Government of India

Ministry of Water Resources,

River Development & Ganga Rejuvenation

Central Ground Water Board

South Western Region, Bengaluru

in collaboration with

University of Agricultural Sciences, Bengaluru

जल बचत - जल संचय

Jal Kranti Abhiyan

Proceedings of

GROUND WATER CONFERENCE

on

STATE SPECIFIC GROUND WATER ISSUES OF KARNATAKA

Venue

North Block Auditorium, UAS, GKVK, Bengaluru

23rd March 2016

JAL KRANTI ABHIYAN

GROUND WATER CONFERENCE

23rd March, 2016, UAS, GKVK, Bengaluru

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PREFACE

Water the "Elixir of life" is the most important natural resource. Urban and rural economic growth has put tremendous pressure on ground water resources across the country. Importance of ground water in the Indian context can be understood from the fact that more than 85% India's rural domestic water, 50% of its urban water requirements and more than 50% of its irrigation requirements are being met from this precious natural resource. The increasing dependence on ground water resources as a reliable source of water has resulted in large-scale indiscriminate exploitation in most parts of the country, without considering recharging capacities of aquifers and other environmental issues. Therefore ground water levels are declining at an alarming rate resulting in drying up of potential aquifer systems. Also, the potential aquifers are getting increasingly polluted due to geogenic and anthropogenic contaminants including disposal of untreated industrial effluents and sewage etc., Ground water resources are polluted due to high concentration of Arsenic, Fluoride, Iron and Heavy metals in excess of limits prescribed for drinking purposes in many parts of the country. Thus, our nation is reeling under water crisis and going to be further deteriorated in the time to come.Recycle and reuse of waste water and water efficient irrigation practices in agriculture sector will help in conserving the precious water resources. Central Ground Water Board is propagating new techniques and practices in water management.

Government of India has launched a nation-wide campaign named 'Jal Kranti Abhiyan' with the aim to create awareness amongst various stakeholders about the importance of water scarcity and water conservation. In order to address various state specific ground water issues through wider consultations among various stakeholders, one day "Ground Water Conference" at Bengaluru has been organised. This Ground Water Conference will help to share the experience of Scientists, Professionals, Technocrats, Academicians, Farmers, Industrialists, NGOs and other Stakeholders in this field to propogate and popularise the sustainable management practices to achieve water security.

This compilatiopn comprises 22 technical papers sharing the knowledge and experience of experts in the field of water management. I am happy that the papers are brought out as Coference Proceedings will definitely help those inmvolved in water conservation and management.

The support and encouragement of Sri K.B.Biswas, Chairman, Central Ground Water Board, is placed on record. The tremendous effort and hard work put in by the officers and the staff of Central Ground Water Board, South Western, Bengaluru, and UAS, Bengaluru, in organising the events are appreciated. The effort putforth by Sri S.S.Hegde, Dr.M.A.Farooqi, Sri K.Koti Reddy and Sri J. Sivaramakrishnan, in compiling this volume is worth appreciating.

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Disclaimer

The views expressed in the technical papers in this volume need not be that of the CGWB, SWR, Bengaluru and the responsibility lies with the authors

CONTENTS

BOREWELL ECONOMICS AND SUSTAINABLE GROUNDWATER MANAGEMENT

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Preamble

Groundwater irrigates 70 to 80 percent of the area irrigated in India. More than 60 percent of the food production is from groundwater. The area under food grains in India forms 63 % of the cropped area, out of which 48 % of area under food grains and 45 % of the cropped area are irrigated. Paddy and wheat account for 42 % and 35% of food production respectively contributing to food security but, at a prohibitive cost of water resource in general and groundwater resource in particular. Small and marginal farmers constitute 83 % of operational holdings cultivating 41 % of the area (Chandrakanth, 2015). In this study, a random sample of 30 bore well farmers with drip irrigation is compared with a sample of 30 borewell farmers with conventional irrigation in Eastern Dry Zone and Central Dry Zone of Karnataka.

