Environ Dev Sustain (2013) 15:587–606
DOI 10.1007/s10668-012-9394-0

Economic implications of groundwater exploitation in hard rock areas of southern peninsular India

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Received: 28 May 2012 / Accepted: 22 September 2012 / Published online: 5 October 2012
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Abstract The present paper analyses the consequences of groundwater exploitation by using field-level data collected from two distinct well irrigated areas of Karnataka. The study results show that the consequences arising out of groundwater overexploitation are severe in high well interference area compared to low well interference area. The burden of well failure is more or less equally shared by all categories of farmers but small farmers are the worst victims of resource scarcity. As a result, overexploitation of groundwater has different impacts on different categories of farmers in terms of access to groundwater, cost and returns to groundwater irrigation and its negative externality cost. The study suggests maintaining inter-well distance to prevent resource mining and calls for supply and demand side interventions. The institutional reform is necessary to restore surface water bodies to facilitate aquifer recharge.

Keywords Farming community · Groundwater · Hard rock areas · Irrigation · Overexploitation

1 Introduction

An impressive development that has taken place in Indian agriculture, since independence, is the swift expansion of groundwater irrigation. Over the last 60 years, Indian farmers have pumped massive investment into groundwater structures, which is estimated to be in order of US$ 12 billion (Shah 1993, 2007). The ultimate irrigation potential from groundwater source is 64.05 million ha, as compared to 46 million ha of land currently under groundwater irrigation (Government of Karnataka 2005). Groundwater meets nearly 55 per cent of irrigation, 85 per cent of rural and 50 per cent of urban industrial needs (Government of India 2007) and up to 80 per cent of the country's total agricultural production may, in one form or another, be dependent on groundwater (Dains and Pawar

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1987). The gross irrigated area in India in 1960–1961 was 28 million ha, and in 1998–1999, it moved up by 76 million ha with a sharp Compounded Annual Growth Rate (CAGR) of 2.2 per cent (Scott et al. 2003). It is evident from the data that the tanks recoded a reduced growth rate by 1.1 per cent, whereas much of the growth is accounted by groundwater (Government of India 2007).

India withdraws an estimated 231 billion cubic metre of water from the ground annually, the largest amount in the world. Considering that groundwater is a critical input for livelihoods, irrigating about 70 per cent of the cropped area and supplying 80 per cent of domestic water, it is clear that the economy is approaching a flashpoint (EPW 2007). Groundwater overexploitation has been recognized as a serious problem in India since the late 1980s (Moench 1992; Dhawan 1988, 1995; Macdonald et al. 1995; Bhatia 1992; Chandrakanth and Arun 1997; Shivakumaraswamy and Chandrakanth 1997; Reddy 2005; Palanisami et al. 2008), and the rate of extraction of groundwater far exceeds the rate of replenishment in many blocks leading to progressive lowering of the water table (Deb Roy and Shah 2003; Government of India 2007).

Groundwater development helped farmers use more intensive production techniques that required higher inputs and associated capital investments (Moench 2003). Globally, agricultural groundwater use of around 900 km^3 a year supports an annual output valued at \$210–\$230 billions, yielding a gross productivity of about \$0.23–\$0.26 per cubic metre of water abstracted (Molden 2007:396). In Asia, groundwater irrigation contributes about US\$10–12 billion business per year, and if we consider farmer's earnings from selling groundwater for irrigation, the contribution may goes up nearly US\$ 25–30 billion per year (Shah 1993, 2007). On the other hand, groundwater also proven to enhance the wage rate and employment opportunities for agricultural labourers as well as reducing rural poverty (Shah and Raju 1987; Shah 1993; Narayanamoorthy and Deshpande 2003). While past studies have highlighted the positive benefits of groundwater irrigation, the recent studies have been focusing on the issues of costs of groundwater irrigation, overexploitation, externalities, etc. (Janakarajan 1993; Nagaraj et al. 1994; Vaidyanathan 1996; Chandrakanth and Arun 1997; Shivakumaraswamy and Chandrakanth 1997; Nagaraj 1994; Reddy 2005; Janakarajan and Moench 2006; Anantha 2009; Anantha and Raju 2008, 2010; Palanisami et al. 2008). 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). Therefore, assessing the impacts of groundwater irrigation in the context of overexploitation assumes greater importance in taking measures to sustain the resource for future generation. This paper is an attempt to understand the effects of declining groundwater resource in the hard rock areas of Karnataka, India.

