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Downward Dividends of Groundwater Irrigation in Hard Rock Areas of Southern Peninsular India

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DOWNWARD DIVIDENDS OF GROUNDWATER IRRIGATION IN HARD ROCK AREAS OF SOUTHERN PENINSULAR INDIA

Anantha K H[1]

Abstract

An important input for sustainable agricultural development in hard rock areas is access to groundwater irrigation. In hard rock areas, due to cumulative well interference, the life of irrigation wells and their groundwater yield is gradually declining and creating several externalities. As a result, the dividends of groundwater irrigation are declining. This study is an attempt to assess the impact of declining groundwater on benefits of irrigation in the central dry zone of Southern peninsular India. The study clearly suggests the need for supply and demand side interventions. Therefore, the objective of public policy should be to minimise adverse ecological effects with minimum damage to the interests of the poor in the areas under stress.

Introduction

Groundwater is one of the lead inputs for agricultural development in arid and semi-arid regions of India.[i] With rapidly declining public investment in irrigation and the associated environmental problems, groundwater irrigation has emerged as an important input for secured agricultural development in recent years. Institutional changes and technological progress have made it possible to meet the increasing demand for secure irrigation systems through innovative techniques to drill deeper wells and subsidised rural development programmes. The advent and spread of energised pumping technology enabled rapid groundwater development and the emergence of socio-economic systems that depend on its reliability (Shah 1993; Dhawan 1995; Burke and Moench 2000).[ii]

Ever since groundwater was recognised as an alternative source of irrigation, the face of Indian agriculture shifted more to the water-intensive cropping system (Dhawan 1988; Shah 1993; Janakarajan 1993; Nagaraj 1994). This prompted development of well and bore-well irrigation in many drought-prone regions. As a result, there was an increase in the net irrigated area. This ultimately led to over-exploitation of groundwater (Janakarajan 1993; Nagaraj *et al* 1994; Vaidyanathan 1996; Chandrakanth and Arun 1997; Shivakumaraswamy and Chandrakanth 1997; Nagaraj 1994; Reddy 2003; Janakarajan and Moench 2006; Anantha and Raju 2008; Palanisami *et al* 2008). Currently, in India, about 60 per cent of the cultivated area is irrigated by groundwater (Shah 2007). Groundwater development helped farmers use more intensive production techniques that required higher inputs and associated capital investments (Moench 2003). The demand for groundwater irrigation has led to an increase in the number of wells. Since the same aquifer was shared by many users, the extraction rate exceeded its natural recharge rate. Thus, development was inconsistent with investment, resulted in

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competitive extraction and a concomitant secular lowering of the groundwater table. This indicates that as groundwater over-exploitation became severe, agricultural production declined and the over all economic future of regions became uncertain.

Further, the lack of knowledge among farmers about the overwhelming effects of groundwater over-exploitation influenced a strong socio-economic and environmental predicament. A major portion of India's irrigation wells is located in the hard rock areas where both recharge and discharge potential presently face severe stress (Nagaraj and Chandrakanth 1995). The hard rock areas have hard non-porous, igneous and metamorphic rocks, expected to store not more than 10 per cent of the annual rainfall (Radhakrishna 1971). The benefits of irrigation have been highlighted in numerous studies but the negative impact of declining groundwater on agricultural development has not been adequately analysed. This paper is an attempt to understand the effects of declining groundwater in the Central Dry Zone of Karnataka. In this study, downward dividends of groundwater irrigation refer to the adverse impact of depletion of groundwater on its access and utilisation. This affects the welfare of communities depending on groundwater. In this context, the downward dividends may include unequal access to groundwater, reduction in the well yield, increasing well depth, increasing cost per unit of water, declining water use efficiency and debt burden.

The paper is organised as follows: It begins with the introductory section. The analytical approach, including methodology, is presented in Section 2. Section 3 comprises the results and discussion on access to groundwater, cost and returns from groundwater irrigation, negative externality cost, water use efficiency and financial implications of groundwater over-exploitation. Section 4 summarises the broad findings of the study.

Analytical approach

The central dry zone is one of the hard rock areas that lies in the central part of the state. The zone consists of 17 taluks covering a total geographical area of 20,112.81 sq. kms. The rainfall ranges between 455.5 to 717.4 mm in the zone. Agriculture is the major occupation with about 60 per cent of the working population cultivating land. Using the index of cumulative well interference (ICWI), two taluks were selected for a detailed analysis based on the magnitude of the problem of cumulative well interference.[iii] The selected taluks are in the low well interference area (LWIA) and high well interference area (HWIA).

Using the Participatory Rural Appraisal (PRA) method, the number of wells (both functional and non-functional), the depth of the wells, approximate distance between the wells, the size of the farms and farmers names were mapped in each village. The PRA method was helpful in locating irrigation wells in relation to cumulative well interference. Using the PRA map a sample of 225 farmers who had irrigation wells that were densely placed was drawn from ten villages in two taluks. According to data obtained from Department of Mines and Geology (DMG) and Central Ground Water Board (CGWB), the LWIA is less affected by the problem of cumulative well interference. Therefore, we considered LWIA for comparison with HWIA.[iv] The information gathered includes the socio-economic profile, details of irrigation wells, access to groundwater irrigation, details about agricultural inputs and outputs and so on. Outputs are based on harvest figures reported in kilograms or quintals by farmers and converted to weight measures, based on the nearest market setting. The estimation methods and relevant concepts are explained below.

