collects the data. RT 441 deals with change in well, and indicates when the well destroyed (or failed), when new well was constructed. There is no information on volume of groundwater yield of well(s) extracted by farmer.

METHODOLOGY

In the period after 1980, due to increasing probability of initial and premature failure of borewells/tubewells, investment on drilling and casing of irrigation wells which was hitherto considered as fixed cost, needed to be considered as variable cost, as the marginal cost is increasing, even without considering the cost of subsidized energy. Thus, the total cost of groundwater irrigation can be divided into variable cost and fixed cost. Even though, farmers are not charged for electricity to pump groundwater for irrigation, they still incur the component of variable cost due to increased drilling of wells on the farm necessitated due to premature and initial failures. The variable cost of drilling and casing of borewell is amortized for the average life / economic life of irrigation well and the operation and maintenance costs are included. The variable cost of groundwater, thus, represents the cost of drilling and casing since farmers are forced to invest on new borewells due to high probability of initial and premature failures. However, as the farmers use the irrigation pumpsets and accessories, conveyance structure, drip irrigation, borewell recharge, water storage structure, and electrical installation, investment on these are considered for depreciation for around ten years, irrespective of failure of irrigation wells. The variable cost and fixed cost are divided across volume of groundwater used for irrigation. The labor cost of irrigation is considered along with labor costs of other cultural operations. The annual cost of irrigation thus, pertains to amortized variable cost of all irrigation borewells on farm. This total cost of irrigation is then apportioned for each crop according to the volume of groundwater used in each crop. Thus, cost of irrigation per ha cm = [Total annual cost of irrigation]/ [volume of water used for the crop in ha cms of groundwater used].

Initial, Premature Failure, Economic Life and Age of Wells

Initial failure of borewell refers to a borewell which did not yield any groundwater at the time of drilling and thereafter. Subsistence life of borewell refers to the number of years a borewell yielded groundwater for the Pay Back Period (PBP). The payback period is obtained by dividing the sum of the total investment on drilling, casing, IP set, conveyance structure, storage structure, drip/sprinkler structure, recharge structure, electrification charges of borewell by the annual net returns per farm. The hypothesis is that an irrigation borewell is considered to have served its purpose, if it has at least paid back the total investment made for the purpose. This implies that PBP indicates the period in which a borewell recovered the investment made. Premature failure refers to the borewell which served below the subsistence life or the PBP. Economic life/age of borewell refers to the number of years a borewell yielded groundwater beyond the PBP.

Amortized Cost of Borewell

In order to obtain the annual share of groundwater irrigation cost, borewell investment has been amortized with the assumption that investment on drilling and casing is no longer a fixed cost, as the farmers frequently invest on new wells due to increasing probability of well failure. For the sample farmers, the probability of borewell failure is 0.7.Therefore, for most farmers, investment on borewell exploration equal to the cost of drilling and casing, renders as a variable cost and investment on IP sets and accessories, and other costs of electrification are the fixed cost. This variable cost or investment is amortized over the average life of the well. Thus the amortized cost varies with amount of capital investment, age of the borewell, discount rate, and year of construction of borewell. The amortization methodology employed by Diwakara and Chandrakanth (2007), described in detail below, is used in this study.

Compounding Investment on Borewells

Since, farmers invest on irrigation well/s during different time periods, their wells have different vintages. In this study, it was found that the investment on borewells is increasing at the compound growth rate of 2 percent by comparing the investment made on the first well and the last well on farms in the study area. Thus, in order to bring all historical costs on borewells on par, investments made by different farmers in different years, were compounded to the present year (2013) at a discount rate of two percent. The compounded investment is later divided into the fixed cost component (= irrigation pumpsets plus conveyance structure, drip irrigation structure and so on) which are amortized over ten years, plus the variable cost of drilling and casing the borewell, which are amortized over the actual life of borewell, since farmers lose both the drilling cost and casing cost once the well fails initially or prematurely. Hence, these two costs are separately amortized to obtain the yearly variable cost and fixed cost of irrigation borewell.