2 Materials and methods

The central dry zone is one of the hard rock areas that lie in the central part of Karnataka. The zone consists of 17 taluks covering a total geographical area of 20,112.81 sq. km. The rainfall ranges between 455.5 and 717.4 mm in the zone. Agriculture is the major occupation with about 60 % of the working population cultivating land. In these areas, the cropping pattern is governed by access to groundwater in the absence of major surface irrigation schemes. A wide range of crops are grown in the study areas. In kharif season, the farmers grow paddy, ragi, maize and vegetables for regular income. Perennial cash crops such as coconut and arecanut comprise of large areas and short-term cash crops such as groundnut is also present in the system. A very limited amount of land is allocated to summer paddy owing to water scarcity problem. It is important to note that cash crops have a major share in the gross irrigated area, especially in Hosadurga.

Using the index of cumulative well interference (ICWI), two taluks—Madhugiri and Hosadurga with index value of 2.6 and 1.5, respectively—were selected for a detailed analysis based on the magnitude of the problem of cumulative well interference. Cumulative well interference refers to the 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).The selected taluks are in the low well interference area, Hosadurga, and high well interference area, Madhugiri.

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, 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 nine villages in two taluks. The information gathered includes the socioeconomic 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. The primary survey was carried out during September to December 2007. According to data obtained from Department of Mines and Geology (DMG) and Central Ground Water Board (CGWB) (GoK 2005), Hosadurga is less affected by the problem of cumulative well interference. Therefore, we considered Hosadurga for comparison with Madhugiri. The estimation methods and relevant concepts are explained below.

2.1 Annual cost of irrigation

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

The amortized cost of irrigation is the sum of amortized investment on all wells on the farm, pump sets 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 % was used in amortization, reflecting long-term sustainable rate (Chandrakanth et al. 1998a, b, c, 2004). The capital cost of the well was amortized over its entire life span. An interest rate of 2 % represented the rate of inflation in the cost of well components like labour, pump sets and other accessories.

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

$$\text{Amortised investment on well} = \left[(\text{CI}) \times (1+i)^{\text{AL}} \times i\right] / \left[(1+i)^{\text{AL}} - 1\right] \quad (1)$$

$$\text{CI} = (\text{II}) \times (1+i)^{(\text{dc}-\text{di})} \quad (2)$$

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.

$$\begin{aligned}\text{Amortized cost of borewell} = {} & [(\text{Compounded cost of borewell}) \\ & \times (1+i)^{\text{AL}} \times i)] / [(1+i)^{\text{AL}} - 1]\end{aligned} \quad (3)$$

$$\text{Compounded cost of borewell} = (\mathrm{BW}_{\text{cost}}) \times (1+i)^{(2007-\text{year of drilling})} \tag{4}$$

$$\begin{aligned}\text{Amortized cost of pump set and accessories} = \{[(&\text{compounded cost of pump set} \\ &+ \text{compounded cost of pump house}) \\ &\times (1+i)^{\mathrm{AL}} \times i]/[(1+i)^{\mathrm{AL}} - 1]\}\end{aligned} \tag{5}$$

$$\begin{aligned}\text{Amortized cost of conveyance} = \{[(&\text{Compounded cost of conveyance pipe used}) \\ &\times (1+i)^{\mathrm{AL}} \times i)/(1+i)^{\mathrm{AL}} - 1]\}\end{aligned} \tag{6}$$

2.2 Average life of well

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

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.

2.3 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).

2.3.1 Physical access

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

$$\ln \mathrm{wu} = \ln \alpha + \beta_1 \ln \mathrm{wd} + \beta_2 \ln \mathrm{wy} + \beta_3 \ln \mathrm{cw} \tag{8}$$

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).

2.3.2 Economic access

The economic access to groundwater was measured by amortized cost of groundwater per acre-inch and hypothesized 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 as follows:

$$\ln \mathrm{cw} = \ln \alpha + \beta_1 \ln \mathrm{wd} + \beta_2 \ln \mathrm{wy} + \beta_3 \ln \mathrm{gia} \tag{9}$$

where cw = amortized 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).

2.4 Negative externality

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

$$\mathrm{NEC} = \mathrm{AC_{PW}} - \mathrm{AC_{FW}} \tag{10}$$

where, NEC = negative externality cost, $\mathrm{AC_{PW}}$ = amortized cost per well, $\mathrm{AC_{FW}}$ = amortized cost per functioning well.

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

1. in hard rock areas, due to rapidly declining groundwater levels, the average age and life of wells both are falling
2. if all wells on the farm are functioning, then there will be no externality
3. if the failure rate of wells is high, then the difference between the amortized 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 amortized cost per well minus amortized cost per functioning well gives the negative externality or the social cost per well faced by farmer.