Indian Easement Act

With domination of small holdings, violation of isolation distance between wells ought to happen reinforced by the Indian Easement Act (http://www.nih.ernet.in/rbis/rights.htm) where, owner of land has legitimate right for the water under his/her land. When Indian Easement Act was enacted in 1882, the science of hydrogeology did not explain those who enacted the law that whenever any farmer is lifting groundwater, s/he is actually drawing groundwater from neighboring farmer's lands also, due to interaction of cones of depression leading to cumulative interference among wells. Therefore, the Act virtually allowed farmers to over-pumping, resulting in reciprocal negative externalities, forcing farmers to frequently invest on bore wells, due to initial / premature, failure of bore wells. The economics of bore well irrigation should accordingly account for this externality since over pumping in one well can dry up the neighboring well/s due to interference. In hard rock areas, which constitute 65 percent of India's geographical area, it is further difficult to delineate the aquifer boundaries. It is crucial to honor that sustainability in groundwater pumping and use requires sacrifice in extraction to be in consonance with recharge of groundwater.

Sustainable use is more important than efficient use in groundwater irrigation

Given the poor recharge in hard rock areas which is around 5 to 10 percent of the rainfall, our pumping should be in consonance with the recharge effort. Hydrogeologists use the word 'groundwater development' which includes both the recharge (supply side) and extraction or pumping (demand side)' (recharge). However, in practice, when 'groundwater development' is used, it largely refers to groundwater pumping or extraction. Thus, in groundwater irrigation, sustainability in pumping is more important than 'efficiency' in pumping and use. Efficiency focuses on 'short run' while 'sustainability' focuses on 'long run'. Accordingly, the objective of realizing 'more crop per drop', 'maximizing output per acre of irrigated area' are myopic as they discount the (long run) cost of groundwater irrigation, which not only includes cost of pumping or extraction, but also the cost imposed in the future due to over-pumping at present. The objective of this paper is to demonstrate these costs and find to what extent groundwater irrigation in the Eastern dry Zone (EDZ) and Central Dry Zone (CDZ) in Karnataka are sustainable.

Crop pattern on borewell irrigation farms in EDZ and CDZ

The Eastern Dry Zone is well connected with Bangalore Metropolitan in the west and Chennai Metropolitan in the east and therefore, there is always a continuous flow of demand for vegetables, fruits, milk and other products. This property in itself is an advantage for EDZ since this results in a continuous backward linkage creating aggregate demand for fruits, vegetables, flowers, milk and other commodities. Accordingly in EDZ, farmers using drip irrigation are cultivating 9 crops in Kharif, 9 crops in Rabi and 11 crops in summer season, a majority of which are vegetables (Tomato, Potato, Cabbage, Cauliflower, carrot, coriander leaves, knolknol, onion, beans ridge gourd, chilli, pumpkin, capsicum under irrigated and ragi, horse gram, sesamum under rain-fed conditions). The cropping intensity is 170 percent, the simpson index of diversity is 0.89. while the irrigation intensity is 220 percent. This is similar to farmers with conventional irrigation, who also have crop pattern similar to drip irrigation farmers, where 7 crops in grown in Kharif, 5 in rabi and 5 crops in summer. In both drip and conventional irrigation farms, no perennial crops are cultivated. Therefore, the crop pattern in Eastern Dry Zone is (1) largely market driven (2) capital intensive (3) groundwater intensive (4) risky, (5) skilled-labor intensive, (6) diverse with high simpson index (Figures 1 through 8) (Kiran Kumar R Patil, 2014).

