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Sustainability and Equity Implication of Groundwater Depletion in Hard Rock Areas of Karnataka - An Economic Analysis*

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INTRODUCTION

Groundwater is the elixir of dryland agriculture. As a source of irrigation it has gained considerable prominence in water starved semi-arid regions of India. Since the advent of green revolution, groundwater in hard rock areas is reeling under stress due to overdraft owing to competing demands from agriculture, domestic and industrial sectors. At present though the extent of groundwater utilised is only 30 per cent of the potential, there is wide spatial variation in the utilisation of this resource. Currently, around 55 per cent of total irrigation in Karnataka is through groundwater source. The rate of extraction of groundwater is greater than the natural rate of recharge in several places creating severe imbalance between extraction and recharge leading to secular or long-term overdraft and cumulative well interference in several regions. This affects the user cost of groundwater for different uses and its impact will be on both present and future generations. The study aims at estimation of economic costs associated with over-exploitation and its consequences on sustainability, equity and economic viability of coping mechanisms.

METHODOLOGY AND DATABASE

In the study district (Tumkur), a typical hard rock area in Karnataka, 73 per cent of irrigation is by groundwater. This district has the maximum number of dark blocks, an index of over-exploitation of groundwater. Among the dark blocks, of the district, Tiptur taluk has the highest ratio of net groundwater draft to utilisable groundwater. In this taluk, the areas having access to canal and tank irrigation have been selected to study the effect of conjunctive use on groundwater overdraft. The primary data collected from 35 farmers each are drawn in three groundwater conditions: (a) Groundwater without any water bodies for recharge (GW),

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(b) Conjunctive use of ground water with tank irrigation (CUTI) and (c) Conjunctive use of ground water with canal irrigation (CUCI) were drawn for empirical analysis.

The indicators were developed for evaluating sustainability and equity issues concerning groundwater overdraft in different water exploitation regimes. The extent of inequity in groundwater was analysed by computing Gini coefficient. Using partial budgeting framework the economics of adoption of drip system of irrigation (conservation) over drilling an additional well (depletion) was evaluated. The appraisal of investment on drip system versus additional well using flow irrigation for coconut was analysed using discounted cash flow measures. For arriving at groundwater irrigation cost, the investment on wells has been amortised to get the annual share of capital cost.

RESULTS AND DISCUSSION

Trends in Groundwater Utilisation

The over-exploitation of groundwater in the Tiptur taluk emerged during the nineties with the shift in the cropping pattern especially the significant increase in the area under coconut plantations. The area under food crops in the taluk has declined during the nineties while that of non-food crops has shown an increase during the same period. The area under non-food crops grew at the compound growth rate of 4 per cent per annum during 1989-90 to 1998-99 whereas the growth in the area under food crops declined at the rate of 1 per cent per annum. The area under coconut during 1989-90 in the taluk was 15,536 hectares and it increased to 21,427 hectares during 1998-99. Interestingly only a meagre area of 793 hectares of coconut was irrigated during 1989-90, which formed only 5 per cent of the area under coconut. The coconut plantations brought under irrigation increased five-fold during the year 1995-96. Between 1995-96 and 1998-99 the irrigated coconut area almost doubled with 11,105 hectares being brought under irrigation by the end of 1998-99, which accounted for 52 per cent of area under coconut.

Sustainability

The concept of sustainability is defined differently based on the characteristics of the resource, viz., renewable or non-renewable. According to one definition, the sustainability indicates maintenance of production capacities at levels which at least prevent depletion (extinction), and which at most give future generation the opportunity to enjoy a measure of consumption equal to that of the present generation (Jacobs, 1991, p. 312). Some of the physical indicators include, *inter alia,* well density, well age, area irrigated per well, yield of irrigation of wells, water extracted per annum, rate of well failure, reduced yield, increased depth of irrigation wells and replacement of pump. The economic indicators include cost of well deepening, cost of extraction, investment on coping mechanisms like drip irrigation, and investment on additional wells. These measures are discussed below.

Morphological Changes in Groundwater Structures

Though traditional dug wells existed during the 1950s, their number and spread were limited, and the water lifting devices were labour intensive. During the 1960s, dug well irrigation emerged due to fillip given to the rural electrification programme of the Rural Electrification Corporation (Government of India). The life of these wells was around 11 years till the 1970s (Table 1). During 1980s, dug-cum-borewells became prominent with a depth ranging from 80 to 160 ft and their productive period shrunk compared with the dug wells. Consequently on the failure of dug-cum-borewells, farmers ventured into drilling surface borewells with a depth ranging from 200 to 400 ft since 1990s. This was facilitated due to accessibility of improved exploration and extraction technology. The mode of extraction of groundwater during 1970s and 1980s was from the ordinary pumpset of 3 horse power (HP) capacity, which were replaced later in the 1980s by submersible pumpsets to extract water from the deeper layer of the aquifer.