Annual cost of irrigation

The annual cost of irrigation was estimated by amortising the capital cost on well investment. The annual irrigation cost was arrived at by adding the amortised cost of irrigation wells, amortised cost of conveyance structures, annual repairs and maintenance costs on the farm.

The amortised cost of irrigation is the sum of amortised investment on all wells on the farm, pumpsets and accessories, conveyance structures, overground storage structure and annual repairs and maintenance cost of all wells. In this study, as in other studies, a discount rate of 2 per cent was used in amortisation reflecting long-term sustainable rate (Chandrakanth *et al* 1998a, 1998b, 1998c, 2004). The capital cost of the well was amortised over its entire life span. An interest rate of 2 per cent represented the rate of inflation in the cost of well components like labour, pumpsets and other accessories.

The amortised investment on each well was estimated with the help of following formula:

Amortised Investment on Well = $[(CI)*(1+i)^{AL}*i]/[(1+i)^{AL}-1]$ (1)

$CI = (II)*(1+i)^{(dc-di)}$ (2)

II = initial investment on well

dc = year of data collection (2007)

di = year of drilling irrigation well

AL = average life of wells

i = interest rate

CI – compounded investment

Amortised cost of borewell = $[(\text{Compounded cost of borewell})*(1+i)^{AL}*i)]/[(1+i)^{AL}-1]$ (3)

Compounded cost of borewell = $(BW_{cost})*(1+i)^{(2007\text{-year of drilling})}$ (4)

Amortised cost of pump set and accessories =

$\{[(\text{Compounded cost of pump set + Compounded cost of pump house})*(1+i)^{AL}*i]/[(1+i)^{AL}-1]\}$ (5)

Amortised cost of conveyance =

$\{[\text{Compounded cost of conveyance pipe used})*(1+i)^{AL}*i)/(1+i)^{AL}-1]\}$ (6)

Average life of well

Average life of well = $\sum_{i=1}^{n}(fi)(xi) \div \sum_{i=1}^{n}(fi)$ over i (7)

Where,

f = frequency of wells worked

x = age of well (1,2,3,4....n)

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

Access to groundwater

Access to groundwater was measured in terms of physical and economic access. Physical access to groundwater was related to resource yield, which depends on the depth of the wells and availability of water. Economic access to groundwater is related to its cost of extraction. Physical access to groundwater can be measured in terms of the number of wells, depth and yield levels whereas economic access is determined by cost per acre-inch of water extraction and area irrigated (Chandrakanth *et al* 2004).

Physical access: Physical access was analysed by regressed groundwater used per acre of gross irrigated area as a function of average well depth, well yield and amortised cost per acre-inch of groundwater. It was hypothesised that physical access to groundwater varied directly with well depth, well yield and inversely with amortised cost of groundwater per acre-inch in the log-linear relation:

$$\ln wu = \ln a + b_1 \ln wd + b_2 \ln wy + b_3 \ln cw \qquad (8)$$

Where,

wu = Water used per acre of gross area irrigated

wd = Well depth (ft)

wy = Water yield (gallons per hour)

cw = Cost of water (Rupees per acre-inch of water)

Economic access: The economic access to groundwater was measured by amortised cost of groundwater per acre-inch and hypothesised to vary inversely with well depth, water yield from the well and gross irrigated area. The economic access to groundwater was regressed on well depth (ft), water yield for the well (in gallons per hour) and gross irrigated area (in acres). The estimated function in log-linear form is:

$$\ln cw = \ln a + b_1 \ln wd + b_2 \ln wy + b_3 \ln gia \qquad (9)$$

Where,

cw = Amortised Cost of Groundwater (Rs per acre-inch)

wd = Well Depth (ft)

wy = Groundwater Yield from the Well (gallons per hour)

gia = Gross Irrigated Area (in acres)

Negative Externality

The annual negative externality cost of irrigation wells was estimated as the difference between the amortised cost per well and the amortised cost per functioning well. This can be written as:

$$NEC = AC_{PW} - AC_{FW} \qquad (10)$$

Where,

NEC = Negative Externality Cost

AC_{PW} = Amortised cost per well

AC_{FW} = Amortised cost per functioning well

The difference between AC_{PW} and AC_{FW} was considered as the externality cost due to the following reasons:

(i) in hard rock areas, due to rapidly declining groundwater levels, the average age and life of wells both are falling

(ii) if all wells on the farm are functioning, then there will be no externality

(iii) if the failure rate of wells is high, then the difference between the amortised cost per well and that of working well would also be high as the cost of well failure due to interference would be apparent and hence the externality cost. Thus, the amortised cost per well minus amortised cost per functioning well gives the negative externality or the social cost per well faced by farmer.

Water use efficiency

In order to estimate the efficiency in the usage of water on the farm, the volume of water used per farm was estimated. Since there was no measuring equipment like water meter or electricity to use measuring equipments like energy meters, samples of 15 borewells were chosen covering all the villages for discharge measurement. The measurement of discharge was carried out by volumetric method - the number of seconds taken to fill a water container of 15 litres for each selected well was used to compute irrigation water used within the boundary of their classification like horsepower. This data was extrapolated to obtain the groundwater yield in gallons per hour (GPH). An extensive discussion was held with hydrologists and water resource engineers of the region to confirm the result.