Figure 1. Carrot cultivation - drip irrigation, Kolar Dt

Figure 2: Potato cultivation – drip irrigatin, Kolar Dt

Figure 3: Tomato cultivation – drip irrigation, Kolat Dt

Figure 4: Coriander cultivation – drip irrigation, Kolar Dt

Figure 5: Banana cultivation - drip irrigation,Chitradurga Dt

Figure 6: Papaya cultivation – drip irrigation, Chitradurga Dt

Figure 7: Pomegranate cultivation – drip irrigation, Chitradurga Dt

Figure 8: Arecanut cultivation – drip irrigation, Chitradurga Dt

Figure 9: Shared well farmer cultivating Palak, Chitradurga Dt

Figure 10: Shared well farmer - Chrysanthemum, Chitradurga

Figure 11: Borewell recharged, Chitradurga Dt

Figure 12: Borewell recharged, Chitradurga Dt

In CDZ under drip farms, 7 crops (Ragi, Foxtail millet, little millet, groundnut, maize, cotton, jowar) are cultivated in kharif, no crop is cultivated in rabi, and 5 perennial crops (Arecanut, Coconut, Pomegranate, Papaya and Banana) are cultivated with simpson index of 0.76. As the CDZ receives low rainfall compared with EDZ and also as CDZ does not enjoy the location advantage of EDZ, no vegetables are cultivated under drip irrigation in CDZ.

In EDZ under conventional irrigation farms, the crop pattern is comparable with that of drip irrigation farms with simpson index of 0.88. In the CDZ under conventional irrigation farms, flower, leafy vegetables, maize, onion, cucumber, jowar, Bengal gram are cultivated, with the highest simpson index of 0.9. Overall, in drip irrigation system, the crop pattern involves cultivation of several crops with high diversification compared with farmers using conventional irrigation systems. This shows that drip irrigation farmers are not only water saving, but are also profusely risk averse when compared with conventional irrigation farms. Also the crop pattern is influenced by infrastructure such as roads, terminal markets, storage including the metropolitan population.Another unique feature of EDZ is that farmers are adopting drip irrigation for narrow spaced crops, which has been an innovation by the farmers of India, since drip irrigation was first adopted in India for broad spaced crops, which then was adapted for narrow spaced crops.

Proportion of well failure

What is striking is the low percentage of functioning wells in hard rock areas. In the EDZ, the percentage of functioning wells was 29 percent for farmers with drip irrigation, which is the lowest compared with farmers with conventional irrigation in EDZ as well as farmers in CDZ.

The low percentage of functioning wells in itself is the reason for farmers adopting drip irrigation in EDZ for narrow spaced crops. Other reasons for adoption of drip irrigation for narrow spaced crops are (1) economic scarcity of labor, (2) savings in chemicals and fertilizers as also plant protection chemicals, (3) increased productivity of crops and vegetable crops in drip irrigation. Accordingly each farm with drip irrigation, had at least 5 bore wells of which 1 to 2 wells were functional depending upon the percentage of functioning bore wells. The pay back period was 5 years for drip irrigation farms in EDZ followed by 11 years for farmers with bore wells in CDZ.

The average age of functioning bore wells ranged from 2 years on conventional irrigation farms of EDZ to 8.68 years for bore wells on conventional irrigation farms in CDZ. What is alarming is the increasing proportion of well failure which ranges from 56 percent in EDZ for farmers with conventional irrigation to 71 percent in EDZ for farmers with drip irrigation in EDZ on the one hand and on the other, the declining age of functioning wells, which is a meager 2 years in EDZ for farmers using conventional irrigation to 9 years for farmers using conventional irrigation in CDZ. What is to be appreciated is that the value of drip irrigation was first recognized by farmers in CDZ as they were the first to adopt drip irrigation in 1990, which was followed by EDZ farmers (Table 1).

Depth of bore wells

The depth of bore wells has been lower in CDZ when compared with EDZ. By historical considerations, the experience of farmers in EDZ with regard to irrigation bore wells and farming practices is to be greatly appreciated. Accordingly, in EDZ for farmers using drip irrigation, the depth of bore wells is 717 feet (with a range of 200 to 1200 feet); followed by farmers following conventional irrigation, with depth of bore wells of 722 feet (ranging from

Table 1: Details of irrigation wells with percentage of failure

Particulars	Drip Irrigation farms EDZ	Drip irrigation farms CDZ	Conventional irrigation farms EDZ	Conventional irrigation farms CDZ
Number of borewells per farm	5	5	3	2
	(1 to 10)	(1 to 16)	(1 to 6)	(1 to 6)
% of Initial failures	32	49	28	44
% of Premature failures	14	3	12	2
% of wells which exactly served payback period	24	5	16	0 (0)
% of Functioning Borewells	29	43.33	44	53.65
Pay back period (years)	5	11	11	
	(2 to 12)	(3 to 21)	(1 to 16)	
Age of functioning borewells (years)	4.75	7	2.05	8.68
	(1 to 34)	(0 to 33)	(1 to 8)	(1 to 20)
Range of drilling Year of borewells	1979 to 2013	1980 to 2013	1990 to 2013	1992 to 2013
Range of years of adoption of drip irrigation	2004 to 2012	1990 to 2012	Not applicable	Not applicable

