Combating Negative Externalities of Drought

Groundwater Recharge through Watershed Development Programme

An important impact parameter visualised and utilised under the watershed development programme (WDP) is its role in augmenting groundwater recharge. In hard rock areas, the life of irrigation wells and their groundwater yield is gradually declining due to many factors especially the interference of irrigation wells due to violation of isolation distance among wells, overdraft of groundwater, etc. Interference among wells is a negative externality. This study is a modest attempt to estimate the impact of WDP in reducing the cumulative interference externality by augmenting groundwater recharge for irrigation in Basavapura watershed in Gowribidanur, a drought prone area in Karnataka.

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Initial and premature failure of irrigation wells are a predicament to farmers in hard rock areas due to cumulative well interference induced by drought situation. While demand side policies promote rapid extraction of groundwater, thereby exacerbating the predicament of well failure, supply side policies like watershed development programmes help dampen negative externalities. With the primary survey data from farmers of Basavapura watershed in Karnataka, India, this study proves that watershed development programmes have potential to alleviate the effect of drought by increasing groundwater recharge. This has contributed to increased physical and economic access to groundwater for farmers through increased pumping at reduced costs of extraction.

Watershed development programmes are currently absorbing huge funds out of state and central schemes. Over the years, the focus of the programme has changed substantially. It began from a technically dominated programme and culminated into peoples' participatory schemes. However, throughout the travelogue, there are sporadic instances of single impact focused watershed development programmes. One of the important impact parameters visualised and utilised under the watershed development programme is the groundwater recharge. Therefore there was a need to design and implement programme specifically focusing on the role of watershed programme in augmenting groundwater resources. In hard rock areas, the life of irrigation wells and their groundwater yield is gradually declining due to factors singularly or in combination inter alia, interference of irrigation wells due to violation of isolation distance among wells, overdraft of groundwater without regard to recharge. In India, given the distribution of holdings, obscurity in property rights and frequently occurring droughts, interference among wells is a negative externality. This study focuses on the role of watershed development programme in reducing this externality.

The main focus of this study is to estimate in economic terms, the role of watershed development programme in reducing the effect of well interference externality.

This study is a modest attempt to estimate the impact of watershed development programme (WDP) in reducing the cumulative interference externality by augmenting groundwater recharge for irrigation in Basavapura watershed in Gowribidanur, a drought prone area in Karnataka, implemented in 1994. The physical impacts of WDP translated in economic terms are outlined in Table 1. The role of WDP in reducing the negative externality due to cumulative interference and thereby improving efficiency and equity is examined with two hypotheses, namely:

(a) Reduction in extraction costs 'with' over 'without' WDP reflects the magnitude of negative externality internalised by the watershed development.

(b) Increase in net returns 'with' over 'without' WDP reflects the magnitude of negative externality internalised by the watershed development.

Analytical Approach

Basavapura watershed, Gowribidanur taluk, Kolar district, Karnataka in the eastren dry agro climatic zone was selected for the impact of WDP. This watershed has 948 acres with 692 acres of arable and 257 acres of non-arable land. The annual rainfall is 679 mm. The watershed has 420 (16 per cent) acres of irrigated land and 272 (39 per cent) acres under rain fed agriculture. The annual utilisation of groundwater for irrigation in the taluk is 87 million cubic metres (MCM) with 77 wells per MCM of groundwater. Central Ground Water Board (CGWB) initiated WDP here during 1993-94.[1] A sum of Rs 844,600 ($ 18,360) was invested in the programme since 1994. Major portion (81 per cent) of the expenditure was on check dams and percolation tanks.

Using Participatory Rural Appraisal (PRA), wells in the upstream and downstream (both functional and non-functional); well depth; location of water harvesting structures; distance among wells; distance between wells and water harvesting structures; farm size and farmer's name were mapped. This helped to locate vintages and locations of irrigation wells in relation to cumulative interference and water harvest structures. Using the PRA map, a sample of 40 farmers who had irrigation well/s, which were densely placed, was drawn from the watershed. Another sample of 20 farmers was drawn outside the watershed who owned irrigation wells which were densely placed for comparison.

In this study, negative externality in well irrigation refers to: well that dries up because of new well(s) coming in (but not because of decline in rainfall) or a well that loses a large degree of its yield because of new well(s) coming in (but not because of decline in rainfall) and/or a well that is deepened because of new well(s) coming in.