The efficiency in the use of the groundwater on the farms was estimated by comparing the economic optimum use with the actual groundwater used by the farmers. The economic optimum use of groundwater was measured by estimating a production function with gross returns per farm per annum realised from the groundwater-irrigated crops as the dependent variable and the total volume of groundwater used per farm per annum as the independent variable. The estimated Cobb Douglas production function is given below:

$$Y = AX^{a} \qquad (11)$$

The form of Cobb Douglas model is $Y = AX^{a}$ with gross returns (Y) depending on the volume of groundwater used (X) for irrigation in acre-inch. The optimum volume of irrigation water was estimated under the current pricing regime. The optimum dose of irrigation water X* was obtained by equating the marginal returns from groundwater with the price of groundwater as:

$$X^* = (a \times Y) \div P_x \qquad (12)$$

Here P_x = Annual amortised cost of well irrigation per acre-inch of groundwater used in rupees.

To sum up, this study used the above analytical framework for the estimation purpose. The concept of amortised cost is an appropriate way of discounting groundwater cost because groundwater is considered as a social good. The physical and economic access to groundwater describes the feasibility of groundwater irrigation in view of increasing drawdown. Similarly, the concept of efficiency in use of water describes the level of groundwater used efficiently on the farm.

Results and Discussion

Access to land and water resources

Availability and access to land and water resource is critical for livelihood in agrarian economies. Equitable access to these resources provides the foundation for an asset pyramid that would not have been possible with landlessness and rain-fed agriculture. It enables access to higher yields while reducing the risk of loss. Adequate availability of land and water resource is the prerequisite for achieving sustainable development. In the hard rock areas, access to land and water resources provided opportunities for thousands of small farmers to deal with their poverty. Due to their unfavorable location, there was limited access to land and water resources.

The average farm size was higher in LWIA (10.7 acres) than in HWIA (6.1 acres). However, the proportion of area under irrigation was about 47 per cent in LWIA compared to 51 per cent in HWIA. The average farm size varied positively with land holding size in both the areas (Table 1). The physical access to groundwater resource clearly indicates that small farmers were facing the worst of the resource scarcity problem while large farmers were comparatively better off. The gross area irrigated per functioning well for small, marginal and medium farmers was slightly higher in HWIA than in LWIA. However, gross area irrigated per functioning well for large farmers was 2.12 hectares in LWIA and 2 hectares in HWIA. This indicates inequality in the pattern of resource utilisation between small and large farmers. This is largely attributed to land ownership and access to credit facility because it would enhance access and utilisation of the resource on a larger scale.

Table 1: Access to Land and Irrigation equipments in the Sample Areas

Size class	Total land owned (acres)	Total operated land (acres)^	Total irrigated land (acres)	No. of borewells owned	Average area irrigated per well (acres)$
LWIA [102]	**1076.3**	**1087.6[10.7]**	**511.4**	**232**	
Marginal[N=10]	20.5	22.1[2.2]	13.8 (2.7)	11 (81.8)	0.62
Small [N=37]	186.6	227.8[6.1]	108.9 (21.3)	55 (70.9)	1.13
Medium [N=26]	252.4	265.7[10.2]	126.5 (24.7)	62 (58.1)	1.42
Large [N=29]	616.8	572.2[19.7]	262.2 (51.3)	104 (48.1)	2.12
HWIA [123]	**804**	**751.1[6.1]**	**383.1**	**398**	
Marginal [N=15]	26.7	26.05[1.7]	17.3 (3.4)	46 (23.9)	0.64
Small [N=73]	342.3	357.5[4.9]	181.5 (47.4)	245 (21.2)	1.41
Medium [N=22]	212.0	207.3[9.4]	90.3 (23.6)	69 (34.8)	1.52
Large [N=13]	223.0	160.3[12.3]	94.0 (24.5)	38 (50.0)	2.00

Notes: (1) $ Average extent of irrigated area is calculated for functioning wells only and this includes area irrigated through water markets as well.
(2) Figures in parentheses indicate percentage of functional wells and area irrigated.
(3) ^ Total operated land is greater than the total land owned and this is due to land leased in for cultivation purposes.
(4) Figures in square brackets indicate the respective average farm size.

Source: Primary survey.

The distribution of irrigation equipment (borewells) seems to be less equitable in HWIA than in LWIA where large farmers owned more wells (Table 1). This was due to the high rate of well failure. Farmer invested in additional wells or deepened existing wells. But the resource-poor small and marginal farmers could not do so due to their poor capital base. This situation aggravated the inequity in resource extraction between resource rich and resource-poor farmers. However, the proportion of functioning borewells in LWIA was in favour of marginal and small farmers due to the variation in the occurrence of groundwater.

