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Impact of micro irrigation on groundwater savings, productivity, and profitability of principal crops in the Eastern Dry Zone and Central Dry Zone of Karnataka: a resource economic analysis

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Abstract This study aims at estimating the cost of irrigation and its implications on water savings, productivity, net returns, and relative profitability. The study finds that irrigation cost forms a sizeable proportion of the total cost of production in both flow irrigation and micro irrigation systems. The economic analysis indicates that the crops considered are profitable—as reflected in the net returns realized, with and without irrigation cost—but upon accounting for the irrigation cost with externalities we see a sharp fall in net returns for all the crops. Nevertheless, micro irrigation enabled water savings, and it enhanced productivity and relative profitability.

Keywords Micro irrigation impact, externalities, groundwater irrigation cost, water productivity, profitability

JEL codes Q15, Q25, Q28, Q29

Groundwater irrigation plays a critical role in agriculture in India, especially in rural areas: it provides employment opportunities and, thereby, improves food and income security and reduces poverty—leading to economic growth. Surface irrigation is uncertain in semi arid regions; and groundwater irrigation serves as a lifeline for many farmers—more than 60% of irrigated agriculture depends on groundwater. India is the largest user of groundwater for agriculture in the world. Groundwater contributed 70–80% to agricultural productivity and the value of agricultural output (Zaveri et al. 2016).

But other uses compete with irrigation to extract groundwater, and the cumulative pressure has depleted the resource, especially in hard-rock regions (Kumar 2016; Zaveri et al. 2016) and in the western, central, and southern peninsular parts of India (Saha et al. 2017). Groundwater based irrigation for agriculture is under threat; wells are being deepened, deeper wells are being drilled, and high energy pumps are being used to pump groundwater.

The state of Karnataka does not have assured sources of surface water for irrigation, and it has the highest proportion of drought prone areas, 79%, in the country. As the demand for groundwater irrigation spirals, over exploitation is diminishing its supply (Santhosh et al. 2013), but individual owners of wells are not investing in groundwater recharge, making groundwater exploitation a “tragedy of the commons”. Further, climate change poses a bigger threat.

Groundwater resources are so scarce, and the competing pressures on these are so intense, that India needs an approach to manage these resources and sustain farmer food and income security. India has regulations for rationalizing the use of water and electricity for irrigation, but the issue is so sensitive—socio economically and politically—that it is not plausible to enforce those regulations. Therefore, we must examine technological options, like micro irrigation (drip irrigation), to use groundwater efficiently.

We use the natural resource economics accounting framework in this study to estimate the costs of flow and drip irrigation, and their implications on net returns, in Karnataka. The study also analyses the impact of drip irrigation on water savings, productivity, and relative profitability. In this study "micro irrigation" refers only to drip irrigation, and "conventional irrigation" refers only to flow irrigation, and in both cases the source of irrigation is groundwater.

Methodology

Groundwater is extremely scarce in the eastern and central agroclimatic zones of Karnataka; and farmers have been practising micro irrigation not only for wide-spaced crops—like grapes, mulberry, and pomegranate—but also for narrow-spaced crops like tomatoes, capsicum, and other vegetable crops.

Sampling framework

Karnataka has 10 agroclimatic zones. Groundwater resources are the most over exploited in the Eastern Dry Zone (EDZ) and in the Central Dry Zone (CDZ); and so we chose these for this study.

Next, we identified the districts that are the most groundwater-starved: (in the EDZ) Kolar, Chikkaballapur, and Bangalore rural; and (in the CDZ) Tumkur and Chitradurga. We also identified the blocks and taluks.

At the third stage, we set up the treatment group by randomly selecting 45 farmers that practised drip irrigation. For the counterfactual, we randomly selected 20 farmers practising flow irrigation.

This is an impact study, and we need to know the demonstration effect; therefore, we selected farmers practising both flow irrigation and drip irrigation and who have similar crop patterns.

Most farmers in the study allocated a small proportion of their farm to drip-irrigating one crop or the other; hence, it was difficult to find an adequate sample size for the control group.

We used a pre-tested structured questionnaire and personal interviews to elicit the primary data for the year 2019 from the sample respondents.

Conceptual and analytical framework

Karnataka does not charge farmers for using electricity-driven irrigation pumpsets up to 10 horsepower (HP), only a flat rate of INR 300 per HP per year (up to 10 HP) is charged.

Cost of groundwater irrigation (drip and flow)

First, we consider the actual life span of all capital equipments—irrigation borewells, pumpsets, conveyance structures, drip irrigation, and water storage structures.

Next, we amortize the capital investment; it varies by the capital investment in groundwater structures, productive age of borewell, and the discount rate.