Choice of Discount Rate

From the sample data, the investment on earliest well (IEW) and the investment on latest well (ILW) were compared using the formula IEW $(1+i)^n$ = ILW and interest rate 'i' was solved to obtain approximately two per cent. Accordingly, two per cent discount rate was used to reflect the cost of social capital, and hence commercial bank interest rate for agriculture loan was not be used as the opportunity cost of capital. The amortized cost of borewell was worked out as under:

Amortized cost of irrigation = (Amortized cost of Borewell + Amortized cost of pump set + Amortized cost of conveyance + Amortized cost of over ground structure + annual Repairs and maintenance cost of pump set and accessories) given by

$$\text{Amortized cost of BW} = \text{Compounded cost of BW} \times \frac{(1+i)^{AL} \times i}{(1+i)^{AL} - i} \quad (1)$$

where, AL= Average Age or life of borewell, i = 2 per cent

$$\text{Compounded cost of BW} = \text{Historical investement of BW} \times (1+i)^{(2013\text{-year of drilling})}$$

$$\text{Amortized cost of P\&A} = \text{Compounded cost of P \& A} \times \frac{(1+i)^{10} \times i}{(1+i)^{10} - i} \quad (2)$$

The working life of Pumpsets (P) and Accessories (A) is considered to be ten years since farmers used them for at least 10 years.

$$\text{Compounded cost of P \& A} = \text{Historical investement of P \& A} \times (1+i)^{(2013\text{– year of install.of P\&A})}$$

$$\text{Amortized cost of conveyance structure (CS)} = \text{Compounded cost of CS} \times \frac{(1+i)^{10} \times i}{(1+i)^{10} - i} \quad (3)$$

The working life of conveyance structure (CS) is considered as 10 years. The usual mode of conveyance of groundwater is through PVC pipe

$$\text{Compounded cost of CS} = \text{Historical investement of CS} \times (1+i)^{(2013\text{– year of install.of CS})}$$

$$\text{Amortized cost of micro-irrigation structure (MIS)} = \text{Compounded cost of MIS} \times \frac{(1+i)^{10} \times i}{(1+i)^{10} - i} \quad (4)$$

The working life of micro (or drip) irrigation structure (MIS) is considered to be 10 years since farmers usually replace them after 10 years. Here

$$\text{Compounded cost of MIS} = \text{Historical investement of MIS} \times (1+i)^{(2013\text{– year of install.of MIS})}$$

As a coping mechanism to endure with the persistent problems imposed by variations in supply of voltage in electricity to run irrigation pumps and supply of electricity during off- peak load hours and low yields of borewell, farmers have built over ground storage structures (OSS). The amortized cost of over ground storage structure is estimated as under

$$\text{Amortized cost of over ground storage structure} = \text{Compounded cost of OSS} \times \frac{(1+i)^{10} \times i}{(1+i)^{10} - i} \quad (5)$$

$$\text{Compounded cost of OSS} = \text{Historical cost of OSS} \times (1+i)^{(2013\text{– year of construc. of OSS})}$$

$$\text{Amortized cost of borewell recharge structure} = \text{Compounded cost of BRS} \times \frac{(1+i)^{AL} \times i}{(1+i)^{AL} - i} \quad (6)$$

Here, AL= Average life/ age of borewell

$$\text{Compounded cost of BRS} = \text{Historical cost of BRS} \times (1+i)^{(2013\text{– year of construc. of BRS})}$$

Yield of Irrigation Borewell

The field measurements of the groundwater yield of borewells were made by recording the number of seconds taken to fill in a bucket or over ground container structure with groundwater of known volume. Initially the borewell was pumped for ten to fifteen minutes so that the initial pump yield bias is avoided. This was linearly extrapolated to obtain the groundwater yield in gallons per hour.

Groundwater in Conventional Irrigation System

The ha cms of groundwater used for each crop in each season (summer, Kharif, Rabi) in the conventional system of irrigation is estimated as : [(area irrigated in each crop) * (frequency or number of irrigations per month) * (number of months of crop) * (number of hours for one irrigation for the cropped area in question) * (Average yield of borewell in Gallons Per Hour)] /22611= groundwater use for each crop in ha cms.

Groundwater in Drip / Sprinkler Irrigation System

The data on number of liters of water emitted by the drip emitter/sprinkler at the time of pumping the borewell were collected. It was found that farmers in general put on the pump for as many hours as the electricity is available. Thus, drip irrigation even though saved water, may not have saved the power, as it was invariant over hours of electricity supply. However, only through capacity building, farmers can be trained not only to apply appropriate quantity of irrigation water but also to run pump for appropriate number of hours (Andanigowda, 2014, *pers. comm*). The details of direct estimation of water used through drip irrigation is given below.