Access to groundwater

The physical access to groundwater revealed that the large farmers were better off compared to small farmers because they could invest in additional wells and deepen existing wells. The proportion of functioning wells in the study area followed a positive association with the size of the landholding (Table 2). As the size of landholding increased the proportion of functioning wells also increased indicating that access to resource was determined by the land-ownership. Besides, water extracted per functioning well also proportionate to size of landholding. In the hard rock areas due to the rapidly depleting groundwater resource, the proportion of functioning wells also declining constantly. This also explains the density of wells. It is important to note that the wells per farm were high in the case of small and marginal farmers compared to medium and large farmers in both the areas (Table 2). It implies that the small and marginal farmers were new to the resource extraction activity. Thus, the number of wells owned by them was high but the functioning wells were low because of resource scarcity. Large farmers could deepen the wells so they had a higher number of functioning well compared to the small farmers. This was obvious given the resource capability of these farmers. The larger number of wells per farm in HWIA reflected the intensity of competitiveness among different farmers as a result of resource scarcity. It motivated even small farmers to sink more wells. More often than not, a majority of these wells failed while the remaining wells yielded less water. Thus, to sustain crops and to continue with agriculture the farmers either deepened existing wells or sunk new wells.

The results indicate that the annual irrigation cost per acre was higher for marginal (Rs. 3,527 and Rs. 11,357) and small farmers (Rs. 2,300 and Rs. 6,074) than the medium (Rs. 1,189 and Rs. 4,796) and large farmers (Rs. 1,648 and Rs. 4,530) in LWIA and HWIA respectively (Table 2). Importantly, the operation and maintenance cost was the major component in the annual irrigation cost of irrigation wells. The irregular supply of power and deeper aquifers resulted in frequent burning of motors and pumps. More often, small and marginal farmers, due to financial crisis, purchased low quality accessories that were vulnerable to irregular power supply. Therefore, the repair and maintenance cost was huge for small and marginal farmers.

Table 2: Access to Groundwater Resource by Farmers in the study area

Particulars	LWIA				HWIA			
	MF	SF	MDF	LF	MF	SF	MDF	LF
Proportion of functional wells	49.5	75.0	62.1	81.8	40.7	30.4	49.0	67.9
Wells per farm	1.97	1.17	1.13	0.93	3.86	2.31	1.34	0.73
Functional wells per farm	0.46	0.88	0.70	0.85	0.49	0.70	0.65	0.57
Annual irrigation cost per acre (Rs)	3527	2300	1189	1648	11357	6074	4796	4530
Water extracted per functional well (acre-inch)	16.0	77.5	50.7	67.6	57.4	82.5	48.8	110.8
Number of failed wells per functioning well	1.0	0.3	0.6	0.2	1.5	2.3	1.0	0.5

Note: MF: Marginal Farmers; SF: Small Farmers; MDF: Medium Farmers; LF: Large Farmers

The water yield and the area irrigated by these wells varied between villages that were affected by severe well interference problem and those that were not. For instance, in LWIA, nearly 37 per cent of the wells were irrigating a gross area of more than 10 acres compared to 25.4 per cent of the wells irrigating the same area in HWIA. Similarly, less than 15 per cent of the wells were irrigating more than 5 acres of net irrigated area in both LWIA and HWIA. This implies that the gross irrigated area (GIA) and net irrigated area (NIA) of LWIA was high due to low well interference and the cropping pattern. However, in HWIA, the area irrigated per well (both GIA and NIA) was low due to low yield of wells and fragmented landholdings.

There was a positive relation between water extracted per functioning well and functional wells per farm in both areas. It indicates that higher the functioning well per farm, higher the water extraction. Since medium and large farmers owned more functional wells and had large land holdings, the water extraction per well was higher compared to marginal and small farmers. Similarly, the wells owned by small and marginal farmers did not get sustainable yield they were shallow and located in areas where cumulative well interference was a severe problem. This had a critical link with the rural livelihood systems because a majority of the people directly or indirectly depended on groundwater for subsistence. Any change in the supply of this critical resource had an overwhelming effect on the society.

Table 3: Physical Access to Groundwater Resource in the Study Area

Dependent variable = Groundwater used per acre of gross irrigated area (acre-inches)

Variables	Coefficients	t-statistics
Intercept	2.41	0.87
Well depth (ft)	0.787*	4.64
Well yield (gallon per hour)	1.07*	3.37
Cost per acre-inch (Rs.)	-0.356*	-8.21
R^2 = 0.39		

Note: * significant at 1 per cent level.

From the regression analysis, it has been found that well yield had a positive influence on volume of groundwater used while cost of groundwater exerted a negative influence. The results show that for one per cent increase in groundwater yield per well, the groundwater used per acre increased by 1.07 per cent. For one per cent increase in cost of groundwater, the groundwater used declined by 0.35 per cent and for one per cent increase in the well depth, the groundwater used increased by 0.78 per cent. The significant positive sign of the well depth indicates that the groundwater used was increasing. This indicates that there is an economic rationale for deepening of wells. But, not all farmers could afford it due to resource constraints. However, caution needs to be exercised while interpreting the results. The result indicated may not be a feasible solution for physical access to groundwater in the study area where aquifers are fast depleting leading to resource exhaustion. In such case, deeper wells may lead to well failure and deterioration in the economic condition of the household.

This has a negative impact on household income, which is directly related to groundwater used on the farm to stabilise productivity. Therefore, it is predicted that resource replenishment would enhance the physical access to groundwater, which in turn would enhance the household living condition by allowing the peasant community to stabilise productivity.