3 Results and discussion

3.1 Ownership of groundwater structures

Landholding size seems to be a major factor for owning different types of groundwater structures. Table 1 demonstrated that as the landholding size increases the preference to have borewell technology increases in Hosadurga, where the proportion of borewells is in increasing trend as we move towards larger landholding sizes. The ownership of different types of groundwater structures in Madhugiri gives a different picture as well interference problem is severe. Evidently, the groundwater structures owned by small farmers in Madhugiri are due to the reason that a majority of them are late comers in the resource extraction activity. In this situation, small and marginal farmers are unable to strike water as this area is already suffering from acute well interference problem. In the course of competition, even if they are able to mop the capital required for additional wells, they would have to bear greater risk of not striking adequate groundwater in this area.

The burden of groundwater overexploitation in terms of failed wells is equally distributed among all categories of farmers in Madhugiri (Table 1). The open wells are the first causality of overexploitation of groundwater. This has been evidenced clearly from

Table 1 Distribution of wells across landholding size

Landholding size (Ha)	Hosadurga					Madhugiri				
	No. of BW	No. of DW	No. of DCBW	Total wells	% of wells dried up	No. of BW	No. of DW	No. of DCBW	Total wells	% of wells dried up
Marginal (up to 1)	11	0	0	11	18.2	27	14	5	46	76.1
Small (1.01–3)	52	3	0	55	29.1	168	41	36	245	78.8
Medium (3.01–5)	58	4	0	62	41.9	49	17	3	69	65.2
Large (more than 5)	99	4	1	104	51.9	28	6	4	38	50.0
Total	220	11	1	232	42.2	272	78	48	398	73.4

Source Primary survey

Percentage of dried wells represents all types of completely failed wells

BW Borewell, *DW* Dug well, *DCBW* Dug-cum-borewell

our survey data. The causality of groundwater overexploitation in terms of defunct wells is highest in both the areas irrespective of the degree of well interference problem (Table 1). Therefore, none of the open wells and DCBW is functional. At the surface, it appears that the numbers of wells are high, but it is not so in terms of functioning wells. After the open wells become dry, the concern of the farmers shifts to restoration of well irrigation at any cost. Oblivious to the risk involved, farmers incur heavy expenditure on drilling borewells, most of them making repeated attempts. Even in respect of successful borewells, many farmers have had to incur expenditure in deepening borewells, because the borewells which succeeded initially were dry after running for a few years. This process has led to owning more number of wells to sustain crops.

In the study area, the ownership rights over groundwater structures viz., borewells and open wells are enjoyed by a sole owner, but not by joint well owners. This is of fundamental importance in the understanding of emerging groundwater problems and potential solutions, because it has become a central point of overexploitation. It accelerates the rate of extraction of groundwater as they enjoy the ownership rights as well as freedom to extract groundwater as and when required. The survey conducted in 9 villages show that about one-third of large farmers owned nearly 50 % of wells in Hosadurga (Table 2). Similarly, in Madhugiri, the maximum number of wells owned by small farmers is an indication of high well failure due to the problem of resource mining by large farmers.

Janakarajan and Moench (2006) revealed that larger the land area owned, greater was the possibility of striking groundwater. In this respect, the scope of sustaining groundwater irrigation is far better for large land owners compared to small holders. But it is difficult to predict for how long they will sustain in the course of competitive deepening. In this context, it is important to note that while the threat of getting eliminated from the race of competitive deepening is seemingly just around the corner for the resource-poor farmers, the resource-rich farmers have the capability of sustaining the adverse effects of competitive deepening. This is simply because the resource-rich farmers are not constrained to the same extent as resource-poor farmers in mobilizing finance for well drilling or well deepening activities.

Table 2 Ownership of wells across size class of landholding in Hosadurga and Madhugiri

Landholding size (Ha)	Total number of wells owned	Functioning wells (%)	Total extent of land irrigated (ha)	Average extent irrigated area per well (ha)[a]
Marginal farmer ($N = 10$)	11	81.8	5.58	0.62
Small farmer ($N = 37$)	55	70.9	44.08	1.13
Medium farmer ($N = 26$)	62	58.1	51.16	1.42
Large farmer ($N = 29$)	104	48.1	106.11	2.12
Hosadurga ($N = 102$)	232	57.8	206.93	1.54
Marginal farmer ($N = 15$)	46	23.9	6.99	0.64
Small farmer ($N = 73$)	245	21.2	73.43	1.41
Medium farmer ($N = 22$)	69	34.8	36.54	1.52
Large farmer ($N = 13$)	38	50.0	38.05	2.00
Madhugiri ($N = 123$)	398	26.6	155.01	1.46