In the absence of electricity meter and water flow meter, estimation of water yield from borewell was an onerous task. About 87 per cent of the functioning wells in the sample (within and outside watershed) were borewells. Field measurements of water yield from 36 borewells (12 borewells in each village within and outside the watershed) were taken for different delivery pipe sizes and water pressures as expressed by farmers. After 10 minutes, the pump is put on, if the water fell between 0 and 0.5 metres from the source, the pressure was considered as 'low pressure' (LP), between 0.5 metre and 1 metre as 'medium pressure (MP)' and beyond 1 metre, as 'high pressure' (HP) (see Figure). The water yield of the borewells was measured by recording the number of seconds taken to fill a bucket of water of say ten litres for each of the wells. This was extrapolated to obtain the groundwater yield in gallons per hour (GPH). The yield of water from other types of wells was also estimated.[2] The limitation of this method in measuring yield of irrigation well is well recognised.

The groundwater extracted on a farm is the sum of the groundwater extracted for each crop over kharif, rabi and summer seasons. Groundwater extracted for a crop (GWEC) is estimated as under:

GWEC = (A × F × N × D × I × Y) ÷ 22,611. Here

A = area irrigated in each crop

F = frequency of irrigation per month

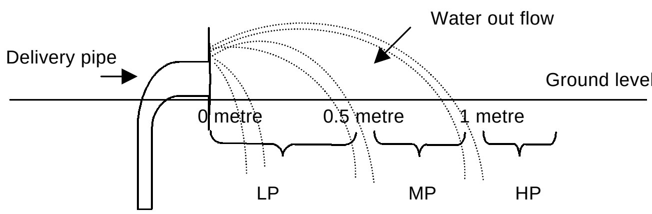
N = number of months of crop receiving irrigation

I = number of hours to irrigate the crop area

Y= Average yield of well in gallons per hour.[3]

Cost of irrigation is worked out as the amortised cost of (both functioning and non functioning) irrigation well(s), conveyance, storage structure, and annual repairs and maintenance costs. The cost of irrigation depends on the type of well (dug well, dug-cum-borewell, borewell, filter point well), current status of well (functioning or non-functioning), year of construction, average age/life of well, and the chosen discount rate.

Figure: Pressure of Groundwater Flow from Irrigation Borewells Indicated by Farmers for Estimating the Groundwater Yield in Basavapura Watershed, Karnataka



Note: Pressure refers to horizontal distance (in metres) between pumped groundwater from the outlet and the ground when pump is on. LP = Low pressure, MP = Medium pressure and HP = High pressure

Well Age and Well Life

'Age' of irrigation well refers to wells 'functioning' at the time of collection of field data (during 2000). The age of the well is the year 2000 minus the year of well construction or sinking or drilling. The average 'age' of wells included 'age' of those wells, which are still functioning given by

$\sum(f_i X_i) \div \sum(f_i)$. Here,

f = Number (frequency) of wells in each age group;

X = Age group of wells (0,1,2,3,…, n in years)

i = ranges from zero to n, where n refers to the longest age of well in the group

Such of those wells constructed/drilled during 2000 and still functioning at the time of field data, were assumed to have zero age, as the effect of interference is to increase both the initial and current failures. However, few wells were drilled during the year 2000.

Table 1: Physical and Economic Benefits due to WDP on Irrigation Wells Located in Area with High Interference among Wells

Physical Benefits	Economic Benefits
Enhanced life of irrigation well	Reduced amortisation cost as the cost is spread over larger number of years
Higher yield of irrigation well	i Reduced cost of extraction as the cost is spread over larger volume of water extracted
	ii Increased net returns due to increased gross irrigated area devoted to high value water intensive crops

Table 2: Number of Functional and Non-functional Wells in Basavapura WDP, Karnataka, 2000

(in numbers)

Type of Well	Within WDP Area						Outside WDP Area					
	Before WDP (in 1994)			After WDP (in 2000)			Before WDP (in 1994)			After WDP (in 2000)		
	F	NF	Total	F	NF	Total	F	NF	Total	F	NF	Total
Dugwell	7	9	16	11	5	16	10	–	10	–	10	10
	(18.9)	(60)	(30.8)	(18)	(45.5)	(22.2)	(45.5)		(45.5)		(76.9)	(29.4)
Borewell	27	4	31	46	5	51	12	–	12	21	3	24
	(73)	(26.7)	(59.6)	(75.4)	(45.5)	(70.8)	(54.5)		(54.5)	(100)	(23.1)	(70.6)
Dug cum		2	2	1	1	2	–	–	–	–	–	–
Borewell	–	(13.3)	(3.8)	(1.6)	(9)	(2.8)						
Filter point well	3	–	3	3	–	3	–	–	–	–	–	–
	(8.1)		(5.8)	(5)		(4.2)						
Total	37	15	52	61	11	72	22	0	22	21	13	34
	(71)	(29)	(100)	(85)	(15)	(100)	(100)	(0)	(100)	(62)	(38)	(100)

Note: Figures in parentheses represent the percentages to the respective total.
WDP = warshed development programme.
F – Functional wells, NF – Non functional wells.

