Artha Vijnana
Vol. XXXIX No.3 September.1997 pp.341-359

Well Interference and Aftermath: An Economic Analysis of Well Irrigation in Hard Rock Areas of Karnataka

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It has been brought out by many studies that well irrigation has many advantages over the canal and tank irrigation. However, only a few studies have analysed the interrelated problems of well irrigation. The present paper analyses the impact of well interference in terms of economic equity and sustainability by using field level data collected from well irrigated areas of Karnataka. The study concludes that net income per well and water use efficiency are lower in higher well interfered area compared to low interfered area. The price of water (per unit) pumped out from well is also much higher in well interfered area. Finally, the study suggests that the norms of inter-well distance in relation to groundwater availability should be strictly followed to avoid the adverse problem of well interference. For increasing the water use efficiency under the groundwater constrained situation, drip and sprinker method of irrigation should be promoted.

Introduction

The phenomenon of interactive effect of wells or well interference is the groundwater nexus between wells. Among the connected wells. groundwater withdrawal from one well results in reduction of groundwater yield and water level in the other. There may be either. one well to one well interaction or one well to many wells multiple interactive effects. The interference phenomena are obscure to the extent that one or more number of wells may be causing the problem. Hence, it is proper to study the predicament faced by the farmers due to 'cumulative' well interference. as it is difficult to discern the effect of a specific well on another well. Cumulative refers to the sum total effect of overpumping of groundwater from several (types and numbers of) wells resulting in reduction in the yield and water level in the surrounding wells. The National Geophysical Research Labouratory. Hyderabad. conducted number of tests on pump sets and recorded the discharge and water levels for wells with different inter-well spacings. They concluded that the isolation distance between (i) open well to open well should be 182 meters: and (ii) open well to Dug-Cum-Bore Well (DCBW) or Bore Well (BW) should be 250 meters to avoid the problem of interference. Hence. wells which are spaced below the threshold isolation distance limits prescribed are likely to be more affected from interference than those wells which pass this threshold.

*Department of Agricultural Economics. University of Agricultural Sciences. Hebbal. Bangalore 560024. This research was sponsored by the Ford Foundation (Grant number 920-0753). New Delhi. The authors are grateful for helpful comments from Dr. John Ambler and Dr. Ujwal Pradhan of the Ford Foundation. New Delhi. Dr K. Palanisamy. Tamilnadu Agricultural University. Coimbatore. Sri V. Jagannathan. Senior Hydrogeologist. Central Groundwater Board. Bangalore and Dr. Gurumurthy. Professor of Statistics. Dr. N. Nagaraj and Sri H. Chandrashekar. UAS. Bangalore. They are thankful to V. Gowramma. M. G. Nagaraja. M. G. Padma and M. Shamaladevi for their assistance

The main focus of this study is to estimate in economic terms, the effect of well interference (local overdraft) when pumping by a farmer significantly affects the pumping conditions of his/her neighbour. This effect may be localised in nature and may not be associated with a general decline in water table. The well failure or interference between wells occurs when a farmer's extraction is affected by the pumping cone of another farmer. In this study, the well failure/interference is defined as: (i) well that dries up because of new well (s) coming in (but not because of decline in rainfall); (ii) well that loses a large degree of its yield because of new well (s) coming in (but not because of decline in rainfall); and (iii) a depended well because of new well (s) coming in.

The well interference problem poses serious threats to the sustainability and equity in well irrigation. A large farmer who can afford to dig, drill or deepen one or many irrigation wells can seriously hamper the irrigation prospects of neighbouring small farmer who is irrigating with one or a few wells. In the long run, the small farmer may be forced to shift his/her operations to dry land agriculture which is a clear equity issue. The valuation of the effects of interference provides valuable information regarding the predicament faced by farmers due to well interference which is largely induced by human actions and hence retractable if there can be a social will. The challenge however, is to locate the patches where interference is predominant. Towards this endeavour we have used participatory rural appraisal technique and sampling technique, the details of which are provided in subsequent sections. When the process of withdrawal of groundwater without regard to recharge efforts goes unabated, the resource may itself become unsustainable, clearly reducing the economic life of well, which underscores the sustainability issue.

Objectives and Hypotheses:

The objectives of the study are : i. Analysis of economics of irrigation and water use efficiency; ii. Economic loss estimation due to cumulative well interference externality; iii. Economics of coping mechanisms in mitigating well interference externality.

This study encompasses a group of villages where irrigation wells suffer from cumulative interference (Interfered-High-failure-Area, IHA) and another group of villages where interference does not lead to high well failure called (Interfered-Low-well-failure-Area, ILA) where irrigation wells do not relatively suffer from interference. The hypotheses of the study are:

i. Economic returns from well irrigation are lower in IHA than in ILA; ii. Water use efficiency is higher in IHA than in ILA; iii. Economic losses due to well interference externality are higher in IHA than the ILA; iv. Cost of coping mechanisms is higher in IHA than in ILA.

Sampling Design

At the *taluk*/village level, it is difficult to have the list of *taluk*s/villages which suffer from well failures due to interactive effect(s) of well(s). Hence, we need to generate a realistic index which uses the available secondary source of information. We developed five different indices (refer note at the end of the article) each providing a proxy for locating the *taluk*/village having well failure due to interactive effect(s) of well(s) and chose one of the five indices which best reflected the problem.The chosen index is the

(Number of Irrigation Pump sets) per (million cubic meter of utilisable groundwater for irrigation) in a taluk/village[1]. This index reflects, the dependency of a number of wells on a unit of groundwater for irrigation. Hence, the taluk/village with the highest number of wells per unit of groundwater reflects high well interference problems compared to a *taluk* which has the lowest number of wells per unit of groundwater. For a comparison of the well interference problems in the most affected and the least affected situation, we have chosen five villages with the highest number of wells per unit of groundwater and two villages with the lowest number of wells per unit of groundwater in each agroclimatic zone of the Karnataka State excepting the southern transitional., coastal, hilly and north-eastern dry zones, as these zones did not pose interference problems as described in this study.