Amortized cost of groundwater irrigation = (amortized cost of borewell (BW) + amortized cost of pumpset + amortized cost of conveyance structures + amortized cost of water storage structure) + annual repairs and maintenance cost of pumpset (P) and accessories (A):

Amortized cost of BW =

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

where,

AL= average life of BW (5 years),

i= discount rate = 2%

compounded cost of BW = (historical investment in BW) × (1 + i) (2019 year of drilling)

amortized cost of P and A =

$$(\text{compounded cost of P and A}) \times \frac{(1+i)^{5} \times i}{(1+i)^{5}-1} \quad (2)$$

Amortized cost of storage structure (SS) =

$$(\text{compounded cost of SS}) \times \frac{(1+i)^{5} \times i}{(1+i)^{5}-1} \quad (3)$$

Amortized cost of micro irrigation structure (MI) =

$$(\text{compounded cost of MI}) \times \frac{(1+i)^{6} \times i}{(1+i)^{5}-1} \quad (4)$$

Then, we add the annual amortized cost to the cost of operations and maintenance (O&M) and the labour cost of irrigation.

Finally, we apportion the total cost of groundwater irrigation to each crop by the volume of groundwater used; per acre inch, the cost of irrigation is [total annual cost of irrigation] / [volume of groundwater used for each crop in acre inch].

Rationale for compounding investments in borewells

Farmers invested in borewells and groundwater structures at different times; so, their vintages differ. To bring the historical costs on par, we compounded the investments to the present, 2019, and we used 2% as the discount rate.

Kiran Kumar et al. (2016) compare the investment in the earliest well (IEW) to the investment in the latest well (ILW) using the formula IEW (1+i) n= ILW, and find that the interest rate, i, was approximately 2%; and the commercial bank interest rate for agriculture loans cannot be used. Other studies in the hard rock areas of Karnataka also consider an interest rate of 2% (Diwakara and Chandrakanth 2007; Kiran Kumar et al. 2016; Anitha 2018). We, too, chose 2% as the discount rate, therefore.

Estimating the cost of negative externality in groundwater irrigation

If no borewell fails, there is no externality. But farmers in hard rock areas deepen their borewells, and drill deeper borewells, and so the probability that borewells will fail is very high.

Also, groundwater extraction is interdependent and involves reciprocal externality. One farmer's extraction from his borewell depends on the extraction by neighbouring wells at a time, and over time. And all the users of groundwater impose external costs on each other simultaneously and over time. Therefore, the cumulative interference of wells, and the magnitude of externality, increases (Nagaraj et al. 1994; Kiran Kumar et al. 2016).

We hypothesize that wells fail due to reciprocal negative externality; hence, the difference between the amortized cost per well and the amortized cost per functioning well will reflect the magnitude of negative externality.

The amortized cost per well is the total amortized cost divided by all the wells on the farm. The amortized cost per functioning well is the total amortized cost divided by the number of functioning wells on the farm. Subtracting the amortized cost per well from the amortized cost per functioning well gives us an empirical measure of the externality per farm borewell.

Cost of on farm improved groundwater storage structures

In hard-rock areas, the supply of electricity to agricultural pumpsets is irregular, especially during the summer. And the discharge of water from borewells is low. So, farmers cannot irrigate their land continuously, especially if they practise drip irrigation.

To cope, farmers build improved groundwater storage structures, pump groundwater whenever electricity is available—in the day and night—and store it to irrigate during the day.

Typically, the structures measure 18 m × 18 m × 3.5 m. To prevent seepage and loss, farmers line the structures with HDPE plastic. Depending on the quality of the material, the investment is huge—INR 60,000–90,000. Banks lend farmers the sum at an interest rate of 5% per annum.

The lifespan of the storage structure averages six years. We compute the annual cost of improved storage by amortizing the total investment over the lifespan.

Estimating the water used in micro-irrigation

The volume of groundwater used per crop (acre-inches) in the conventional system is estimated as

[(area irrigated per crop) × (frequency or number of irrigations per month) × (duration of irrigation given to crop in months) × (number of hours given to each irrigation) × (average yield of borewell in gallons per hour)] / 22611.

Under drip irrigation it is

(number of emitters per cropped area × water discharged per emitter (litres/hour) × number of hours irrigated the cropped area for one irrigation × duration of crop irrigated in months × frequency of irrigation per month (in number) × crop duration in months)] / 4.54/22611,

where,

4.54 is the factor to convert litres per hour to gallon per hour.

We analyse the physical (agronomic) productivity of irrigation (output per acre-inch of water applied) and its economic productivity (net returns per acre-inch of water applied).

The impact, or the change that occurred due to the adoption of micro-irrigation, is measured as the average change in the outcome considering treatment and control. The difference between the water applied through drip irrigation and flow irrigation method for each crop is considered as water saving.

The costs and returns are computed considering the actual input costs incurred and the price received by the farmer at the farm gate. This comprises all the material input cost, machinery and labour cost, groundwater irrigation cost, and marketing expenses.