Table 4: Economic access to groundwater

Dependent variable: Cost of groundwater (Rs/acre-inch)

Variable	Coefficient	t-statistics
Intercept	5.91*	4.29
Depth (Feet)	0.74*	3.19
Yield (Gallons per hour)	-1.76*	-4.12
Gross Irrigated Area (Acre)	-0.71	-9.24
R^2 = 0.496		

Note: * significant at 1 per cent level.
Dependent variable = Natural logarithm of (1/cost per acre-inch of water)

Although the physical access to groundwater is determined by the depth of the well, its yield and the cost of groundwater, the economic access to groundwater is the major focal point in resource extraction and utilisation in agriculture development. Economic access provides an opportunity to enhance farm productivity by minimising the cost of extraction.

Economic access to groundwater decreased with the yield of the well and gross irrigated area but increased with depth of the well. This indicates that one per cent increase in the depth of the well increased economic access to groundwater by 0.74 per cent. However, as expected, the one per cent increase in yield and gross irrigated area decreased economic access to groundwater by 1.76 per cent and 0.71 per cent respectively (Table 4). This suggests that the increasing the depth of wells has a direct relation with increasing the cost of groundwater. This will have a devastating effect on the sustainability of the resource and farmers' welfare in this region.

Cost and returns from groundwater irrigation

A comparison of the annual cost and returns from groundwater irrigation indicates that irrigation cost contributes to the major difference in the cost of cultivation, which is higher, by 54 per cent, in HWIA than LWIA (Table 5). The rise in the annual irrigation cost is a partial indicator of scarcity of groundwater in HWIA. As indicated elsewhere the major portion of irrigation cost is that incurred on rising repair and maintenance works. During our field visit, it was learnt that many farmers complained about frequent burning of motors due to low voltage and fluctuation in power supply. This results in higher annual repair and maintenance costs on the farm. Due to rising irrigation cost, the net income is negative in both the areas, but LWIA is marginally better off compared to HWIA. Although gross income per well and per acre in HWIA and LWIA are comparable, considerable differences exist in terms of net income.

Table 5: Annual cost and returns from well irrigation per farm

Particulars	LWIA		HWIA	
	Per well	Per acre	Per well	Per acre
Volume of water extracted from well (M^3)	5992	1919	7039	2231
Volume of water extracted from well (AI)	58.3	18.7	68.5	21.7
Human+bullock labour (Rs.)	6691 (23)	2143	8150 (20)	2584
fertiliser cost (Rs.)	7028 (24)	2251	7462 (18)	2365
Other variable cost (Rs)	521 (2)	167	2699 (7)	855
Opportunity cost of capital @ 9 per cent[$]	1282 (4)	410	1648 (4)	522
Irrigation cost (Rs.)	13851 (47)	901	21410 (52)	1784
Total cost (Rs.)	29373 (100)	5872	41369 (100)	8110
Gross income (Rs.)	29331	9394	33037	10474
Net income (Rs.)	-42	3522	-8332	2364

Note: 1. [$] Interest rate during the fourth quarter of 2007 was considered to indicate the realistic opportunity cost of capital as field work was carried out during this time.

2. Figures in parentheses indicate percentage to the total cost.

3. One acre-inch (AI)= 102.79M^3.

The disaggregate picture demonstrates that the volume of water per acre was 16 per cent higher in HWIA. Similarly, all other costs (labour costs, fertiliser costs and other costs) were higher in HWIA. This clearly indicates that the irrigated agriculture in HWIA suffered from severe overdraft compared to LWIA. The cultivation of perennial crops, like coconut, in LWIA was a coping mechanism contributing to reasonable use of inputs such as groundwater resource. Therefore, the ideal solution would be to augment supply of groundwater and diversify the cropping pattern into low water intensive crops. Hence, improvement in the resource base supports the increasing demand for groundwater.

Statistical significance of Groundwater benefits

The statistical significance of the benefits of groundwater irrigation has been estimated by comparing the means with regard to major indicators between small and large farmers in LWIA and HWIA. The results indicate that there was considerable difference in the total quantity of groundwater used on the farm in the two areas (Table 6). In LWIA, the groundwater used on the farm by marginal and small farmers together was 68.53 acre-inches and 93.44 acre-inches by large farmers. Similar difference was observed in HWIA. A comparison of the total groundwater used in both areas shows that HWIA used more than LWIA. It was obvious because HWIA was dominated by short-term food crops that are hydrophilic. In terms of net returns per farm as well as per acre of GIA, small and large farmers were in a comfortable position in HWIA when compared to their counterparts in LWIA. For instance, the net return per farm as well as per acre of GIA was negative (Rs. -6212 per farm and Rs. -1120 per acre of GIA) in the case of small and marginal farmers in LWIA. However, the same category of farmers operated in the comfort zone because they earned Rs. 1300 and Rs. 792 per farm as well as per acre of GIA, respectively. The cost of groundwater per acre-inch corresponded with the water used in both the areas. The average cost per acre-inch of water was nearly one-and-a-half times higher for small farmers in LWIA whereas in HWIA, this amount was in the reverse order. This implies that the large farmers had higher gross irrigated area as demonstrated earlier which consumed more water, hence high cost per acre-inch of water. The results are statistically significant except for net return per farm and per acre of GIA signifying that there was a need for improving efficiency in the use of the resource in irrigated agriculture.