Participatory Rural Appraisal (PRA) Approach to Study the Interactive Effect(s) of Well(s) Within a Selected Village or a Portion of Village ?

The secondary source of information to locate the well failure(s) largely due to well interference (by one well to another well) or cumulative well interference (by one well to many wells; or by many wells to one well; or among many wells themselves) is not available with the Department of Agriculture or the Department of Mines & Geology or any other source. The only recourse to such a vital information is through PRA mapping of closely spaced or densely located wells with respect to (1) year of drilling of wells, (2) inter-well distance, (3) depth of wells, (4) water yield, (5) method of locating groundwater in well and many other variables which contribute to interference. Hence, after choosing the *taluk* and the village using the statistical approach already highlighted, locating closely spaced wells, through a base map of all wells in the village or a portion of the village, aids in identification of pockets of density of wells in a village or its portion. The location of wells in the village and their mapping can be done only by the farmers of a selected village. In addition, mapping of items 1 through 5 listed above cannot be done singularly but by the cumulative efforts of the farmers. Hence the PRA mapping is *sine-qua-non* to the study of well failures due to interactive effects of wells.

Why IHA and ILA were Chosen from the Same *Taluk*

The villages representing IHA and ILA are chosen from the same *taluk* since the problem of well interference has to be investigated under *ceteris paribus* conditions, which necessitates that aquifer conditions, crop patterns, rainfall, agroclimatic conditions, hydro-geological characteristics, have all to be similar for examining the implication of well interference in IHA and ILA. If we do not choose our sample from the same *taluk*, it is most likely that some of the above variables like rainfall, crop pattern would differ and would result in discrepancy in investigating the implications of well interference.

In order to confirm, whether the villages so chosen do reflect the problems of well interference, a preliminary survey was made and discussions were held with farmers to confirm the prevalence of well interference phenomenon. After the choice of villages,

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[1] We are thankful to Sri V. Jagannathan, Senior hydrogeologist, Central Groundwater Board, Southern Region, Jayanagar, Bangalore, for developing chosen index.

primary data for the 1993-94 the latest year which received good rainfall in the ILA and IHA villages, were obtained.

Analytical Frame Work

The methodology of costing irrigation well, measuring economic losses due to mortality of wells before their average expected life, estimating the cost of coping mechanisms due to well mortality and the functional analyses procedures are explained (Shivakumaraswamy, 1995). The determination of well life is a precursor to the above exercise.

i) Well life

The life of the well is estimated using the commonly used 'life tables' technique in statistical theory.

ii) Costing Irrigation Well

Groundwater is extracted from two types of irrigation wells in the IHA area namely 'Dug Well' (DW) and 'Bore Well' (BW). Due to cumulative well interference and other extraneous causes responsible for reducing the life of the DW, DW is bored inside. Such DWs are referred commonly as dug cum bore wells (DCBW). Farmers have wells with different vintages. With only the cross section data on costs (with heavy reliance on recall memory) the estimation of cost of irrigation well poses several empirical problems.

DWs are no longer functioning in both the IHA and ILA. However, the cost of DCBW was estimated considering an allocation to the cost of DW portion of the investment in DCBW. Accordingly the cost of DCBW was computed for each farmer as: $DCBW_{cost} = \{ AC_{DW} \times [AL - (YEAR_{imp} - YEAR_{cons})] + IMP_{cost} \} \times (1 + i)^{1995-YEARimp}$
where,
$DCBW_{cost}$ = Estimated cost of DCBW at current prices (1995)
AC = Amortised cost of dug well = $\{DW_{cost} \times [1 + i]^{AL} \times i\} \div \{[1 + i]^{AL} - 1\}$
AL = Average life of well estimated through life table (explained earlier)
$YEAR_{imp}$ = Year of improvement of dug well
$YEAR_{cons}$ = Year of construction of dug well
IMP_{cost} = Historical improvement cost (such as cost of in bores)
DW cost = Historical cost of dug well (includes the cost of earth work, lining, pump, pumphouse, motor, conveyance pipes, all electrical and miscellaneous expenses while construction of DW incurred in the year of construction - which varied from 1960 to 1985).
The interest rate i = 5 per cent has been considered in this to take care of the inflation rate of the well components like labour charges, pump costs and so on.

The cost of the BW has been considered at current prices considering the average physical units and measurements of BW.

iii) Amortised Cost of Well

The amortisation cost of well is the annual fixed cost component of irrigation water. The magnitude of amortised cost depends upon the type of well, year of construction, the expected life
Amortised cost of DCBW = $\{[\text{Estimated cost of DCBW}] \times [1 + i]^{AL} \times i\} \div \{[1 + i]^{AL} - 1\}$

Amortised cost of BW = $\{[\text{Cost of BW at current prices}] \times [1 + i]^{AL} \times i\} \div \{[1 + i]^{AL} - 1\}$

$i = 0.1$ (= annual inflation rate)

The Average Life (AL) of DCBW is estimated as 7 years and the AL of BW is estimated as 5 years for both IHA and ILA[2].

iv) Amortised Cost of Over-Ground Storage Tank (OGS)

As a coping mechanism to endure with the persistent problems imposed by supply of low voltage electricity to run irrigation pumps and supply of electricity during off-peak load hours (like between 10 pm and 5 am, when farmers would be able to obtain better voltage for their pumps, when compared with the supply of electricity between 12 noon and 6 pm, when farmers will have to compete with industrial units for running their pumps) and low yield of well(s), farmers have built OGS.