As opposed to 'age', 'life' of irrigation well refers to the number of years a well already functioned and is no longer functioning at present (time of field data collection). Well life is applicable to totally 'failed'/or 'abandoned' wells after they functioned for some time, including initial failures. Well life was estimated using the same formula as for 'age', considering only wells, which functioned and failed prematurely, or which never functioned due to initial failure. In this study, 'non-functioning' wells and 'failed' wells are used synonymously as there were was no instance of a well which failed initially or prematurely, but became functional later on.

Amortised cost of irrigation is the sum of amortised investment on all wells on the farm, amortised cost of all pumpsets and accessories, amortised cost of all conveyance structures, amortised cost of overground storage structure and annual repairs and maintenance cost of all wells. The amortised investment on each dugwell/borewell is estimated as under:

$AIW = [(CI) *(1+i)^{AL} * i] \div [(1+i)^{AL}-1]$

Here,

AIW = amortised investment on well

$CI = (II)* (1+i)^{(d-c)}$

II = initial investment on well

d = year of data collection (2000)

c = year of drilling/constructing irrigation well

AL = average life of wells

i = interest rate

Amortised investment on dug cum borewell (AIDCBW) is estimated as under:

$AIDCBW = \{[EIDCBW *[1+i]^{AL} * i]\div\{[1+i]^{AL} - 1\}$

$EIDCBW = \{AC_{DW}* [AL - m - c)] + IC\}* (1+i)^{(d - m)}$

Here, EIDCBW = estimated investment on dug cum borewell which is the cost of dugwell portion of the investment in dug cum borewell at current prices (in 2000)

AC_{DW} = amortised cost of DW, similar to AIW.

m = year of improvement of dugwell

c = year of construction of dugwell

d = year of data collection (2000)

IC = historical improvement cost (such as cost of in bores in the dugwell)

The annual cost of irrigation is derived as the sum of amortised investment on all wells, conveyance structures, storage structures, and annual repairs and maintenance costs on the farm. The discount rate of 2 per cent is used in amortisation reflecting long-term sustainable rate. In this study the annual cost of irrigation and amortised cost of irrigation are thus synonymous. Thus, the value of groundwater in this study is underestimated due to use of social discount rate. Labour cost of irrigation was merged with the cost of other cultural operations. Investment on WDP is amortised considering the life of WDP as 15 years and distributed over the estimate of total groundwater extracted by all farms in the watershed.[4] In order to account for the amortised investment on the watershed programme in the annual cost of irrigation, the amortised investment on watershed programme was added to the annual cost of irrigation on the farm.

Access to Groundwater

The WDP is expected to improve the accessibility to groundwater resource for farmers. Two types of accessibility measures were used in this study: (i) physical accessibility and (ii) economic accessibility. Physical access to groundwater is defined as the volume of groundwater used per acre of gross irrigated area (GIA). Economic access refers to the volume of groundwater extracted per rupee of amortised cost of irrigation. Physical access is hypothesised to increase with the yield of irrigation well and to decrease with cost per acre inch of groundwater. The relationship in log linear form is estimated as:

$\text{Log Pa} = \log \alpha + B_1 \log Wy + B_2 \log Cw$

Here Pa = groundwater used per acre of GIA;

Wy = well yield in GPH, and

Cw = annual cost per acre inch of groundwater

Factors influencing economic access to groundwater inter alia are water used on the farm and distance of irrigation well from water harvest structures. Economic access is hypothesised to increase with water used on the farm and decrease with the distance of irrigation well from water harvesting structures. The relationship is assumed to follow a log linear form:

$\text{Log Ea} = \log \delta + B_1 \text{Log Wuf} + B_2 \text{Log Wd}.$

Here Ea = economic access = groundwater extracted in acre inches per rupee of amortised cost of irrigation)

Wuf = groundwater used on the farm in acre-inches,

Wd = distance of well from water harvesting structures in metres.