Simpson Diversity Index

Simpson's Index = $1 - \Sigma_{i=1}^{n} P_i^2$

where, Pi is the proportion of area under each crop in acres to the total gross cropped area.

The index ranges from 0 to 1. If the index is closer to 1, it indicates high diversification; if the index is closer to 0, it implies low diversification.

Results and discussion

Groundwater is the main source of irrigation in the study area. The conventional method of flow irrigation is widely practised. However, of late, in response to the scarcity of groundwater, there has been a marked shift towards drip irrigation.

Key profile of sample respondents

The respondents in both groups are middle aged, on average, mature in their profession, and capable of making the right farm management decisions (Table 1). In both groups, the average family size is seven.

Table 1 Key profile of respondents in Eastern and Central Dry Zone of Karnataka

Particulars	Farmers with micro irrigation (MI)	Farmers with flow irrigation (FI)
Sample size (number)	45	20
Average age of the respondent (Years)	45	49
Average size of family (Number)	7	7
Literacy (%)	100	90
Average level of education (No of years studied)	12	9
Proportion of respondents studied up to 10th standard (%)	60	75
PUC (%)	28	20
Graduation (%)	12	5
Proportion of general category (%)	17	20
Proportion of OBC (%)	74	75
Proportion of SC and ST (%)	9	5
Proportion of small farmers < 5 acres (%)	50	40
Proportion of medium 5–10 acres (%)	40	30
Proportion of large farmers > 10 acres (%)	10	15
Average size of landholding (acres)Range	5.76 (1.0 to 19)	5.15 (2.0 to 11)
Gross cultivated area (acres)	7.69	7.77
Net cultivated area (acres)	4.8	5.6
Gross irrigated area (acres)	5.45	4.25
Net irrigated area (acres)	2.55	2.1
Net area under rainfed (acres)	2.24	3.5
Proportion of irrigated area (%)	53.5	37.5
Proportion of rainfed area (%)	46.5	62.5

The literacy rate of farmers practising micro irrigation, 100%, is higher than that of farmers practising flow irrigation, 90%. About 60% of the micro-irrigation respondents and 75% of the flow irrigation respondents had schooled up to the 10th standard on average, followed by PUC and graduation. Most farmers in both groups are small and medium-size farmers; the proportion of large farmers is very low. Most farmers in both groups are members of Other Backward Castes.

Gross and net cultivated area

On average, the landholding size is 5.76 acres for micro-irrigation farmers and 5.15 acres for flow irrigation farmers. The gross cultivated areas is about the same for both cases, but the gross irrigated area formed about 70.8% of the gross cultivated area in the case of micro-irrigation farms but 55.0% in the case of flow irrigation farms (Table 1). The proportion of area irrigated is 53.0% for micro irrigation farms but 37.0% for flow irrigation farms, mainly because micro irrigation facilitated the efficient use of water and water savings. The saved water is used to irrigate a larger area. Flow irrigation farms cannot minimize water use and expand the area under irrigation, and that is why they have a larger proportion of rainfed areas than micro irrigation farms.

Cropping pattern under micro-irrigation

Micro-irrigation farmers cultivated kharif crops on more than 41% of their gross cropped area, rabi crops on 19%, and summer crops on 18% of their gross cropped area (Table 2). The perennial crops occupied around 22% of the total gross cropped area. Around 21% of the gross cropped area is devoted to finger millet, which is grown under rainfed conditions and is a main staple food crop in the area.

Around 53% of the total gross cropped area was allocated to cash crops, mainly vegetables. Among vegetables, tomato is the most popular; farmers cultivate it on 53% of their gross cropped area. Beans, cabbage, and carrots are also grown. Among perennial crops, mango, areca nut, coconut, grapes, and pomegranate are prominent.

The cropping diversity is high, as micro-irrigation farms grow several crops on a small scale; their diversity score on the Simpson's Index is 0.92. Compared to flow irrigated farms, the cropping intensity and irrigation intensity of micro-irrigation farms is high, mainly because micro-irrigation enables farmers to not only use groundwater more efficiently but also to expand the cultivable area under saved water. These results are in conformity with the results of other studies (Kiran Kumar et al. 2014; Anitha 2018).

Thus, the cropping pattern is highly diversified, and a combination of annual and perennial crops ensures regular cash flow. None of the respondents grew rice, sugarcane, or banana, which are all water guzzling crops, showing that farmers are prudently using groundwater and diversifying crop patterns to minimize risk.

Cropping pattern of respondents practising flow irrigation

Around 44% of the gross cropped area of flow irrigation farms is devoted to kharif crops, 16% to rabi crops, and 11.5% to summer crops. Over 28% of the gross cropped area is under perennial enterprises like mulberry, coconut, and mango (Table 3). In rain fed conditions, the cropping system based on finger millet and mixed crops occupy almost 13% of the gross cropped area, as does the cropping system based on groundnut with mixed crops.