The groundwater used for irrigation in each crop (ha cms) in Drip irrigation = {Number of drips or emitters for the cropped area X groundwater discharged per emitter per hour (liters per hour) X No. of hours to drip irrigate the cropped area for one irrigation X frequency of irrigations per month (in number) X Duration of crop irrigated in months /4.54/22611}

The groundwater used for irrigation in each crop in ha cms in sprinkler irrigation = {Number of sprinklers for the cropped area X No. of hours to irrigate the cropped area for one irrigation X groundwater discharged per sprinkler (in liters per hour) X frequency of irrigation per month (in number) X Duration of crop irrigated in months /4.54/22611}

One ha cm is equivalent to 22611 gallons or 3630 cubic feet and one cubic feet is equivalent to 28.32 litres. Total groundwater use per farm is total ha cms of groundwater used in all seasons across all crops including perennial crops.

Annual Cost of Irrigation

In Karnataka, farmers using irrigation pumpsets (below 10 hp capacities) for groundwater are not charged for electrical power. Government of Karnataka however, imposed a flat charge of Rs. 300 per hp per year up to 10 hp pump set since April 1997. However, the KPTCL / Government of Karnataka have been soft towards seeking electricity dues from farmers for reasons of political economy. Hence, there is no explicit payment towards electricity for pumping groundwater, other than annual operation and maintenance charges of the irrigation pump set and borewell upto 10 hp.

The electricity tariff for Irrigation Pumpsets: Instead of tariff, there is subsidy. The amount of subsidy to be paid by the Government towards free supply of electricity to 21.06 lakhs Irrigation Pumpsets below 10 hp, and 22.90 lakh Bhagyajyothi / Kuritjyothi households is increased to Rs.5381 crores for 2013-14 from Rs.4722 crores paid for 2012-13. The bulk of this increase is on account of the increase in the consumption of Irrigation Pumpsets users which are going up from 15318 million units estimated for 2012-13 to 16679 million units in 2013-14 (https://www.karnataka.gov.in/kerc/court-orders/court-orders-2013/tariff_order_13-14/press_note/press_note_english.pdf). However, the implicit cost of irrigation is relevant for farmers in hard rock areas due to high probability of initial and premature borewell failure, which forces farmers to invest in additional borewell(s) to at least remain on the original production possibility curve. The investment on failed borewells is increasing due to violation of isolation distance between irrigation borewells, over extraction or mining of groundwater, lack of efforts to recharge groundwater, and reciprocal negative externality. The resulting transaction costs are due to forced investment on drilling and casing of additional borewells since the borewells drilled failed initially or prematurely to yield groundwater.

Probability of Successful Borewell

Following Nagaraj, Chandrakanth and Gurumurthy (1994), the probability of successful borewell is computed by fitting negative binomial distribution (NBD) to the discrete data on classes of borewell success across in different categories of farms. It is found that for the sample farms, the negative binomial probability of well success ranged from 0.27 on borewell recharge farms to 0.68 on farms which shared their well water among relatives. What is crucial to note is that the probability of well failure which is the converse of the probability of well success is 0.73 on borewell recharge farms, 0. 68 to 0.72 on drip irrigation farms. Thus, since the borewell failure probability was high, farmers shifted to drip irrigation as well as began recharging their well water in HRAs of Karnataka (Fig 1). This gives an indication of the high probability of borewell failure in hard rock areas of Karnataka.

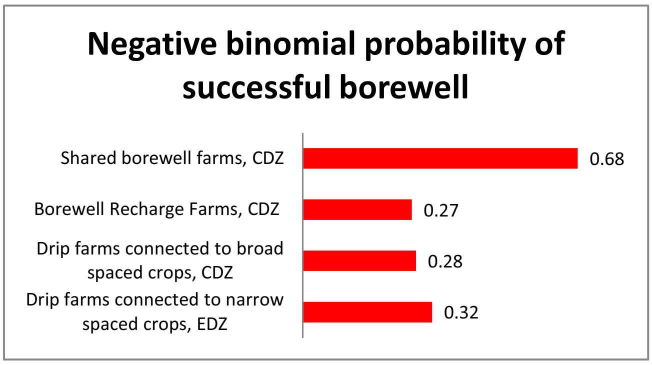

Fig.1. Negative Binomial Probability of successful borewell in Hard Rock Areas of Karnataka

Returns to Groundwater Irrigation and Irrigation Efficiency

The cost of cultivation is obtained as the sum of cost of human labor, bullock labor, machine hours, seeds and fertilizers, application of manure, plant protection measures, bagging, and transporting, cost of irrigation for each crop, interest on working capital @ seven per cent, risk premium @ two per cent and management cost @ five per cent on variable cost. Gross return for each crop is the value of the output and the by product at the prices realized by farmers.