Assessing Impact of Watershed Development

Before the commencement of the WDP, the sample of 40 farmers were having 52 irrigation wells, of which 16 (31 per cent) were dugwells, 31 (59 per cent) were borewells, two (4 per cent) were dug cum borewells and the rest three (6 per cent) were filter point wells. Among the 52 irrigation wells, 15 (29 per cent) were non functional and 37 (71 per cent) were functional earlier due to the implementation of WDP (Table 2). With the introduction of WDP, the number of wells increased to 72 (at a growth rate of 6.4 per cent per year). Among them, 16 (22 per cent) were dugwells, 51 (71 per cent) were borewells, two (3 per cent) were dug cum borewells and the rest 3 (4 per cent) were filter point wells. During 2000, five (31 per cent) dugwells, five (10 per cent) borewells and one (50 per cent) dug cum borewell was totally abandoned due to well failure. Among the 16 dugwells, the number of non-functioning wells were nine (56 per cent) before implementation of watershed programme. After programme implementation four dugwells got recharged yielding groundwater and the number of non-functioning dugwells decreased to five (31 per cent). Outside the watershed, before the WDP, farmers had a total of 22 irrigation wells (all of them functional) of which 10 (45 per cent) were dugwells and 12 (55 per cent)

Table 3: Average Age and Life of Wells in Basavapura Watershed, Karnataka, 2000

(In years)

Type of well	Within WDP Area				Outside WDP Area	
	Before WDP (in 1994)		After WDP (in 2000)		After WDP (in 2000)	
	Average Age	Average Life	Average Age	Average Life	Average Age	Average Life
Dugwell	48	41	49	45	38	18
Borewell	4.4	4	10	9	8	7
Dug cum bore well	13	10	19	13	_	_
Filter point Well	14	14	20	20	_	_

Note: - Age of wells (2000 – year of construction).
Life of wells (year of failure – year of construction .
1994 was the year of WDP.

were borewells. After the WDP, number of irrigation wells increased to 34 of which 13 (38 per cent) were non-functional, wherein on an average, two wells non-functioning per year.

The proportion of functioning wells increased from 71 per cent to 85 per cent due to WDP. The proportion of non-functioning wells declined from 29 per cent to 15 per cent (Table 2). Outside WDP area, all irrigation wells were functional before 1994. Here, the proportion of non-functioning wells is 38 per cent due to scarcity induced by cumulative well interference. All dugwells outside WDP area completely dried up after 1994. Inside WDP, four dugwells and one dug cum borewell got recharged.

Recharging the Water Table

Borewell is the popular mode of water extraction after the 1980s both within and outside WDP area. Due to the influence of water harvesting structures constructed for groundwater recharge, the life of dugwells, borewells, dug cum borewells and filter point wells increased by four, five, three and six years respectively in WDP (Table 3). The dugwells outside WDP have a mere 40 per cent of the life of dugwells in WDP area. The life of borewells outside WDP was seven years; while the life of borewells within WDP area was nine years.

Since1994, 20 new borewells were drilled in the WDP area. Outside WDP area 12 new borewells drilled. The age and life of borewells within WDP area was 4.45 and 4.3 years which is 12 and 24 per cent higher than the age and life of borewells outside WDP area, respectively. Farmers have taken advantage of the increased life and age of wells in WDP and have extracted higher volume of water (105 acre inches) compared with before programme implementation (70 acre inches) and outside WDP area (75 acre inches). This further influences the economic access of farmers having irrigation well within WDP, the frequency of investment to drill additional wells and the associated investment in irrigation.

The yield of borewells was 1,150 gallons per hour (GPH) before implementation of WDP and increased to 1,426 GPH by 24 per cent (during May 2000) (Table 4). The yield of dugwells before WDP was 264 GPH and increased to 446 GPH by 69 per cent after the WDP. Outside WDP the yield of borewells was 1,470 GPH before WDP (1994) and decreased to 1,242 GPH (by 15

Table 6: Investment on WDP in Basavapura, Karnataka, 2000

Activities	Physical Unit	Coverage	Total Expenditure
Check dams	No	18	623289
Percolation tank	No	1	63259
Earthen bund	No	1	1367
Boulder checks	No	93	51070
Rubble checks	No	35	47160
Vegetative checks	Sq m	460	13930
Gully revetment	Sq m	790	44495
Total investment	Rs	–	844600
Total amortised investment per year*	Rs	–	74024
Total well farmers within watershed	No	74	
Total gross irrigated area in the watershed	Acre	863	
Average water used per acre of gross irrigated area (For sample farmers)	Acre-inch	–	9
Total water used on the total gross irrigated area in the watershed	Acre-inch	–	7767.5
Amortised cost of watershed treatment per acre inch*	Rs	–	9.53

Note: *Discount rate is 2 per cecnt; life of watershed structures considered is15 years. Amortised cost of WDP per acre-inch = [Rs74,024 ÷ 7,767.5 acre-inch]= Rs 9.53

Table 4: Groundwater Yield of Wells in Basavapura Watershed, Karnataka, 2000

(In gallons per hour)

Well Type	Within WDP						Outside WDP					
	Before WDP (in 1994)			After WDP (in 2000)			Before WDP (in 1994)			After WDP (in 1994)		
	SF	LF	Overall	SF	LF	Overall	SF	LF	Overall	SF	LF	Overall
Dugwell	371	157	264	401	491	446	1477	538	1008	0	0	0
Borewell	1106	1194	1150	1421	1431	1426	1314	1625	1470	940	1544	1242
Dug cum borewell	–	626	626	–	626	626	–	–	–	–	–	–
Filter point well	1698	1867	1783	1867	1867	1867	–	–	–	–	–	

Note: (1) SF = Small Farmers; LF = Large Farmers, (2) WDP in Basavapura was initiated during 1994.