Table 6: Statistical significance of groundwater benefits

Particulars	Mean		Standard Deviation		t-value
	Marginal and Small Farmers	Large Farmers	Marginal and Small Farmers	Large Farmers	
			LWIA		
Total water used on the farm (acre-inch)	68.53	93.44	90.95	78.50	9.74*
Net return per farm (Rs.)	-6212	941.2	14481	30703	-0.846
Net return per acre of GIA (Rs.)	-1120	519.9	783.9	5349.6	-0.359
Net return per acre-inch of water (Rs.)	69.10	83.7	455.7	355.9	1.930***
Cost per acre-inch of water (Rs.)	644	461.84	686	765.99	7.50*
			HWIA		
Total water used on the farm (acre-inch)	74.36	99.22	72.49	103.31	9.45*
Net return per farm (Rs.)	1300.97	2380.48	32330	25279	0.587
Net return per acre of GIA (Rs.)	792.92	2141.26	12950	12569	1.01
Net return per acre-inch of water (Rs.)	167.78	273.08	784.85	1153.52	2.43**
Cost per acre-inch of water (Rs.)	939.37	1197.86	1448.66	2569.10	5.243*

Note: *, ** and *** significant at 1, 5 and 10 per cent level.

Negative Externality Cost

The negative externality cost was increasing due to the rapidly declining average age and life of wells in the hard rock areas. Thus, the increasing rate of well failure resulted in investment in coping mechanisms to secure a sustainable yield. The rising negative externality cost due to overexploitation indicated that the physical scarcity of groundwater in terms of decreased water yield from the wells and economic scarcity in terms of rising irrigation cost per acre-inch was evident in HWIA.

The negative externality in terms of failed wells in hard rock areas increased over time (Chandrakanth and Arun 1997; Shivakumaraswamy and Chandrakanth 1997; Nagaraj *et al* 2003). In LWIA, the proportion of failed wells increased with landholding size (Table 7). In the case of HWIA, the proportion of failed wells showed a mixed pattern. Since the proportion of failed wells was increasing, the capital investment on these wells was net loss to the farmers. Thus, the total amount of negative externality in these two areas was increasing. However, the total negative externality cost in HWIA was more than three times higher than in LWIA. The large gap in terms of negative externality cost of groundwater over-exploitation between LWIA and HWIA was due to physical as well as economic scarcity of groundwater resources. The total negative externality cost for the sample farmers was colossal, Rs. 8,35,260 in HWIA and Rs. 2,97,943 in LWIA (Table 7). The negative externality cost per farm was as high as Rs. 6,791 in HWIA and Rs. 2,921 in LWIA. These results were supported by the findings of Chandrakanth and Arun (1997) and Nagaraj *et al* (2003).

Table 7: Negative externality cost of well irrigation in the study area

Particulars	Marginal farmers	Small farmers	Medium farmers	Large farmers	Total	Marginal farmers	Small farmers	Medium farmers	Large farmers	Total
			LWIA					HWIA		
Total number of failed wells	2 (18.2)	16 (29.1)	26 (41.9)	55 (52.9)	99 (42.7)	36 (78.3)	193 (78.8)	45 (65.2)	19 (50.0)	293 (73.6)
Total negative externality cost (Rs)	536.9	49,452	88,816	1,59,407	2,97,943	1,86,029	3,67,287	1,08,001	1,73,942	8,35,260
Negative externality cost per well (Rs)	2,644	3,167	6,113	7,667	5,780	23,177	17,802	13,352	10,206	17,306
Negative externality cost per functioning well (Rs)	60	1,268	2,612	3,321	2,292	16,912	7,346	4,696	9,663	8,189
Negative externality cost per farm (Rs)	27	1,337	3,416	5,497	2,921	12,402	5,031	4,909	13,380	6,791
Negative externality cost per hectare of GIA (Rs)	96	1,122	1,736	1,502	1,440	26,614	5,072	2,956	4,571	5,424

The total negative externality cost for farmers varied from Rs. 536.9 for marginal farmers to Rs. 1,59,407 for large farmers in LWIA while the amount was higher with variations in HWIA (Table 7). Similarly, the negative externality per acre of gross irrigated area was also similar in LWIA. Small farmers were suffering the most in HWIA. This paradoxical situation was clearly explained by the comparatively higher yield of borewells in LWIA, which reduced the negative externality cost. The increasing negative externality cost in the study area was due to scarcity caused by the problem of cumulative well interference. The farmers failed to include negative externality as a cost while taking the decision on the proportion of groundwater to be used for irrigation and the investment on well improvement or on new wells because they tend to be myopic.

Water use efficiency

The efficiency in the use of groundwater per farm was estimated by comparing the economic optimum use of groundwater with actual use. The results indicated that the water extracted per farm was lowest

(58.46 acre-inch) for HWIA compared to LWIA (76.02 acre-inch). This was a pointer towards higher inadequacy of groundwater for farmers in HWIA. The actual water used by small farmers in LWIA was higher by 21 per cent over the same category farmers in HWIA. On the other hand, the water used by large farmers in LWIA was higher by 10 per cent over large farmers in HWIA (Table 8). This confirmed that groundwater scarcity was a severe problem in HWIA.