Net returns from borewell irrigation are the gross returns from gross irrigated area minus the cost of production of all crops. The cost of cultivation of all crops in this study, accordingly, includes the cost of irrigation explicitly since volumetric measurements of groundwater applied are made for all crops. Irrigation efficiency is measured in physical and economic terms. Physical efficiency/ technical efficiency refers to more crop per drop of groundwater irrigation while Economic efficiency refers to more net returns per rupee of groundwater irrigation.

RESULTS

The average size of land holding was the highest among farmers who have artificially recharged irrigation well/s on the farm (15 acres) in Central Dry Zone followed by farms with drip irrigation connected to narrow spaced crops in Eastern Dry Zone. Accordingly, the gross irrigated area and net irrigated area were also the highest among the borewell recharge farms compared with all other categories of sample farmers. The volume of groundwater extracted per farm was the highest among borewell recharge farms (140 ha cms) followed by shared well farms (88.75 ha cms).

Variable Cost of Groundwater Irrigation

The variable cost of groundwater irrigation increased with degree of initial failure of borewells (Table 1). The lower limit of the cost of groundwater irrigation on flow or conventional irrigation farms varied from Rs. 177 to Rs. 696 per ha cm corresponding to the number of initial failure/s of borewell, while the upper limit of the cost of groundwater irrigation on drip irrigation farms varied from Rs. 1834 per ha to Rs. 4607 per ha cm. On drip irrigation farms the cost of groundwater increases since the amortized cost of groundwater is divided by a lower denominator on drip farms when compared with the higher denominator on flow irrigation farms. Considering that drip irrigation is still to catch up in many parts of India, the cost of groundwater irrigation ranges from around Rs. 200 to Rs. 700 per ha cm. This is devoid of the energy cost for pumping. With the inclusion of energy cost for pumping, the groundwater cost will further increase.

On farms connected to drip irrigation, the variable cost of groundwater irrigation per ha cm varied from Rs.1834 to Rs. 4607 per ha cm. For instance farmers with zero initial failures, who formed around 57% of all sample farms, incurred the variable cost of ranging from Rs. 177 to Rs. 2937 per ha cms. When farmer faces two initial failures, the cost per ha cm increased to Rs 430 to Rs. 4307. With the exception of three initial failures, the cost per ha cm increased with the initial failures.

The variable cost of groundwater per ha cm was the highest for farms connected to narrow spaced crops in Eastern Dry Zone (Rs 2089 per ha cm) forming 71 per cent of the total water cost, while fixed cost component forms (Rs. 865 per ha cm) the remaining 29 per cent. The next in the hierarchy was the farms connected with drip serving broad spaced crops in Central Dry Zone, where the variable cost component formed 69 per cent and fixed cost component formed remaining 31 per cent. The total cost of water on borewell recharge farm was Rs. 586 per ha cm. Out of the total water cost, variable cost formed 43 per cent; the lowest among all the sample category and fixed cost formed remaining 57 per cent. The total cost of groundwater was the lowest among shared well farmers which was to the tune of Rs. 358 per ha cm with variable and fixed cost forming 56 and 44 per cent, respectively (Table 2).

Table 1. Range in variable cost of groundwater per ha cm across flow and drip irrigation

Number of initial failures of borewell per farm	% of sample farms	Range in cost per ha cm of groundwater (flow to drip irrigation)
0	57	177-2937
1	18	230-2824
2	11	430-4607
3	5	186-1834
4	5	696-3156
5 and above	4	290-4467

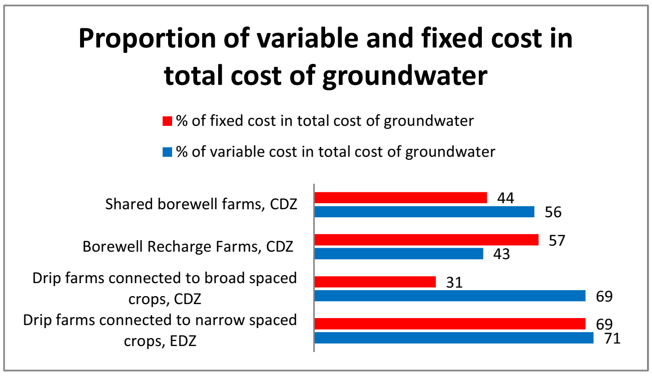

Fig.2. Proportion of variable and fixed cost of groundwater

The proportion of variable cost of groundwater irrigation (Fig.2) varied from 56% to 71%, while that of fixed cost varied from 44% to 69%. Thus, the proportions widely vary even within the HRAs which are the prima facie constraints against any generalization regarding groundwater costing, and are specific to the hydrogeological and agroclimatic conditions besides efforts to recharge.