TABLE 1: MORPHOLOGICAL CHANGES IN GROUNDWATER STRUCTURES

Well type (1)	Year (2)	Depth range and average (ft) (3)	Age (years) (4)	Type of pump (5)
Dug well	1965-1980	25 - 40 (30)	11	Centrifugal
Dug-cum-borewell	1980-1990	80 - 160 (120)	6.2	Centrifugal
	1990-2001	90 - 150 (130)	5.75	Submersible
Borewell	Before 1985	80 - 150 (140)	12	Submersible (5 HP)
	1985-1995	100 - 320 (250)	6.5	Submersible (7.5 HP)
	1996-2001	220 - 495 (385)	3	

Groundwater Development at Different Vintages

The vintages of borewells at different points in time indicate the nature and degree of groundwater extraction (Table 2). The depth of borewells, ranged from 80 to 150 feet in 1985, which doubled during 2001. The borewells, yielding 3,500 gallons per hour during 1985, dwindled to yield 800 gallons per hour in 2001. Further, there has been an increase in irrigation pump capacity from 5 to 7.5 HP. In addition, farmers also consider the number of stages of pump due to increased depth to groundwater. Investment per well increased from Rs. 53,605 to Rs. 74, 190 in the last two decades, an increase to the tune of 2 per cent compound growth rate. Earlier studies in the area reported similar results (Nagaraj and Chandrakanth, 1995).

The cost of deepening increased since 1990 from Rs. 15,000 to Rs. 17,880 in 2001. The cost of drilling an additional well was also colossal with an increase from Rs. 23,000 to Rs. 35,294 in the same period. The additional expenditure on pump repairs also increased alarmingly over the years from Rs. 2,000 in 1985 to Rs. 4,000 in 2001. The inter-well distance has shrunk almost three times. The increased intensity of investment in wells indicated the economic scarcity of the groundwater.

TABLE 2. DETAILS OF IRRIGATION WELLS AT DIFFERENT VINTAGES AT 2001 PRICES

Particulars of irrigation borewell (1)	During 1985 (2)	During 1995 (3)	During 2001 (4)
Range of depth (ft)	80-150	200-320	300-495
Average depth (feet)	124	250	357
Yield (gallons/hr)	3500	2000	800
HP used	5	6	7.5
Number of stages of pump	6	8	12
Placement of pump from the top (ft)	60-120 (100)	80-240 (150)	200-340 (230)
Premature failure of wells (per cent)	0	17.5	48
Initial failure of wells (per cent)	0	19	43
Investment on wells (Rs.)			
1. Drilling cost	12,289	14,871	22,080
2. Pump and conveyance cost	29,805	30,792	38,810
3. Other cost	11,511	11,212	13,300
Total	53,605	56,875	74,190
Deepening cost (Rs.)	0	15,028	17,880
Investment on additional well due to failure of previous well (Rs.)	23,334	29,715	35,294
Expenditure on pump repairs (Rs.)	2,000	3,000	4,000
Cost of pump replacement (Rs.)	-	7,000	10,000
Isolation distance (ft)	1,500	800	525

Note: Figures in parentheses are the mean values.

Over a decade, the dynamics of well irrigation-induced activities reflect disturbing trends in groundwater development posing threats to sustainability. The total number of wells swelled almost three times simultaneously with reduction in the percentage of functional wells, functional dug wells and dug-cum-borewells. Well density has increased and the investment per well has increased by one and a half times. The water extracted per well reduced by three times and the annual irrigation cost increased by three times. The cost per acre-inch of water increased sharply from Rs. 51 to Rs. 264, almost five-fold increase (Table 3). The average life of a borewell decreased from 11 to 3 years. The marginal value product (MVP) of the water has been increasing over time reflecting scarcity induced water use efficiency.

TABLE 3. INVESTMENT PARTICULARS AND IRRIGATION COST OF BOREWELL AT 2001 PRICES

Particulars (1)	1990 (2)	1995 (3)	2001 (4)
Total number of wells	56	101	147
Percentage of functioning borewells	99	75	41
Percentage of functioning dug wells	60	30	0
Percentage of functioning dug-cum-borewells	36	23	14
Wells per acre (Number)	0.12	0.26	0.5
Investment on functional well (Rs.)	54,780	56,875	74,190
Water extracted per well per annum (acre inches)	199	143	65.75
Annual irrigation cost per well (Rs.)	10,222	11,768	17,329
Annual irrigation cost per acre (Rs.)	3,235	3,353	4,279
Cost per acre inch of water (Rs.)	51	82	264
Marginal value product (MVP)* of water per acre inch for coconut (Rs.) (the increase in MVP is reflective of scarcity rent)	660	1,074	1,379

Note: * MVP of water is calculated using residual method that deducts the cost of non-water inputs from total value of output.