The amortised cost of OGS is = $\{\text{Cost}_{OGS} \times [1 + i]^{10} \times i\} \div \{[1 + i]^{10} - 1\}$,

where, Cost_{OGS} is the historical cost of OGS. The maintenance cost of OGS is assumed as zero since the OGS is an earthen structure without any concrete lining with an average dimension of 30 feet x 40 feet x 2 feet holding 2400 cubic feet of water with a life of ten years.

v) Annual Cost of Irrigation

The annual cost of irrigation is estimated in order to study the economics of groundwater irrigation. The annual cost of irrigation includes all the apportioned cost of infrastructure developed by the farmers to make use of the resource.

The annual cost of irrigation = Amortised cost of well + amortised cost of over-ground storage tank + average annual repair cost of irrigation well, pump set, electrical parts if any. The labour cost of irrigation is merged with the cost of labour for other cultural operations. The annual cost of irrigation pertains to each irrigation well. This is estimated by considering the unrecovered amortised cost for DCBW, which is a negexternality cost. Thus, the annual cost of irrigation internalises the cost of well interference externality. In the study area, for BW, the annual cost of irrigation does not include the negexternality cost because, there were no significant failures of BWs due to interference as most of the BWs were of recent origin.

vi) Economics of Irrigation

The cost of crop production is obtained by summation of human labour cost, bullock labour cost, cost of seed, cost of manure, cost of fertiliser, cost of plant protection chemicals and expenditure on transportation and bagging, the apportioned annual cost of irrigation, the opportunity cost of working capital at 10 per cent per year and the opportunity cost of dry land agriculture.

The gross income for each crop is the total output valued at the current price realised per unit of output. The net returns from well irrigation is gross returns from well irrigation from gross irrigated area under the particular well less the cost of production of all the crops under this well. The establishment cost of perennial crops

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[2] In the ILA, all the 12 bore wells were working at the time of data collection in Dec 1994. However, the expected average life of bore wells could not be estimated for this set of data. Hence, the expected average life of bore wells is assumed to be that of the average life of borewells in ILA village.

like coconut and mulberry has not been considered as this study concentrates on well irrigation.

vii) Negative Externality Due to Well Interference

The effect of cumulative interference is valued in terms of the net returns which ought to have accrued over the expected average life of a well, but did not accrue due to failure of well to yield irrigation water, much before its expected average life. While estimating the loss in net returns per year due to well failure before its expected average life, we have assumed that the level of net returns from the existing well would portray the net returns from the erstwhile DWs. The only difference would be in the size of the irrigated area under crops. As the DW productivities are lower and are relatively more vulnerable to cumulative interference, compared with DCBW, we have assumed that the major difference between the DWs and DCBWs is reflected in the reduced cropped area under irrigation due to interference, since the crop pattern remained unchanged over the years across the different well types.

Due to cumulative well interference, there would be reduction in the yield of water from the DW. This would have resulted in reduced area under DW irrigation. Hence, we considered the net returns from one acre of each crop in 1993-94 and multiplied with the irrigated area under each crop in the pre-interference period of a particular well, as indicative of the loss in returns per year at current prices. This annual loss for DW is linearly extrapolated over the number of years of well failure given by:

(Annual loss) x (Expected life of the dug well - actual number of years the dug well actually worked).

Similarly the annual loss for DCBW is linearly extrapolated over the number of years of DCBW failure given by:

(Annual loss) x (Expected life of the DCBW - actual number of years the DCBW actually worked).

Succinctly, in dug well, Net Returns Measure of Negative externality_{DW} = Σ\{(Average Net Returns per acre of the crop_i in 1993-94) x (Area under the crop_i under dug well in the pre-interference period)\} x [AL- ($YEAR_{imp}$ - $YEAR_{cons}$)]

Similarly in DCBW, Net Returns Measure of Negexternality $_{DCBW}$ = Σ \{(Average Net Returns per acre the crop_i in 1993-94) x (Area under the crop_i under dug cum bore well in the pre-interference period)\} x [AL - ($Year_{fail}$ - $Year_{imp}$)]

viii) Water Use Efficiency

The volume of groundwater used on the farm is estimated by considering the number of pump hours per day in different seasons, yield of well and the number of non-rainy days in each season in Chamarajanagar *taluk* as:

Volume of water extracted = [(Number of hours of pumping in kharif x yield of well in kharif x 100 days) + (Number of hours of pumping in rabi x yield of well in rabi x 100 days) + (Number of hours of pumping in summer x yield of well in summer x 120 days). The number of non-rainy days in Chamarajanagar *taluk* was 100 each in kharif and rabi and 120 in summer.

The efficiency of groundwater use on the farms is estimated by comparing the economic optimum groundwater use with actual groundwater use by the farmers in IHA and ILA. The economic optimum of groundwater use is measured by estimating a production function with gross returns per farm per annum as the dependent variable and the total volume of groundwater used per farm per year and area under high water intensive crops as independent variables. In this process, the following commonly used models of (1) Cobb Douglas $Y = AX^{\alpha}$,(2) Transcendental $Y = AX^{\alpha} e^{\tau X}$ and (3) Log Log Inverse $Y = AX^{\alpha} e^{\tau/X}$, were tried.

The Transcendental model yielded econometrically meaningful results and hence has been used for finding the Water Use Efficiency (WUE). The optimum dose of irrigation water X^* is obtained by equating the Marginal return (MR) = $\{(a / X)+ t\} \times Y)$ from groundwater with F (the estimated factor price of groundwater) as

$$X^* = (\alpha Y) \div (F - \tau Y)$$

Here F, the estimated marginal factor cost of irrigation water = annual amortised cost of well irrigation per gallon of groundwater used. The elasticity of gross returns for the entire farm ε with respect to groundwater use is given by $\varepsilon = [\alpha + \tau X]$.

Considering the sample farmers in IHA (45) and ILA (35), the data for all the farmers have been used to estimate the negative externality return. The cost of coping mechanism is estimated for only those farmers who have coped with negative externality. The economics of irrigation and water use efficiency have been estimated only for those farmers whose wells were working at the time of data collection (1994). It is to be noted that the economics of irrigation estimated includes the negative externality component. We have not been able to perform this analysis crop wise due to sample size limitation.