ECONOMICS OF GROUNDWATER IRRIGATION

The cost of groundwater irrigation formed 11 to 22 percent of the total cost of cultivation of broad spaced crops with drip irrigation (Table 2). In absolute terms the cost of groundwater

Table 2. Irrigation efficiency of crops in Drip irrigation farms connected to broad spaced crops in Central Dry zone of Karnataka (Rs/acre)

Crop	Water used in ha cms	VC of ground-water	FC of ground-water	TC of ground-water	TC of culti-vation	% TC of groundwater to TC of cultivation	Output	GR	NR including irrigation cost	NR excluding irrigation cost	NR per rupee of ground-water	Crop per drop = output per ha cm
Coconut in nos.	8	6876	393	7269	33216	22	4635	36502	3286	10555	0.45	579.4
Banana (qtl)	32	18293	271	18564	95312	19	41	114531	19219	37784	1.04	1.3
Papaya (qtl)	14	21107	2494	23601	141649	17	193	233500	91851	115452	3.89	13.8
Arecanut (qtl)	12	8553	409	8962	62743	14	9	114824	52080	61043	5.81	0.8
Pomegranate (qtl)	10	17250	514	17764	169025	11	39	340540	171515	189279	9.66	3.9

Note: VC: variable cost of groundwater, FC: Fixed cost of groundwater, TC : Total cost , NR: Net returns, GR: Gross returns; qtl: quintals

Table 3. Irrigation efficiency of crops in Drip irrigation farms connected to narrow spaced crops in Eastern Dry zone of Karnataka (Rs/acre)

Crop	Water used in ha cms	VC of ground-water	FC of ground-water	TC of ground-water	TC of culti-vation	% TC of groundwater to TC of cultivation	Output	GR	NR including irrigation cost	NR excluding irrigation cost	NR per rupee of ground-water	Crop per drop = output per ha cm
Knol kohl (qtl)	12.08	22324	3776	26100	71822	36	155	90666	18844	44944	0.72	12.83
Coriander*	4.7	11765	7328	19093	59334	32	150	75000	15666	34759	0.82	31.91
Capsicum (qtl)	8.18	17583	6067	23650	153216	15	50	180000	26784	50434	1.13	6.11
Carrot (qtl)	7.59	17349	2120	19469	77528	25	109	108571	31043	50512	1.59	14.36
Beans (qtl)	10.31	25944	4251	30195	127881	24	70	182500	54619	84814	1.81	9.22
Red onion (qtl)	9.32	19034	5625	24659	80962	30	96	136693	55731	80390	2.26	10.30
Cabbage (qtl)	10.05	24045	2304	26349	154253	17	230	230476	76223	102572	2.89	22.89
Tomato (qtl)	12.16	20840	2107	22947	166490	14	110	238689	72199	95146	3.15	9.05
Potato (qtl)	11.92	25778	762	26540	121032	22	227	211012	89980	116520	3.39	19.04
Cauliflower (hds)	8.54	7321	2308	9629	74089	13	14545	118182	44093	53722	4.58	1703.16

Note: VC: variable cost of groundwater, FC: Fixed cost of groundwater, TC : Total cost , NR: Net returns, GR: Gross returns; *(in 100 bunches); qtl: quintals

irrigation varied from Rs. 7269 per acre of coconut to Rs. 23601 per acre in papaya. On drip irrigated farms for broad spaced crops, the percentage of groundwater irrigation cost varied from 11 percent (in pomegranate) to 22% in coconut (Fig 3).

The cost of groundwater irrigation formed 13 to 36 percent of the total cost of cultivation considering drip irrigation for narrow spaced crops (Table 3, Fig 4). In absolute terms, the cost of groundwater irrigation ranged from Rs. 7321 per acre of cauliflower to Rs. 25944 per acre of beans. In comparison with broad based crops, the percentage of groundwater cost is higher for narrow spaced crops ranging from 15% in capsicum to 36% in Knolknol. It is crucial to note that the cost of groundwater forms substantially lower proportion of total cost in all crops on farms with on farm borewell recharge. For instance, the groundwater cost ranged from 4 to 9 percent of the total cost of cultivation. In absolute terms, the groundwater cost ranged from Rs. 1416 per acre of onion to Rs. 9458 per