170 feet to 1140 feet). In the CDZ, the depth of bore wells of farmers with drip irrigation is 342 feet (with a range of 100 feet to 700 feet), followed by farmers with depth of bore wells of 257 feet (with a range of 80 to 480 feet). The probability of obtaining a successful well hovers around 0.3, which shows that the probability of well failure is 0.7. The yield of the functioning well is around 1800 gallons per hour.

However, the effort to pump groundwater through high horse power capacity ranging from 5 HP pump for drip irrigation farms of CDZ to 20 HP pump for drip irrigation farms of EDZ with the uniform yield of around 1800 gallons per hour. The nominal investment on all wells

Table 2: Investment on bore wells

PARTICULARS	Drip irrigation farms in EDZ	Drip irrigation farms in CDZ	Conventional irrig farmers in EDZ	Conventional irrigation farmers in CDZ
Depth of borewell in feet	717	342	722	257
(range)	(200 to 1200)	(100 to 700)	(170 to 1140)	(80 to 480)
Probability of obtaining a successful borewell	0.32	0.28	0.32	0.28
Horse power of IP set	20	5	8	6
(range)	(5 to 20)	(4 to 8)	(5 to 20)	(3 to 10)
Yield of functioning well in Gallons per hour	1805	1786	1778	1866
(range)	(1066 to 2333)	(1000 to 2333)	(1333 to 2333)	(1167 to 2333)
Irrigation water per farm in ha cms (or acre inches) (range)	72.94	69.21	79.74	71.63
	(11 to 261)	(15.58 to 267)	(40.33 to 197.60	(18 to 135)
Investment on drip irrigation per farm in 2013 prices (Rs.)	213402	96550	Not applicable	Not applicable
	(40800 to 1033817)	(20808 to 385503)		
Nominal investment on all borewells per farm (Rs.)	944212	406917	558223	172023
	(271895 to 2142239)	(94443 to 1654190)	(222613 to 879103)	(82128 to 320073)
Nominal Investment per functioning borewell (Rs.)	377684	167226	279111	132927
	(173760 to 961894)	(86757 to 480887)	(179974 to 628588)	(82128 to 263479)
Amortized cost of drilling and casing per borewell (Rs.)	29570	11755	23962	7748
Amortized cost on drilling and casing per functioning borewell (Rs.)	54804	24155	39629	14440
	-68%	-66%	-70%	-59%
Amortized cost on IP set, drip, conveyance, storage structures per functioning borewell (Rs.)	25246	12186	17110	10208
	-32%	-34%	-30%	-41%
Total amortized cost per functioning borewell	80050	36341	56739	24648
Annual Negative externality per borewell (Rs.)	(Rs 54804 minus 29570 =) 25233	(Rs 24155 minus 11755=) 12399	15667	6692

on the conventional irrigation farm in CDZ is Rs. 1.72 lakhs while that on drip irrigation farms in EDZ is Rs. 9.44 lakhs. The total amortized cost per functioning well ranges from Rs. 24648 in CDZ conventional farms to Rs. 80050 on drip irrigation farms.

The negative externality defined as the amortized cost per functioning bore well minus the amortized cost per bore well, is the highest for farms with drip irrigation in the EDZ (Rs. 25233 per bore well per year), while that for borewell with conventional irrigation is the lowest for CDZ (Rs. 6692) for farms with conventional irrigation. The proportion of fixed cost of bore well in terms of pump cost, electrical installation, pipe cost, forms around 30 to 40 percent, while the proportion of variable cost of bore well in terms of drilling and casing costs, is around 60 to 70 percent. This further reiterates the increasing negative externality of groundwater irrigation since farmers are forced to drill new bore wells due to high probability of initial and premature failure of irrigation wells (Table 2).