The cash crops, mainly vegetables, occupied about 45% of the total gross cropped area; tomato occupied 42%. The other crops grown are beans, cabbage, beetroot, carrot, and potato. Flow irrigation farms score 0.70 on the Simpson Diversity Index; and their cropping intensity, irrigation intensity, and cropping diversity is lower than in micro-irrigation farms.

Our cropping pattern analysis shows that the crops cultivated are not only input intensive but also water intensive; in both cases the diversification towards horticultural crops was high.

Resource economics approach to costing groundwater irrigation

We use the resource economics approach to cost groundwater irrigation and estimate the return on investment. In hard rock areas, the probability of borewell failure is high, the well density is high, and the extraction rate exceeds the recharge rate; hence, wells fail frequently. Of late, due to the rapid and intensive over-exploitation of groundwater, the depth of borewells has increased massively, by 1,000–

Table 2 Cropping pattern of sample respondents with micro irrigation

Season	Crops	Area (acres)	Gross cropped area (%)
Kharif Rainfed	Finger millet (Ragi) + Dolichus	73	0.21
	Pigeon pea	5	0.01
	Horsegram	4	0.01
Major irrigated crops	Maize	6	0.012
	Tomato	25	0.072
	Cabbage	8	0.023
	Beans	10	0.029
Other vegetables	Capsicum, ridge guard, carrot, brinjal, cucumber, ladies finger	12	0.035
Sub total		143 (0.42)	0.413
Rabi-Major irrigated crops	Tomato	28.5	0.08
	Cabbage	8	0.023
	Beans	6	0.014
	carrot	5	0.014
	Potato	3.5	0.010
	Flowers	3.5	0.010
Other vegetables	Brinjal, cucumber, cauliflower, ladies finger, bottle guard,	10.75	0.031
Sub total	onion &other leafy vegetables	65.25 (0.18)	0.19
Summer	Tomato	46.5	0.13
	Beans	4.5	0.01
	Cucumber	4.5	0.01
	Other vegetables	9.5	0.027
Sub total		65 (0.18)	0.18
Perennials	Mango (Rainfed)	19	0.054
	Coconut	8	0.023
	Grapes	8	0.023
	Pomegranate	6	0.01
	Arecanut	15	0.04
	Guava	4	0.011
	Mulberry	6	0.014
	Sapota (Chikko)	4	0.01
	Papaya	3	0.008
Sub total		73 (0.22)	0.22
Total GCA		346.23	
NCA		216	
GIA		247	
NIA		**115**	
Irrigation intensity		**214**	
Cropping intensity		**194.0**	
Simpson's Index		0.92	

Note Figures in the parenthesis indicates proportion of Gross Cropped Area (GCA) to the total

Table 3 Cropping pattern of sample respondents with flow irrigation

Crops/season	Area (acres)	GCA (%)
Kharif		
Finger millet based mixed cropping (rainfed)	21.5	0.138
Groundnut based intercropping	20	0.128
Tomatoes	10	0.064
Beans	6	0.038
Beet root	5	0.032
Other vegetables	6	0.038
Total	**68.5**	0.4405
Rabi		
Tomatoes	10	0.064
Potatoes	5	0.032
cabbage	6.5	0.042
Carrot	3.5	0.022
Sub total	**25**	0.161
Summer		
Tomatoes	9	0.058
French beans	5.0	0.032
Water melon	4.0	0.026
Sub total	**18**	0.115
Perennial		
Mulberry irrigated	10	0.064
Mango rainfed	29	0.186
Coconut semi irrigated	5	0.032
Sub total	44	0.283
Total GCA	155.5	
NCA	112.5	
GIA	85	
NIA	42	
Cropping intensity	177	
Irrigation intensity	188	
Simpson's Index	0.70	

1,700 ft, and the well failure rate has risen and the average productive lifespan of the wells has decreased drastically. Based on the well inventory in the study area, borewells turned out to be unproductive approximately in five years with micro irrigation and four years without micro-irrigation. We consider that the average life of a borewell and we amortize the capital investment on the well structures over five years for micro irrigation farms and four years for flow irrigation farms at the discount rate of 2%.

The variable cost on operations and maintenance (O&M) includes electricity (at the subsidized flat rate) and repairs and replacements. The cost of O&M is high because the electricity voltage fluctuates wildly during the day and farmers need to run their motor frequently and spend more on repairs. The annual cost of irrigation is the sum of annual amortized cost plus the variable cost.

The investment in well irrigation depends mainly on the number of failed and functional wells, depth of borewell, horsepower of the irrigation pumpsets, the number of stages of the pump, improved conveyance, and storage structures. Accordingly, the cost of irrigation differs.