Source Primary survey

[a] Average extent of irrigated area is calculated for functioning wells only, and this includes area irrigated through water markets as well

However, the sole ownership is the indication of the property rights claimed over groundwater. The operation of the law of inheritance has perpetuated the problem of sole ownership of land. With the problem of fragmentation of land, every single farmer, who can afford to drill borewell, is now enjoying the property rights over groundwater by extracting substantial quantity of groundwater. In the event of competitiveness to bring more area under irrigation, small and marginal farmers tend to have experimented with drilling more wells even though they did not strike adequate quantity of groundwater. Therefore, the area irrigated per well by small and marginal farmers is low when compared with that by medium and large farmers (Table 2). For instance, both in Hosadurga and Madhugiri, the area irrigated per well in the case of marginal farmers is less than 1 ha, and in the case of small farmers, it is less than 1.5 ha. But in the case of large farmers, the area irrigated per well is more than 2 ha in both the conditions. This is manly due to less number of wells owned by small and marginal farmers with low depth affects the quantity and could pump only 3–4 h in a day compared to large farmers who are having 4–6 bore wells and pump simultaneously from 2 to 3 functioning wells using compressor pumps. More number of wells necessarily resulted in increased costs to the farmers as reflected in the cost of irrigation at farm level. Despite little variations in the area irrigated per well, farmers tend to spend more money on wells in terms of capital costs as well as running (labour and maintenance) costs.

3.2 Growth, depth and cost of borewells

Growth of groundwater structures (wells) is associated with many factors. Falling water levels and competition among farmers have major implications for the growth of wells in the study area. This has had a variety of impacts. First, there has been a change in the type of wells. Traditional open wells/dug-cum-borewells could not be used when water levels fell and new technologies for both wells and pumping proliferated in recent decades. Now, large numbers of defunct open wells have turned into storage tanks in the wake of infrequent power supply and voltage fluctuation.

Table 3 Details of borewells in Hosadurga and Madhugiri

Particulars	Before 1985	During 1985–1990	During 1991–1995	During 1996–2000	During 2001–2007
Hosadurga					
Total No. of borewells	8	12	36	80	84
Average depth (ft)	154	164	187	179	215
HP used	4.3	4.91	4.55	4.22	4.52
Initial failure of wells (per cent)	0	8.3	22.2	38.75	33.33
Investment on wells (Rs. in current prices)					
Drilling cost	7,022	9,338	8,671	8,968	10,890
Investment on additional well (Rs)	7,505	8,812	8,188	9,853	11,273
Madhugiri					
Total No. of borewells	9	13	72	85	94
Average depth (ft)	281	404	373	383	490
HP used	8.1	8.5	8.5	9.5	9.5
Initial failure of wells (per cent)	11.11	0	22.22	30.58	26.59
Investment on wells (Rs in current prices)					
Drilling cost	15,447	13,525	16,422	17,836	24,582
Investment on additional well (Rs)	11,595	22,856	17,775	18,775	26,114

Source Primary survey

The growth of wells seems to be high in Madhugiri compared to Hosadurga (Table 3). This uneven growth is because of frequent well failure problem. Since Madhugiri is suffering from cumulative well interference problem, frequent well failure and declining yield rate are quite obvious in this area. Similarly, the depth of borewells is increasing constantly with the number of borewells both in Madhugiri and Hosadurga, but the severity is high in Madhugiri. Table 3 reveals that the depth of borewells in Madhugiri is always higher than that of Hosadurga. The difference is almost two times. This is a clear indication of competitive extraction behaviour of farmers in Madhugiri.

Declining groundwater table, as well as availability of a variety of drilling technologies have major implications on the cost of obtaining access to groundwater. The cost of drilling borewells is much lower in Hosadurga compared to Madhugiri because water tables are higher. Importantly, the water required by the crops is less in Hosadurga compared to Madhugiri due to cropping pattern. This reduces the pressure on groundwater resource and hence declining cost of drilling.