Component-wise investment on bore well

The total investment on bore well drilled in 2013, ranged from Rs. 1.25 lakhs for farmers in central dry zone with conventional irrigation, to Rs. 2.63 lakhs per bore well for farmers in Eastern Dry zone with conventional irrigation. The cost of bore well in EDZ is higher than that of CDZ with uniform yield of groundwater. This is due to the extent of cumulative interference which is higher in EDZ than in CDZ because of relatively small sized holdings than CDZ. In EDZ, the cost of drilling and casing formed 47% to 48% of the total cost of bore well while in CDZ this cost formed 23 to 32 percent. The cost of pumpset and accessories formed the remaining 50 percent of the bore well in EDZ, while it formed 41% to 53% of the bore well cost in CDZ. Thus, no generalizations can be made with regard to the proportion of drilling and casing cost with that of pumpset and accessory costs as it depends upon the extent of interference (Table 3).

Table 3: Component wise Investment on irrigation bore well/s drilled in 2013

Particulars	Drip irrigation farms in EDZ	Drip irrigation farms in CDZ	Conventional irrigation farms, EDZ	Conventional irrigation farms CDZ
Average Depth (feet)	1003	400	898	292
Depth of casing (feet)	44	40	40	46
Pump HP (mode)	20	6	15	6
Pump stage (mode)	26	8	20	8
Cost of Drilling and Casing (Rs.)	120825 -48	35382 (32)	124780 (47)	29087 (23)
Pump set cost (Rs.)	100000 -39	58735 (53)	98466 (37)	51300 (41)
Electrification Charges (Rs.)	15000 -6	8000 -7	9000 (3)	10500 (8)
Cost of over ground storage structure (Rs.)	-	18000	18000 (7)	15000 (12)
Cost of conveyance structure (Rs.)	17500 -7	8300 -8	13000 (5)	20000 (16)
Total investment on bore well (Rs.)	253325	128417	263246	125887
Operational and maintenance cost per year (Rs.)	15000	7500	12000	8000
Estimated water yield of well (GPH)	1854	1900	1933	1625

Average size of holding of farmers and cost of groundwater

In the study area of Kolar-Chikkaballapur –Chitradurga districts, for farmers possessing bore wells, the holding size varied from 5.23 acres for farms in EDZ with conventional irrigation to 9.28 acres for farms in EDZ with drip irrigation. The proportion of area irrigated in these farms varied from 50 to 52 percent in EDZ to 53 to 70 percent in CDZ. The net area irrigated (gross irrigated area) per functioning borewell ranged from 2.2 acres (4.84 acres)for farms with drip irrigation in EDZ to 2.97 acres (5.63 acres) for farms with drip irrigation in CDZ. The cost of groundwater varied from Rs. 2954 per ha cm for drip irrigated farm in EDZ to Rs. 1400 per ha cm for drip irrigated farm in CDZ. For conventional irrigation farms, the cost of groundwater varied from Rs. 600 per ha cm for conventional irrigation farms in CDZ to Rs. 2204 per ha cm in EDZ (Table 4).