Table 5: Cropping Pattern in Basavapura WDP, Karnataka, 2000

(In acres)

Crops	Within WDP Area				Outside WDP Area			
	Before 1994		After 1994		Before 1994		After 1994	
	Area	Proportion	Area	Proportion	Area	Proportion	Area	Proportion
Maize	108.00	30.51	117.75	25.23	79.50	35.89	78.50	40.89
Mulberry	66.00	18.64	109.00	23.35	38.00	17.16	30.50	15.89
Paddy	24.00	6.78	88.00	18.85	27.50	12.42	24.00	12.50
Ragi	27.00	7.63	54.75	11.73	9.00	4.06	8.00	4.17
Sugar cane	9.00	2.54	26.00	5.57	2.50	1.13	2.50	1.30
Sunflower	15.00	4.24	24.00	5.14	30.50	13.77	17.50	9.11
Grass (fodder)	14.50	4.10	3.00	0.65	11.00	4.97	1.50	0.78
Flower	3.00	0.85	10.50	2.25	2.50	1.13	6.50	3.39
Chilli	4.25	1.20	4.75	1.02	7.00	3.14	5.00	2.60
Tomato	3.50	0.99	4.00	0.86	4.00	1.81	4.00	2.08
Onion	58.50	16.53	3.50	0.75	9.50	4.29	10.50	5.47
Groundnut	5.50	1.54	18.50	3.96	0.50	0.23	0.50	0.26
Brinjal	-	-	2.25	0.48	-	-	-	-
Potato	15.75	4.45	0.75	0.16	-	-	3.00	1.56
Total	354.00	100.00	467.00	100.00	222.00	100.00	192.00	100.00

Note: - WDP in Basavapura was undertaken in 1994.

per cent) later on by 2000. The yield of dugwells before WDP was 1,008 GPH and all the dugwells non-functioning due to groundwater depletion by 2000. In the WDP yield of dugwells in kharif increased (by 70 per cent) from 264 gallons per hour (GPH) to 446 GPH. Among the nine dugwells, which completely dried up before WDP, four wells got recharged. In the WDP, the yield of borewells in kharif increased from 1,150 GPH to 1,426 GPH, an increase of 24 per cent. Yield of filter point wells in kharif increased marginally by 5 per cent and was not influenced by water harvesting structures, as they were located on the river path

In the WDP, gross irrigated area (GIA) devoted to water intensive crops like paddy and sugarcane increased from 33 acres to 114 acres (by 245 per cent) as a result of the implementation of WDP (Table 5) using higher volumes of groundwater resource available due to groundwater recharge. However, outside this WDP, the GIA under water intensive crops like paddy and sugar cane decreased marginally from 30 acres to 26 acres (by 13 per cent) due to groundwater depletion. In the WDP, farmers devoted 48 per cent of their irrigated area to water intensive crops like paddy, sugarcane, and mulberry. This is due to the larger volumes of groundwater they are reaping, reinforced by the degree of groundwater recharge from the surrounding water harvesting structures. Here, the water intensive crops like sugar cane and paddy share 24 per cent of the total gross irrigated area and contribute to 34 per cent of the net return generated.

Costs and Returns to Groundwater

The amortised cost of watershed development structures (Table 6) is taken as the annual fixed cost component of investment in the WDP and is included in the annual cost of irrigation to estimate the economics of irrigation. The amortised cost of WDP per acre-inch of water extracted by farmers was estimated as Rs 9.53. Before WDP, groundwater used per acre of GIA for small and large farmers was 5.95 and 5.96 acre-inches, respectively. After WDP water use per acre of GIA increased to 8.3 acre inches (by 39 per cent) for small farmers and to 9.21 acre inches (by 55 per cent) for large farmers (Table 7). Cost of irrigation per acre-inch of groundwater used, before WDP implementation in Basavapura micro watershed was Rs 180 and Rs 164 for small and large farmers, respectively. This decreased to Rs 105 (by 42 per cent) for small farmers and to Rs 81 (by 51 per cent) for large farmers due to WDP.The net returns per acre-inch of groundwater used for small and large farmers in Basavapura was Rs 1,226 and Rs 1,037 before WDP. After WDP the net return per acre inch of groundwater used increased marginally to Rs 1,260 (by 3 per cent) for small farmers and to Rs 1,485 (by 43 per cent) for large farmers. The net returns per acre of GIA increased from Rs 7,298 to Rs 10,505 (by 44 per cent) for small farmers and from Rs 6,181 to Rs 13,678 (by 121 per cent) for large farmers after WDP.