Results

We have chosen Chamarajanagar *taluk* to represent the southern dry zone and the IHA are Masagapura, Madapura, Bhogapura, Kirigasuru and Kadalli. The ILA are Harave, Veeranapura. The field data pertain to the year 1993-94.

i) Well Command Area and Well Life

The proportion of area under well command in small and large farmers in both IHA and ILA involves an equity issue. In the IHA, the proportion of area under well command for small farmers is 28 per cent and that for large farmers is 37 per cent (Table 1). Large farmers in IHA are better off as their absolute area under well command (3.73 acres) is more than the total holding size of small farmers (3.48 acres). Small farmers hence are vulnerable even with respect to the proportion of area under well command in the situation where cumulative well interference has been largely responsible for the predicament. This is yet another equity concern in the situation dominated by well interference. In the ILA, small farmers are better off since around 80 per cent of their area is under well command.

In the IHA, out of 29 Bws, 18 BWs were working. The average life of failed BWs in IHA was just two years, since five BWs failed to yield water in the initial stage itself out of 11 failed BWs. The average life of failed BWs in the IHA, without considering the wells which initially failed, was just three years. In our sample, 18 BWs were still working at the time of enumeration (Dec 1994 to Jan 1995). These wells have worked on an average till 1994 - 95 for five years as mentioned. It may also be noted that these BWs may last only for a few more years, which need to be investigated. Thus the average life of working BWs may be more than five years[3].

Table 1: Holding Size and Well Command Area in IHA and ILA (Acres)

Land type	IHA			ILA		
	Small farmers	Large farmers	Over all	Small farmers	Large farmer	Over all
Well	0.98 (28)	3.73 (37)	2.58 (35)	3.1 (82)	6.32 (43)	5.8 (45)
Dry	2.5 (72)	6.47 (63)	4.82 (65)	0.7 (18)	8.33 (57)	7.2 (55)
Total	3.48 (100)	10.2 (100)	7.40 (100)	3.8 (100)	14.65 (100)	13 (100)

Note: 1. The holding size and well command area are computed irrespective of whether the well is working or not (in acres).
2. Figures in parentheses are the percentages to the respective total.

The life and initial yield of the DW in IHA and ILA do not differ markedly and at present they have all ended up in total failure. This may be due to secular or long term over draft (Veeman, 1975) in both the areas. Considering the 'working DCBWs' *per se*, in IHA, the yield has reduced by eight per cent from the initial year till 1994-95. Taking all DCBWs in the IHA, the yield has reduced by 82 per cent over seven years or at the rate of 12 per cent per annum[4]. Judging only the working DCBWs in the ILA, the yield has increased by 16 per cent from initial year till 1994-95. Considering all DCBWs in the ILA, the yield has reduced by five per cent in five years or at the rate of one per cent per annum.

ii) Crop Pattern

The area under water intensive crops (Table 2) in the IHA (64 per cent) is much higher than that in the ILA (44 per cent). This provides ample evidence for competitive extraction behavior exploiting the groundwater 'fastest and the mostest' (Wantrup, 1968). The initial phase of equity issue is to examine the proportion of different types of wells with small and large farmers (Table 3). Considering the well failure due to well interference and their impact in the IHA, the burden of failed DWs and failed DCBWs falls equally on small and large farmers, as almost 50 per cent of the failed wells in both categories of wells are owned by small farmers. Hence, the concern towards the small farmers due to interference negative externality is substantiated in the situation where interference is apparent. In addition, the ability of small farmers in bearing the brunt of well failure is limited by the size of their holding, savings, re-investment and economic resilience potentials. Even if they are able to mop the capital required for additional well, they would bear greater risk of not striking (adequate) groundwater since their area is already suffering from acute well interference problems. The proportion of BWs owned in both IHA and ILA, by small farmers is low due to the heavy investment for BW. Shah (1988) highlighted that this interference externality affects the poor both spatially and temporally. This is corroborated by Kolavalli and Atheeq (1993) who

[3] According to suggestion provided by Professor Gurumurthy, Professor of Statistics, University of Agricultural Sciences, Bangalore, dated Feb 10, 1995.

[4] We realise the limitations associated with such a linear reduction in well yield.

Table 2: Cropping Pattern in IHA and ILA (Area in Acres)

Crops	IHA				ILA			
	Kharif	Rabi	Summer	Total	Kharif	Rabi	Summer	Total
1 Paddy	0.09	-	-	0.09	0.09	-	-	0.09
2 Ragi	0.22	-	-	0.22	0.23	-	-	0.23
3 Jowar	-	-	-	0.00	0.27	-	-	0.27
4 Sugarcane	1.66	1.66	1.66	4.98	1.50	1.50	1.50	4.50
5 Mulberry	0.70	0.70	0.70	2.10	1.11	1.11	1.11	3.33
6 Coconut	0.25	0.25	0.25	0.75	0.84	0.84	0.84	2.52
7 Turmeric	0.22	0.22	-	0.44	0.19	0.19	-	0.38
Net area irrigated	-	-	-	3.21	-	-	-	4.23
Gross area irrigated	-	-	-	8.58	-	-	-	11.32

Note: 1) The above crop pattern is for farmers with functional wells at the time of data collection (1994)
2) Net area irrigated: is the total area irrigated by well in the kharif season. This is calculated by Σ (net area irrigated by well in kharif in all farms) / Number of farmers whose wells were working.
3) Gross area irrigated: is the total area irrigated by well in kharif, rabi and summer seasons. For sugarcane, mulberry and coconut, three times the actual area irrigated in kharif is considered as the gross area irrigated. For turmeric, two times the actual area irrigated in kharif. is considered as the gross area irrigated. This is calculated by Σ (gross area irrigated by well in the year on all farms) / Number of farmers whose wells were working.
4) In both IHA and ILA, water intensive crops like onion, tomato, brinjal, beans and banana are being cultivated. However, in the sample considered, the area under these crops was negligible.