The problem of initial failure of wells also indicates the severity of groundwater overexploitation in both the areas (Table 3). As the number of wells increases, the isolation distance between wells decreases. For example, as farmers perceived, the isolation distance between two borewells is ranging from 15 to 60 m in Madhugiri and 100 to 200 m in Hosadurga. As a result, the cost of drilling increases considerably, especially in Madhugiri, where isolation distance between wells decreases severely leading to problem of well failure. Thus, the investment on additional well is increasing over time, and it is considerably high in Madhugiri (Table 3). For instance, investment on additional well in Hosadurga was Rs. 7,505 prior to well interference period, that is, 1985, while it was Rs.

Table 4 Cost of drilling per well across landholding size (at current prices)

Landholding size (ha)	Hosadurga				Madhugiri			
	Total No. of farmers	Av. depth (ft)	Av. cost per well (Rs.)	Av. HP	Total No. of farmers	Av. depth (ft)	Av. cost per well (Rs.)	Av. HP
Marginal farmer (up to 1)	10	197	10,978 (11)	4.3	15	490	21,583 (46)	10.3
Small farmer (1.01–3.0)	37	192	9,392 (55)	4.4	73	426	22,723 (242)	8.9
Medium farmer (3.01–5.0)	26	186	9,125 (62)	4.7	22	360	19,220 (69)	9.2
Large farmer (more than 5.0)	29	195	9,900 (104)	4.4	13	393	18,509 (38)	8.7
Total	102	192	9,624 (232)	4.5	123	417	21,573 (398)	9.1

Source: Primary survey

Figures in parentheses indicate number of wells (all types of wells)

11,595 in Madhugiri during the same period. Gradually, investment on additional wells started rising due to high rate of well failure because of the declining water table. Consequently, the investment on additional wells is increasing sharply in Madhugiri (more than two times during 2001–2007).

The major implication of cumulative well interference is the ever increasing cost. Our survey results show that the cost incurred on well drilling by individual farmers is quite high in Madhugiri as compared to Hosadurga. In particular, cost incurred on well drilling looks quite disproportionate to landholding size (Table 4). For instance, the amount spent per well located in the Madhugiri works out to Rs. 17,152 when compared to Rs. 9,624 in Hosadurga. Further, the rate is disproportionate in the cost of drilling well as reflected in terms of landholding size as well. The current average cost of drilling per well is highest among small and marginal farmers in Madhugiri compared to their counterparts in Hosadurga. This implies that the consequences of cumulative interference problem on access to resource are severe in Madhugiri.

Falling water levels and competition among farmers have major implications for the resource extraction technology that can be used. Changing technology for the extraction of groundwater from deep aquifers and the use of high power motors has had huge impact on energy demand. Until 1990s, manually lifting device, for example, *yetha* was the main means of water extraction from the open wells. That is now not in practice due to change in types of wells that can be used for irrigation in the wake of declining water tables. Dug-cum-borewells were used for some time with low capacity (3.5 HP) pump sets. Later, with the availability of borewell technology coupled with declining water tables, high horsepower is being used in relation to depth.

Such steep rise in horsepower disturbed the balance between groundwater recharge and extraction resulting in the decline of water levels in areas characterized by high well density. A sharp decline in the water tables and their reduced thickness have resulted in lower aquifer transmissibility. This implies that the rate of pumping should be reduced significantly to stabilize the water tables. Unless proper measures to control over-pumping of the resources are undertaken in future, even with the same rate of pumping, the rate of water table decline will be much faster. This observation corroborates with the findings of earlier studies in the semi-arid areas (Janakarajan and Moench 2006).

However, declining water levels have encouraged increases in water use efficiency. Until 1980s, open channels were used for conveying water from wells to the fields. Now, the farmers often use underground pipelines and hose pipes. Overground storage tanks are common in Madhugiri to store water due to low voltage power supply as well as frequent power cut. Therefore, high well and equipment costs disproportionately affect small farmers. While large farmers have the resources to survive unsuccessful investments in well drilling and well deepening, for a small farmer, the losses are often unsustainable.

3.3 Incidence of well failures

The total number of wells distributed across villages is given in Table 5. It is revealed that the total number of wells owned was more than one-and-a-half times for Madhugiri (398) as compared to Hosadurga (232). It was observed that around 73 % of the wells