The investments in wells and other components at historical prices are not directly comparable with the net returns estimated by considering the current year prices. Hence, we compounded the historical investments from the year of the cost incurred to the present period at an interest rate of 2%, as it represented the rate of inflation in the cost of well components (Chandrakanth 2015; Kiran Kumar et al. 2016; Nagaraj et al. 2003).

On average, the compounded investment per functioning well is around INR 470,000 in the case of micro-irrigation farms, about 39% higher than the INR 289,000 for flow irrigation farms (Table 4). This difference is mainly due to high capital investment in failed and functional deep borewells, micro irrigation (drip), and improved storage structures. In the case of micro-irrigation farms, the total annual amortized cost of groundwater irrigation amounts to INR 114,733 per functioning well, 38% higher than the INR 71,161 for flow irrigation farms. Adding O&M costs raises the total cost of irrigation per borewell per year to INR 139,000 in the case of micro-irrigation farms, 32% higher than the INR 93,911 for flow irrigation farms.

Around 65 acre-inches of water was extracted from the borewells on micro-irrigation farms but 69 acre-inches from flow irrigation farms, indicating that flow irrigation farms extracted around 6% more water. The externality cost was around 45% of the total irrigated cost on micro-irrigation farms but 32% on flow irrigation farms (Table 4).

The implicit cost of irrigation in hard-rock areas is increasing because the probability of initial and

Table 4 Cost of irrigation with externality cost under micro-irrigation and flow irrigation

Particulars	MI	Fl
Total borewells	170	68
Functioning borewells	48	22
Total of all investments/ functioning well (INR)	472,753	289,500
Amortized cost of borewell (INR)	27,790	24,695
Amortized cost of I P set & conveyance (INR)	19,793	13,925
Amortized cost of micro-irrigation (INR)	26778	
Amortized cost of failed borewells and deepening (INR)	33,944	23,337
Amortized cost of improved storage (INR)	5,090	7,955
Other sundry items	1,338	1,249
Total amortized cost/functioning well (INR)	114,733	71,161
Operation and maintenance cost (INR)	21,200	19,750
Electricity charges @ INR 300/HP	3,000	3,000
Total	139,033	93,911
Gross area irrigated/well (acres)	5.45	4.25
Water extracted per acre of GCA (Acre inches)	12.26	16.1
Water extracted /well (Acre inches)	65	69
Annual Irrigation cost/well (INR)	139,033	93,911
Cost per acre inch of water	2,138	1,364
Cost per acre of Gross irrigated area (GIA)	25,510.6	22,096.7
Externality cost particulars		
Amortized cost/borewell	51,321	41,158
Amortized cost/functioning well	114,733	71,161
Annual negative externality /well (INR)	63,412	30,003
Proportion of externality out of total irrigated cost (%)	45	32

premature borewell failure is high, forcing farmers to invest in additional borewells, high capacity irrigation pumpsets, improved storage structures, and micro irrigation to remain on the original production possibility curve. Therefore, the overall irrigation cost per acre and per acre-inch is higher, as layers of investments are needed to cope with groundwater scarcity. This high irrigation cost prompts farmers to cultivate commercial crops to recover their investments at the earliest. If adequate efforts are not made now to recharge the groundwater, groundwater irrigation in hard-rock areas will become prohibitive in the future.

Cost of failed borewell

The recharge of groundwater is low in hard rock areas, and the over extraction of groundwater and overcrowding of borewells raises the extraction rate above the recharge rate; hence, the probability of well failure is high (Nagaraj et al. 1995; Anitha 2019). On average, every farmer in the study area has lost their investment in at least three or four failed wells (Table 4).

The investment must include the investment in functioning and failed borewells since a farmer invests in the hope that the borewell will serve at least up to the payback period while knowing that it may fail initially or prematurely since in hard-rock areas the probability of well failure is very high.

There is no effort to recharge the groundwater. The indiscriminate drilling of borewells and over-extraction of groundwater violates the isolation distance (the distance between borewells). Thus, the investment on borewells is increasing due to reciprocal negative externality.

Negative externalities in well irrigation

To compute the negative externalities, we consider all forced investments in deepening wells, drilling deeper wells consequent to the failure of existing wells, and the costs incurred in adopting other mechanisms to cope with the decline in the discharge of water.

We estimate the annual externality cost of irrigation as the difference between the amortized cost per functioning well and the amortized cost per well. The externality cost is the cost of well failure due to the cumulative interference of irrigation wells. The negative externality cost computed per borewell in micro-irrigation farms is about INR 63,421, almost 52% more than the INR 30,003 for flow irrigation farms. Thus, every acre inch of water pumped imposes a reciprocal external cost of INR 976 on micro-irrigation farms and INR 435 on flow irrigation farms.