Table 3: Distribution of Different Types of Wells in the Sample

Well type	IHA (76 wells)			ILA (40 wells)		
	Small	Large	Overall	Small	Large	Overall
1. DW	22	25	47	6	22	28
	(47)	(53)	(100)	(21)	(79)	(100)
2. DCBW *	22	25	47	6	22	28
	(47)	(53)	(100)	(21)	(79)	(100)
3. BW	6	23	29	0	12	12
	(21)	(79)	(100)	(0)	(100)	(100)
Total Wells	28	48	76	6	34	40
1. Completely failed DWs	22	25	47	6	22	28
2. Completely failed DCBWs	20	17	37	1	4	5
3. Completely failed BWs	4	7	11	0	0	0
Total failed wells	24	24	48	1	4	5
Total Working wells	4	24	28	5	30	35

Note: 1) Figures in parentheses are percentage to the total.
2) For the 28 farmers in IHA and 35 farmers in ILA whose wells were working, each farmer had one working well per farm on an average.
* All the DWs had in-bores and hence DWs and DCBWs do not differ in number.

highlight the deterrence to investment by small farmers due to increasing well investments. In the ILA, the brunt of well failure in DWs and DCBWs is borne by large farmers.

iii) Economics of Well Irrigation

A comparison of annual cost of irrigation of different types of wells in IHA and ILA, indicates that the irrigation pumpset repair and maintenance cost for both DCBW and BW is higher in IHA which contributes to the major difference in the cost of irrigation between IHA and ILA (Table 4). The rise in the annual repair cost is a partial indicator of scarcity of groundwater and electricity. In both IHA and ILA, the problem of low voltage electricity to run irrigation pump sets persist and are manifest in DCBWs and BWs differently. In the case of DCBWs the repair costs shoot up due to problems of low voltage, since water is jointly lifted by two machines - (i) the irrigation pumpset and (ii) the air compressor. The low voltage obviously in the IHA, and the interference induced scarcity increases the externalities and hence increases the repair costs. The annual cost of DCBW irrigation is 36 per cent higher and BW irrigation is 8.6 per cent higher in the IHA compared with ILA and this dampens the net returns obtainable from well irrigation in IHA. The net income in ILA is higher by 17 per cent over that in IHA even though the gross income per well in IHA and ILA are comparable (Table 5). In ILA, the proportion of perennial crops is 52 per cent, while in IHA, the proportion is 33 per cent. This contributes for the reduction in other variable costs in ILA, as the annual costs on seed, plant protection chemicals, manures, are lower compared with IHA, where the proportion of perennial crops is lower. In addition the greater proportion of light water perennial crops like coconut and mulberry in ILA in itself is a coping mechanism contributing towards a reasonable use of groundwater resource compared with IHA.

Table 4: Annual Cost of Well Irrigation

Area	Amortised cost of Well	Amortised cost of OGS	Amortised cost of conveyance	Annual repairs and maintenance	Total annual cost of irrigation
1. IHA					
DCBW	9080 (72)	42	0	3485 (28)	12607
BW	12100 (81)	70	561	2046 (14)	14777
2. ILA					
DCBW	6953 (75)	52	0	2209 (24)	9214
BW	11398 (83)	121	648	1430 (10)	13597

Notes: 1. Figures in parentheses are percentage to the total cost

2. Amortised cost of DCBW = {[Estimated cost of DCBW] x $[1 + i]^{AL}$ x i} / {$[1 + i]^{AL}$ - 1}

3. Amortised cost of BW = {[Cost of BW at current prices] x $[1 + i]^{AL}$ x i} / {$[1 + i]^{AL}$ - 1}, i = 0.1 (annual inflation rate)

4. Amortised cost OGS = {$Cost_{OGS}$ X $[1 + i]^{10}$ x i} / {$[1 + i]^{10}$ - 1}, where, $Cost_{OGS}$ is the historical cost of over-ground storage tank.

The AL of DCBW is estimated as seven years and the AL of BW is estimated as five years for both IHA and ILA.

5. The annual cost of irrigation = Amortised cost of well + amortised cost of over-ground storage tank + average annual repair cost of irrigation well, pump set, electrical parts if any.

Table 5 : Annual Cost and Returns from Well Irrigation Per Farm

Base	IHA Per Well	Per acre	ILA Per Well	Per acre
Vol of water lifted from well M^3	13774 134AI	1610 16AI	14964 145AI	1321 13AI
Human+ Bullock labour in Rs.	7580 (21)	885	8138 (26)	719
Fertiliser cost in Rs.	3776 (10)	442	3134 (10)	278
Other variable cost Rs.*	7198 (20)	842	5321 (17)	470
Opportunity cost of capital @ 10%	1855 (5)	216	1659 (5)	146
Opportunity cost of dry land	1765 (5)	206	2538 (8)	224
Irrigation cost	14000 (39)	1635	10717 (34)	946
Total cost	36174 (100)	4226	31507 (100)	2783
Gross income	61243	7154	61022	5390
Net income	25069	2928	29515	2607

Note: 1 AI = Acre Inch, 1 Acre Inch = 102.79 M^3

2. The gross area irrigated per well was 8.56 acres in IHA and it was 11.32 acres.

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

4. The opportunity cost of dry land referes to the net income from dry land crop(s) for the well irrigated area, which would have accrued, if there were no irrigation facility on the farm.