The shift in crop pattern towards coconut followed by sub-division of holdings resulted in unsystematic tapping of groundwater causing resource scarcity in an area already in 'dark' category. During 1994-95 to 1998-99, water extracted for coconut increased six-fold from 0.77 to 4.71 lakh acre-inches while during this period, there was decline in the rainfall. The rapid expansion of coconut area resulted in increased demand for groundwater for irrigation exerting pressure on groundwater resource.

The implications of groundwater overdraft are analysed by comparing the productivity levels of coconut gardens with functional and failed borewells and subsequent fall in land value. The productivity of coconut fell by 50 per cent in coconut gardens with failed borewells compared to gardens having functional borewells (Table 4). The land value that is strongly associated with economic access to groundwater also decreased by almost Rs. one lakh in the study area. Thus, the difference between the dry land and irrigated coconut garden indicated the value of groundwater. Around 15 per cent of the total sample farmers are affected due to well failures.

TABLE 4. IMPLICATIONS OF GROUNDWATER OVERDRAFT ON PRODUCTIVITY AND LAND VALUE AT 2001 PRICES

Particulars	Coconut garden with functioning borewell	Coconut garden with failed borewell/s	Fall in the land value/ productivity due to failed borewell
(1)	(2)	(3)	(4)
Value of coconut garden (Rs. lakh/acre)	2.50	1.5	1.0
Productivity (Number of coconuts per tree)	100-120	50-70	50

Equity Issues

With respect to equity, out of the total irrigation wells, the medium and large together comprising 69 per cent of the total farmers owned 80 per cent of the wells. Similarly, 88 per cent of the wells in the gross irrigated area were operated by medium and large farmers (Table 5). This clearly reflects the inequity persisting in groundwater irrigation, in addition to the existing inequity in land holding distribution. This skewed distribution of wells and lopsided irrigated area in the groundwater system revealed that the resource rich farmers have better access to groundwater in areas where groundwater is scarce. Both temporal and spatial inequities persist in over-exploited areas.

The cost of groundwater irrigation decreased with the increase in the size of holding. The amount seemed higher for small farmers (Rs. 5,881 per acre) than the medium (Rs. 4,569 per acre) and large farmers (Rs. 3,815 per acre). With regard to the cost per acre-inch of water extracted considering all wells, it was the highest in case of small farmers, viz. Rs. 422 per acre-inch. In contrast, the large farmers incurred an irrigation cost of Rs. 346 per acre-inch of water.

TABLE 5. ACCESS TO IRRIGATION FOR DIFFERENT CATEGORIES OF FARMERS

Particulars (1)	Small farmers (<5 acres) (2)	Medium farmers (5 - 10 acres) (3)	Large farmers (> 10 acres) (4)
Number of wells	32 (21)	61 (42)	54 (37)
(a) Functional (per cent)	28	38	41
(b) Failed (per cent)	72	62	59
Wells per farm	2.9	3.8	6.75
Functional wells per farm	0.8	1.44	2.76
Annual irrigation cost per acre (Rs.)	5,881	4,569	3,815
Water extracted per functioning well (acre inch)	62.5	62	61.3
Water extracted per acre of coconut (acre inch)	21.2	15.6	14.1
Number of failed wells per functioning well	2.6	1.63	1.44
Water use across size groups			
Percentage of water used	16	41	43
Percentage of gross area irrigated	12	43	45
Proportion of functioning wells	16	43	41
Cost per acre-inch of water considering only functional well(s) (Rs.)	276	291	270
Cost per acre inch of water (considering functional and non-functional wells) (Rs.)	422	385	346

Note: Figures in parentheses indicate percentage.

However, considering only the functioning well the cost per acre-inch of water is marginally higher in the case of small farmers (Rs. 276) as against large farmers (Rs. 270). It is observed that for every one functioning well, a small farmer suffers 2.6 failures, while the medium farmer suffers relatively lower, 1.63 wells, and the large farmer suffers from 1.44 failures. This implies the higher cost of groundwater for small farmers. The economic access to water greatly differs across the different sizes of holdings as they range between Rs. 346 to Rs. 422. Thus the study draws the attention of policy makers to provide/offer policy support for small and marginal farmers through different programmes. The Gini-coefficient values indicate that there is an inequity in both net income and volume of water extracted across size groups. The magnitude of the coefficient is similar for net income and volume of water extracted (0.71 and 0.72 respectively).