The gross return per farm was highest for farmers in LWIA (Rs. 38,245) compared to HWIA (Rs. 28,203). The gross return per farm for different size classes indicate that it was 25 per cent higher for large farmers in LWIA and higher by 4 per cent for small farmers in LWIA compared to HWIA. On the other hand, the cost per acre-inch of water extracted (marginal cost) was maximum for HWIA (Rs. 230) and the lowest for LWIA (Rs. 137). The ratio of gross income per acre-inch to cost per acre-inch was the highest for LWIA (1.1) followed by HWIA (0.5). Though, there was much scope to reach economic optimum by increasing groundwater use, the scarcity of the resource became a hindrance.

Table 8: Water Use efficiency per farm

Particulars	Unit	LWIA [N=102]			HWIA [N=123]		
		Small [N=47]	Large [N=55]	Total [N=102]	Small [N=88]	Large [N=35]	Total [N=123]
Elasticity (b)	Per cent	0.44	0.52	0.50	0.36	0.39	0.43
Gross returns (Y)	Rs.	24682	49836	38245	23575	39837	28203
Actual water use (WU) (X)	Acre-inch	59.76	89.91	76.02	49.24	81.63	58.46
Average gross returns (Y/X)	Rs. Per acre-inch	413	554	502	479	488	482
Marginal return of water (MR)	Rs.	147	206	144	35	88	121
Marginal cost of water (MC)	Rs.	181	99	137	190	311	230
MR/MC ratio		0.8	2.1	1.1	0.2	0.3	0.5
Optimum water use (X*)	Acre-inch	60	262	137	45	50	53
Gross returns at optimum water use (X*)	Rs.	24781	145093	68817	21386	24380	25437
Gross return per ha at actual water use (X)	Rs.	23950	22127	22640	26319	23798	25244
Gross returns per ha at optimum WU (X*)	Rs.	24060	64486	34522	24029	14599	20238
Increase in gross returns per ha	Rs.	110	42359	11882	-2290	-9199	-5006

The optimal use of groundwater was high in LWIA than the actual water use. However, the optimal use of groundwater was lower than the actual water use in HWIA (Table 8). This implies that the groundwater extraction in this area was beyond the replenishment capacity of the aquifers. Thus, the unit cost of water extraction was higher and the yield of the well lower. This poses serious threat to development of agriculture based on groundwater as it has a very close link with food production and rural development. Similarly, sustainability of groundwater was a major issue because the resource base was weakening due to heavy demand.

The elasticity of returns with respect to use of water was highest in LWIA (0.50), which shows that the efficiency in use was relatively better than in HWIA. In LWIA, the elasticity of returns ranged from 0.44 per cent for small farmers to 0.52 per cent for large farmers. The overall elasticity was 0.50 per cent, indicating that the farmers were operating in the second zone of production function. The actual use of water fell short by 45 per cent compared with the corresponding economic optimum use of water. However, in HWIA, the actual use of water was 10 per cent higher over economic optimum. Thus, in view of sustainability of groundwater resources, it can be suggested that farmers should take the initiative to adopt water-saving technologies to optimise the use of water.

Financial implications of groundwater scarcity

In order to understand the vulnerability and the pressure on households due to groundwater overdraft, the magnitude of burden of household debt was examined. This burden was assessed with the help of debt-asset ratios.[v] Households reporting outstanding debts ranged between 38.2 per cent in LWIA to nearly 49 per cent in HWIA (Table 9). The average debt per household was highest in HWIA (Rs. 60,475), in LWIA it was Rs. 44,974. The average debt per household was 34 per cent higher in HWIA over LWIA. Among the different landholding groups, marginal and small farmers were worst affected as far as the debt ratio was concerned in both areas. But the magnitude was high in HWIA where groundwater resource had reached a critical level. As a result, investment in restoring resource endowments increased. One reason for the high incidence of debt was problem of cumulative well interference resulting in well failure and non-availability of institutional loans. However, during our survey, it was learnt that the crop loans obtained through primary agricultural co-operatives was invested in deepening of wells, buying pump sets and building storage tanks. In view of the rapidly declining water table, this investment became redundant as the rate of well failure multiplied. As a result, the capacity to repay the principal loan amount was considerably reduced and the entire loan accumulated gradually.

Table 9: Extent of Household's Indebtedness across Size Class in the Study Area

Size class	Percentage of indebted households	Loan outstanding (Rs/household)	Loan-Repayment Ratio (LAR)	Total asset value (Rs/household)	Debt-Asset Ratio (DAR)
LWIA [N=102]	**38.2**	**44,974**	**0.50**	**137,439**	**0.32**
Small	32.4	23,500	0.60	100,229	0.23
Large	41.4	78,750	0.30	197,448	0.39
HWIA [N=123]	**48.8**	**60,475**	**0.60**	**154,613**	**0.39**
Small	50.7	61,040	0.50	130,637	0.47
Large	30.8	24,000	0.80	306,153	0.08

The debt-asset ratio indicates the ability of the household to solve the debt problem. That is, higher the debt-asset ratio, lower the repayment capacity and *vice versa*. Given the high rate of interest, (ranges between 24 per cent and 36 per cent per annum) for informal borrowing, an inverse relationship exists between debt-asset ratio and creditworthiness. High debt-asset ratio indicates low creditworthiness because it diverts the household income to interest payments keeping the capital debt unchanged. The high debt-asset ratio limits the productive investment of the household that would help repay the loans. This only encourages repayment of interest rate rather than the loaning amount. As a result, the household gets into the *debt trap*, which makes households vulnerable to the increasing debt ratio.