* Includes expenditure on seed , manure, plant protection chemicals and transportation cost.

iv) Negative Externality Due to Cumulative Well Interference

The net return which is not accrued to farmer from the very year of well failure due to well interference is a negative externality (negexternality). Farmers in IHA suffered a negexternality of Rs. 1.79 in DW for every rupee of corresponding negexternality in ILA and a negexternality of Rs. 1.9 in DCBW for a rupee of corresponding negexternality in ILA. The negexternality is higher for DW than for DCBW (Table 6). A major factor attributable is the longer range of 0 to 24 years in the actual life of DWs in IHA and ILA. In decision making regarding the extent of use of groundwater for irrigation and regarding the investment on well improvement or on new wells, farmers fail to include negexternality as a cost as they tend to be myopic. Hence, it is desirable to estimate the net negexternality by deducting the well improvement cost from the estimated cost of the well (Table 7).

Table 6: Negative Externality Cost of Well Interference

Area	Expected life (years)	Net return measure of Negexternality (Rs.)
IHA		
DW	8	90100
DCBW	7	40388
ILA		
DW	6	50293
DCBW	7	21120
IHA / ILA ratio	For DW	1.79
	For DCBW	1.90

Note: 1. Loss in Return Negexternality in DW = Σ {(Average Net Returns per acre of the crop$_i$ in 1993-94) x (Area under the crop$_i$ under DW in the pre-interference period)} x [AL- ($YEAR_{imp}$ - $YEAR_{cons}$)]
2. Loss In Returns Negexternality$_{dcbw}$ = Σ {(Average Net Returns per acre of the crop$_i$ in 1993-94) x (Area under the crop$_i$ under DCBW in the pre-interference period)} x [AL - ($YEAR_{fail}$ - $YEAR_{imp}$)]

When we do not consider the negexternality as a cost, the annual cost of DCBW irrigation is 27 per cent higher in IHA compared to ILA. On the contrary, when we consider the negexternality cost also, the annual cost of DCBW irrigation is 37 per cent higher in IHA compared to ILA. This difference of 10 per cent in annual cost of DCBW irrigation indicates the higher negexternality cost in IHA compared with ILA. This is also portrayed when we consider the cost per M^3 of water. It can be observed that the negexternality contributes to a hike in price of groundwater to the tune of 60 per cent in IHA and 50 per cent in ILA.

v) Water Use Efficiency

The groundwater extracted per well in IHA is seven per cent lower than that in ILA (Table 8). However, the groundwater extracted in IHA is 22 per cent higher than that in ILA when extraction is considered on per acre of gross irrigated area basis, as they grew higher proportion of water intensive crops like sugarcane and turmeric. The net income per acre inch (AI) of water in ILA is 8.5 per cent higher compared to the net income per acre inch of water in IHA.

Table 7: Annual Cost of Irrigation With and Without Negexternality Cost in DCBW Irrigation

Area	Annual cost of DCBW irrigation with negexternality	Annual cost of DCBW irrigation without negexternality	Vol. of water used in M^3	Price per M^3 with negexternality cost	Price per M^3 without negexternality cost	Percentage contribution of negexternality to price of water
IHA	12607	7853	11758	1.07	0.67	60
ILA	9214	6182	13356	0.69	0.46	50

Note: 1. Annual cost of well irrigation without negexternality is estimated in the following two steps:
Step I: Cost of DCBW without negexternality cost in IHA = Estimated cost of DCBW (Rs.44,293) - Amortised cost measure of negexternality (Rs.22661 for DW) = Rs. 21632.
Step II: Annual cost of DCBW well irrigation without negexternality (in IHA) = Cost from step I (=Rs.21632) * (capital recovery factor at i=10 % and Average life of DCBW of 7 years) negexternality is Rs. 12,607 in IHA and Rs. 9214 in ILA.

Table 8 : Measures of Water Use and Water Efficiency on the Farm

Particulars	IHA	ILA
1 Groundwater extracted per well	$13788M^3$ =134 AI	14964 M^3 =145 AI
2 Groundwater extracted per farm	$13788M^3$ =134 AI	14964 M^3 =145 AI
3 Groundwater used per acre of gross irrigated area	$1609M^3$ =16 AI	1316 M^3 =13 AI
4 Gross income per farm Rs.	61,243	61,022
5 Gross income per AI of water Rs.	457	420
6 Net income per farm	25,069	29,515
7 Net income per AI of water Rs.	187	203
8 Economic optimum Groundwater use on the farm	$14782M^3$ =143 AI	19605 M^3 =190 AI
9 Actual groundwater use on the farm	$13788M^3$ =134 AI	$14964M^3$ =145 AI
10. Total annual cost of irrigation	14000	10717
11 Cost per AI of irrigation	104	74
12 Cost per M^3 Rs.	1.01	0.72
13. Net income per AI ÷ Cost per AI	1.8	2.74

Note: 1. AI = acre inch. The economic optimum water use on the farm is estimated using the transcendental gross returns function with volume of water used per farm and area under high water intensive crops as independent variables.
2. Groundwater extracted = [(Number of hours of pumping per day in Kharif x yield of the well in kharif x 100 days) + (Number of hours of pumping per day in Rabi x yield of the well in Rabi X 100 days) + (Number of hours of pumping per day in Summer x yield of the well in summer x 120 days). The number of non-rainy days in Chamarajanagar *taluk* is 100 each in kharif and Rabi and 120 days in summer.