The groundwater extraction per acre of GIA was 5.96 acre-inches before WDP, and increased (by 50 per cent) to 8.96 acre-inches due to the recharge after WDP. The groundwater extraction by small farmers was 5.95 acre-inches per acre of GIA before WDP and increased (by 39 per cent) to 8.3 acre-inches. The groundwater extraction by large farmers was 5.96 acre-inches per acre of GIA and increased by 55 per cent to 9.21 acre-inches. The extraction per acre of GIA by small and large farmers is higher than the groundwater extraction by their peers outside WDP area whose groundwater extraction per acre of GIA was 5.6 and 8.8 acre inches, respectively (Table 7).

Irrigation cost per acre inch of groundwater in Basavapura watershed was Rs 168 before the WDP, and this decreased (by 48 per cent) to Rs 87 due to the increased availability of groundwater after WDP. The net return per acre inch of groundwater used was Rs 1,097 before WDP, and increased to Rs 1,424 (by 30 per cent) due to the WDP. The cost of irrigation per acre-inch of water decreased by 42 and 51 per cent for small and large farmers, respectively after WDP. The cost incurred by farmers outside the watershed programme is 22 per cent higher than farmers in the WDP (Table 7).

The net returns per acre of GIA increased in the watershed, after WDP from Rs 6,505 to Rs 12,758 by 96 per cent. The net return per acre-inch of groundwater used increased by 3 and 43 per cent for small and large farmers, respectively after WDP. The net return per farm gained by small and large farmers in Basavapura is 57 and 42 per cent higher than small and large farmers outside WDP respectively. Water harvesting structures have improved economic access to water resource for irrigation by increasing groundwater recharge, reducing the cost of irrigation and increasing the net returns per acre of gross irrigated area (Table 7).

Irrigation cost per acre-inch of groundwater used for farmers in the upstream and downstream was Rs 292 and Rs 139, respectively before WDP. After the WDP due to the recharge effect of water harvesting structures, this decreased by 67 per cent to Rs 97 for farmers in the upstream and by 40 per cent to Rs 83 for farmers in the downstream. The irrigation cost per

Table 7: Impacts of WDP in Basavapura, Karnataka, 2000

Particulars	Within WDP Area							Outside WDP Area (in 2000)		
	Before WDP (in 1994)			After WDP (in 2000)			Per Cent Change			
	Small Farmers	Larger Farmers	Overall	Small Farmers	Larger Farmers	Overall		Small Farmers	Larger Farmers	Overall
Gross irrigated area (acre)	5.8	11.4	8.8	7.5	15.1	11.7		5.7	13.6	9.6
Cropping intensity (per cent)	192	146	156	216	164	175	19	181	159	165
Groundwater used per acre of gross irrigated area (acre-inch)	5.95	5.96	5.96	8.3	9.21	8.96	50	5.6	8.8	7.86
Irrigation cost per acre-inch Of groundwater used (Rs)	180	164	168	105	81	87	-48	257	74	112
Net returns per acre of gross irrigated area (Rs)	7298	6181	6508	10505	13678	12758	96	6051	8757	7961
Average distance of wells From water harvesting structures (metre)	NA__	NA__	NA__	269	188	225	NA	NA__	NA__	NA__
No of farmers	18	22	40	18	22	40		10	10	20

Note: Irrigation cost and net returns before WDP was calculated based on the current prices. Irrigation cost is amortised cost per acre-inch which includes amortised cost of irrigation wells plus the amortised cost of watershed treatment. " — " –NA.

acre-inch decreased by 51 and 29 per cent for small farmers in the upstream and downstream, respectively, the irrigation cost decreased by 83 and 42 per cent for large farmers in the upstream and downstream, respectively, after the WDP (Table 8).

The net returns per acre of gross irrigated area for farmers in the upstream and downstream was Rs 6,508. After WDP, the net returns per acre of GIA for farmers in the upstream increased to Rs 10,810 (by 66 per cent) and to Rs 13,672 (by 110 per cent) for farmers in the downstream. The irrigation intensity for farmers in the upstream and downstream was 198 per cent and 174 per cent, respectively. After WDP implementation irrigation intensity increased to 219 per cent (by 21 per cent) for farmers in the upstream and this increased marginally to 175 per cent (by 1 per cent) for farmers in the downstream (Table 8).