Table 5 Incidence of well failure across landholding size

Landholding size (ha)	Borewells	Open wells	Completely failed borewells	Completely failed open wells[a]	Total failed wells	Total wells functioning	Total number of wells
Marginal farmer (up to 1)	11 (100)	0 (0.0)	2 (18.2)	0	2 (18.2)	9 (81.8)	11
Small farmer (1.01–3.0)	52 (94.5)	3 (5.5)	13 (25.0)	3	16 (29.1)	39 (70.9)	55
Medium farmer (3.01–5.0)	58 (93.5)	4 (6.5)	22 (37.9)	4	26 (41.9)	36 (58.1)	62
Large farmer (More than 5.0)	99 (95.2)	5 (4.8)	50 (50.5)	5	55 (52.9)	49 (47.1)	104
Hosadurga	220 (94.8)	12 (5.2)	87 (39.5)	12	99 (42.7)	133 (57.3)	232
Marginal farmer (up to 1)	27 (58.7)	19 (41.3)	17 (63.0)	19	36 (78.3)	10 (21.7)	46
Small farmer (1.01–3.0)	168 (68.6)	77 (31.4)	116 (69.0)	77	193 (78.8)	52 (21.2)	245
Medium farmer (3.01–5.0)	49 (71.0)	20 (29.0)	25 (51.0)	20	45 (65.2)	24 (34.8)	69
Large farmer (More than 5.0)	28 (73.7)	10 (26.3)	9 (32.1)	10	19 (50.0)	19 (50.0)	38
Madhugiri	272 (68.3)	126 (31.7)	167 (61.4)	126	293 (73.6)	105 (26.4)	398

Figures in parentheses in columns 2, 3, 6 and 7 indicate percentage to total wells, in column 4 indicate percentages to total number of borewells

Source Primary survey

[a] All the open wells and dug-cum-borewells have failed in the study area; hence, we have considered them as open wells for general understanding

(borewells + open wells) had failed in Madhugiri, whereas in the Hosadurga, the proportion of total failed wells was around 42 %. Among the total failed wells, the rate of failure was high in the case of borewells compared to open wells. For instance, in Madhugiri, around 61 % of failed wells belonged to borewell category. Similarly, in Hosadurga, the proportion of completely failed borewells to total borewells was about 40 %. On the other hand, all the open wells and dug-cum-borewells have become defunct in both the areas due to cumulative well interference problem.

In Hosadurga, the proportion of still functioning wells is around 58 % compared to 26.4 % in Madhugiri. This negative externality could link with social and economic condition of the rural agrarian livelihood system. The most visible implications of well failure problem are increasing cost on additional wells, cost on well deepening, reduction in area per well and loss of gross and net income from agriculture. Considering the well failure due to well interference and their impact in the Madhugiri, the burden of open well falls equally on both small and large farmers, as more than 50 % of the failed wells in both categories of wells were owned by small farmers. Hence, the concern towards the small and marginal farmers due to interference of 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.

3.4 Access to groundwater irrigation

The data regarding 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 6). As 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 was also proportionate to the 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 6). It implies that the small and marginal farmers were new to the resource extraction activity. Thus, the number of wells owned by them was

Table 6 Access to groundwater resource by farmers in the study area

Particulars	Hosadurga				Madhugiri			
	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)	3,527	2,300	1,189	1,648	11,357	6,074	4,796	4,530
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

MF marginal farmers, *SF* small farmers, *MDF* medium farmers, *LF* large farmers high, but the functioning wells were less because of water scarcity. Large farmers could deepen the wells so they had a higher number of functioning wells compared to the small farmers. This was obvious, given the resource capability of these farmers. The larger number of wells per farm in Madhugiri 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 Hosadurga and Madhugiri, respectively (Table 6). 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.

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 Hosadurga, nearly 37 % of the wells were irrigating a gross area of more than 4 ha compared to 25.4 % of the wells irrigating the same area in Madhugiri. Similarly, less than 15 % of the wells were irrigating more than 2 ha of net irrigated area in both Hosadurga and Madhugiri. This implies that the gross irrigated area (GIA) and net irrigated area (NIA) of Hosadurga was high due to resource availability coupled with landholding size and cropping pattern. However, in Madhugiri, 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 landholdings, 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 7 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
$R^2 = 0.39$		

* Significant at 1 % level

From the regression analysis, it has been found that well yield had a positive influence on volume of groundwater used, while the cost of groundwater exerted a negative influence (Table 7). The results show that for 1 per cent increase in groundwater yield per well, the groundwater used per acre increased by 1.07 %. For 1 per cent increase in cost of groundwater, the groundwater used declined by 0.35 %, and for 1 per cent increase in the well depth, the groundwater used increased by 0.78 %. The significant positive sign of the well depth indicates that the groundwater use 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 stabilize 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 farmers to stabilize the productivity.