Cost of Coping Mechanisms

Due to predicament of well failure the farmers are resorting to coping mechanisms to manage the reduced supply of groundwater so that they at least wish to be on the same iso-revenue curve. Economic scarcity of water has led to adoption of micro-irrigation techniques, which also enhance the water use efficiency. The coping cost on different coping mechanisms incurred by different categories of farmers was estimated (Table 6). On an average, a small farmer was forced to incur coping cost of Rs. 18,762 per acre of gross irrigated area compared to Rs. 12,109 and Rs. 14,320 by medium and large farmers respectively. The expenditure on coping mechanism reflects the cost of negative externality due to incidence of over-exploitation of groundwater. Consequently the brunt of negative externality is

inflicted on both the poor and rich farmers, however, the impact is more on small farmers.

TABLE 6. COST OF COPING MECHANISMS AT 2001 PRICES

Coping mechanism (1)	Small farmers (2)	Medium farmers (3)	Large farmers (4)
Deepening of well	8,000	10,511	11,808
Additional well	42,500	33,000	40,000
Conveyance pipes from borewell drilled at distant fragments	3,536	4,565	15,208
Drip system per acre of coconut garden	10,000	10,000	11,875
Coping cost per acre of GIA	18,762	12,109	14,320

Note: Majority of the large farmers and a few small and medium farmers adopted more than one coping mechanisms.

The coping mechanisms like drilling additional well(s), well improvement (deepening) and adoption of drip irrigation, which are capital intensive are generally adopted by large farmers. The coping mechanisms such as adoption of indigenous drip system and buying water, which are less capital intensive, are largely adopted by the small and medium farmers.

Negative Externality Cost Due to Over-exploitation

For computing negative externality, it is desirable to compare the groundwater-over-exploited situation with normal extraction of groundwater. In this study, wells located in the tail-end areas of tank/command areas were chosen to represent normal situation where the rate of extraction will be more or less similar. In the GW system, there has been upward trend in the annual maintenance and repairs costs, and the electricity charges due to the high pump capacity and increasing depth of the borewells. In the case of CUTI and CUCI, the annual cost of groundwater irrigation and the cost per acre-inch of water have been constant due to positive interaction effects of recharge. The physical scarcity in terms of decreased water yield from the wells and economic scarcity in terms of rise in irrigation cost per acre-inch in GW is evident (Table 8).

The conjunctive use systems considered in the study involve both private and public investments. As public investments suffer from subsidy distortions, the true value of water does not reflect its marginal cost. Accordingly the negative externality computed is a bit underestimated since it includes the positive externality due to recharge from tanks/canals as indicated above. Nevertheless, the externality per well is a colossal Rs. 18,590 (Table 7). The externality cost per acre-inch of water considering only functional wells is around Rs. 159. However, considering both functional and non-functional wells negative externality cost works out to be Rs. 283. This is due to deeper depth of the wells, higher rate of well failure and lower average age of wells in the groundwater situation as compared with the control.

TABLE 7: NEGATIVE EXTERNALITY COST DUE TO OVER-EXPLOITATION

Particulars (1)	Groundwater over-exploited situation (2)	Groundwater use area under the tank and/or canal command * (3)	Negative externality cost (difference between over-exploited and the normal situation) (4)
Investment per functional borewell	74,190	55,600	18,590
Annual irrigation cost per well	17,329	10,325	7,004
Annual irrigation cost per acre	4,279	2,419	1,860
Cost per acre-inch of water considering only functional well(s) (Rs.)	264	105	159
Cost per acre inch of water (considering functional and non-functional wells) (Rs.)	388	105	283

*In this area the groundwater recharge helps to sustain the yield of irrigation wells.

Economic Appraisal of Investment on Drip Irrigation

In the recent years, the demand for drip irrigation system has been increasing due to acute scarcity of groundwater in the area. Given the high rate of well failures in the area, farmers need to reconcile between investing on additional wells and use of drip irrigation. The analysis is for a five acre established coconut farm adopting drip irrigation. On an average, the drip system requires an investment, which is half the investment on an additional well. The associated benefits include about 44 per cent saving in water, additional improvement in yield of about 20 per cent and high water use efficiency.