The debt-asset ratio varied greatly among the size classes in two areas. This clearly reflected the disadvantages of the problem of resource scarcity. Though farmers in LWIA also reported a high incidence of debts, their position was more comfortable than that of HWIA, which was reeling under the problem of cumulative well interference. In HWIA, the debt-asset ratio was inversely related to farm size indicating that debt burden was heavier on smaller farmers compared to medium and large farmers. This explains the financial needs of the households to restore resource endowments to maintain inter-generational equity. Thus, to avoid long-term consequences of increasing debt burden on the farming community, steps must be taken to ensure suitable pricing incentives for agricultural products and to strengthen the resource base to augment the supply of groundwater. This will help farmers to increase production and strike a balance between demand for loan and repayment.

Conclusion

The current situation has occurred mostly due to the problem of cumulative well interference, which induces rapid decline in the water table in view of heavy drawdown in hard rock areas. The comparison of 'high' and 'low' well interference areas confirms the fact that the cost of irrigation cost to the major difference in the cost of cultivation which is higher by 54 per cent in HWIA compared to LWIA. The rise in the annual cost of irrigation is a partial indicator of scarcity of groundwater in HWIA. Since watershed programmes have reduced the cost while augmenting supply through recharge (Chandrakanth *et al* 2004), efforts should be made towards effective implementation of such programmes.

The econometric effects on physical and economic access to groundwater present a conflicting picture. The results indicate that the depth of the well enhances the physical access to groundwater while that of economic access suffers. Therefore, the feasible solution would be to augment supply by taking recharge measures, which would enhance the resource base and balance demand and supply of groundwater. The negative externality cost of groundwater depletion and water use efficiency suggests that the low water-intensive crops and micro-irrigation systems would be better coping mechanisms to enhance efficiency and reduce negative externality costs. Since these mechanisms augment supply of groundwater, the pressure on this resource can be reduced to some extent. Therefore, farmers need to be educated on water conservation strategies to overcome the negative externalities of groundwater depletion.

The estimated water use efficiency clearly suggests the need for sustainable resource management. In LWIA, the actual water use falls short by 45 per cent compared with the corresponding economic optimum water use. Besides, in HWIA, the actual water use was 10 per cent higher over economic optimum. In fact, the cropping pattern followed in LWIA itself was a coping mechanism to reduce the stress on groundwater. Thus, keeping sustainability of groundwater resources, it can be suggested that farmers should take initiatives to adopt water saving technologies. In order to optimise the water use, farmers need to diversify the cropping pattern with water efficient crops.

The Economic implication of groundwater scarcity is severe as debt burden is taking its toll in both LWIA and HWIA. The outstanding loan amount on securing groundwater was 34 per cent higher in HWIA than LWIA. This is a partial indicator of the problem of resource scarcity. Therefore, the short-term policy focus should be more on farmers' welfare. This could be achieved by providing pricing incentives for their products, marketing facilities, infrastructure support such as better roads, transport, storage etc. This would strengthen the rural household economy to withstand such economic shocks.

The analysis clearly indicates the need for supply and demand side interventions. In hard rock areas, the low rainfall and limited supply of surface water sources are the major causes for the current level of groundwater exploitation. The fact is that in India livelihood and natural resources are intricately connected for a vast majority of the population. Therefore, the objective of the public policy should be to maximise equity in access to the resource where it is plentiful and to minimise adverse ecological effects in area under stress with minimum damage to the interests of the resource-poor.

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End Notes

i Globally, agricultural groundwater use of around 900 cubic kilometers a year supports annual output valued at $ 210 - $ 230 billion, yielding a gross productivity of about $ 0.23 - $ 0.26 per cubic meter of water abstracted. However, much of this use is concentrated in Bangladesh, China, India, Iran, Pakistan and the United States, which account for well over 80 per cent of global groundwater use (CAWMA 2007:396).

ii Several motives exist for this seemingly suboptimal choice – First, groundwater can be obtained individually and has the resilience of aquifers to dry periods. Second, its positive effect on the social and economic transition of many farmers and the protection groundwater provides against drought have allowed poor farmers to gradually progress into middle class status (Llamas and Santos 2005).

iii Cumulative well interference refers to the sum total effect of over-pumping of groundwater from several wells resulting in reduction in the yield and water level in the surrounding wells (Shivakumaraswamy and Chandrakanth 1997:1).

iv According to Groundwater Estimation Methodology – 1997, in safe areas, the stage of groundwater development is less than 70 per cent and there is no significant long-term decline of pre monsoon or post monsoon water level trend. In semi-critical areas, the stage of development is 70-90 per cent and water table during either pre or post monsoon shows a significant long term declining trend. In critical areas, stage of groundwater development is more than 90 per cent and long-term water level trend of either pre-monsoon or post monsoon shows a falling trend. Overexploited areas where groundwater development is more than 100 per cent and long term water table trend during both pre-monsoon and post-monsoon show significant declining trend (GoK 2005).

v Debt-asset ratio is defined as the ratio between total debt outstanding of a household and the fixed and durable assets the households own.

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