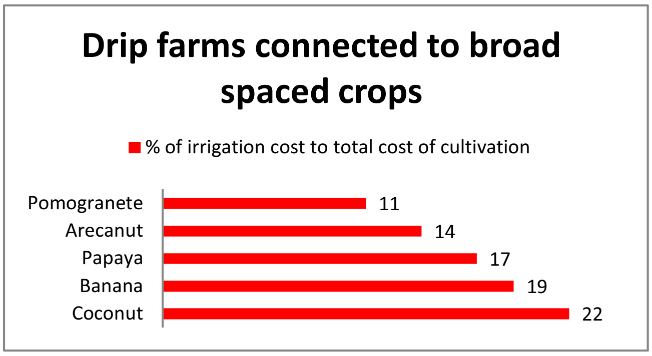

Fig.3. Proportion of groundwater irrigation cost in drip farms for broad spaced crops

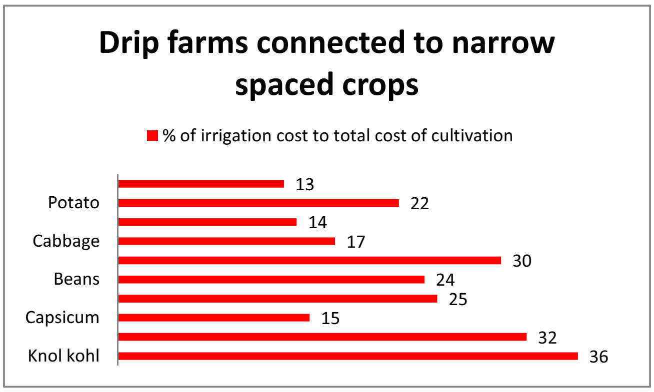

Fig.4. Proportion of groundwater irrigation cost in drip farms for narrow spaced crops

Table 4. Irrigation efficiency of crops in Borewell recharge farms in Central Dry zone of Karnataka (Rs/acre)

Crop	Water used in ha cms	VC of ground-water	FC of ground-water	TC of ground-water	TC of culti-vation	% TC of groundwater to TC of cultivation	Output	GR	NR including irrigation cost	NR excluding irrigation cost	NR per rupee of ground-water	Crop per drop = output per ha cm
Papaya (qtl)	15.25	9359	189	9548	107842	9	127	145476	37634	47182	3.94	8.33
Maize (qtl)	9.89	1616	182	1798	22907	8	24	32952	10045	11843	5.59	2.43
Pomegranate (qtl)	11.46	9087	154	9241	150005	6	25.53	217982	67977	77218	7.36	2.33
Coconut in nos.	8.41	2490	355	2845	32906	9	4880	57600	24694	27539	8.68	580.26
Arecanut (qtl)	12.16	4910	285	5195	66123	8	8	116726	50603	55798	9.74	0.66
Sapota (qtl)	12.03	2281	217	2498	66141	4	102	96428	30287	32785	12.12	8.48
Mango (qtl)	12.36	2775	221	2996	65507	5	290	105957	40450	43446	13.50	23.46
Banana (qtl)	36.24	4729	213	4942	70583	7	44	157121	86538	91480	17.51	1.21
Onion (qtl)	13.28	1476	265	1741	39514	4	71	85062	45548	47289	26.16	5.35

Note: VC: variable cost of groundwater, FC: Fixed cost of groundwater, TC : Total cost , NR: Net returns, GR: Gross returns; qtl: quintals

Table 5. Irrigation efficiency of crops in Shared borewell farms in Central Dry zone of Karnataka (Rs/acre)

Crop	Water used in ha cms	VC of ground-water	FC of ground-water	TC of ground-water	TC of culti-vation	% TC of groundwater to TC of cultivation	Output	GR	NR including irrigation cost	NR excluding irrigation cost	NR per rupee of ground-water	Crop per drop = output per ha cm
Menthe (bunches)	2.91	1549	658	2207	17743	12	13333	21667	3924	6131	1.78	4581.79
Arecanut (qtl)	13.06	10443	199	10642	68635	16	8	112759	44124	54766	4.15	0.61
Palak (bunches)	3.97	2079	1109	3187	33550	10	38462	57692	24143	27330	7.58	9688.16
Maize (qtl)	10.77	1100	75	1175	17263	7	24	30198	12935	14110	11.01	2.23
Onion (qtl)	16.19	1952	95	2047	42823	5	95	94989	52166	54213	25.48	5.87
Cucumber (qtl)	6.36	672	739	1411	27997	5	86	70444	42447	43858	30.08	13.52
Chrysanthemum*	39.52	4603	259	4862	192370	3	19433	397000	204630	209492	42.09	491.73
Crossandra*	22.89	4293	345	4638	424472	1	26115	652885	228413	233051	49.25	1140.89

* indicates that Chrysanthemum and Crossandra are measured in metres of stringed flowers

acre of papaya (Table 4). The groundwater cost formed the lower proportion of the total cost in all the crops on farms sharing irrigation well water among siblings. The ground water cost ranged from 1 to 16 per cent of the total cost of cultivation. In absolute term, the groundwater cost ranged from Rs. 1175 per acre of maize to Rs. 10642 per acre of arecanut (Table 5) (Plates 1 to 8).