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 utilization in agriculture development. Economic access provides an opportunity to enhance farm productivity by minimizing 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 1 per cent increase in the depth of the well increased economic access to groundwater by 0.74 %. However, as expected, the 1 per cent increase in yield and gross irrigated area decreased economic access to groundwater by 1.76 and 0.71 %, respectively (Table 8). This suggests that increasing the depth of wells has a direct relation with increasing the cost of groundwater. This will ultimately have negative effects on the sustainability of the resource and farmers' welfare in this region.

3.5 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 %, in Madhugiri than Hosadurga (Table 9). The rise in the annual irrigation cost is a partial indicator of scarcity of groundwater in Madhugiri. As indicated elsewhere, the major portion of irrigation cost is incurred on rising repair and maintenance works. During our field visit, it was learnt that many farmers complained about frequent burning of

Table 8 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
$R^2 = 0.496$		

Dependent variable = natural logarithm of (1/cost per acre-inch of water)

* Significant at 1 per cent level

Table 9 Annual cost and returns from well irrigation per farm

Particulars	Hosadurga		Madhugiri	
	Per well	Per acre	Per well	Per acre
Volume of water extracted from well (m^3)	5,992	1,919	7,039	2,231
Volume of water extracted from well (AI)	58.3	18.7	68.5	21.7
Human + bullock labour (Rs.)	6,691 (23)	2,143	8,150 (20)	2,584
Fertiliser cost (Rs.)	7,028 (24)	2,251	7,462 (18)	2,365
Other variable cost (Rs.)	521 (2)	167	2,699 (7)	855
Opportunity cost of capital at 9 per cent[a]	1,282 (4)	410	1,648 (4)	522
Irrigation cost (Rs.)	13,851 (47)	901	21,410 (52)	1,784
Total cost (Rs.)	29,373 (100)	5,872	41,369 (100)	8,110
Gross income (Rs.)	29,331	9,394	33,037	10,474
Net income (Rs.)	−42	3,522	−8,332	2,364

Figures in parentheses indicate percentage to the total cost

One acre-inch (AI) = 102.79 m^3

[a] 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

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 Hosadurga is marginally better off compared to Madhugiri. Although the gross income per well and per acre in Madhugiri and Hosadurga are comparable, considerable differences exist in terms of net income.

The disaggregate picture demonstrates that the volume of water per acre was 16 % higher in Madhugiri. Similarly, all other costs (labour costs, fertilizer costs and other costs) were higher in Madhugiri. This clearly indicates that the irrigated agriculture in Madhugiri suffered from severe overdraft compared to Hosadurga. The cultivation of perennial crops, like coconut, in Hosadurga 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.

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 Hosadurga and Madhugiri. The results indicate that there was considerable difference in the total quantity of groundwater used on the farm in the two areas (Table 10). In Hosadurga, 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 Madhugiri. A comparison of the total groundwater used in both areas shows that Madhugiri used more than Hosadurga. It was obvious because Madhugiri 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 Madhugiri when compared to their counterparts in Hosadurga. For instance, the net return per farm as well as per acre of GIA was negative (Rs. −6,212 per farm and Rs. −1,120 per acre of GIA) in the case of small and marginal farmers in Hosadurga. However, the same category of farmers operated in the comfort zone because they earned Rs. 1,300 and Rs. 792 per farm as well as per acre of GIA, respectively. The cost of groundwater per acre-inch

Table 10 Statistical significance of groundwater benefits

Particulars	Mean		SD		*t* value
	Marginal and small farmers	Large farmers	Marginal and small farmers	Large farmers	
	Hosadurga				
Total water used on the farm (acre-inch)	68.53	93.44	90.95	78.50	9.74*
Net return per farm (Rs.)	−6,212	941.2	14,481	30,703	−0.846
Net return per acre of GIA (Rs.)	−1,120	519.9	783.9	5,349.6	−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*
	Madhugiri				
Total water used on the farm (acre-inch)	74.36	99.22	72.49	103.31	9.45*
Net return per farm (Rs.)	1,300.97	2,380.48	32,330	25,279	0.587
Net return per acre of GIA (Rs.)	792.92	2,141.26	12,950	12,569	1.01
Net return per acre-inch of water (Rs.)	167.78	273.08	784.85	1,153.52	2.43**
Cost per acre-inch of water (Rs.)	939.37	1,197.86	1,448.66	2,569.10	5.243*

*, ** and *** significant at 1, 5 and 10 per cent level

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 Hosadurga, whereas in Madhugiri, 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.

3.6 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 Madhugiri.