Net returns per rupee of irrigation cost for farmers in the upstream and downstream was 4.4 and 7.52 before WDP implementation. After the WDP, this increased to 13.26 (by 201 per cent) for farmers in the upstream and to 17.9 (by 138 per cent) for farmers in the downstream. The higher rate of increase in the upstream is an apparent pointer to the contribution of WDP, since the downstream benefits are obvious (Table 8).

Access to Groundwater

Physical access is the volume of groundwater used per acre of GIA, is directly proportional to water yield of irrigation well and inversely proportional to amortised cost of water per acre-inch. For a per cent increase in the cost of water per acre-inch, physical access fell by 0.19 per cent (Table 9). If the cost of water per acre-inch increases by a rupee (from the geometric mean of Rs 87 per acre-inch) the water used per acre of GIA falls (significantly) by 0.01926 acre-inch (=435 gallons). This indicates that farmers do respond to negative externalities in groundwater extraction inside the watershed. If the electricity provided for pumping groundwater is priced, the farmers will make adjustments in their crop pattern to maximise net returns to scarce groundwater. In the absence of WDP, this response would have been elastic. This also demonstrates the indispensability of groundwater for irrigation in the watershed. For a per cent increase in well yield, the physical access rose by 0.77 per cent (Table 9). If the well yield increases by one more gallon per hour (from the geometric mean of 1,502 GPH), the water used per acre of GIA increases significantly by 0.0046053 acre-inch (=104 gallons).

In 2000 there were 61 functioning wells irrigating a gross area of 467 acres, extracting 105 acre-inches per farm. Before the WDP, 37 functioning wells irrigated a gross area of 354 acres extracting 70 acre-inches per farm. At the same time, there were 21 functional wells irrigating a gross area of 192 acres extracting 75 acre-inches per farm outside WDP areas. This shows the influence on the physical access to water resource through watershed programme.

The cumulative interference effect on productivity of functioning wells is dampened by the groundwater recharge in the surrounding water harvesting structures. The extraction of groundwater in the WDP area is higher than outside WDP area. This is due to the cultivation of water intensive crops like paddy and sugar cane. This shows that the physical access to groundwater resource has improved.

Economic access to groundwater increased with water used on the farm. For a per cent increase in water used on the farm, economic access increased by 0.57 per cent. The distance of irrigation well from water harvest structures did not significantly influence the economic access in the watershed. This apparently is a positive indication of the distribution of benefits across farms irrespective of the distance of the irrigation wells from the water

Table 9: Analysis of Physical Access to Groundwater in Basavapura Watershed, Karnataka, 2000

Dependent variable: Natural Log of groundwater used per acre of gross irrigated area
(Geometric mean groundwater use per acre = 8.96 acre-inches)

	Coefficient	t- value	R^2	Geometric Mean
Natural Logarithm of Intercept	-2.673*	-3.392	0.62*	
Independent variables				
1 Natural Logarithm of well yield (Gallons per hour)	0.772*	7.247		1502
2 Natural Logarithm of cost of water per acre-inch (Rs)	-0.187*	-3.418		87

Note: *Significant at 1 per cent.

Table 10: Regression Analysis of Economic Access to Groundwater

Dependent variable: Natural Logarithm of Groundwater extracted per rupee of amortised cost of irrigation
(Geometric mean = 0.011 acre-inch per rupee of amortised cost of irrigation)

	Coefficient	t- value	R^2	Geometric Mean
Natural Log of Intercept	-5.983*	-6.373	0.359*	
Independent variables				
1 Natural Log of water used on the farm (acre-inch)	0.57*	4.332		105
2 Natural Log of well distance from water harvesting structures (metres)	-0.203	-1.433		225

Note: * Significant at 1 per cent.

Table 8: Impacts of WDP for Different Classes of Farmers in Upstream and Downstream, in Basavapura, Karnataka

Particulars	Before WDP (in 1994)						After WDP (in 2000)					
	Upstream Farmers			Downstream Farmers			Upstream Farmers			Downstream Farmers		
	SF	LF	Overall	SF	LF	Overall	SF	LF	Overall	SF	LF	Overall
Gross Irrigated area(acre)	5	4.8	4.98	7.2	12.8	11.4	7.3	15.4	9.4	7.9	15.0	13.2
Cropping intensity (per cent)	185	118	153	202	151	157	219	194	207	210	158	164
Groundwater used per acre of gross irrigated area (acre-inch)	4.99	5.21	5.0	7.3	6.0	6.2	7.4	9.88	8.4	10.14	9.06	9.2
Irrigation cost per acre-inch of groundwater used (Rs)	221	508	292	141	139	139	109	85	97	100	80	83
Net returns per acre of gross irrigated area (Rs)	7240	4207	6508	7378	6346	6508	10458	11313	10810	10592	14219	13672
Number of farmers	12	4	16	6	18	24	12	4	16	6	18	24