Table 4: Economics of GW irrigation in Eastern and Central Dry Zone of Karnataka

Particulars	Drip irrigation farmers in EDZ	Drip irrigation farmers in CDZ	Conventional irrigation farmers in EDZ	Conventional irrigation farmers in CDZ
Average size of land holding	9.38	7.87	5.23	7.88
(irrigated land area) (acres)	-4.61	-6.07	-2.79	-4.11
Number of farmers with drip	30	30	0	0
irrigation	-100	-100		
Gross irrigated area per farm (acre)	6.62	12.2	5.29	5.73
	(1 to 26)	(2.4 to 43.4)	(2 to 15)	(3.2 to 12)
Gross irrigated per functioning	4.84	5.63	3.62	4.42
borewell (acres)	(0.87 to 9)	1.77 to 10.5)	(0.66 to 6)	(3 to 11)
Irrigation intensity (%)	220	189.56	234	200
Net irrigated area per functioning well (acre)	2.2	2.97	1.54	2.21
Net irrigated area per farm (acre)	3.01	6.44	2.26	2.87
Groundwater extracted per farm	72.94	69.21	79.74	71.63
(acre inches or ha cms per year)	(11 to 261)	5.58 to 267)	3 to 197.60	(18 to 135)
Groundwater extracted per acre of gross irrigated area (acre inches or ha cms)	11.01	5.67	15.07	12.5
Groundwater extracted per functioning well	53.37	32 (11 to 77)	54.56	55.35
(acre inches or ha cm in 2013)	(11 to 86)		(14 to 93)	(17 to 92)
Variable cost of groundwater	2089	972	1629	415
(Rs per ha cm or acre inch)	(295 to 9255)	(68 to 9517)	20 to 3764)	18 to 1686)
Fixed cost of groundwater	865	428	575	184
(Rs per acre inch or ha cm)	(317 to 3791)	156 to 2046)	05 to 1212)	104 to 716)
Total cost of groundwater per acre inch or ha cm	2954	1400	2204	599

Returns from bore well irrigation

The gross returns per functioning bore well ranged from Rs. 4.98 lakhs for farms with conventional irrigation in CDZ to Rs. 5.58 lakhs for drip irrigation farms in EDZ. Similarly the net returns per functioning bore well ranged from Rs. 1.6 lakhs for farms with conventional irrigation in CDZ to Rs. 4.06 lakhs for farms with drip irrigation in EDZ. The net returns per ha cm of groundwater were around Rs. 7000 for farms with drip irrigation, while they were about Rs. 4000 for farms with conventional irrigation. The net returns per rupee of water cost was Rs. 7.32 for farms with conventional irrigation in CDZ, to Rs. 5.08 for farms with drip irrigation in CDZ. This shows that farms in CDZ are not only efficient but also sustainable with respect to groundwater use on both drip irrigation and conventional irrigation farms, when compared with farms with drip irrigation in eastern dry zone (Table 5).

Table 5: Returns from borewell irrigation in EDZ and CDZ in Karnataka (2013)

Particulars	Drip irrigation farms in EDZ	Drip irrigation farms in CDZ	Conventional irrigation farms, EDZ	Conventional irrigation farms CDZ
Gross returns per farm (Rs.)	1395726	1085773	831998	644396
	(263850 to 4707000)	(212100 to 2732700)	(487400 to 1322280)	(200400 to 1081800)
Net returns per farm (Rs.)	555073	512016	312342	310731
Gross returns per acre (Rs.)	210676	166147	157209	112414
	(121783 to 451800)	(33878 to 264175)	(73867 to 330570)	(33400 to 263672)
Net returns per acre of gross irrigated area (Rs)	83786	75463	44070	54205
	(6980 to 247046)	(11420 to 168283)	(23702 to 145646)	(10719 to 120419)
Gross returns per functioning well (Rs.)	558290	501126	569262	497942
	(243000 to 2273600)	(202783 to 1112000)	(162467 to 998000)	(100200 to 947320)
Net returns per functioning well (Rs) Range	406158	227609	159581	240102
	(10470 to 1325423)	(59018 to 673135)	(50457 to 397458)	(32159 to 609128)
Gross returns per acre inch (Rs.)	22635	15688	10434	8996
	(6802 to 41798)	(4653 to 54069)	(5607 to 30633)	(2811 to 19078)
Gross returns per rupee of water (Rs.)	6.47	11	5	15
	(1.93 to 27)	(4.43 to 39.5)	(4.5 to 14.6)	(3.17 to 45)
Net returns per acre inch or ha cm of groundwater (Rs)	7610	7398	3917	4338
	(784 to 22603)	(1470 to 37554)	(1799 to 37843)	(1092 to 8713)
Net returns per rupee of water	2.57	5.08	1.32	7.23
	(0.08 to 15.75)	(1.74 to 28)	(1.26 to 7.06)	(1.01 to 26.77)