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 Hosadurga, the proportion of failed wells increased with landholding size (Table 11). In the case of Madhugiri, 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

Table 11 Negative externality cost of well irrigation in the study area

Particulars	Marginal Hosadurga	Small	Medium	Large	Total	Marginal Madhugiri	Small	Medium	Large	Total
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

two areas was increasing. However, the total negative externality cost in Madhugiri was more than three times higher than in Hosadurga. The large gap in terms of negative externality cost of groundwater overexploitation between Hosadurga and Madhugiri 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 Madhugiri and Rs. 2,97,943 in Hosadurga (Table 10). The negative externality cost per farm was as high as Rs. 6,791 in Madhugiri and Rs. 2,921 in Hosadurga. These results were supported by the findings of Chandrakanth and Arun (1997) and Nagaraj et al. (2003).

The total negative externality cost for farmers varied from Rs. 536.9 for marginal farmers to Rs. 1,59,407 for large farmers in Hosadurga, while the amount was higher with variations in Madhugiri (Table 11). Similarly, the negative externality per acre of gross irrigated area was also similar in Hosadurga. Small farmers were suffering the most in Madhugiri. This paradoxical situation was clearly explained by the comparatively higher yield of borewells in Hosadurga, 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 and do not take long-term effects into consideration.

Since all externalities associated with private exploitation arise primarily because losers find it impossible to extract suitable compensation from the emitters of the externalities under the existing structure of property rights, public control over water resources by a well informed and just authority will result in effective elimination. The proposed spacing regulations tend to exclude the late comers and create and strengthen the monopoly of existing owners. In other words, spacing regulations single out the poor to bear the cost of maintaining the ecological balance. Therefore, acceptable interventions by the government to augment supply of water and its management could solve the inequity that persists in groundwater extraction.

In India, groundwater is regulated through supply regulation of electricity rather than fixing the electricity charges appropriately. Though it has helped in checking the over-exploitation in the short run, it is not an efficient solution in the long run (Reddy 2005). Therefore, economic pricing of electricity with proper monitoring facilities would be more appropriate in order to internalize these externalities. The other way of minimizing these externalities is to strengthen the resource base, that is, replenishing groundwater through water harvesting. Since both Madhugiri and Hosadurga are well connected with surface water bodies such as irrigation tanks, the integration of these sources with groundwater development perhaps is a potential solution for sustainable water resource management in these areas. The benefits of such integration would be enormous when compared with the losses due to depletion, and hence, it makes economic and ecological sense. Therefore, state has to take major responsibility while community participation in terms of cost-sharing and management of resource is a must for sustainability. This creates sense of ownership among the community.

Groundwater overexploitation is also attributed to the cultivation of water-intensive commercial crops on a large scale. Hence, there is a need for a benevolent cropping pattern which consumes less water. The author’s experience indicates that there are voluntary initiatives by farmers to shift cropping pattern to less water-intensive tree crops such as mango and other fruits orchards. These farmers need to be motivated with appropriate incentives to strengthen their economic condition. Incentives for farmers on resource utilization should be linked to the use of water-saving technologies (e.g., drip/sprinkler) and water conservation (e.g., farm ponds/rainwater harvesting structures) mechanisms. This type of collective community management of groundwater resource will improve equity in access to water and sustainability of the resource.

Besides, attention needs to be paid to the linkages between long-term groundwater management issues and short-term coping mechanisms. In this direction, government should promote the community managed aquifer recharge strategy developed by Andhra Pradesh Farmer Managed Groundwater Systems Project (2006). Under this strategy, institutions involving farmers play a key role in aquifer recharge as well as in reversing the target of declining water levels. Further, the problem of inequity existing in well irrigation could possibly be addressed by promoting group investments in well irrigation where sharing the cost and benefits among the farmers is crucial. The group investment on well irrigation could probably solve the problem of overexploitation of groundwater, hence minimizing the negative externality. The social regulation over groundwater use is necessary to counteract overexploitation which minimizes the pressure on groundwater resource.

4 Conclusions

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 is the major difference in the cost of cultivation which is higher by 54 % in Madhugiri compared to Hosadurga. The rise in the annual cost of irrigation is a partial indicator of scarcity of groundwater in Madhugiri.

The econometric 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 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. Therefore, the objective of the public policy should be to maximize equity in access to the resource where it is plentiful and to minimize adverse ecological effects in area under stress with minimum damage to the interests of the resource-poor.

Acknowledgements The author would like to thank Profs. KV Raju, MG. Chandrakanth and RS Deshpande for their useful suggestions on the earlier versions of this paper. The author also grateful to two anonymous referees of this journal for their constructive comments. However, the usual disclaimers apply.

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