Note: Irrigation cost is amortised cost per acre-inch which includes amortised cost of irrigation wells plus the amortised cost of watershed treatment. Net returns per rupee of irrigation cost was derived to compare the net returns per acre-inch of groundwater with the irrigation cost per acre-inch of groundwater, and calculated as: [Net returns per acre-inch of groundwater used ÷ irrigation cost per acre-inch of groundwater].

harvest structures within the watershed where WDP is undertaken (Table 10). This is a positive development from the equity view point.

The results of the study amply confirm the positive role of watershed development programme. Using 'Before-After', after the WDP, the cost per acre-inch of groundwater reduced by (Rs 168 minus Rs 87 =) Rs 81, i e, a reduction by 48 per cent, when compared with the cost before WDP. Using 'With -Without' figures, with the WDP, the cost per acre-inch of groundwater reduced by (Rs 112 minus Rs 87 =) Rs 25, i e, a reduction by 22 per cent.

Using 'Before-After' figures, in the upstream, the cost per acre-inch of groundwater reduced by (Rs 292 minus Rs 97 =) Rs 195, a reduction by 67 per cent. In the downstream, the cost per acres-inch of groundwater reduced by (Rs 139 minus Rs 83 =) Rs 56, a reduction by 40 per cent. These are indications that WDP is responsible for reducing the cost of groundwater, even after including the negative externality cost due to the 'tragedy of commons'.

Using 'Before-After' figures, after the WDP, the net return per acre of gross irrigated area (GIA) increased by (Rs 12,758 minus Rs 6508 =) Rs 6,250, i e, an increase by 96 per cent, when compared with the net returns before WDP. Using 'With-Without' figures, with the WDP, net return per acre of GIA increased by (Rs 12,758 minus Rs 7,961 =) Rs 4,797, i e, an increase by 60 per cent.

Using 'Before-After' figures, after the WDP, in the upstream, the net return per acre of GIA increased by (Rs 10,810 minus Rs 6,508 =) Rs 4,320, i e, an increase by 66 per cent. In the downstream, the net return per acre of GIA increased by (Rs 13,672 minus Rs 6,508 =) Rs 7,164, i e, an increase by 110 per cent. Considering savings in the cost of groundwater and/or the enhanced net returns, the WDP impacts in reducing the tragedy of the commons which lead to negative externality due to well interference are well appreciated.

Considering the WDP experience of six years, and conservative estimates in the reduction in the cost of groundwater by 22 per cent and enhanced net returns to the tune of 60 per cent, the Basavapura watershed development programme has apparently proved its contribution towards reducing the effect of drought and reducing the commons tragedy. The negative externality due to partial and complete failure of irrigation wells has been reduced due to watershed development programme. Thus, construction of water harvesting structures through watershed development approach enhances the groundwater recharge in hydro-geological situations even if there is cumulative interference effect among irrigation wells.

As long as there is a WDP, proximity of irrigation wells to water harvesting structures is not a requirement for deriving the benefit from recharge as seen in this study. The watershed development programme contributed richly to physical and economic access to groundwater resource for irrigation. The watershed development programme has helped to reduce the gap between the small and large farmers in respect to physical access to groundwater resource. The small farmers in fact have been able to reap higher net returns per acre of GIA. EPW

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Notes

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1 The initiative taken by V S Prakash, the then hydrogeologist of CGWB,in this regard is commendable.

2 For the estimation of yield of dugwell, farmers were asked to indicate the water column height the well would regain after 24 hours of pumping. For round shaped dugwells the expression ($\pi r^2 h * 6.2288) \div 24$ gives the yield of water in gallons per hour where r = radius of dugwell (in feet), h = height of water column the dugwell regains after 24 hours of pumping (in feet). The volume of water impounded in the well after 24 hours of pumping varies from season to season depending on rainfall, recharge etc.

3 One acre-inch has 22,611 gallons of water

4 The average water extracted per acre of gross irrigated area is 9 acre-inches. The total gross irrigated area of the entire watershed was 863 acres. Thus, the total groundwater use is 7,768 acre-inches and the cost of watershed project pe acre-inch of groundwater extracted is 20 cents (Rs 9.53). An exchange rate of 1 Rupee = US $ 0.02 is taken.