Economics of bore well recharge

In CDZ the rainfall varies from 400 mm to 650 mm which is lower than the rainfall in EDZ of 750 mm. Thus, unless borewells are recharged, the probability of initial and premature failures will exacerbate and marginal and small farmers will find it extremely difficult to cope with. In Central dry zone predominantly in Chitradurga district, due to efforts of a hydrogeologist by name Sri Devaraja Reddy, many farmers have undertaken bore well recharge. The economics of bore well recharge was estimated using the partial budgeting technique (Table 6). In order to recharge the bore well, a 10 feet X 10feet X 10 feet pit is dug around the bore well. At the bottom one foot of the bore well, around 100 to 200 holes are drilled and covered with wire mesh to avoid silt entering the bore well. Then for 4 feet, boulders will be filled around the casing of the bore well, next 1.5 feet will be filled with 40 mm jelley, next 1.5 feet with baby jelley. A layer of charcoal powder will be spread to absorb micro organisms. Then a plastic sieve will be spread above the charcoal powder. Then 2 feet sand will be spread on the top to enable silt free water to recharge the bore well.

There may be other methods which are in vogue too. The cost of recharging is usually 10 percent to 20 percent of the cost of bore well including pumpset. It was assumed that the recharge would serve for around 10 years. Using the four components of partial budgeting namely the added costs of groundwater recharge which was amortized for 10 years worked to Rs. 3340 per year. The reduced returns were the returns foregone in the space of groundwater recharge which was a meager Rs. 125. Thus, on the debit side the added costs and reduced returns totaled Rs. 3465 per bore well. On the credit side, the reduced costs were the reduced negative externality cost, due to bore well recharge, estimated as Rs. 9013 per bore well. The added returns due to recharge isRs. 191994. The economic impact of bore well recharge is Rs. 197583 per bore well. It is certainly economical to recharge the borewell as the additional benefit is around Rs. 2 lakhs per recharged bore well per year (Table 6, Figures 9,10).

Table 6: Economic impact of artificial recharge of borewell in Central Dry Zone, 2013 (Rs. per well)

Added costs due to recharge of borewell	Reduced costs due to borewell recharge
Amortized cost of GW recharge per well year = 3340 per well per year.	Reduced externality per borewell is the difference in the externality borne by non irrigation borewell recharge farmers over borewell recharge farmers. The externality per borewell on farms with borewell recharge is Rs. 3386 and on non borewell recharge farms (control farms) is Rs. 12399. Hence, the difference gives the extent of reduced externality =12399 to 3386=9013.
Reduced returns due to recharge of borewell	Added returns due to the artificial groundwater recharge in the borewell
Gross returns foregone on the area used for recharging the borewell = 112414 per acre X 0.00075 acre = Rs. 84	Due to recharge, farmers realize the additional gross returns of Rs. 6,89,936 from recharged well minus gross returns per non recharged well = 689936 to 497942 = 191994
Acres devoted for GW recharge around well = 0.00075	
Total debit side = 3340+84 = Rs.3424	Total credit side = Rs. 201007
Credit minus debit = 201007 – 3424 = Rs. 1,97,583	

Crop wise costs and returns and impact on sustainable use

According to resource economic considerations, the cost of groundwater irrigation is included in the cost of cultivation of crops. Accordingly, in the EDZ, the most profitable crop under drip irrigation is potato which is giving the net-benefit cost ratio (BC ratio) of 1.74, followed by Red onion 1.69, Cauliflower 1.60, Cabbage 1.49, Beans / Tomato 1.43, Carrot 1.40, Coriander /Knolkhol 1.26, Capsicum 1.17. In CDZ , including the cost of groundwater, the most profitable crop is pomegranate 2.01 followed by arecanut 1.83, papaya 1.65, Banana

Table 7: Net returns for crops in Drip irrigation farms in Eastern Dry zone of Karnataka (Rs/acre)