Estimating the cost of production by incorporating the cost of groundwater irrigation

In estimating the production cost of crops, the cost of water is ignored; it is assumed that water is free. But farmers make massive investments in drilling deeper wells to access groundwater in hard rock areas, installing mechanisms to extract water like higher horsepower pumpsets, and in improving storage and conveyance structures. Thus, it is crucial to include the cost of groundwater in the production cost and assess its implications on net returns.

The Commission for Agricultural Costs and Prices (CACP) uses a method to calculate the cost of irrigation, but the method has a few limitations. One is that they do not include the full cost of groundwater irrigation or the cost of negative externalities—owing to the mushrooming of irrigation borewells that do not maintain the isolation distance—and so they underestimate the cost of cultivation. The CACP does not have adequate information on the volume of water used for crops in the Record Type forms.

In computing depreciation, the CACP considers that the lifespan of the borewells averages 10 years, which is subjective and a myth. Wells have failed initially and prematurely for many farmers in the study area; in those cases, the depreciation is zero and the cost is infinity. Also, the failure of wells in hard-rock areas raises the cost of groundwater irrigation, but their method ignores this.

Relative profitability of groundwater-irrigated crops under micro irrigation

The diversity of groundwater-irrigated crops is high, and we consider only the crops that occupy a significant proportion of the gross cropped area. We compute the cost of production for all the crops considered and compare its relative profitability with and without the cost of irrigation in both micro-irrigation and flow irrigation farms (Tables 5 and 6).

We find that on micro irrigation farms the irrigation cost forms 18–33% of the total cost of production of seasonal crops and 20–49% of the total cost of production of perennial crops. All the crops are profitable, as reflected in the net returns realized—with

Table 5 Cost and returns for the principal crops grown under micro irrigation (INR per acre)

Particulars/crops	Tomato	Cabbage	Carrot	Beans	Potato	Onion	Capsicum
Cost of inputs	80,100	31,816	16,500	21,500	38,000	17,620	42,730
Labour & Machinery cost	35,165	49,300	24,000	27,500	18,500	13,550	29,850
Marketing cost	32,745	10,150	13,500	13,500	17,530	12,330	19,550
Total cost without irrigation cost	148,010	91,266	54,000	62,500	74,030	43,500	92,130
Irrigation cost (IC)	33,077	29,449	26,675	26,675	25,608	18,139	26,675
Total with IC	181,087	120,715	80,675	89,175	99,638	61,639	181,087
Irrigation cost as% of the total cost	18.3	24.3	33.0	29.9	25.7	29.4	22.4
Output/ac (Qtl/acre)	185	215	80.0	61.50	101.50	62.50	126.5
Gross returns	305,250	182,000	135,000	131,250	126,700	90,675	169,625
Net returns without IC	158,250	90,734	81,000	68,750	52,670	47,175	77,495
Net return after accounting IC	125,173	61,285	54,325	42,075	27,062	29,036	50,820
% fall in NR	21	32.4	33	38.8	48.6	38.4	34.4
Cost to Return ratio without IC	2.07	1.99	2.5	2.1	1.7	2.08	1.84
Cost to Return ratio with IC	1.70	1.51	1.74	1.52	1.31	1.52	1.48

Table 6 Per-acre cost and returns for the principal crops under micro irrigation

Particulars/crops	Coconut	Pomegranate	Areca nut	Grapes	Mulberry	Chrysanthemum
Cost of inputs	18,350	52,350	18,500	27,450	12,530	23,480
Labour & Machinery cost	11,550	39,530	33,250	15,330	12,300	34,600
Marketing cost	3500	12,350	3,700	31,500	0	32,800
Total cost without Irrigation cost (IC)	33,400	104,230	55,450	74,280	24,830	90,880
Irrigation cost	32,692	26,995	39,479	37,345	24,541	38,412
Total with IC	66,092	131,225	94,929	111,625	49,371	129,292
Irrigation cost as% of the total cost	49.40	20.5	41.5	33.4	49.7	29.7
Output/ac (nuts/acre)	3900	38.0	8.75	89.5	130.0	58.0
Gross returns (INR/Acre)	116,000	181,716	197,000	179,000	91,000	286,000
Net returns without (IC)	82,600	77,486	141,550	104,720	66,170	195,120
Net return with IC	49,907	50,490	102,071	67,375	41,629	156,708
% fall in NR	39.60	53.00	28.00	35.60	37.00	19.70
Cost to Return ratio without IC	3.47	1.74	3.55	2.4	3.66	3.14
Cost to Return ratio with IC	1.75	1.38	2.07	1.60	1.84	2.21

and without irrigation cost per acre—but their relative profitability varies depending on the degree of net returns. Accounting for the irrigation cost reduces the net returns on micro irrigation farms for seasonal crops from 21% to 48.6% and for perennials from 19.7 % to 53.0%. After accounting for irrigation cost in the cost of production on flow irrigation farms, the net returns for perennials fell from 29.8% to 53.2% and for annual crops from 24.5–57.5%.