The transcendental water use efficiency function (Table 9) indicated that farmers in IHA have marginal return of Rs. 1.77 for the 13,788th M^3 of groundwater for all the three seasons, while farmers in ILA have marginal return of Rs. 1.96 for the 14,964th M^3 of water. The average return is Rs. 4.44 per M^3 of water in IHA and Rs. 4.08 per M^3 in ILA. Since elasticity of gross returns is 0.4 in IHA and 0.48 in ILA, both the technologies are in the second region. This indicates that the farmers in IHA and ILA are operating in the rational region even though they may not be exactly using the economic optimum dose of water for irrigation which is reflected in the divergence of MR/MC ratio away from unity. In the IHA, the MR/MC ratio is 1.75 while in the ILA, the MR/MC ratio is 2.72. The actual water use in IHA falls short by seven per cent compared with the economic optimum, while the actual water use in ILA falls short by 23 per cent compared with the corresponding economic optimum. Hence, at present, the ILA farmers are realising relatively higher MR compared with the Marginal Cost (MC) of water, than the IHA farmers. Nevertheless, the farmers in IHA are relatively more efficient in the use of groundwater than the farmers in ILA. This is due to the scarcity in groundwater imposed in IHA compared to ILA. In this sense the negexternality cost can also be considered as 'scarcity cost' or 'scarcity price' or 'scarcity rent of water'.

Implications

The net income per well is 24 per cent lower in IHA over ILA and as the total repair costs for IHA-DCBW is Rs.3485. The repair cost net of negexternality is Rs. 2380. Hence, the inter-well distance in relation to groundwater availability should be strictly adhered to. And due to irregular and low voltage electricity, farmers are incurring additional cost of Rs. 2380 on the repair of irrigaton pump set in IHA-DCBW. Hence, electrical stability should help reduce these costs apart from providing normalcy to agricultural operations (Table 10).

The WUE given by the MR/MC ratio, in IHA is 15 per cent lower than in ILA, since the Marginal Factor Cost (MFC) of water in IHA is 33 per cent higher than that in ILA. The price per M^3 of water is Rs.1.01 in IHA and Re. 0.72 in ILA. Hence, pricing electrical energy either on flat rate or pro rata basis to generate funds for Karnataka Electricity Board (KEB) to provide uniform power supply to irrigation pump sets and to increase WUE is desirable.

Water use efficiency can be enhanced using drip and sprinkler systems for high water crops in the region. Well interference is reducing net returns by Rs. 40,388 in IHA-DCBW and by Rs. 21,120 in ILA-DCBW. Hence, reduction of negexternalities by extension efforts to educate farmers for growing light water commercial crops, irrigation literacy and regulation of well drilling is necessary. The cost of coping with negexternality is 110 per cent higher in IHA over ILA. Hence, group investments for well irrigation can be encouraged after examining pilot projects for their feasibility.

Table 9 : Gross Return Function Analysis

Area	IHA	ILA
α_1	2.73 (5.5)	1.29 (2.1)
t_1	-0.000169 (-3.8)	-0.000054 (-1.26)
α_2	1.18 (2.08)	0.396 (0.98)
t_2	-0.097 (-0.49)	0.182 (0.87)
Log a	-13.4	-1.39
R^2	0.78	0.58
MR	1.77	1.96
MC/M^3 (F)	1.01	0.72
Optimum volume of water M^3	14782	19605
Actual volume of water used per farm M^3	13788	14964
volume of water used in M^3 per acre of NAI	4295	3537
Volume of Water used in M^3 per acre of GAI	1610	1321
Elasticity	0.40	0.48

Note : 1. The marginal return to marginal factor cost ratio in IHA is 1.75 and that in ILA is 2.72.

2. Figures in parenthesis are 't' values.

3. NAI: Net Area Irrigated; GAI : Gross Area Irrigated.

Table 10: Status of Proof of Hypotheses with Causal Factors and

Hypotheses	Causality	
1. Economic returns per well are lower in IHA than in ILA (proved)	1. Net income per well is 24 per cent lower in IHA over ILA	1. Inter groundv strictly
	2. The total repair costs for IHA-DCBW is Rs. 3485. The repair cost net of negexternality is Rs. 2380.	2. Due electric additio repair Hence reduce providi operati
2. Water Use Efficiency (WUE= MR ÷ MC) is higher in IHA than in ILA (Proved).	The WUE in IHA is 15 per cent higher than in ILA, since the MR/MC ratio is closer to unity in IHA than in ILA. The price per M^3 of water is Rs.1.01 in IHA and Rs. 0.72 in ILA.	1. Pric flat rat funds power increa: 2. WU and sp crops
3. Negexternalities due to well interference are higher in IHA than the ILA (proved).	Well interference is reducing Net returns by Rs.40,388 in IHA-DCBW and Rs.21,120 in ILA-DCBW.	Reduc extens regarc irrigat well d
4. Cost of coping mechanism is higher in IHA than the ILA (proved).	The cost of coping with negexternality is 110 per cent higher in IHA over ILA.	Grouṛ can b pilot
5. The economic life of irrigation well in IHA is lower than that of the ILA. (inconclusive).	In ILA, 80 per cent of DCBWs and all BWs, were still working. In IHA, 20 per cent of DCBWs and 65 per cent of BWs were working. Hence comparison as stated in hypothesis could not be made.	Not a

Table 10: Status of Proof of Hypotheses with Causal Factors and Policy Implications

Hypotheses	Causality	Policy Implications
1. Economic returns per well are lower in IHA than in ILA (proved)	1. Net income per well is 24 per cent lower in IHA over ILA	1. Inter-well distance in relation to groundwater availability should be strictly adhered to.
	2. The total repair costs for IHA-DCBW is Rs. 3485. The repair cost net of negexternality is Rs. 2380.	2. Due to irregular and low voltage electricity, farmers are incurring additional cost of Rs. 2380 on the repair of IP set in IHA-DCBW. Hence electrical stability should help reduce these costs apart from providing normalcy to agricultural operations.
2. Water Use Efficiency (WUE= MR ÷ MC) is higher in IHA than in ILA (Proved).	The WUE in IHA is 15 per cent higher than in ILA, since the MR/MC ratio is closer to unity in IHA than in ILA. The price per M^3 of water is Rs.1.01 in IHA and Rs. 0.72 in ILA.	1. Pricing electrical energy either on flat rate or pro rata basis to generate funds for KEB to provide uniform power supply to IP sets and to increase WUE. 2. WUE can be enhanced using drip and sprinkler systems for high water crops in the region.
3. Negexternalities due to well interference are higher in IHA than the ILA (proved).	Well interference is reducing Net returns by Rs.40,388 in IHA-DCBW and Rs.21,120 in ILA-DCBW.	Reduction of negexternalities by extension efforts to educate farmers regarding light water crops, irrigation literacy and regulation of well drilling.
4. Cost of coping mechanism is higher in IHA than the ILA (proved).	The cost of coping with negexternality is 110 per cent higher in IHA over ILA.	Group investments for well irrigation can be encouraged after examining pilot projects for their feasibility.
5. The economic life of irrigation well in IHA is lower than that of the ILA. (inconclusive).	In ILA, 80 per cent of DCBWs and all BWs, were still working. In IHA, 20 per cent of DCBWs and 65 per cent of BWs were working. Hence comparison as stated in hypothesis could not be made.	Not applicable.