The net returns per ha cm of groundwater used was the highest among those sample farmers with drip irrigation for narrow spaced crops (Rs. 7610) followed by farmers with drip irrigation for broad spaced crops (Rs. 7398). The net returns per ha cm were Rs.3674 on borewell recharge farms. The economic efficiency reflected in terms of net returns per rupee of irrigation water cost was the highest among farmers who shared their groundwater among their relatives (sharing institution (Rs. 10.83) followed by farmers with borewell recharge technology (Rs. 8.17), where as the net returns per rupee of groundwater cost was Rs. 5.08 for farmers with drip irrigation for broad spaced crops (Rs. 5.08) and Rs. 2.57 for farmers with drip irrigation for narrow spaced crops (Table 6, (Fig 5). Net returns per rupee of irrigation cost was relatively higher on farms with supply side groundwater technology (borewell recharge farms and shared well farms) compared with farms with demand side groundwater technology (drip irrigation farms) reflecting the existence of positive externality on such farms. Economic efficiency of individual crops with respect to groundwater irrigation was also relatively higher on these farms compared with drip irrigation farms (Plates 9 to 12). For farmers who are undertaking borewell recharge on their farm,

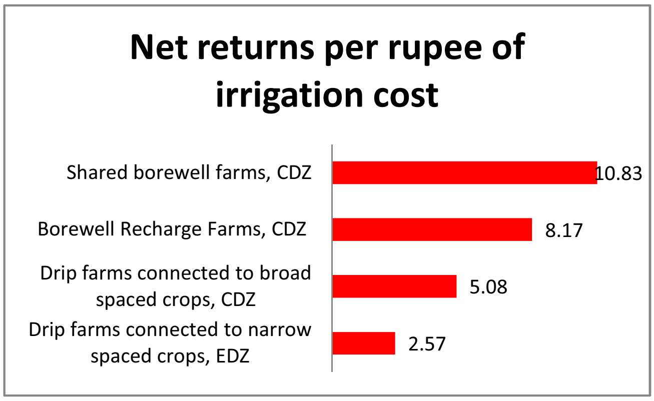

Fig.5. Net returns per rupee of cost of water on different types of irrigation well farms.

Plates 1-8. (1) Carrot cultivation - drip irrigation, Kolar district. **(2)** Potato cultivation – drip irrigatin, Kolar district. **(3)** Tomato cultivation – drip irrigation, Kolat district. **(4)** Coriander cultivation – drip irrigation, Kolar district. **(5)** Banana cultivation - drip irrigation, Chitradurga district. **(6)** Papaya cultivation – drip irrigation, Chitradurga district. **(7)** Pomegranate cultivation – drip irrigation, Chitradurga district. **(8)** Arecanut cultivation – drip irrigatin, Chitradurga district.

the net return is Rs. 8.17 per rupee of groundwater cost and further increases to Rs. 10.83 for farmers who are sharing their borewell water. This shows that farmers who are recharging their well and farmers who are sharing their well water, will have reduced externalities, since their probability of well success is higher than those farmers who are not undertaking recharge or who are indiscriminately drilling wells without regard to sharing their well water.

CONCLUSIONS

The groundwater irrigation cost ranges from around 10 percent to 36 percent of the total cost of cultivation across

Plates 9-12. (9) Shared well farmer cultivating Palak, Chitradurga district. **(10)** Shared well farmer - Chrysanthemum, Chitradurga. **(11)** Borewell recharged, Chitradurga district. **(12)** Borewell recharged, Chitradurga district.