The partial budgeting analysis of drip adoption over flow method with an additional well proved the economic worth of drip irrigation. Further, the economic measures of IRR (36 per cent for drip irrigation with existing well and 33 per cent for flow irrigation with additional well), NPV (Rs. 1.12 lakhs for drip irrigation and 0.45 lakhs for flow irrigation) and BCR (1.9 for drip irrigation and 1.5 for flow irrigation) indicated that the investment on drip irrigation is economically feasible (Table 8). Although in both the cases the investment is feasible, from the viewpoint of conservation of the resource for present and future development, drip irrigation is desirable.

TABLE 8. FINANCIAL FEASIBILITY OF DRIP VS ADDITIONAL WELL

Particulars (1)	Drip irrigation to coconut garden with one functioning well (2)	Flow irrigation method to coconut garden with additional well (3)
Internal rate of return (per cent)	36	33
Net present value (Rs.)	1,12,727	44,392
DCBR	1.9	1.5

Note: A discount rate of 10 per cent is taken as the opportunity cost of capital and the benefits and costs are discounted at this rate.

The partial budgeting and cash flow analysis was computed for 10 years where the economic life of the drip system was assumed to be 10 years and that of borewell was 5 years in flow method; irrigating by using flow method and replacing another borewell after the end of 5 years was considered.

Impacts of Conjunctive Use: Conjunctive use systems facilitated realisation of higher incomes over the GW system due to recharge of wells, which decrease the failure of wells. The groundwater recharge could be experienced both in physical terms as well as economical impacts (Table 9). Increased well life, negligible well failure, increase in the water yield of the wells and higher crop diversity are some of the main physical impacts of the conjunctive use in the CUCI and CUTI areas. The economical impacts include little or no investment on the coping mechanisms like drilling additional wells, deepening of wells and adoption of the drip system. Due to conjunctive use, the life of wells increased, failure of wells reduced, water yield from wells stabilised and irrigation cost reduced. Thus, the conjunctive use of surface and groundwater had a positive effect on sustainability of the groundwater promoting intra and intergenerational equity.

TABLE 9. IMPACTS OF CONJUNCTIVE USE OF WATER

Particulars (1)	GW (2)	CUTI (3)	CUCI (4)
I. Physical impacts			
1. Well life (years)			
(a) Dugwell	11	15.5	17
(b) Dug-cum-borewell	6	>15	>15
(c) Borewell	5	>15	>15
2. Failure of wells (per cent)			
(a) Dugwell	100	37	60
(b) Dug-cum-borewell	86	nil	nil
(c) Borewell	48	nil	nil
3. Yield of water from borewells (GPH)	800	3000	3000
4. Irrigation wells per acre	0.5	0.18	0.2
5. Crop diversity	coconut, arecanut, paddy.	coconut, arecanut, betel vine, banana, maize, mulberry groundnut, paddy,	coconut, beetle vein, arecanut, paddy, mulberry, green gram, nizer.
II. Economic impacts (Rs.)			
1. Investment on borewells	74,190	55,600	54,400
2. Investment on additional well	35,294	NIL	NIL
3. Investment on deepening of well	17,880	NIL	NIL
4. Investment on drip irrigation system (Rs./acre)	11,000	NIL	NIL
5. Cost per acre-inch of water	264	105	164
6. Income per acre of gross irrigated area	7,684	16,289	8,993
7. Net return per acre inch of water pumped	475	709	571

POLICY IMPLICATIONS

Regulatory Interventions: There is a need for institutional restructuring of groundwater regulations such as using permits for drilling wells, maintenance of inter-well space, optimum number of wells, use of efficient pump technologies and banning additional wells in over-exploited areas till the groundwater situation improves. State policies such as subsidised electricity for groundwater irrigation

have an adverse impact on groundwater development. Hence, appropriate pricing, incorporating marginal cost of extraction is desirable.

Demand-side Interventions: Adoption of drip irrigation should be made mandatory in dark talukas, where farmers have invested in additional wells, to sustain groundwater irrigation. Groundwater depletion is also attributed to cultivation of water-intensive commercial crops on a large scale. Thus, there is a need for benign crop pattern, which needs less water.

Supply-side Interventions: Efforts should be made to bridge the gap between extraction and recharge, on the community basis through people's participation for the construction of water harvesting structures, and desilting the existing tanks so that groundwater supply can be augmented through recharge. The government should consider artificial recharge projects in 'dark' and 'grey' taluks on priority basis.

Other Interventions: The problem of inequity existing in well irrigation, where physical and economic access to groundwater is restricted for the poor, could possibly be addressed by promoting group investment programmes like Ganga Kalyan Yojana for the benefit of small and marginal farmers. Since farmers are the bulk users of groundwater, they need to be educated regarding the scarcity value of this precious resource.

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