Note

1. Statistical criteria developed

The following criteria were considered in order to choose the *taluks* with highest degree of well interference problems:

Criterion 1: Concentration of number of wells or IP sets per 100 hectares of net sown area = (No.of IP sets / Net area sown) for each *taluk*. The *taluks* are then arranged in descending order of magnitude.

Result: According to this criterion, the topers were the coastal *taluks* of Honnavar, Kundapura and so on. Upon verification with the Central Groundwater Board, it was learned that even though these coastal *taluks* have high well density, they also receive very high rainfall and hence have relatively good groundwater potential. So considering the net area sown hides the groundwater availability for irrigation in that area sown and accordingly does not provide a sound basis to reflect the interference problems.

Criterion 2: Concentration of number of wells or IP sets per million cubic meter of utilisable groundwater for irrigation = (No.of IP sets / Utilisable groundwater for irrigation in million cubic meters) for each *taluk*. The *taluks* are then sorted in descending order of magnitude of the above ratio. This criterion was suggested by Sri V. Jagannathan, Senior Hydrogeologist, Central Groundwater Board, South Western region, Bangalore.

Result : This criterion considered the number of wells or IP sets that are depending upon a given volume of groundwater. The *taluks* which topped the list are Devanahalli, Malur, Naragund, Hukkeri, Bangalore North, Kolar, Hosakote, Chikodi Chennapattana, Gubbi, Shidlaghatta, Chikkaballapur, Anekal and so on. The *taluks* which did not show interference problems were Supa, Hosanagara, Narasimha Raja Pura, Mundagod, Bhadravathi, Sagar, Soraba, Jeevaragi, Srinkeri, Kundagol, Chitapur, Karawar and so on. This criterion provided a reasonably good estimate of *taluks* which suffered from well interference problems. However, since a majority of the *taluks* suffering from interference problems were located in the Eastern Dry Agro Climatic Zone, we decided to choose the *taluk* which topped with respect to well interference in six (out of the ten) agroclimatic zones and which does not have substantial surface irrigation projects. The agroclimatic zones chosen were North Eastern Transition zone, Northern Transition Zone, Northern Dry Zone, Central Dry Zone, Eastern Dry Zone and Southern Dry Zone. The Hilly Zone, Coastal Zone, Southern Transitional Zone and North Eastern Dry Zone were not considered as this criterion did not provide evidence of the acute groundwater interference problems in these zones.

For the selection of villages for the selected *taluks* in selected zone, the villagewise availability of groundwater for irrigation was computed by using the ratio

(Village Net sown area/sown area) x Utilisable groundwater for Irrigation for *taluk* net

The data on net sown area for the village and the *taluk* pertain to 1992-93. The villages were sorted in the descending order of magnitude of the criterion 2. The villagewise number of wells per MCM of utilisable groundwater was then computed and the villages were ranked in the descending order of the number of wells per MCM of utilisable groundwater for irrigation. For the purpose of choosing the sample farmers, four villages with high number of wells per MCM of utilisable groundwater for irrigation were chosen as study villages and two villages with lower ratio were chosen as control villages. During this choice, villages with any kind of surface irrigation facility (from major, medium, minor irrigation sources) were excluded and only the top four villages which did not have any sort of surface irrigation facility were considered and also two control villages were chosen for the sake of comparison with those villages, with low number of wells per MCM of utilisable groundwater for irrigation. In order to confirm, whether the villages so chosen do reflect the problems of well interference, the research team visited each of the villages and contacted the farmers to confirm the prevalence of well interference phenomenon. After the choice of villages, data for the latest year which received good rainfall in the villages were obtained.

Criterion 3: The number of IP sets per MCM of utilisable groundwater divided by the gross area irrigated was another criterion. The results according to this criterion were not pragmatic.

Criterion 4: The proportion of DCBWs out of total DWs was another criterion. The results according to this criterion were also not pragmatic.

Criterion 5: Concentration of number of wells or irrigation pump sets per million cubic meter of utilisable groundwater for the *taluk* in relation to the state figure and the gross area irrigated by wells per MCM of utilisable groundwater in each *taluk* relation to the state figure : Groundwater use intensity index (GUII):

{[(Number of IP sets/utilisable groundwater in MCM) for each *taluk*] / [(Number of IP sets/utilisable groundwater in MCM) for each state]} + {[Gross area irrigated by IP sets/utilisable groundwater in MCM) for each *taluk*] / [Gross area irrigated by IP sets/utilisable groundwater in MCM) for the State]}

The *taluk*s were sorted according to descending order of magnitude of GUII.

Result: This criterion provided a twin measure of groundwater interference, the number of wells per MCM of utilisable groundwater and the gross area irrigated by wells per MCM of utilisable groundwater. Both the criteria 2 and 5 identified almost the same set of *taluk*s affected by well interference problems. Professor M.V. Nadkarni, the steering committee member of the project however expressed that Criterion 5 is tautological and hence criterion 2 was retained.

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