different crops cultivated in Karnataka's hard rock areas. Given the high variation in the cost of groundwater irrigation, such proportions vary widely constraining any generalization in this regard. At present, since the groundwater irrigation cost is not computed while working out the cost of cultivation; the net returns are over estimated to the extent of the cost of groundwater. Hence in HRA, as groundwater is a vital source of irrigation, groundwater cost needs to be computed for all (food) crops, in order that their MSP properly accounts for the cost of groundwater irrigation, and is accordingly paid for. The current methodology adopted by DES does not properly account for groundwater irrigation, and hence, it is in order to revise the methodology followed by DES, CACP, NABARD, Commercial Banks, Cooperatives and State Departments by properly accounting for the cost of groundwater by estimating the reciprocal negative externalityin the groundwater irrigation as suggested in this study. The cost of groundwater irrigation on flow irrigation farms ranged from Rs. 177 to Rs. 696 per ha cm, while ranging from Rs. 1834 to Rs. 4607 per ha cm on drip irrigation farms. This cost is not included in the cost of cultivation of crops by DES or in Farm Management Surveys. By including the cost of groundwater irrigation, the extent of over estimation of net returns will correspondingly reduce by at least 10 to 36 percent depending upon the crop.

While agronomists highlight the concept of 'more crop per drop' which assumes that groundwater is available without limit, and hence does not consider the cost of groundwater resource, the economists highlight the concept of maximising net returns per Rupee of the cost of groundwater incorporating scarcity value of groundwater. Accordingly, the net return to groundwater irrigation, ranges from Rs. 2.57 per rupee of cost of groundwater on drip irrigation farms to Rs. 10.83 per rupee of groundwater on farms which are sharing their well waters. This shows that sustainable practices such as recharging borewells and sharing groundwater (with have nots), enhances the net returns to groundwater irrigation.

These cues need to be shared with the farmers through capacity building programs highlighting the costing methodology of groundwater as well as the need for wise use / sustainable use of groundwater. This needs the support of agricultural extension / irrigation extension through creation of Irrigation Management Service (on the lines of Arizona groundwater management) which can educate farmers and stake holders regarding all aspects of groundwater resource, extraction, sustainable use, irrigation as well as recharge and the economics of irrigation. The band of agricultural engineering graduates and agricultural economics graduates from State Agricultural Universities need to be utilized for educating all stakeholders in this regard.

Table 6. Returns to groundwater irrigation across groundwater institutions and technologies in Eastern and Central Dry Zone of Karnataka

Particulars	Drip farms connected to narrow spaced crops, Kolar (n=30)	Drip farm connected to broad spaced crops, Chitradurga (n=30)	Shared well farms, Chitradurga (n=30)	Borewell Recharge farms, Chitradurga (n=30)
Average size of land holding (irrigated land area) (acres)	9.38 (4.61)	7.87 (6.07)	8.17 (4.77)	15 (9.89)
Gross irrigated area per farm (acre)	6.62 (1-26)	12.2 (2.4-43.4)	7.93 (0.75-21)	17.03 (4-47)
Net irrigated area per farm (acre)	3.01	6.44	3.40	8.08
Irrigation intensity (%)	220	189	233	210
Groundwater extracted per farm (ha cms per year)	72.94 (11-261)	69.21 (15.58-267)	88.75 (16 -238)	140 (26.18-397)
Groundwater extracted per functioning well (ha cms in 2012-13)	53.37 (11-86)	32 (11-77)	71.96 (9.28-127)	56 (8.72-150)
Amortized cost of drilling and casing + O and M costs per farm	152376	67303	17732	35182
Amortized investment on over-head storage structure, drip irrigation structure, artificial recharge structure, pump and motor, electricity charges and conveyance structure per farm	63115	29654	14144	46898
Variable cost of groundwater (Rs per ha cm)	2089 (71%)(295-9255)	972 (69%)(68-9517)	199 (56%)(18.59-1874)	251 (43%) (43-1127)
Fixed cost of groundwater (Rs per ha cm)	865 (29%)(317-3791)	428 (31%)(156-2046)	159 (44%)(39-875)	335 (57%) (97-1564)
Net returns per ha cm of groundwater (Rs) Range	7610 (784-22603)	7398 (1470-37554)	3888 (1277-16418)	3674 (1859-14533)
Net returns per acre of gross irrigated area (Rs) Range	83786 (6980-247046)	75463 (11420-168283)	43506 (15786-355787)	43457 (20810-80536)
Net returns per functioning well (Rs) Range	406158 (10470-1325423)	227609 (59018-673135)	279795 (34432-896356)	288789 (31045-561485)
Net returns per rupee of irrigation cost (Rs) Range	2.57 (0.08-15.75)	5.08 (1.74-28)	10.83 (1.6-61.88)	8.17 (1.32-18.29)
Negative Binomial Probability of well success	0.32	0.28	0.68	0.27

Note : figures in the parenthesis indicate range

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