If the cost of irrigation is not accounted for, the gross returns per acre on vegetable crops ranged from INR 300,000 to INR 130,000 and the net returns from INR 150,000 to INR 47,000. Tomato turned out to be the most profitable vegetable crop; after accounting for all costs, including the irrigation cost, its net return was INR 94,000 per acre. The other profitable vegetable crops were chrysanthemum, carrot, and capsicum. Grapes, areca nut, and pomegranate turned out to be most profitable perennial crops (Table 5–6). The results clearly indicate that in ignoring the cost of groundwater irrigation in estimating the cost of production, the net returns for crops are being overestimated.

Even after accounting for the cost of irrigation in the total cost of production, however, the net returns-to-cost ratio exceeds 1 for all the crops, indicating that the investment on these crops generated adequate returns due to access to groundwater irrigation. A similar trend was evident for flow irrigation farms. The gross returns of annual crops varied from INR 268,000 to INR 96,000 and for perennials from INR 175,000 to INR 78,000 (Tables 7–8).

Water savings and the physical and economic productivity of water

We analyse the irrigation water productivity (output per unit of water) and economic water productivity (net returns per unit of water applied) for all the 13 crops in both micro-irrigation farms and flow irrigation farms (Tables 9–11). Compared to flow irrigation farms, micro-irrigation saved 21.5–32% of the groundwater applied per acre, and the productivity per acre is 11–26% higher. The productivity per acre-inch of water is 31–48% higher on micro-irrigation farms than on flow irrigation farms (Table 10). The highest productivity per unit of water was observed in crops like chrysanthemum, tomato, capsicum, and pomegranate. The net returns realized per acre-inch of water are 33–63% higher on micro-irrigation farms than on flow irrigation farms (Table 11). The highest returns per unit of water were observed for chrysanthemum, tomato, capsicum, mulberry, onion, pomegranate, and coconut.

Thus, micro irrigation enhances both irrigation water use efficiency and economic water use efficiency for the principal crops considered in the study. In micro-irrigation, the quantity of water required is delivered continuously to each plant at its root zone through micro-tubes, avoiding water stress and ensuring the availability of water where it is most needed (Nagaraj

Table 7 Cost and returns for the principal crops grown under flow irrigation (INR per acre)

Particulars/crops	Coconut	Pomegranate	Arecanut	Grapes	Mulberry	Chrysanthemum
Total inputs cost without Irrigation cost (IC)	32,944	107,560	57,500	75,600	27,103	94,565
Irrigation cost	28,234	23,870	32,054	31,099	22,506	35,191
Total cost with IC	61,178	131,430	89,554	106,699	49,609	129,756
Irrigation cost as% of the total cost	46.1	18.4	35.7	29.1	44.4	27.1
Output/ac (nuts/acre)	3,200	31.5	6.5	80.5	110.5	43
Gross returns (INR/Acre)	86,050	175,570	146,950	169,050	78,455	212,650
Net returns without IC	53,106	70,010	89,450	93,450	51,352	118,085
Net return after accounting IC	24,872	46,140	57,396	62,351	28,846	82,894
% fall in NR	53.2	34	35.8	33.3	43.8	29.8
Cost to Return ratio without IC	2.61	1.66	2.55	2.23	2.89	2.29
Cost to Return ratio with IC	1.40	1.35	1.64	1.58	1.58	1.64

Table 8 Costs and returns for principal crops (flow irrigation, INR per acre)

Particulars/crops	Tomato	Cabbage	Carrot	Beans	Potato	Onion	Capsicum
Total cost without Irrigation cost	143,513	95,320	58,540	71,500	82,430	53,750	110,550
Irrigation cost	30,690	24,824	22,506	23,051	23,188	17,050	23,870
Total cost with IC	174,203	120,144	81,046	94,551	105,618	70,800	174,203
Irrigation cost as% of the total cost	17.6	20.6	27.7	24.3	22.0	24.0	17.7
Output/ac (nuts/acre)	141	151	70.0	52.5	90.5	55.5	102.5
Gross returns (INR/Acre)	268,550	156,100	129,000	129,625	131,525	96,575	161,812
Net returns without irrigation cost (IC)	125,037	60,780	70,460	58,125	69,552	42,825	62,650
Net return with IC	94,347	35,956	47,954	35,704	29,507	25,775	38,780
% fall in NR	24.5	40.8	32	38.5	57.5	39.8	38.1
Cost to Return ratio without IC	1.87	1.6	2.20	1.81	1.63	1.79	1.57
Cost to Return ratio with IC	1.54	1.3	1.6	1.4	1.3	1.40	1.29