Crop	Water used in ha cms	TC of groundwater	TC of cultivation	% TC of groundwater to TC of cultivation	Output in quintals	GR	NR including irrigation cost	Crop per drop = output per ha cm	B:C ratio GR/TC of cultivation
Knol kohl	12.08	26100	71822	36	155	90666	18844	12.83	1.26
Coriander (bunches)	4.7	19093	59334	32	150	75000	15666	31.91	1.26
Capsicum	8.18	23650	153216	15	50	180000	26784	6.11	1.17
Carrot	7.59	19469	77528	25	109	108571	31043	14.36	1.4
Beans	10.31	30195	127881	24	70	182500	54619	6.8	1.43
Red onion	9.32	24659	80962	30	96	136693	55731	10.3	1.69
Cabbage	10.05	26349	154253	17	230	230476	76223	22.89	1.49
Tomato	12.16	22947	166490	14	110	238689	72199	9.04	1.43
Potato	11.92	26540	121032	22	227	211012	89980	19.04	1.74
Cauliflower in heads	8.54	9629	74089	13	14545 heads	118182	44093	1703.16	1.6

1.20, Coconut 1.10 (Tables 7,8).

According to agronomic considerations of more crop per drop, the most profitable crop considering output in quintals, in EDZ is Cabbage giving 22.89 quintals per ha cm of water followed by potato 19.04 quintals per ha cm, carrot 14.36 quintals per ha cm, Knolkhol 12.83 quintals per ha cm, Red onion 10.30, Tomato 9.04 quintals per ha cm, Beans 6.80 quintals per ha cm, Capsicum 6.11 quintals per ha cm. In CDZ, papaya gives the highest crop per drop of 13.8 quintals per ha cm of water followed by Banana 12.81 quintals per ha cm, Pomegranate 3.9 quintals per ha cm, Arecanut 0.8 quintal per ha cm and coconut 580 nuts per ha cm of water.Thus, for sustainable extraction and use of groundwater for irrigation, farmer should consider growing crops given by the BC ratio under drip irrigation as detailed above (Tables 7, 8).

Table 8: Net returns for crops in Drip irrigation farms in Central Dry zone of Karnataka (Rs/acre)

Crop	Water used in ha cms	TC of groundwater	TC of cultivation	% TC of groundwater to TC of cultivation	Output in Quintals	GR	NR including irrigation cost	Crop per drop = output per ha cm	B:C ratio GR/TC of cultivation
Coconut No. of nuts	8	7269	33216	22	4635	36502	3286	579	1.1
Banana Quintals	32	18564	95312	19	410	114531	19219	12.81	1.2
Papaya Quintals	14	23601	141649	17	193	233500	91851	13.8	1.65
Arecanut Quintals	12	8962	62743	14	9	114824	52080	0.8	1.83
Pomegranate Quintals	10	17764	169025	11	39	340540	171515	3.9	2.01

Conclusion

In the economics of bore well irrigation, since the life of the bore wells used to be at least around 25 to 30 years earlier, the investment on bore well used to be treated as fixed cost and accordingly, the variable cost of water for irrigation was virtually zero. However, due to climate change and the associated impact on groundwater availability, the groundwater recharge is relegated, which further affects the supply side of groundwater. Groundwater development unfortunately treated groundwater as an exploitable resource, without giving importance to groundwater recharge. Due to ever increasing demand for groundwater irrigation supporting crops, vegetables, fruits, flowers in different parts of the state, given the impetus to extract groundwater with zero cost of energy, as also due to the poor implementation of Groundwater Regulation and Control Act of 2011, the resource is over exploited resulting in secular overdraft of groundwater. In this study, the groundwater cost is accounted in the cost of cultivation of crops, thereby indicating the scarcity value of the precious resource, creating awareness for farmers, users, uses, policy makers regarding the economic importance of groundwater for irrigation which consumes more than 90 percent of the withdrawal.

In this study, it has been found that the groundwater recharging of individual bore well is economically worthwhile as farmer can receive Rs. 2 lakhs per recharged bore well as net return per year. The net returns per rupee cost of groundwater was Rs. 5.08 for drip irrigation farms in Central Dry Zone. The net returns per acre inch of groundwater was the highest being Rs. 7610 for drip irrigation farmers in EDZ followed by drip irrigation farmers in CDZ Rs. 7398, Rs. 4338 for conventional irrigation farmers in CDZ and Rs. 3917 for conventional irrigation farmers in EDZ.

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