Table 9 Water savings due to micro-irrigation over flow irrigation

Particulars/crops	Water used in micro-irrigation (Acre inches)	Yield/ac (Qtls)	Water used in FI	Yield/Ac (Qtls)	Saving water (%)	Increased productivity over flow (%)
Coconut (nuts/Acre	15.32	3900	20.7	3,200	25.9	18.0
Arecanut	18.5	8.75	23.5	7.50	21.25	14.2
Grapes	17.5	89.5	22.8	80.5	23. 24	10.0
Pomegranate	12.65	38.0	17.5	31.5	27.71	18.4
Mulberry	11.5	130	16.5	110.5	31.25	15.0
Tomato	15.5	185	22.5	145	31.11	21.6
Cabbage	13.8	215	18.2	185	13.95	13.0
Carrot	12.5	80	16.5	65.5	24.24	18.2
Beans	12.5	61.5	16.9	51.0	26.03	17.1
Potato	12.0	101.5	17.0	90.5	29.4	10.9
Onion	8.5	62.5	12.5	55.5	32.0	11.20
Capsicum	12.5	126.5	17.5	102.5	28.5	18.9
Chrysanthemum	18.0	58	25.8	43.0	30.2	25.8

Table 10 Physical and economic productivity per acre-inch of water

Crops	Water productivity in MI (Qtls/ac. inch)	Water productivity in flow irrigation (Qtls/ac. inch)	% difference in increased productivity/ ac inch of water over flow
Coconut (nuts/Acre	254.5	154.6	39.3
Arecanut	0.47	0.3	32.2
Grapes	5.1	3.5	31.0
Pomegranate	3.0	1.8	40.1
Mulberry	11.3	6.7	40.7
Tomato	11.9	6.4	46.0
Cabbage	15.5	10.1	34.7
Carrot	6.4	3.9	37.9
Beans	4.9	3.0	38.6
Potato	8.4	5.3	37.0
Onion	7.3	4.4	39.6
Capsicum	10.1	5.8	42.1
Chrysanthemum	3.2	1.6	48.3

Table 11 Net returns per acre and per acre-inch of water (micro-irrigation and flow irrigation)

Crop	NR/Acre **MI**	NR/Acre **FI**	NR/acre inch of water **MI**	NR/acre inch of water **FI**	Difference in net returns per acre inch of water over Flow (%)
Coconut	49,907	24,872	3,257	1201	63.1
Arecanut	102,071	57,396	5,517	2,442	55.7
Grapes	67,375	62,351	3,850	2,735	28.9
Pomegranate	50,490	46,140	3,991	2,636	33.9
Mulberry	41,625	28,846	3,619	1,748	51.7
Tomato	125,173	94,347	8,075	4,193	48.1
Cabbage	61,284	35,956	4,441	1975	55.5
Carrot	54,325	47,954	4,346	2,906	33.1
Beans	42,075	35,074	3,366	2075	38.3
Potato	47,062	29,507	3,922	1,735	55.7
Onion	29,036	25,775	3,416	2,062	39.6
Capsicum	50,820	38,780	4,065	2,216	45.4
Chrysanthemum	156,708	82,894	8,706	3,213	63.1

2020). The precision makes micro-irrigation more efficient than flow irrigation; it also reduces the water loss through evaporation and run-off (Kabbur et al. 2020).

Thus, to promote efficiency in water use, more economic incentives need to be provided for micro-irrigation, along with technical advice, so that more farmers switch from flow irrigation to micro irrigation.

Conclusion and policy interventions

Given the economic scarcity of groundwater in the study area, massive investments have been made in extracting and using it; and the over-extraction of groundwater resources, deepening of the existing borewells, and the drilling of deeper borewells is fast exhausting the resource. The cost of groundwater irrigation has increased, and the use of groundwater has become unsustainable, affecting the income and livelihood security of the farmers in rural areas that use groundwater for irrigation. The demand–supply gap of groundwater in the study areas of Karnataka is widening.

The recharge and discharge components need to be balanced with demand- and supply-side management tools and solutions. Arresting the further depletion of groundwater, and promoting judicious and sustainable use, need sound technological, institutional, and policy measures. Groundwater is a state subject; and both the central and state governments should initiate appropriate measures to arrest groundwater depletion and find alternative sources of water for conjunctive irrigation.

Micro irrigation enhances water productivity and relative profitability; it needs to be incentivized and scaled up. But outreach has so far been left to vendors selling micro irrigation equipment, whereas outreach plays the central role in sharing the knowledge of micro-irrigation technologies and facilitating its adoption. The follow-up services to the adopters of micro-irrigation need to be strengthened. Krishi Vigyan Kendras and agricultural universities and institutes need to research groundwater irrigation, train farmers in water accounting procedures, and deliver the appropriate technical services to them. And the CACP needs to include the cost of groundwater irrigation in the cost of production.

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